NACE CORROSION ENGINEER'S REFERENCE BOOK

Third Edition

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PREFACE

The third edition of this book is dedicated to the memory of Richard (Dick) Treseder. He is missed as a friend and a mentor, but he is remembered for his many contributions to corrosion science and engineering. Dick conceived and edited the first edition of the NACE Corrosion Engineer's Reference Book, published in 1980. He oversaw the revision of that edition to produce the second edition, published in 1991. With the third edition, the book lives on as a symbol of his many contributions to provide tools for corrosion technologists.

The third edition is an extensive revision of the second edition, which was co-edited by Robert Baboian and Charles G. Munger. It includes new sections to help in the evaluation of corrosion tests and data. All of the sections have been updated and expanded to include many new tables. Most significantly, the number of tables in the section on Conversion Tables, Corrosion Testing, Atmospheric Corrosion, Cathodic Protection, Protective Coatings and Standards has been greatly increased.

NACE International thanks the numerous sources of information and data who have given permission for use in this book. These sources are identified in footnotes following the individual tables and graphs.

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NACE GLOSSARY OF CORROSION-RELATED TERMS

Courtesy of Technical Coordination Committee and Reference Publications Committee

Abrasive: Small particles of material that are propelled at high velocity to impact a surface during abrasive blast cleaning.

Abrasive Blast Cleaning: Cleaning and roughening of a surface produced by the high-velocity impact of an abrasive that is propelled by the discharge of pressurized fluid from a blast nozzle or by a mechanical device such as a centrifugal blasting wheel. (Also referred to as Abrasive Blasting.)

Accelerator: A chemical substance that increases the rate at which a chemical reaction (e.g., curing) would otherwise occur.

Acrylic: Type of resin polymerized from acrylic acid, methacrylic acid, esters of these acids, or acrylonitrile.

Activator: A chemical substance that initiates and accelerates a chemical reaction (e.g., curing). Heat and radiation may also serve as activators for some chemical reactions.

Active: (1) The negative direction of electrode potential. (2) A state of a metal that is corroding without significant influence of reaction product.

Aeration Cell: See Differential Aeration Cell.

Air Drying: Process by which an applied wet coat converts to a dry coating film by evaporation of solvent or reaction with oxygen as a result of simple exposure to air without intentional addition of heat or a curing agent.

Airless Spraying: Process of spraying coating liquids using hydraulic pressure, not air pressure, to atomize.

Alkyd: Type of resin formed by the reaction of polyhydric alcohols and polybasic acids, part of which is derived from saturated or unsaturated oils or fats.

Alligatoring: Pronounced wide cracking over the surface of a coating, which has the appearance of alligator hide.

Amphoteric Metal: A metal that is susceptible to corrosion in both acid and alkaline environments.

Anaerobic: Free of air or uncombined oxygen.

Anion: A negatively charged ion that migrates through the electrolyte toward the anode under the influence of a potential gradient.

Anode: The electrode of an electrochemical cell at which oxidation occurs. Electrons flow away from the anode in the external circuit. Corrosion usually occurs and metal ions enter the solution at the anode.

Anode Cap: An electrical insulating material placed over the end of the anode at the lead wire connection.

Anode Corrosion Efficiency: The ratio of the actual corrosion (mass loss) of an anode to the theoretical corrosion (mass loss) calculated from the quantity of electricity that has passed between the anode and cathode using Faraday's law.

Anodic Inhibitor: A chemical substance that prevents or reduces the rate of the anodic or oxidation reaction.

Anodic Polarization: The change of the electrode potential in the noble (positive) direction caused by current across the electrode/electrolyte interface. (See Polarization.)

Anodic Protection: Polarization to a more oxidizing potential to achieve a reduced corrosion rate by the promotion of passivity.

Anodizing: Oxide coating formed on a metal surface (generally aluminum) by an electrolytic process.

Anolyte: The electrolyte adjacent to the anode of an electrochemical cell.

Antifouling: Preventing fouling. (See Fouling.)

Attenuation: Electrical losses in a conductor caused by current flow in the conductor.

Auger Electron Spectroscopy: Analytical technique in which the sample surface is irradiated with low-energy electrons and the energy spectrum of electrons emitted from the surface is measured.

Austenitic Steel: A steel whose microstructure at room temperature consists predominantly of austenite.

Auxiliary Electrode: An electrode, usually made from a noncorroding material, which is commonly used in polarization studies to pass current to or from a test electrode.

Backfill: Material placed in a hole to fill the space around the anodes, vent pipe, and buried components of a cathodic protection system.

Barrier Coating: (1) A coating that has a high resistance to permeation of liquids and/or gases. (2) A coating that is applied over a previously coated surface to prevent damage to the underlying coating during subsequent handling

Beach Marks: The characteristic markings on the fracture surfaces produced by fatigue crack propagation (also known as clamshell marks, conchoidal marks, and arrest marks).

Binder: The nonvolatile portion of the vehicle of a formulated coating material.

Bituminous Coating: An asphalt or coal-tar compound used to provide a protective coating for a surface.

Blast Angle: (1) The angle of the blast nozzle with reference to the surface during abrasive blast cleaning. (2) The angle of the abrasive particles propelled from a centrifugal blasting wheel with reference to the surface being abrasive blast cleaned.

Blowdown: (1) Injection of air or water under high pressure through a tube to the anode area for the purpose of purging the annular space and possibly correcting high resistance caused by gas blockage. (2) In conjunction with boilers or cooling towers, the process of discharging a significant portion of the aqueous solution in order to remove accumulated salts, deposits, and other impurities.

Blushing: Whitening and loss of gloss of a coating, usually organic, caused by moisture (also known as blooming).

Brittle Fracture: Fracture with little or no plastic deformation.

Brush-Off Blast Cleaned Surface: A brush-off blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Tightly adherent mill scale, rust, and coating may remain on the surface. Mill scale, rust, and coating are considered tightly adherent if they cannot be removed by lifting with a dull putty knife. (See NACE No. 4/SSPC-SP 7.)

Calcareous Coating: A layer consisting of calcium carbonate and other salts deposited on the surface. When the surface is cathodically polarized as in cathodic protection, this layer is the result of the increased pH adjacent to the protected surface.

Calcareous Deposit: (See Calcareous Coating.)

Case Hardening: Hardening a ferrous alloy so that the outer portion, or case, is made substantially harder than the inner portion, or core. Typical processes are carburizing, cyaniding, carbonitriding, nitriding, induction hardening, and flame hardening.

Casein Paint: Water-thinned paint with vehicle derived from milk.

Catalyst: A chemical substance, usually present in small amounts relative to the reactants, that increases the rate at which a chemical reaction (e.g., curing) would otherwise occur, but is not consumed in the reaction.

Cathode: The electrode of an electrochemical cell at which reduction is the principal reaction. Electrons flow toward the cathode in the external circuit.

Cathodic Corrosion: Corrosion resulting from a cathodic condition of a structure, usually caused by the reaction of an amphoteric metal with the alkaline products of electrolysis.

Cathodic Disbondment: The destruction of adhesion between a coating and the coated surface caused by products of a cathodic reaction.

Cathodic Inhibitor: A chemical substance that prevents or reduces the rate of the cathodic or reduction reaction.

Cathodic Polarization: The change of the electrode potential in the active (negative) direction caused by current across the electrode/electrolyte interface. (See Polarization.)

Cathodic Protection: A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Catholyte: The electrolyte adjacent to the cathode of an electrochemical cell.

Cation: A positively charged ion that migrates through the electrolyte toward the cathode under the influence of a potential gradient.

Cavitation: The formation and rapid collapse of cavities or bubbles within a liquid which often results in damage to a material at the solid/liquid interface under conditions of severe turbulent flow.

Cell: See Electrochemical Cell.

Cementation: The introduction of one or more elements into the surface layer of a metal by diffusion at high temperature. (Examples of cementation include carburizing [introduction of carbon], nitriding [introduction of nitrogen], and chromizing [introduction of chromium].)

Chalking: The development of loose, removable powder (pigment) at the surface of an organic coating, usually caused by weathering.

Checking: The development of slight breaks in a coating which do not penetrate to the underlying surface.

Chemical Conversion Coating: An adherent reaction product layer on a metal surface formed by reaction with a suitable chemical to provide greater corrosion resistance to the metal and increase adhesion of coatings applied to the metal. (Example is an iron phosphate coating on steel, developed by reaction with phosphoric acid.)

Chevron Pattern: A V-shaped pattern on a fatigue or brittle-fracture surface. The pattern can also be one of straight radial lines on cylindrical specimens.

Chloride Stress Corrosion Cracking: Cracking of a metal under the combined action of tensile stress and corrosion in the presence of chlorides and an electrolyte (usually water).

Coat: One layer of a coating applied to a surface in a single continuous application to form a uniform film when dry.

Coating: A liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film.

Coating System: The complete number and types of coats applied to a substrate in a predetermined order. (When used in a broader sense, surface preparation, pretreatments, dry film thickness, and manner of application are included.)

Cold Shut: Horizontal surface discontinuity caused by solidification of a portion of a meniscus during the progressive filling of a mold, which is later covered with more solidifying metal as the molten metal level rises. Cold shuts generally occur at corners remote from the point of pour.

Commercial Blast Cleaned Surface: A commercial blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter. Random staining shall be limited to no more than 33 percent of each unit area (approximately 58 cm^2 [9.0 in^2]) of surface and may consist of light shadows, slight streaks, or minor discolorations caused by stains of rust, stains of mill scale, or stains of previously applied coating. (See NACE No. 3/SSPC-SP 6.)

Concentration Cell: An electrochemical cell, the electromotive force of which is caused by a difference in concentration of some component in the electrolyte. (This difference leads to the formation of discrete cathodic and anodic regions.)

Concentration Polarization: That portion of polarization of a cell produced by concentration changes resulting from passage of current though the electrolyte.

Conductive Coating: (1) A coating that conducts electricity. (2) An electrically conductive, mastic-like material used as an impressed current anode on reinforced concrete surfaces.

Contact Corrosion: See Galvanic Corrosion.

Continuity Bond: A connection, usually metallic, that provides electrical continuity between structures that can conduct electricity.

Continuous Anode: A single anode with no electrical discontinuities.

Conversion Coating: See Chemical Conversion Coating.

Corrosion: The deterioration of a material, usually a metal, that results from a reaction with its environment.

Corrosion Fatigue: Fatigue-type cracking of metal caused by repeated or fluctuating stresses in a corrosive environment characterized by shorter life than would be encountered as a result of either the repeated or fluctuating stress alone or the corrosive environment alone.

Corrosion Inhibitor: A chemical substance or combination of substances that, when present in the environment, prevents or reduces corrosion.

Corrosion Potential (E_{corr}): The potential of a corroding surface in an electrolyte relative to a reference electrode under open-circuit conditions (also known as rest potential, open-circuit potential, or freely corroding potential).

Corrosion Rate: The rate at which corrosion proceeds.

Corrosion Resistance: Ability of a material, usually a metal, to withstand corrosion in a given system.

Corrosiveness: The tendency of an environment to cause corrosion.

Counter Electrode: See Auxiliary Electrode.

Counterpoise: A conductor or system of conductors arranged beneath a power line, located on, above, or most frequently, below the surface of the earth and connected to the footings of the towers or poles supporting the power line.

Couple: See Galvanic Couple.

Cracking (of Coating): Breaks in a coating that extend through to the substrate.

Crazing: A network of checks or cracks appearing on the surface of a coating.

Creep: Time-dependent strain occurring under stress.

Crevice Corrosion: Localized corrosion of a metal surface at, or immediately adjacent to, an area that is shielded from full exposure to the environment because of close proximity of the metal to the surface of another material.

Critical Humidity: The relative humidity above which the atmospheric corrosion rate of some metals increases sharply.

Critical Pitting Potential (E_p, E_{pp}): The lowest value of oxidizing potential (voltage) at which pits nucleate and grow. The value depends on the test method used.

Curing: Chemical process of developing the intended properties of a coating or other material (e.g., resin) over a period of time.

Curing Agent: A chemical substance used for curing a coating or other material (e.g., resin). (also referred to as Hardener.)

Current Density: The current to or from a unit area of an electrode surface.

Current Efficiency: The ratio of the electrochemical equivalent current density for a specific reaction to the total applied current density.

DC Decoupling Device: A device used in electrical circuits that allows the flow of alternating current (AC) in both directions and stops or substantially reduces the flow of direct current (DC).

Dealloying: The selective corrosion of one or more components of a solid solution alloy (also known as parting or selective dissolution).

Decomposition Potential: The potential (voltage) on a metal surface necessary to decompose the electrolyte of an electrochemical cell or a component thereof.

Decomposition Voltage: See Decomposition Potential.

Deep Groundbed: One or more anodes installed vertically at a nominal depth of 15 m (50 ft) or more below the earth's surface in a drilled hole for the purpose of supplying cathodic protection.

Depolarization: The removal of factors resisting the current in an electrochemical cell.

Deposit Attack: Corrosion occurring under or around a discontinuous deposit on a metallic surface (also known as poultice corrosion).

Dezincification: A corrosion phenomenon resulting in the selective removal of zinc from copper-zinc alloys. (This phenomenon is one of the more common forms of dealloying.)

Dielectric Coating: A coating that does not conduct electricity.

Dielectric Shield: An electrically nonconductive material, such as a coating, sheet or pipe, that is placed between an anode and an adjacent cathode, usually on the cathode, to improve current distribution in a cathodic protection system.

Differential Aeration Cell: An electrochemical cell, the electromotive force of which is due to a difference in air (oxygen) concentration at one electrode as compared with that at another electrode of the same material.

Diffusion Limited Current Density: The current density that corresponds to the maximum transfer rate that a particular species can sustain because of the limitation of diffusion (often referred to as limiting current density).

Disbondment: The loss of adhesion between a coating and the substrate.

Double Layer: The interface between an electrode or a suspended particle and an electrolyte created by charge-charge interaction leading to an alignment of oppositely charged ions at the surface of the electrode or particle. The simplest model is represented by a parallel plate condenser.

Drainage: Conduction of electric current from an underground or submerged metallic structure by means of a metallic conductor.

Driving Potential: Difference in potential between the anode and the steel structure.

Drying Oil: An oil capable of conversion from a liquid to a solid by slow reaction with oxygen in the air.

Elastic Deformation: Changes of dimensions of a material upon the application of a stress within the elastic range. Following the release of an elastic stress, the material returns to its original dimensions without any permanent deformation.

Elastic Limit: The maximum stress to which a material may be subjected without retention of any permanent deformation after the stress is removed.

Elasticity: The property of a material that allows it to recover its original dimensions following deformation by a stress below its elastic limit.

Electrical Isolation: The condition of being electrically separated from other metallic structures or the environment.

Electrochemical Cell: A system consisting of an anode and a cathode immersed in an electrolyte so as to create an electrical circuit. The anode and cathode may be different metals or dissimilar areas on the same metal surface.

Electrochemical Equivalent: The mass of an element or group of elements oxidized or reduced at 100% efficiency by the passage of a unit quantity of electricity.

Electrochemical Potential: The partial derivative of the total electrochemical free energy of a constituent with respect to the number of moles of this constituent where all other factors are kept constant. It is analogous to the chemical potential of a constituent except that it includes the electrical as well as chemical contributions to the free energy.

Electrode: A conductor used to establish contact with an electrolyte and through which current is transferred to or from an electrolyte.

Electrode Potential: The potential of an electrode in an electrolyte as measured against a reference electrode. (The electrode potential does not include any resistance losses in potential in either the electrolyte or

the external circuit. It represents the reversible work to move a unit of charge from the electrode surface through the electrolyte to the reference electrode.)

Electrokinetic Potential: A potential difference in a solution caused by residual, unbalanced charge distribution in the adjoining solution, producing a double layer. The electrokinetic potential is different from the electrode potential in that it occurs exclusively in the solution phase. This potential represents the reversible work necessary to bring a unit charge from infinity in the solution up to the interface in question but not through the interface (also known as zeta potential).

Electrolyte: A chemical substance containing ions that migrate in an electric field.

Electrolytic Cleaning: A process for removing soil, scale, or corrosion products from a metal surface by subjecting the metal as an electrode to an electric current in an electrolytic bath.

Electromotive Force Series: A list of elements arranged according to their standard electrode potentials, the sign being positive for elements whose potentials are cathodic to hydrogen and negative for those anodic to hydrogen.

Ellipsometry: An optical analytical technique employing plane-polarized light to study films.

Embrittlement: Loss of ductility of a material resulting from a chemical or physical change.

EMF Series: See Electromotive Force Series.

Enamel: (1) A paint that dries to a hard, glossy surface. (2) A coating that is characterized by an ability to form a smooth, durable film.

End Effect: The more rapid loss of anode material at the end of an anode, compared with other surfaces of the anode, resulting from higher current density.

Endurance Limit: The maximum stress that a material can withstand for an infinitely large number of fatigue cycles.

Environment: The surroundings or conditions (physical, chemical, mechanical) in which a material exists.

Environmental Cracking: Brittle fracture of a normally ductile material in which the corrosive effect of the environment is a causative factor. Environmental cracking is a general term that includes all of the terms listed below. The definitions of these terms are listed elsewhere in the glossary.

Corrosion Fatigue
Hydrogen Embrittlement

Hydrogen-Induced Cracking–(Stepwise Cracking)
Hydrogen Stress Cracking
Liquid Metal Cracking
Stress Corrosion Cracking
Sulfide Stress Cracking

The following terms have been used in the past in connection with environmental cracking but are now obsolete and should not be used:

Caustic Embrittlement
Delayed Cracking
Liquid Metal Embrittlement
Season Cracking
Static Fatique
Sulfide Corrosion Cracking
Sulfide Stress Corrosion Cracking

Epoxy: Type of resin formed by the reaction of aliphatic or aromatic polyols (like bisphenol) with epichlorohydrin and characterized by the presence of reactive oxirane end groups.

Equilibrium Potential: The potential of an electrode in an electrolyte at which the forward rate of a given reaction is exactly equal to the reverse rate; the electrode potential with reference to a standard equilibrium, as defined by the Nernst equation.

Erosion: The progressive loss of material from a solid surface due to mechanical interaction between that surface and a fluid, a multicomponent fluid, or solid particles carried with the fluid.

Erosion–Corrosion: A conjoint action involving corrosion and erosion in the presence of a moving corrosive fluid or a material moving through the fluid, leading to accelerated loss of material.

Exchange Current: The rate at which either positive or negative charges are entering or leaving the surface when an electrode reaches dynamic equilibrium in an electrolyte.

Exfoliation Corrosion: Localized subsurface corrosion in zones parallel to the surface that result in thin layers of uncorroded metal resembling the pages of a book.

External Circuit: The wires, connectors, measuring devices, current sources, etc., that are used to bring about or measure the desired electrical conditions within an electrochemical cell. It is this portion of the cell through which electrons travel.

Fatigue: The phenomenon leading to fracture of a material under repeated or fluctuating stresses having a maximum value less than the tensile strength of the material.

Fatigue Strength: The maximum stress that can be sustained for a specified number of cycles without failure.

Fault Current: A current that flows from one conductor to ground or to another conductor due to an abnormal connection (including an arc) between the two. A fault current flowing to ground may be called a ground fault current.

Ferrite: The body-centered cubic crystalline phase of iron-based alloys.

Ferritic Steel: A steel whose microstructure at room temperature consists predominantly of ferrite.

Filiform Corrosion: Corrosion that occurs under a coating in the form of randomly distributed thread-like filaments.

Film: A thin, not necessarily visible layer of material.

Finish Coat: See Topcoat.

Forced Drainage: Drainage applied to underground or submerged metallic structures by means of an applied electromotive force or sacrificial anode.

Foreign Structure: Any metallic structure that is not intended as a part of a system under cathodic protection.

Fouling: An accumulation of deposits. This includes accumulation and growth of marine organisms on a submerged metal surface and the accumulation of deposits (usually inorganic) on heat exchanger tubing.

Fractography: Descriptive treatment of fracture, especially in metals, with specific reference to photographs of the fracture surface.

Fracture Mechanics: A quantitative analysis for evaluating structural reliability in terms of applied stress, crack length, and specimen geometry.

Free Machining: The machining characteristics of an alloy to which an ingredient has been introduced to give small broken chips, lower power consumption, better surface finish, and longer tool life.

Fretting Corrosion: Deterioration at the interface of two contacting surfaces under load which is accelerated by their relative motion.

Furan: Type of resin formed by the polymerization or polycondensation of furfuryl, furfuryl alcohol, or other compounds containing a furan ring.

Galvanic Anode: A metal that provides sacrificial protection to another metal that is more noble when electrically coupled in an electrolyte. This type of anode is the electron source in one type of cathodic protection.

Galvanic Corrosion: Accelerated corrosion of a metal because of an electrical contact with a more noble metal or nonmetallic conductor in a corrosive electrolyte.

Galvanic Couple: A pair of dissimilar conductors, commonly metals, in electrical contact in an electrolyte.

Galvanic Current: The electric current between metals or conductive nonmetals in a galvanic couple.

Galvanic Series: A list of metals and alloys arranged according to their corrosion potentials in a given environment.

Galvanostatic: Refers to an experimental technique whereby an electrode is maintained at a constant current in an electrolyte.

General Corrosion: Corrosion that is distributed more or less uniformly over the surface of a material.

Graphitic Corrosion: Deterioration of gray cast iron in which the metallic constituents are selectively leached or converted to corrosion products, leaving the graphite intact.

Graphitization: The formation of graphite in iron or steel, usually from decomposition of iron carbide at elevated temperatures. (Should not be used as a term to describe graphitic corrosion.)

Grit: Small particles of hard material (e.g., iron, steel, or mineral) with irregular shapes that are commonly used as an abrasive in abrasive blast cleaning.

Grit Blasting: Abrasive blast cleaning using grit as the abrasive.

Groundbed: One or more anodes installed below the earth's surface for the purpose of supplying cathodic protection.

Half Cell: A pure metal in contact with a solution of known concentration of its own ion, at a specific temperature, develops a potential that is characteristic and reproducible; when coupled with another half-cell, an overall potential that is the sum of both half-cells develops.

Hand Tool Cleaning: Removal of loose rust, loose mill scale, and loose paint to degree specified, by hand chipping, scraping, sanding, and wire brushing. [See SSPC-SP 2.]

Hardener: See Curing Agent.

Heat Affected Zone (HAZ): That portion of the base metal that is not melted during brazing, cutting, or welding, but whose microstructure and properties are altered by the heat of these processes.

Heat Treatment: Heating and cooling a solid metal or alloy in such a way as to obtain desired properties. Heating for the sole purpose of hot working is not considered heat treatment.

High Pressure Water Cleaning: Water cleaning performed at pressures from 34–70 MPa (5,000–10,000 psig).

High Pressure Waterjetting: Waterjetting performed at pressures from 70–170 MPa (10,000–25,000 psig).

High Temperature Hydrogen Attack: A loss of strength and ductility of steel by high-temperature reaction of absorbed hydrogen with carbides in the steel, resulting in decarburization and internal fissuring.

Holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

Hydrogen Blistering: The formation of subsurface planar cavities, called hydrogen blisters, in a metal resulting from excessive internal hydrogen pressure. Growth of near-surface blisters in low-strength metals usually results in surface bulges.

Hydrogen Embrittlement: A loss of ductility of a metal resulting from absorption of hydrogen.

Hydrogen Induced Cracking: Stepwise internal cracks that connect adjacent hydrogen blisters on different planes in the metal, or to the metal surface (also known as stepwise cracking).

Hydrogen Overvoltage: Overvoltage associated with the liberation of hydrogen gas.

Hydrogen Stress Cracking: Cracking that results from the presence of hydrogen in a metal in combination with tensile stress. It occurs most frequently with high-strength alloys.

Impingement Corrosion: A form of erosion-corrosion generally associated with the local impingement of a high-velocity, flowing fluid against a solid surface.

Impressed Current: An electric current supplied by a device employing a power source that is external to the electrode system. (An example is direct current for cathodic protection.)

Inclusion: A nonmetallic phase such as an oxide, sulfide, or silicate particle in a metal.

Inorganic Zinc Rich Coating: Coating containing a metallic zinc pigment (typically 75 wt% zinc or more in the dry film) in an inorganic vehicle.

Intercrystalline Corrosion: See Intergranular Corrosion.

Interdendritic Corrosion: Corrosive attack of cast metals that progresses preferentially along paths between dendrites.

Intergranular Corrosion: Preferential corrosion at or along the grain boundaries of a metal (also known as intercrystalline corrosion).

Intergranular Stress Corrosion Cracking: Stress corrosion cracking in which the cracking occurs along grain boundaries.

Internal Oxidation: The formation of isolated particles of oxidation products beneath the metal surface.

Intumescence: The swelling or bubbling of a coating usually caused by heating. (The term is commonly used in aerospace and fireprotection applications.)

Ion: An electrically charged atom or group of atoms.

Iron Rot: Deterioration of wood in contact with iron-based alloys.

Knife Line Attack: Intergranular corrosion of an alloy along a line adjoining or in contact with a weld after heating into the sensitization temperature range.

Lamellar Corrosion: See Exfoliation Corrosion.

Langelier Index: A calculated saturation index for calcium carbonate that is useful in predicting scaling behavior of natural water.

Line Current: The direct current flowing on a pipeline.

Lining: A coating or layer of sheet material adhered to or in intimate contact with the interior surface of a container used to protect the container against corrosion by its contents and/or to protect the contents of the container from contamination by the container material.

Liquid Metal Cracking: Cracking of a metal caused by contact with a liquid metal.

Long Line Current: Current though the earth between an anodic and a cathodic area that returns along an underground metallic structure.

Low Carbon Steel: Steel having less than 0.30% carbon and no intentional alloying additions.

Low Pressure Water Cleaning: Water cleaning performed at pressures less than 34 MPa (5,000 psig).

Luggin Probe: A small tube or capillary filled with electrolyte, terminating close to the metal surface of an electrode under study, which is used to provide an ion-conducting path without diffusion between the electrode under study and a reference electrode.

Martensite: A hard supersaturated solid solution of carbon in iron characterized by an acicular (needle-like) microstructure.

Metal Dusting: The catastrophic deterioration of a metal exposed to a carbonaceous gas at elevated temperature.

Metallizing: The coating of a surface with a thin metal layer by spraying, hot dipping, or vacuum deposition.

Mill Scale: The oxide layer formed during hot fabrication or heat treatment of metals.

Mixed Potential: A potential resulting from two or more electrochemical reactions occurring simultaneously on one metal surface.

Modulus of Elasticity: A measure of the stiffness or rigidity of a material. It is actually the ratio of stress to strain in the elastic region of a material. If determined by a tension or compression test, it is also called Young's Modulus or the coefficient of elasticity.

Natural Drainage: Drainage from an underground or submerged metallic structure to a more negative (more anodic) structure, such as the negative bus of a trolley substation.

Near-White Blast Cleaned Surface: A near-white blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter. Random staining shall be limited to not more than 5% of each unit area of surface (approximately 58 cm^2 [9.0 in^2]), and may consist of light shadows, slight streaks, or minor discolorations caused by stains of rust, stains of mill scale, or stains of previously applied coating. (See NACE No. 2/SSPC-SP 10.)

Negative Return: A point of connection between the cathodic protection negative cable and the protected structure.

Nernst Equation: An equation that expresses the exact electromotive force of an electrochemical cell in terms of the activities of products and reactants of the cell.

Nernst Layer: The diffusion layer at the surface of an electrode in which the concentration of a chemical species is assumed to vary linearly from the value in the bulk solution to the value at the electrode surface.

Noble: The positive direction of electrode potential, thus resembling noble metals such as gold and platinum.

Noble Metal: (1) A metal that occurs commonly in nature in the free state. (2) A metal or alloy whose corrosion products are formed with a small negative or a positive free-energy change.

Noble Potential: A potential more cathodic (positive) than the standard hydrogen potential.

Normalizing: Heating a ferrous alloy to a suitable temperature above the transformation range (austenitizing), holding at temperature for a suitable time, and then cooling in still air to a temperature substantially below the transformation range.

Open-Circuit Potential: The potential of an electrode measured with respect to a reference electrode or another electrode in the absence of current.

Organic Zinc Rich Coating: Coating containing a metallic zinc pigment (typically 75 wt% zinc or more in the dry film) in an organic resin.

Overvoltage: The change in potential of an electrode from its equilibrium or steady-state value when current is applied.

Oxidation: (1) Loss of electrons by a constituent of a chemical reaction. (2) Corrosion of a metal that is exposed to an oxidizing gas at elevated temperatures.

Oxidation Reduction Potential: The potential of a reversible oxidation-reduction electrode measured with respect to a reference electrode, corrected to the hydrogen electrode, in a given electrolyte.

Oxygen Concentration Cell: See Differential Aeration Cell.

Paint: A pigmented liquid or resin applied to a substrate as a thin layer that is converted to an opaque solid film after application. It is commonly used as a decorative or protective coating.

Paint System: See Coating System.

Parting: See Dealloying.

Passivation: A reduction of the anodic reaction rate of an electrode involved in corrosion.

Passivation Potential: See Primary Passive Potential.

Passive: (1) The positive direction of electrode potential. (2) A state of a metal in which a surface reaction product causes a marked decrease in the corrosion rate relative to that in the absence of the product.

Passive–Active Cell: An electrochemical cell, the electromotive force of which is caused by the potential difference between a metal in an active state and the same metal in a passive state.

Passivity: The state of being passive.

Patina: A thin layer of corrosion product, usually green, that forms on the surface of metals such as copper and copper-based alloys exposed to the atmosphere.

pH: The negative logarithm of the hydrogen ion activity written as:

$$pH = -\log_{10}(a_H^+),$$

where a_H^+ = hydrogen ion activity = the molar concentration of hydrogen ions multiplied by the mean ion-activity coefficient.

Pickling: (1) Treating a metal in a chemical bath to remove scale and oxides (e.g., rust) from the surface. (2) Complete removal of rust and mill scale by acid pickling, duplex pickling, or electrolytic pickling. [See SSPC-SP 8.]

Pickling Solution: A chemical bath, usually an acid solution, used for pickling.

Pigment: A solid substance, generally in fine powder form, that is insoluble in the vehicle of a formulated coating material. It is used to impart color or other specific physical or chemical properties to the coating.

Pipe to Electrolyte Potential: The potential difference between the pipe metallic surface and electrolyte that is measured with reference to an electrode in contact with the electrolyte.

Pitting: Localized corrosion of a metal surface that is confined to a small area and takes the form of cavities called pits.

Pitting Factor: The ratio of the depth of the deepest pit resulting from corrosion divided by the average penetration as calculated from mass loss.

Plastic Deformation: Permanent deformation caused by stressing beyond the elastic limit.

Plasticity: The ability of a material to deform permanently (nonelastically) without fracturing.

Polarization: The change from the open-circuit potential as a result of current across the electrode/electrolyte interface.

Polarization Admittance: The reciprocal of polarization resistance.

Polarization Cell: A DC decoupling device consisting of two or more pairs of inert metallic plates immersed in an aqueous electrolyte. The electrical characteristics of the polarization cell are high resistance to DC potentials and low impedance of AC.

Polarization Curve: A plot of current density versus electrode potential for a specific electrode/electrolyte combination.

Polarization Decay: The decrease in electrode potential with time resulting from the interruption of applied current.

Polarization Resistance: The slope (dE/di) at the corrosion potential of a potential (E)-current density (i) curve. (The measured slope is usually in good agreement with the true value of the polarization resistance when the scan rate is low and any uncompensated resistance is small relative to the polarization resistance.)

Polarized Potential: The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.

Polyester: Type of resin formed by the condensation of polybasic and monobasic acids with polyhydric alcohols.

Postweld Heat Treatment: Heating and cooling a weldment in such a way as to obtain desired properties.

Potential-pH Diagram: A graphical method of representing the regions of thermodynamic stability of species for metal/electrolyte systems (also known as Pourbaix diagram).

Potentiodynamic: Refers to a technique wherein the potential of an electrode with respect to a reference electrode is varied at a selected rate by application of a current through the electrolyte.

Potentiokinetic: See Potentiodynamic.

Potentiostat: An instrument for automatically maintaining a constant electrode potential.

Potentiostatic: Refers to a technique for maintaining a constant electrode potential.

Pot Life: The elapsed time within which a coating can be effectively applied after all components of the coating have been thoroughly mixed.

Poultice Corrosion: See Deposit Attack.

Pourbaix Diagram: See Rotential-pH Diagram.

Power Tool Cleaning: Removal of loose rust, loose mill scale, and loose paint to degree specified by power tool chipping, descaling, sanding, wire brushing, and grinding. (See SSPC-SP 3.)

Precipitation Hardening: Hardening caused by the precipitation of a constituent from a supersaturated solid solution.

Primary Passive Potential: The potential corresponding to the maximum active current density (critical anodic current density) of an electrode that exhibits active-passive corrosion behavior.

Prime Coat: See Primer.

Primer: A coating material intended to be applied as the first coat on an uncoated surface. The coating is specifically formulated to adhere to and protect the surface as well as to produce a suitable surface for subsequent coats. (also referred to as Prime Coat.)

Profile: Anchor pattern on a surface produced by abrasive blasting or acid treatment.

Protective Coating: A coating applied to a surface to protect the substrate from corrosion.

Reduction: Gain of electrons by a constituent of a chemical reaction.

Reference Electrode: An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

Reference Half Cell: See Reference Electrode.

Relative Humidity: The ratio, expressed as a percentage, of the amount of water vapor present in a given volume of air at a given temperature to the amount required to saturate the air at that temperature.

Remote Earth: A location on the earth far enough from the affected structure that the soil potential gradients associated with currents entering the earth from the affected structure are insignificant.

Rest Potential: See Corrosion Potential.

Reversible Potential: See Equilibrium Potential.

Rimmed Steel: An incompletely deoxidized steel. (also called Rimming Steel.)

Riser: (1) That section of pipeline extending from the ocean floor up to an offshore platform. (2) The vertical tube in a steam generator convection bank that circulates water and steam upward.

Rust: Corrosion product consisting of various iron oxides and hydrated iron oxides. (This term properly applies only to iron and ferrous alloys.)

Rust Bloom: Discoloration indicating the beginning of rusting.

Sacking: Scrubbing a mixture of a cement mortar over the concrete surface using a cement sack, gunny sack, or sponge rubber float.

Sacrificial Protection: Reduction of corrosion of a metal in an electrolyte by galvanically coupling it to a more anodic metal (a form of cathodic protection).

Scaling: (1) The formation at high temperatures of thick corrosion-product layers on a metal surface. (2) The deposition of water-insoluble constituents on a metal surface.

Scanning Electron Microscope: An electron optical device that images topographical details with maximum contrast and depth of field by the detection, amplification, and display of secondary electrons.

Sensitizing Heat Treatment: A heat treatment, whether accidental, intentional, or incidental (as during welding), that causes precipitation of constituents (usually carbides) at grain boundaries, often causing the alloy to become susceptible to intergranular corrosion or intergranular stress corrosion cracking.

Shallow Groundbed: One or more anodes installed either vertically or horizontally at a nominal depth of less than 15 m (50 ft) for the purpose of supplying cathodic protection.

Shop Coat: One or more coats applied in a shop or plant prior to shipment to the site of erection or fabrication.

Shot Blasting: Abrasive blast cleaning using metallic (usually steel) shot as the abrasive.

Shot Peening: Inducing compressive stresses in the surface layer of a material by bombarding it with a selected medium (usually steel shot) under controlled conditions.

Sigma Phase: An extremely brittle Fe-Cr phase that can form at elevated temperatures in Fe-Cr-Ni and Ni-Cr-Fe alloys.

Slip: A deformation process involving shear motion of a specific set of crystallographic planes.

Slow Strain Rate Technique: An experimental technique for evaluating susceptibility to environmental cracking. It involves pulling the specimen to failure in uniaxial tension at a controlled slow strain rate while the specimen is in the test environment and examining the specimen for evidence of environmental cracking.

Slushing Compound: Oil or grease coatings used to provide temporary protection against atmospheric corrosion.

Solution Heat Treatment: Heating a metal to a suitable temperature and holding at that temperature long enough for one or more constituents to enter into solid solution, then cooling rapidly enough to retain the constituents in solution.

Solvent Cleaning: Removal of oil, grease, dirt, soil, salts, and contaminants by cleaning with solvent, vapor alkali, emulsion, or steam. (See SSPC-SP 1.)

Spalling: The spontaneous chipping, fragmentation, or separation of a surface or surface coating.

Standard Electrode Potential: The reversible potential for an electrode process when all products and reactions are at unit activity on a scale in which the potential for the standard hydrogen reference electrode is zero.

Standard Jetting Water: Water of sufficient purity and quality that it does not impose additional contaminants on the surface being cleaned and does not contain sediments or other impurities that are destructive to the proper functioning of waterjetting equipment.

Steel Shot: Small particles of steel with spherical shape that are commonly used as an abrasive in abrasive blast cleaning or as a selected medium for shot peening.

Stepwise Cracking: See Hydrogen-Induced Cracking.

Stray Current: Current through paths other than the intended circuit.

Stray Current Corrosion: Corrosion resulting from current through paths other than the intended circuit, e.g., by any extraneous current in the earth.

Stress Corrosion Cracking: Cracking of a material produced by the combined action of corrosion and tensile stress (residual or applied).

Stress Relieving (Thermal): Heating a metal to a suitable temperature, holding at that temperature long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of new residual stresses.

Subsurface Corrosion: See Internal Oxidation.

Sulfidation: The reaction of a metal or alloy with a sulfur-containing species to produce a sulfur compound that forms on or beneath the surface of the metal or alloy.

Sulfide Stress Cracking: Cracking of a metal under the combined action of tensile stress and corrosion in the presence of water and hydrogen sulfide (a form of hydrogen stress cracking).

Tack Coat: A thin wet coat applied to the surface that is allowed to dry just until it is tacky before application of a thicker wet coat. (Use of a tack coat allows application of thicker coats without sagging or runs.)

Tafel Plot: A plot of the relationship between the change in potential (E) and the logarithm of the current density (log *i*) of an electrode when it is polarized in both the anodic and cathodic directions from its open-circuit potential.

Tafel Slope: The slope of the straight-line portion of the E log *i* curve on a Tafel plot. (The straight-line portion usually occurs at more than 50 mV from the open-circuit potential.)

Tarnish: Surface discoloration of a metal resulting from formation of a film of corrosion product.

Thermal Spraying: A group of processes by which finely divided metallic or nonmetallic materials are deposited in a molten or semimolten condition to form a coating.

Thermogalvanic Corrosion: Corrosion resulting from an electrochemical cell caused by a thermal gradient.

Throwing Power: The relationship between the current density at a point on a surface and its distance from the counterelectrode. The greater the ratio of the surface resistivity shown by the electrode reaction to the volume resistivity of the electrolyte, the better is the throwing power of the process.

Topcoat: The final coat of a coating system. (also referred to as Finish Coat).

Transpassive: The noble region of potential where an electrode exhibits a higher-than-passive current density.

Tuberculation: The formation of localized corrosion products scattered over the surface in the form of knob-like mounds called tubercles.

Ultimate Strength: The maximum stress that a material can sustain.

Ultrahigh-Pressure Waterjetting: Waterjetting performed at pressures above 170 MPa (25,000 psig.)

Underfilm Corrosion: See Filiform Corrosion.

Vehicle: The liquid portion of a formulated coating material.

Void: (1) A holiday, hole, or skip in a coating. (2) A hole in a casting or weld deposit usually resulting from shrinkage during cooling.

Wash Primer: A thin, inhibiting primer, usually chromate pigmented, with a polyvinyl butyral binder.

Water Cleaning: Use of pressurized water discharged from a nozzle to remove unwanted matter (e.g., dirt, scale, rust, coatings) from a surface.

Waterjetting: Use of standard jetting water discharged from a nozzle at pressures of 70 MPa (10,000 psig) or greater to prepare a surface for coating or inspection.

Weight Coating: An external coating applied to a pipeline to counteract buoyancy.

White Metal Blast Cleaned Surface: A white metal blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter. (See NACE No. 1/SSPC-SP 5.)

Weld Decay: Intergranular corrosion, usually of stainless steel or certain nickelbase alloys, that occurs as the result of sensitization in the heat-affected zone during the welding operation. (This is not a preferred term.)

Wet Film Gauge: Device for measuring wet film thickness of a coating.

Working Electrode: The test or specimen electrode in an electrochemical cell.

Wrought: Metal in the solid condition that is formed to a desired shape by working (rolling, extruding, forging, etc.), usually at an elevated temperature.

Yield Point: The stress on a material at which the first significant permanent or plastic deformation occurs without an increase in stress. In Some materials, particularly annealed low-carbon steels, there is a well-defined yield point from the straight line defining the modulus of elasticity.

Yield Strength: The stress at which a material exhibits a specified deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain by either the offset method (usually at a strain of 0.2%) or the total-extension-under-load method (usually at a strain of 0.5%.)

GLOSSARY OF CORROSION-RELATED ACRONYMS

ABS	Acrylonitrile-butadiene-styrene plastics
AC	Air cooled
AE	Acoustic emission
AES	Auger electron spectroscopy
ANN	Annealed
AUSS	Austenitic stainless steel
AVT	All volatile treatment for BFW
BFW	Boiler feed water
BWR	Boiling water reactor
CAB	Cellulose acetate-butyrate
CCI	Crevice corrosion index
CCT	Critical crevice corrosion temperature
CD	Current density
CDA	Corrosion data acquisition
CF	Corrosion fatigue
CH	Cold work hardened
CHA	Cold work hardened, aged
CN	Concentric neutral
CP	Cathodic protection
CPP	Critical pitting potential
CPT	Critical pitting temperature
CPVC	Chlorinated poly(vinyl chloride)
CR	Cold rolled
CRA	Corrosion resistant alloy
CS	Carbon steel
CSE	Copper/copper sulfate electrode
CW	Cooling water
DCB	Double cantilever beam test
DIMA	Direct imaging mass analyzer
DSS	Duplex stainless steel
DTA	Differential thermal analysis
DW	Distilled water
EC	Environmental cracking
EDXA	Energy dispersive X-ray analysis
EIS	Electrochemical impedance spectroscopy
ELN	Electrochemical noise technique
EPMA	Electron beam microprobe analysis
EPDM	Ethylene propylene elastomer
EPR	Electrochemical potentiokinetic reactivation
ER	Electrical resistance
OQ	Oil quenched

OTEC Ocean thermal energy conversion
OZ Organic zinc coating
PC Polycarbonate
PD Pit depth
PE Polyethylene
PFA Perfluoro (alkoxy-alkane) copolymer
PHSS Precipitation hardenable stainless steel
PPC Polymer modified Portland cement
PP Polypropylene
PR Polarization resistance
PT Dye penetrant survey
PTA Polythionic acids
PTFE Polytetrafluoroethylene
PU Polyurethane
PVC Poly(vinyl chloride)
PVDC Poly(vinylidene chloride)
PVDF Poly(vinylidene fluoride)
PWHT Post weld heat treatment
PWR Pressurized water reactor
QT Quenched and tempered
RH Relative humidity
RSI Ryzner saturation index
RT X-ray or gamma ray survey
RTP Reinforced thermoset plastics
RX Recrystallized
SAM Scanning Auger microscopy
SAW Submerged arc welding
SBR Styrene-butadiene rubber
SCC Stress corrosion cracking
SCE Saturated calomel electrode
SEM Scanning electron microscopy
SIMS Secondary ion mass spectroscopy
SMAW Shielded metal arc welding
SMLS Seamless pipe or tubing
SMYS Specified minimum yield strength
SRA Stress relief anneal
SRB Sulfate-reducing bacteria
SRC Solvent-refined coal
S/N Fatigue test
SRE Scanning reference electrode
SS Stainless steel
SSC Sulfide stress cracking
SSMS Spark sources mass spectroscopy
SSR Slow strain rate test
SSW Substitute seawater
STA Solution treated and aged

STEM	Scanning transmission electron microscopy
STQ	Solution treated and quenched
SW	Seawater
TEM	Transmission electron microscopy
TFE	Tetrafluoroethylene
TS	Tensile strength
TTS	Temperature, time, sensitization diagram
URD	Underground residential distribution systems
UT	Ultrasonic survey
UV	Ultraviolet spectroscopy
VCI	Volatile corrosion inhibitor
WFMT	Wet fluorescent magnetic particle inspection
WQ	Water quenched
WOL	Wedge-opening load test
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction
YS	Yield strength
ZRP	Zinc rich paint

STANDARD ABBREVIATIONS AND UNIT SYMBOLS

absolute	abs
academic degrees	use periods and run together (M.S., Ph.D., etc.)
alternating current, *n.*	AC
alternating current. *adj* .	A-C
American	Am.[a]
American wire gage	AWG
ampere	A
ampere hour	Ah
angstrom	Å
ante meridiem	a.m.
Association	Assn.[b]
atmosphere	atm
average	avg
barrel	bbl
becquerel	Bq
billion electronvolts	(use GeV, gigaelectronvolts)
Birmingham wire gage	BWG
brake horsepower	bhp
brake-horsepower hour	bhp · h
Brinell hardness number	HB (see ASTM E 10)
British thermal unit	Btu
Brown and Sharpe (gage)	B&S
bushel	bu
calorie	cal
candela	cd
centimetre	cm
centipoise	cP
centistokes	cSt
circular mil	cmil
coefficient	*spell out*
Company	Co.[b]
Corporation	Corp.[b]
coulomb	C
cubic	use exponential form[c]
cubic centimetre	cm^3
cubic decimetre	dm^3
curie	Ci
cycles per minute	cpm
cycles per second	(use Hz. hertz)
day	*spell out*
decibel	dB
degree (angle)	°
degree Celsius	°C
degree Fahrenheit	°F
degree Rankine	°R
degrees of freedom	df
Department	Dept.[b]
diameter	dia (in figures and tables only)
differential	d

direct current, *n*.	DC
direct current, *adj*.	D-C
Division	Div.[(b)]
dollar	$
effective horsepower	ehp
electromotive force	emf
electronvolt	eV
Engineers	Engrs.[(a)]
equation(s)	Eq(s)
farad	F
figure(s)	Fig(s).[(d)]
foot	ft
footcandle	fc
foot pound-force	ft · lbf (use for work, energy) (see lbf · ft)
gallon	gal
gauss	G
gilbert	Gb
grain	*spell out*
gram	g
gravity (acceleration)	*g*
gray	Gy
half hard	$^1/_2$ H
henry	H
hertz	Hz
horsepower	hp
horsepower hour	hp · h
hour	h
Hurter and Driffield scale (film density)	H&D
hydrogen ion concentration. negative logarithm of	pH
inch	in.
inch of mercury	in. Hg
inch of water	in. H_2O
inch pound-force	in · lbf (use for work, energy) (see lbf · in.)
inclusive	incl (in figures and tables only)
Incorporated	Inc.[(b)]
indicated horsepower	ihp
inside diameter	ID (in figures and tables only)
Institute	Inst.[(b)]
integrated neutron flux	nvt. n/cm^2
iron pipe size	IPS
joule	J
K alpha radiation	Kα
kelvin	K
kilocalorie	kcal
kilocycle per second	(see note on cycles per second)
kilogram	kg
kilogram-calorie	kg · cal
kilogram-force	kgf
kilogram metre	kg · m
kilometre	km
kilovolt	kV
kilovolt ampere	kVA
kiloelectronvolt	keV

(*Continued*)

kilovolt peak	kVp
kilowatt	kW
kilowatt hour	kWh
kip (1000 lbf)	*spell out*
kip (1000 lbf) per square inch	ksi
Knoop hardness number	HK
lambert	L
linear	*spell out*
litre	L
logarithm (common)	log
logarithm (natural)	ln
lumen	lm
lux	lx
magnetomotive force	mmf
mass-to-charge ratio	m/e
maximum	max (in figures and tables only)
maxwell	Mx
median effective concentration	EC_{50}
median effective dose	ED_{50}
median lethal concentration	LD_{50}
median lethal dose	LC_{50}
megacycles per second	(see note on cycles per second)
megawatt	MW
meta	*m*
metre	m
microampere	μA
microcurie	μCi
microfarad	μF
microgram	μg
microhenry	μH
microinch	μin.
microlitre	μL
micro-micro (prefix. use pico)	p
micrometre (formerly micron)	μm
microroentgen	μR
microsecond	μs
microvolt	μV
microwatt	μW
mil	*spell out*
mile	*spell out*
miles per hour	mph
milliampere	mA
milli-angstrom	mÅ
millicurie	mCi
milliequivalent	meq
milligram	mg
millihenry	mH
millilitre	mL
millimetre	mm
millimetre of mercury	mm Hg
million electronvolts	MeV
milliroentgen	mR
millisecond	ms
millivolt	mV
milliwatt	mW
minimum	min (in figures and tables only)
minute	min (spell out when used with minimum)

molal	*spell out*
molar	*M*
mole	mol
month (When followed by a date use Jan., Feb., March, April, May, June, July, Aug., Sept., Oct., Nov., Dec. When there is no date, spell out. Examples: Jan. 15, 1983; January 1983)	*spell out*
nanometre (formerly millimicron)	nm
National	Nat.[a]
newton	N
normal	*N*
number(s) (This abbreviation can often be omitted entirely. It is usually understood	No(s).[d]
oersted	Oe
ohm	Ω
ortho	*o*
ounce	oz
outside diameter	OD (in figures and tables only)
page	p.
pages	pp.
para	*p*
parts per billion	ppb
parts per million	ppm
pascal	Pa
per	use the diagonal line in expressions with unit symbols[e]
percent	%
pico (prefix)	p
picofarad	pF
pint	pt
poise	P
Poisson's ratio	μ (ν is preferred in applied mechanics)
post meridiem	p.m.
pound	lb
pound-force	lbf
pound-force foot	lbf · ft (use for torque) (see ft · lbf)
pound-force inch	lbf · in. (use for torque) (see in · lbf)
pound-force per square foot	lbf/ft^2
pound-force per square inch	psi or $lbf/in.^2$
pound-force per square inch absolute	psia
pound-force per square inch gage quart	psig
quart	qt
rad (dose unit)	rd
radian	rad
radio frequency, *n*.	rf

(*Continued*)

radio frequency, *adj* .	r-f
radius	R (in figures and tables only)
Railway	Ry.[b]
Railroad	R.R.[b]
reference(s)	Ref(s)
relative humidity	RH (in figures and tables only)
revolution per minute	r/min
revolution per second	r/s
Rockwell hardness, C scale	HRC
roentgen	R
root mean square	rms
Saybolt Furol seconds	SFS
Saybolt Universal seconds	SUS
second	s
secondary	*sec*
siemens	S
Society	Soc.[b]
socket joint (tables and drawings only)	$\frac{S}{J}$
specific gravity	sp gr
square	use exponential form (exception: psi, ksi)[c]
standard taper (tables and drawings only)	$\frac{T}{S}$
steradian	sr
stokes	St
tensile strength	*spell out*
tertiary	*tert*
tesla	T
thousand electronvolts	keV
thousand pounds	kip
thousand pounds-force per square inch	ksi
ton	*spell out*
torr	*spell out*
United States, *n.*	*spell out*
United States, *adj* .	U.S.
Unites States Pharmacopeia	USP
versus	*spell out*
Vickers hardness number	HV
volt	V
volume (of a publication)	Vol[d]
watt	W
watt hour	Wh
weber	Wb
week	*spell out*
yard	yd
year	*spell out*
Young's modulus	*E*

[a] In footnotes and references only.
[b] At end of name only.
[c] With unit symbols only.
[d] Only when followed by a number.
[e] Exceptions: cpm, mph, psi.

Source: *Manual 20*, pp. 13–15, ASTM, 1995. Reprinted, with permission, copyright ASTM.

SI QUICK REFERENCE GUIDE

Symbol	Name	Quantity	Formula
A	ampere	electric current	base unit
Bq	becquerel	activity (of a radio nuclide)	1/s
C	coulomb	electric charge	A·s
°C	degree Celsius	temperature interval	°C = K
cd	candela	luminous intensity	base unit
F	farad	electric capacitance	C/V
Gy	gray	absorbed dose	J/kg
g	gram	mass	kg/1000
H	henry	inductance	Wb/A
Hz	hertz	frequency	1/s
ha	hectare*	area	10 000 m^2
J	joule	energy, work, heat	N·m
K	kelvin	temperature	base unit
kg	kilogram	mass	base unit
L	litre	volume	m^3/1000
lm	lumen	luminous flux	cd·sr
lx	lux	illuminance	lm/m^2
m	metre	length	base unit
mol	mole	amount of substance	base unit
N	newton	force	$kg·m/s^2$
Ω	ohm	electric resistance	V/A
Pa	pascal	pressure, stress	N/m^2
rad	radian	plane angle	m/m (dimensionless)
S	siemens	electric conductance	A/V
Sv	sievert	dose equivalent	J/kg
s	second	time	base unit
sr	steradian	solid angle	m^2/m^2 (dimensionless)
T	tesla	magnetic flux density	Wb/m^2
t	tonne, metric ton	mass	1000 kg; Mg
V	volt	electric potential	W/A
W	watt	power, radiant flux	J/s
Wb	weber	magnetic flux	V·s
	*allowed with SI		

Source: *Book of Standards*, Vol. 03.02, p. 656, ASTM, 2000. Reprinted, with permission, copyright ASTM.

INTERNATIONAL SYSTEM OF UNITS (SI)

The International System of Units (SI for short) is a modernized version of the metric system. It is built upon seven base units and two supplementary units. Derived units are related to base and supplementary units by formulas in the righthand column. Symbols for units with specific names are given in parentheses. This information is adapted from the revised "Metric Practice Guide," ASTM Standard E380. Factors for converting U.S. customary units to SI units are given in the table entitled "General Conversion Factors."

Quantity	Unit	Formula
	Base Units	
length	metre (m)	
mass	kilogram (kg)	
time	second (s)	
electric current	ampere (A)	
thermodynamic temperature	kelvin (K)	
amount of substance	mole (mol)	
luminous intensity	candela (cd)	
	Supplementary Units	
plane angle	radian (rad)	
solid angle	steradian (sr)	
	Derived Units	
acceleration	metre per second squared	m/s^2
activity (of a radioactive source)	disintegration per second	(disintegration)/s
angular acceleration	radian per second squared	rad/s^2
angular velocity	radian per second	rad/s
area	square metre	m^2
density	kilogram per cubic metre	kg/m^3
electric capacitance	farad (F)	A·s/V
electric conductance	stemens (S)	A/V
electric field strength	volt per metre	V/m
electric inductance	henry (H)	V·s/A
electric potential difference	volt (V)	W/A
electric resistance	ohm (Ω)	V/A
electromotive force	volt (V)	W/A
energy	joule (J)	N·m
entropy	joule per kelvin	j/K
force	newton (N)	$kg·m/s^2$
frequency	hertz (Hz)	(cycle)/s
illuminance	lux (lx)	lm/m^2
luminance	candela per square metre	cd/m^2
luminous flux	lumen (lm)	cd·sr
magnetic field strength	ampere per metre	A/m
magnetic flux	weber (Wb)	V·s
magnetic flux density	tesla (T)	Wb/m^2
magnetomotive force	ampere (A)	–
power	watt (W)	J/s
pressure	pascal (Pa)	N/m^2
quantity of electricity	coulomb (C)	A·s
quantity of heat	joule (J)	N·m
radiant intensity	watt per steradian	W/sr
specific heat	joule per kilogram-kelvin	J/kg·K

(*Continued*)

INTERNATIONAL SYSTEM OF UNITS (SI) (*Continued*)

Quantity	Unit	Formula
stress	pascal (Pa)	N/m^2
thermal conductivity	watt per metre-kelvin	W/m·K
velocity	metre per second	m/s
viscosity, dynamic	pascal-second	Pa·s
viscosity, kinematic	square metre per second	m^2/s
voltage	volt (V)	W/A
volume	cubic metre	m^3
wavenumber	reciprocal metre	(wave)/m
work	joule (J)	N·m

Multiplication Factors	Prefix	SI Symbol
$1\,000\,000\,000\,000 = 10^{12}$	tera	T
$1\,000\,000\,000 = 10^{9}$	giga	G
$1\,000\,000 = 10^{6}$	mega	M
$1\,000 = 10^{3}$	kilo	k
$100 = 10^{2}$	hecto*	h
$10 = 10^{1}$	deka*	da
$0.1 = 10^{-1}$	deci*	d
$0.01 = 10^{-2}$	centi*	c
$0.001 = 10^{-3}$	milli	m
$0.000\,001 = 10^{-6}$	micro	μ
$0.000\,000\,001 = 10^{-9}$	nano	n
$0.000\,000\,000\,001 = 10^{-12}$	pico	p
$0.000\,000\,000\,000\,001 = 10^{-15}$	femto	f
$0.000\,000\,000\,000\,000\,001 = 10^{-18}$	atto	a

*To be avoided where possible.

Source: ASM, *Metals Progress Databook*, p. 183, 1974. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

GENERAL CONVERSION FACTORS

Unit	Conversion to	Multiply by	Reciprocal
Linear Measure			
mil (0.001 inch)	micrometre	25.4	0.03937
mil (0.001 inch)	millimetre	0.0254	39.37
inch	millimetre	25.4	0.03937
foot	metre	0.3048	3.281
yard	metre	0.9144	1.0936
mile	kilometre	1.6093	0.6214
nautical mile	kilometre	1.8532	0.5396
Square Measure			
square inch	square millimetre	645.2	0.00155
square inch	square centimetre	6.452	0.155
square foot	square metre	0.0929	10.764
square yard	square metre	0.8361	1.196
acre	hectare	0.4047	2.471
acre	square metre	4047.	0.0002471
acre	square foot	43560.	0.00002296
square mile	acre	640.	0.001562
square mile	square kilometre	2.590	0.3863
Volume			
cubic inch	cubic centimetre	16.387	0.06102
cubic foot	cubic metre	0.02832	35.31
cubic foot	gallon (U.S.)	7.48	0.1337
cubic foot	litre	28.32	0.03531
cubic yard	cubic metre	0.7646	1.3079
ounce (U.S., liq.)	cubic centimetre	29.57	0.03382
quart (U.S. liq.)	litre	0.9464	1.0566
gallon (U.S.)	gallon (Imperial)	0.8327	1.2009
gallon (U.S.)	litre	3.785	0.2642
barrel (U.S. Petroleum)	gallon (U.S.)	42.	0.0238
barrel (U.S. Petroleum)	litre	158.98	0.00629
Mass			
grain	milligram	64.8	0.01543
ounce (avoirdupois)	gram	28.35	0.03527
pound (avoirdupois)	kilogram	0.4536	2.205
short ton	metric ton	0.9072	1.1023
long ton	metric ton	1.0161	0.9842
Pressure or Stress			
atmosphere	mm Hg @ 0°C	760.	0.001316
atmosphere	pound force per inch^2	14.696	0.06805
atmosphere	bar	1.013	0.9872
atmosphere	megapascal (MPa)	0.1013	9.872
torr (mm Hg)	pascal	133.32	0.007501
inch of water	pascal	248.8	0.004019
foot of water	pound force per inch^2	0.4335	2.307
dyne per centimetre^2	pascal	0.1000	10.00

(*Continued*)

GENERAL CONVERSION FACTORS (*Continued*)

Unit	Conversion to	Multiply by	Reciprocal
(Pressure or Stress)			
pound force per inch^2 (psi)	kilopascal (kPa)	6.895	0.1450
kip per inch^2 (ksi)	megapascal (MPa)	6.895	0.1450
pound force per inch^2	bar	0.06895	14.50
kip per inch^2	kilogram per millimetre^2	0.7031	1.4223
Work, Heat, and Energy			
British thermal unit (Btu)	joule	1055.	0.0009479
foot pound - force	joule	1.356	0.7375
calorie	joule	4.187	0.2389
Btu	foot pound - force	778.	0.001285
kilocalorie	Btu	3.968	0.252
Btu	kilogram metre	107.56	0.009297
Btu per hour	watt	0.2929	3.414
watthour	joule	3600.	0.0002778
horse power	kilowatt	0.7457	1.341
Thermal Properties			
(Btu per foot^2, hour, °F) per inch	(kilocalorie per metre^2, hour, °C) per metre	0.1240	8.064
(Btu per foot^2, hour, °F) per inch	watt per metre, K	0.144	6.944
Btu per foot^2, hour, °F	kilocalorie per metre^2, hour, °C	4.882	0.2048
Btu per foot^2, hour, °F	watt per metre^2, K	5.674	0.1762
Btu per foot^2	kilocalorie per metre^2	2.712	0.3687
Btu per foot^2	joule per metre^2	11360.	0.00008803
Miscellaneous			
pound per foot^3	kilogram per metre^3	16.02	0.06242
pound per gallon (U.S.)	gram per litre	119.8	0.00835
grains per 100 foot^3	milligram per metre^3	22.88	0.0437
ounces per foot^2	gram per metre^2	305.2	0.003277
pound mole (gas)	cubic foot (STP)	359.	0.00279
gram mole (gas)	litre (STP)	22.4	0.0446
day	minute	1440.	0.000694
week	hour	168.	0.00595
year	hour	8766.	0.0001141
U.S. bag cement	kilogram	42.63	0.02346
gallon (U.S.) per bag cement	litre per kilogram	0.0888	11.26
ksi (inch)^{12}	megapascal (metre)^{12}	1.0989	0.9100
cubic foot of water (60°F)	pound of water	62.37	0.01603
board foot	cubic metre	0.00236	423.7
milliampere per foot^2	milliampere per metre^2	10.76	0.0929
gallons (U.S.) per minute	metre^3 per day	5.451	0.1835
pound - force	newton	4.448	0.2248

METRIC AND DECIMAL EQUIVALENTS OF FRACTIONS OF AN INCH

Inches		mm	Inches		mm
1/64	0.015	0.3968	33/64	0.516	13.0966
1/32	0.031	0.7937	17/32	0.531	13.4934
3/64	0.047	1.1906	35/64	0.547	13.8903
1/16	0.063	1.5876	9/16	0.563	14.2872
5/64	0.078	1.9843	37/64	0.578	14.6841
3/32	0.094	2.3812	19/32	0.594	15.0809
7/64	0.109	2.7780	39/64	0.609	15.4778
1/8	0.125	3.1749	5/8	0.625	15.8747
9/64	0.141	3.5718	41/64	0.641	16.2715
5/32	0.156	3.9686	21/32	0.656	16.6684
11/64	0.172	4.3655	43/64	0.672	17.0653
3/16	0.188	4.7624	11/16	0.688	17.4621
13/64	0.203	5.1592	45/64	0.703	17.8590
7/32	0.219	5.5561	23/32	0.719	18.2559
15/64	0.234	5.9530	47/64	0.734	18.6527
1/4	0.250	6.3498	3/4	0.750	19.0496
17/64	0.266	6.7467	49/64	0.766	19.4465
9/32	0.281	7.1436	25/32	0.781	19.8433
19/64	0.297	7.5404	51/64	0.797	20.2402
5/16	0.313	7.9373	13/16	0.813	20.6371
21/64	0.328	8.3342	53/64	0.828	21.0339
11/32	0.344	8.7310	27/32	0.844	21.4308
13/64	0.359	9.1279	55/64	0.859	21.8277
3/8	0.375	9.5248	7/8	0.875	22.2245
25/64	0.391	9.9216	57/64	0.891	22.6214
13/32	0.406	10.3185	29/32	0.906	23.0183
27/64	0.422	10.7154	59/64	0.922	23.4151
7/16	0.438	11.1122	15/16	0.938	23.8120
29/64	0.453	11.5091	61/64	0.953	24.2089
15/32	0.469	11.9060	31/32	0.969	24.6057
31/64	0.484	12.3029	63/64	0.984	25.0026
1/2	0.500	12.6997	–	1.000	25.3995

CONDENSED METRIC PRACTICE GUIDE FOR CORROSION[1],[2]

Multiply	By	To Convert to SI Units:
	Area	
inch^2	645.2	millimetre^2 (mm^2)
inch^2	6.452	centimetre^2 (cm^2)
foot^2	0.092 90	metre^2 (m^2)
foot^2	929.0	centimetre^2 (cm^2)
yard^2	0.836 1	metre^2 (m^2)
	Bending Moment (Torque)	
dyne centimetre	0.000 000 1	newton metre (N·m)
pound-force inch	0.113 0	newton metre (N·m)
pound-force foot	1.356	newton metre (N·m)
	Corrosion Rate	
mil per year (mpy)	0.025 40	millimetre per year (mm/y)[a]
mil per year	25.40	micrometre per year (μm/y)
inch per year (ipy)	25.40	millimetre per year (mm/y)
inch per month (ipm)	304.8	millimetre per year (mm/y)
milligram per decimetre^2 day (mdd)	0.100 0	gram per metre^2 day (g/m^2·d)[a]
milligram per decimetre^2 day	0.004 167	gram per metre^2 hour (g/m^2 ·h)
milligram per decimetre^2 day	100.0	milligram per metre^2 day (mg/m^2·d)
	Current Density	
milliampere per millimetre^2	1000.	ampere per metre^2 (A/m^2)
milliampere per centimetre^2	10.00	ampere per metre^2 (A/m^2)
microampere per centimetre^2	0.010 00	ampere per metre^2 (A/m^2)
milliampere per metre^2	0.001 000	ampere per metre^2 (A/m^2)
microampere per millimetre^2	1.000	ampere per metre^2 (A/m^2)
milliampere per foot^2	10.76	milliampere per metre^2 (mA/m^2)
ampere per inch^2	1 550.	ampere per metre^2 (A/m^2)
ampere per foot^2	10.76	ampere per metre^2 (A/m^2)
ampere per centimetre^2	10 000.	ampere per metre^2 (A/m^2)
ampere per decimetre^2	100.0	ampere per metre^2 (A/m^2)
	Energy	
British thermal unit (Btu) (60°F)	1055.	joule (J)
calorie (mean)	4.190	joule (J)
foot-pound-force	1.356	joule (J)
kilocalorie (mean)	4190.	joule (J)
kilowatt hour	3.600	megajoule (MJ)
	Flow, Volume Per Unit Time	
foot^3 per second	0.028 32	metre^3 per second (m^3/s)
foot^3 per second	2445.	metre^3 per day (m^3/d)
foot^3 per minute	40.78	metre^3 per day (m^3/d)
gallon (U.S. liquid) per minute	5.451	metre^3 per day (m^3/d)
gallon (U.S. liquid) per hour	0.090 85	metre^3 per day (m^3/d)
gallon (U.S. liquid) per day	0.003 785	metre^3 per day (m^3/d)

(*Continued*)

CONDENSED METRIC PRACTICE GUIDE FOR CORROSION[1],[2] (*Continued*)

Multiply	By	To Convert to SI Units:
	Force	
dyne	0.000 01	newton (N)
kilogram-force	9.807	newton (N)
ounce-force	0.278 0	newton (N)
pound-force	4.448	newton (N)
	Length	
angstrom	1×10^{-10}	metre (m)
angstrom	0.100 0	nanometre (nm)
micron	0.001 0	millimetre (mm)
micron	1.000	micrometre (μm)
mil	0.025 40	millimetre (mm)
mil	25.40	micrometre (μm)
inch	2.540	centimetre (cm)
inch	25.40	millimetre (mm)
inch	25 400.	micrometre (μm)
foot	0.304 8	metre (m)
yard	0.914 4	metre (m)
mile	1.609	kilometre (km)
	Mass	
grain	64.80	milligram (mg)
ounce	28.35	gram (g)
pound	0.453 6	kilogram (kg)
pound	453.6	gram (g)
ton (short, 2,000 lb)	907.2	kilogram (kg)
	Mass Per Unit Area	
ounce-mass per foot^2	305.1	gram per metre^2 (g/m^2)
pound-mass per foot^2	4.882	kilogram per metre^2 (kg/m^2)
pound-mass per foot^2	4882.	gram per metre^2 (g/m^2)
pound-mass per inch^2	703.1	kilogram per metre^2 (kg/m^2)
	Mass Per Unit Volume (Density)	
gram per centimetre^3	1000.	kilogram per metre^3 (kg/m^3)
ounce (mass) per inch^3	1730.	kilogram per metre^3 (kg/m^3)
ounce (mass) per gallon (U.S. liquid)	7.489	kilogram per metre^3 (kg/m^3)
ounce (mass) per gallon (U.S. liquid)	7.489	gram per litre (g/L)
pound (mass) per foot^3	16.02	kilogram per metre^3 (kg/m^3)
pound (mass) per gallon (U.S. liquid)	119.8	kilogram per metre^3 (kg/m^3)
	Power	
Btu (thermochemical) per second	1054.	watt (W)
horsepower (electric)	746.0	watt (W)
kilocalorie (thermochemical) per second	4184.	watt (W)

(*Continued*)

CONDENSED METRIC PRACTICE GUIDE FOR CORROSION[1],[2] (*Continued*)

Multiply	By	To Convert to SI Units:
	Pressure or Stress	
atmosphere (normal = 760 torr)	101 300.	pascal (Pa)
centimetre of mercury (0°C)	1 333.	pascal (Pa)
dyne per centimetre^2	0.100 0	pascal (Pa)
inch of mercury (60°F)	3377.	pascal (Pa)
inch of water (60°F)	248.8	pascal (Pa)
kilogram-force per metre^2	9.807	pascal (Pa)
kip per inch^2	6.895	megapascal (MPa)
pound-force per inch^2)	6.895	kilopascal (kPa)
pound-force per foot^2	47.88	pascal (Pa)
	Stress Intensity	
(pound-force per inch^2) inch$^{1/2}$	0.034 75	newton per millimetre$^{3/2}$ (N/mm$^{3/2}$)
(kip per inch^2) inch$^{1/2}$	34.75	newton per millimetre$^{3/2}$ (N/mm$^{3/2}$)
(pound-force per inch^2) inch$^{1/2}$	0.001 099	megapascal metre$^{1/2}$ (MPa·m$^{1/2}$)[a]
(kip per inch^2) inch$^{1/2}$	1.099	megapascal metre$^{1/2}$ (MPa·m$^{1/2}$)[a]
	Temperature	
degree Celsius	$T_K = T_C^\circ + 273.15$	kelvin (k)
degree Fahrenheit	$T_C^\circ = (T_F^\circ - 32)/1.8$	degree Celsius (°C)
	Time	
hour (mean solar)	3600.	second (s)
day (mean solar)	86 400.	second (s)
month (calendar)	2.628	megasecond (Ms)
year (calendar)	31.54	megasecond (Ms)
	Velocity (Speed)	
inch per second	25.40	millimetre per second (mm/s)
foot per second	0.304 8	metre per second (m/s)
inch per minute	0.423 3	millimetre per second (mm/s)
mile per hour	1.609	kilometre per hour (km/h)
mile per hour	0.447 0	metre per second (m/s)
	Volume	
inch^3	16.39	centimetre^3 (cm^3)
fluid ounce (U.S.)	29.57	centimetre^3 (cm^3)
pint (U.S. liquid)	473.2	centimetre^3 (cm^3)
quart (U.S. liquid)	946.4	centimetre^3 (cm^3)
gallon (U.S. liquid)	0.003 785	metre^3 (m^3)
gallon (U.S. liquid)	3.785	litre (L)

[1] This condensed guide is under the jurisdiction of ASTM Committee G-1 on Corrosion of Metals.
[2] This guide is based on ASTM E 380.
[a] Preferred units.

Source: ASTM, E 380. Reprinted, with permission, copyright ASTM.

RELATIONSHIPS AMONG SOME OF THE UNITS COMMONLY USED FOR CORROSION RATES

Unit	mdd	Factor for Conversion to				
		$g/m^2/d$	$\mu m/yr$	mm/yr	mils/yr	in./yr
Milligrams per square decimetre per day (mdd)	1	0.1	36.5/*d*	0.365/*d*	1.144/*d*	0.00144/*d*
Grams per square metre per day ($g/m^2/d$)	10	1	365/*d*	0.365/*d*	14.4/*d*	0.0144/*d*
Micrometres per year ($\mu m/yr$)	0.0274*d*	0.00274*d*	1	0.001	0.0394	0.0000394
Millimetres per year (mm/yr)	27.4*d*	2.74*d*	1000	1	39.4	0.0394
Mils per year (mils/yr)	0.696*d*	0.0696*d*	25.4	0.0254	1	0.001
Inches per year (in/yr)	696*d*	69.6*d*	25400	25.4	1000	1

Note: *d* is metal density in grams per cubic centimetre (g/cm^3).

Source: *Manual 20*, pp. 19–20, ASTM,1995. Reprinted, with permission, copyright ASTM.

TEMPERATURE CONVERSIONS
Celsius—Fahrenheit

The central figures in bold type refer to the temperatures either in degrees Celsius or degrees Fahrenheit which require conversion. The corresponding temperatures in degrees Fahrenheit or degrees Celsius will be found to the right or left respectively.

$°C = 5/9\ (°F - 32°)$ $°F = 9/5\ (°C) + 32°$

°C		°F	°C		°F	°C		°F	°C		°F	°C		°F	°C		°F	°C		°F
−273	**−459**		−62.2	**−80**	−112	−11.1	**12**	54	4.4	**40**	104	20	**68**	154	35.6	**96**	205	115	**240**	464
−262	**−440**		−59.3	**−75**	−103	−10.6	**13**	55	5	**41**	106	20.6	**69**	156	36.1	**97**	207	121	**250**	482
−251	**−420**		−56.7	**−70**	−94	−10	**14**	57	5.6	**42**	108	21.1	**70**	158	36.7	**98**	208	127	**260**	500
−240	**−400**		−53.9	**−65**	−85	−9.4	**15**	59	6.1	**43**	109	21.7	**71**	160	37.2	**99**	210	132	**270**	518
−229	**−380**		−51.1	**−60**	−76	−8.9	**16**	61	6.7	**44**	111	22.2	**72**	162	37.8	**100**	212	138	**280**	536
−218	**−360**		−48.3	**−55**	−67	−8.3	**17**	63	7.2	**45**	113	22.8	**73**	163	41	**105**	221	143	**290**	554
−207	**−340**		−45.5	**−50**	−58	−7.8	**18**	64	7.8	**46**	115	23.3	**74**	165	43	**110**	230	149	**300**	572
−196	**−320**		−42.8	**−45**	−49	−7.2	**19**	66	8.3	**47**	117	23.9	**75**	167	46	**115**	230	154	**310**	590
−184	**−300**		−40.0	**−40**	−40	−6.7	**20**	68	8.9	**48**	118	24.4	**76**	169	49	**120**	248	160	**320**	608
−173	**−280**		−37.2	**−35**	−31	−6.1	**21**	70	9.4	**49**	120	25	**77**	171	52	**125**	257	165	**330**	626
−162	**−260**	−436	−34.4	**−30**	−22	−5.6	**22**	72	10	**50**	122	25.6	**78**	172	54	**130**	266	171	**340**	644
−151	**−240**	−400	−31.7	**−25**	−13	−5	**23**	73	10.6	**51**	124	26.1	**79**	174	57	**135**	275	177	**350**	662
−140	**−220**	−364	−28.9	**−20**	−4	−4.4	**24**	75	11.1	**52**	126	26.7	**80**	176	60	**140**	284	182	**360**	680
−129	**−200**	−328	−26.1	**−15**	5	−3.9	**25**	77	11.7	**53**	127	27.2	**81**	178	63	**145**	293	188	**370**	696
−123	**−190**	−310	−23.3	**−10**	14	−3.3	**26**	79	12.2	**54**	129	27.8	**82**	180	66	**150**	302	193	**380**	716
−118	**−180**	−292	−20.6	**−5**	23	−2.8	**27**	81	12.8	**55**	131	28.3	**83**	181	68	**155**	311	199	**390**	734
−112	**−170**	−274	−17.8	**0**	32	−2.2	**28**	82	13.3	**56**	133	28.9	**84**	183	71	**160**	320	204	**400**	752
−107	**−160**	−256	−17.2	**1**	34	−1.7	**29**	84	13.9	**57**	135	29.4	**85**	185	74	**165**	329	210	**410**	770
−101	**−150**	−238	−16.7	**2**	36	−1.1	**30**	86	14.4	**58**	136	30	**86**	187	77	**170**	338	215	**420**	788
−96	**−140**	−220	−16.1	**3**	37	−0.6	**31**	88	15	**59**	138	30.6	**87**	189	79	**175**	347	221	**430**	806
−90	**−130**	−202	−15.6	**4**	39	0	**32**	90	15.6	**60**	140	31.1	**88**	190	82	**180**	356	226	**440**	824
−84	**−120**	−184	−15	**5**	41	0.6	**33**	91	16.1	**61**	142	31.7	**89**	192	85	**185**	365	232	**450**	842
−79	**−110**	−166	−14.4	**6**	43	1.1	**34**	93	16.7	**62**	144	32.2	**90**	194	88	**190**	374	238	**460**	860
−76	**−105**	−157	−13.9	**7**	45	1.7	**35**	95	17.2	**63**	145	32.8	**91**	196	91	**195**	383	243	**470**	878
−73.3	**−100**	−148	−13.3	**8**	46	2.2	**36**	97	17.8	**64**	147	33.3	**92**	198	93	**200**	392	249	**480**	896
−71.0	**−95**	−139	−12.9	**9**	48	2.8	**37**	99	18.3	**65**	149	33.9	**93**	199	99	**210**	410	254	**490**	914
−67.8	**−90**	−130	−12.2	**10**	50	3.3	**38**	100	18.9	**66**	151	34.4	**94**	201	104	**220**	428	260	**500**	932
−65.0	**−85**	−121	−11.7	**11**	52	3.9	**39**	102	19.4	**67**	153	35	**95**	203	110	**230**	446	265	**510**	950

°C		°F	°C		°F	°C		°F	°C		°F	°C		°F	°C		°F	°C		°F
271	**520**	968	471	**880**	1616	671	**1240**	2264	871	**1600**	2912	1071	**1960**	3560	1271	**2320**	4208	1471	**2680**	4856
276	**530**	986	476	**890**	1634	677	**1250**	2282	877	**1610**	2930	1077	**1970**	3578	1277	**2330**	4226	1477	**2690**	4874
282	**540**	1004	482	**900**	1652	682	**1260**	2300	882	**1620**	2948	1082	**1980**	3596	1282	**2340**	4244	1482	**2700**	4892
288	**550**	1022	487	**910**	1670	688	**1270**	2318	888	**1630**	2966	1088	**1990**	3614	1288	**2350**	4262	1488	**2710**	4910
293	**560**	1040	493	**920**	1688	693	**1280**	2336	893	**1640**	2984	1093	**2000**	3632	1293	**2360**	4280	1493	**2720**	4928
299	**570**	1058	498	**930**	1706	699	**1290**	2354	899	**1650**	3002	1099	**2010**	3650	1299	**2370**	4298	1499	**2730**	4946
304	**580**	1076	504	**940**	1724	704	**1300**	2372	904	**1660**	3020	1104	**2020**	3668	1304	**2380**	4316	1504	**2740**	4964
310	**590**	1094	510	**950**	1743	710	**1310**	2390	910	**1670**	3038	1110	**2030**	3686	1310	**2390**	4334	1510	**2750**	4982
315	**600**	1112	515	**960**	1760	716	**1320**	2408	916	**1680**	3056	1116	**2040**	3704	1316	**2400**	4352	1516	**2760**	5000
321	**610**	1130	520	**970**	1778	721	**1330**	2426	921	**1690**	3074	1121	**2050**	3722	1321	**2410**	4370	1521	**2770**	5018
326	**620**	1148	526	**980**	1796	727	**1340**	2444	927	**1700**	3092	1127	**2060**	3740	1327	**2420**	4388	1527	**2780**	5036
332	**630**	1166	532	**990**	1814	732	**1350**	2462	932	**1710**	3110	1132	**2070**	3758	1332	**2430**	4406	1532	**2790**	5054
338	**640**	1184	538	**1000**	1832	738	**1360**	2480	938	**1720**	3128	1138	**2080**	3776	1338	**2440**	4424	1538	**2800**	5072
343	**650**	1202	543	**1010**	1850	743	**1370**	2498	943	**1730**	3146	1143	**2090**	3794	1343	**2450**	4442	1543	**2810**	5090
349	**660**	1220	549	**1020**	1868	749	**1380**	2516	949	**1740**	3164	1149	**2100**	3812	1349	**2460**	4460	1549	**2820**	5108
354	**670**	1238	554	**1030**	1886	754	**1390**	2534	954	**1750**	3182	1154	**2110**	3830	1354	**2470**	4478	1554	**2830**	5126
360	**680**	1256	560	**1040**	1904	760	**1400**	2552	960	**1760**	3200	1160	**2120**	3848	1360	**2480**	4496	1560	**2840**	5144
365	**690**	1274	565	**1050**	1922	766	**1410**	2570	966	**1770**	3218	1166	**2130**	3866	1366	**2490**	4514	1566	**2850**	5162
371	**700**	1292	571	**1060**	1940	771	**1420**	2588	971	**1780**	3236	1171	**2140**	3884	1371	**2500**	4532	1571	**2860**	5180
376	**710**	1310	576	**1070**	1958	777	**1430**	2606	977	**1790**	3254	1177	**2150**	3902	1377	**2510**	4550	1577	**2870**	5198
382	**720**	1328	582	**1080**	1976	782	**1440**	2624	982	**1800**	3272	1182	**2160**	3920	1382	**2520**	4568	1582	**2880**	5216
387	**730**	1346	587	**1090**	1994	788	**1450**	2642	988	**1810**	3290	1188	**2170**	3938	1388	**2530**	4586	1588	**2890**	5234
393	**740**	1364	593	**1100**	2012	793	**1460**	2660	993	**1820**	3308	1193	**2180**	3956	1393	**2540**	4604	1593	**2900**	5252
399	**750**	1382	598	**1110**	2030	799	**1470**	2678	999	**1830**	3326	1199	**2190**	3974	1399	**2550**	4622	1599	**2910**	5270
404	**760**	1400	604	**1120**	2048	804	**1480**	2696	1004	**1840**	3344	1204	**2200**	3992	1404	**2560**	4640	1604	**2920**	5288
410	**770**	1418	610	**1130**	2066	810	**1490**	2714	1010	**1850**	3362	1210	**2210**	4010	1410	**2570**	4658	1610	**2930**	5306
415	**780**	1436	615	**1140**	2084	816	**1500**	2732	1016	**1860**	3380	1216	**2220**	4028	1416	**2580**	4676	1616	**2940**	5324
421	**790**	1454	620	**1150**	2102	821	**1510**	2750	1021	**1870**	3398	1221	**2230**	4046	1421	**2590**	4694	1621	**2950**	5342
426	**800**	1471	626	**1160**	2120	827	**1520**	2768	1027	**1880**	3344	1227	**2240**	4064	1427	**2600**	4712	1627	**2960**	5360
432	**810**	1490	631	**1170**	2138	832	**1530**	2786	1032	**1890**	3434	1232	**2250**	4082	1432	**2610**	4730	1632	**2970**	5378
438	**820**	1508	637	**1180**	2156	838	**1540**	2804	1038	**1900**	3452	1258	**2260**	4100	1438	**2620**	4748	1638	**2980**	5396
443	**830**	1526	642	**1190**	2174	843	**1550**	2822	1043	**1910**	3470	1243	**2270**	4118	1443	**2630**	4766	1643	**2990**	5414
449	**840**	1544	648	**1200**	2192	849	**1560**	2840	1049	**1920**	3488	1249	**2280**	4136	1449	**2640**	4784	1649	**3000**	5432
454	**850**	1562	653	**1210**	2210	854	**1570**	2858	1054	**1930**	3506	1254	**2290**	4154	1454	**2650**	4802			
460	**860**	1580	660	**1220**	2228	860	**1580**	2876	1060	**1940**	3524	1260	**2300**	4172	1460	**2660**	4820			
465	**870**	1598	666	**1230**	2246	866	**1590**	2894	1066	**1950**	3542	1266	**2310**	4190	1466	**2670**	4838			

ENGLISH/METRIC (SI) STRESS CONVERSION FACTORS

Look up stress to be converted In bold type column. If in Ksi (1,000 psi), read kg/mm² and MPa in righthand column. If in kg/mm², read ksi in lefthand column.
Note: 1 MPa (megapascal) = 1 MN per m² (meganewton per square metre).

ksi		kg/mm²	MPa	ksi		kg/mm²	MPa	ksi		kg/mm²	MPa	ksi		kg/mm²	MPa
–	**0**	–	–	35.55	**25**	17.58	172.4	71.10	**50**	35.16	344.7	106.65	**75**	52.74	517.1
1.42	**1**	0.70	6.89	36.97	**26**	18.28	179.3	72.52	**51**	35.86	351.6	108.07	**76**	53.45	524.0
2.84	**2**	1.41	13.79	38.39	**27**	18.99	186.2	73.94	**52**	36.57	358.5	109.49	**77**	54.15	530.9
4.27	**3**	2.11	20.68	39.82	**28**	19.69	193.1	75.37	**53**	37.27	365.4	110.92	**78**	54.85	537.8
5.69	**4**	2.81	27.57	41.24	**29**	20.39	199.9	76.79	**54**	37.97	372.3	112.34	**79**	55.56	544.7
7.11	**5**	3.52	34.47	42.66	**30**	21.10	206.8	78.21	**55**	38.68	379.2	113.76	**80**	56.26	551.6
8.53	**6**	4.22	41.37	44.08	**31**	21.80	213.7	79.63	**56**	39.38	386.1	115.18	**81**	56.96	558.5
9.95	**7**	4.92	48.26	45.50	**32**	22.50	220.6	81.05	**57**	40.08	393.0	116.60	**82**	57.67	565.4
11.38	**8**	5.63	55.16	46.93	**33**	23.21	227.5	82.48	**58**	40.79	399.0	118.03	**83**	58.37	572.3
12.80	**9**	6.33	62.05	48.35	**34**	23.91	234.4	83.90	**59**	41.49	406.8	119.45	**84**	59.07	579.2
14.22	**10**	7.03	68.95	49.77	**35**	24.61	241.3	85.32	**60**	42.19	413.7	120.87	**85**	59.77	586.1
15.64	**11**	7.74	75.84	51.19	**36**	25.32	248.2	86.74	**61**	42.90	420.6	122.29	**86**	60.48	593.0
17.06	**12**	8.44	82.74	52.61	**37**	26.02	255.1	88.16	**62**	43.60	427.5	123.71	**87**	61.18	599.8
18.49	**13**	9.14	89.63	54.04	**38**	26.72	262.0	89.59	**63**	44.30	434.4	124.14	**88**	61.88	606.7
19.91	**14**	9.85	96.53	55.46	**39**	27.43	268.9	91.01	**64**	45.01	441.3	126.55	**89**	62.59	613.6
21.33	**15**	10.55	103.4	56.88	**40**	28.13	275.8	92.43	**65**	45.71	448.2	127.98	**90**	63.29	620.5
22.75	**16**	11.25	110.3	58.30	**41**	28.83	282.7	93.85	**66**	46.41	455.1	129.40	**91**	63.99	627.4
24.17	**17**	11.95	117.2	59.72	**42**	29.54	289.6	95.27	**67**	47.12	462.0	130.82	**92**	64.70	634.3
25.60	**18**	12.66	124.1	61.15	**43**	30.24	296.5	96.70	**68**	47.82	468.8	132.25	**93**	65.40	641.2
27.02	**19**	13.36	131.0	62.57	**44**	30.94	303.4	98.12	**69**	48.52	475.7	133.67	**94**	66.10	648.1
28.44	**20**	14.06	137.9	63.99	**45**	31.65	310.3	99.54	**70**	49.23	482.6	135.09	**95**	66.81	655.0
29.86	**21**	14.77	144.8	65.41	**46**	32.35	317.2	100.96	**71**	49.93	489.5	136.51	**96**	67.51	661.9
31.28	**22**	15.47	151.7	66.83	**47**	33.05	324.1	102.38	**72**	50.63	496.4	137.93	**97**	68.21	668.8
32.71	**23**	16.17	158.6	68.26	**48**	33.76	331.0	103.81	**73**	51.34	503.3	139.36	**98**	68.92	675.7
34.13	**24**	16.88	165.5	69.68	**49**	34.46	337.8	105.23	**74**	52.04	510.2	140.78	**99**	69.62	682.6

ksi		kg/mm²	MPa	ksi		kg/mm²	MPa	ksi		kg/mm²	MPa	ksi		kg/mm²	MPa
142.20	**100**	70.32	689.5	177.75	**125**	87.90	861.8	213.30	**150**	105.49	1.034	248.85	**175**	123.07	1.207
143.62	**101**	71.03	696.4	179.17	**126**	88.61	868.7	214.72	**151**	106.19	1.041	250.27	**176**	123.77	1.213
145.04	**102**	71.73	703.3	180.60	**127**	89.31	875.6	216.14	**152**	106.89	1.048	251.69	**177**	124.47	1.220
146.47	**103**	72.43	710.2	182.02	**128**	90.01	882.5	217.57	**153**	107.59	1.054	253.12	**178**	125.18	1.227
147.89	**104**	73.14	717.1	183.44	**129**	90.72	889.4	218.99	**154**	108.30	1.062	254.54	**179**	125.88	1.234
149.31	**105**	73.84	724.0	184.86	**130**	91.42	896.3	220.41	**155**	109.00	1.069	255.96	**180**	126.58	1.241
150.73	**106**	74.54	730.8	186.28	**131**	92.12	903.2	221.83	**156**	109.70	1.076	257.38	**181**	127.29	1.248
152.15	**107**	75.25	737.7	187.70	**132**	92.83	910.1	223.25	**157**	110.41	1.082	258.80	**182**	127.99	1.255
153.58	**108**	75.95	744.6	189.13	**133**	93.53	917.0	224.68	**158**	111.11	1.089	260.23	**183**	128.69	1.262
155.00	**109**	76.65	751.5	190.55	**134**	94.23	923.9	226.10	**158**	111.81	1.096	261.65	**184**	129.39	1.269
156.42	**110**	77.36	758.4	191.97	**135**	94.94	930.8	227.52	**160**	112.52	1.103	263.07	**185**	130.10	1.276
157.84	**111**	78.06	765.3	193.39	**136**	95.64	937.7	228.94	**161**	113.22	1.110	264.49	**186**	130.80	1.282
159.27	**112**	78.76	772.2	194.81	**137**	96.34	944.6	230.36	**162**	113.92	1.117	265.91	**187**	131.50	1.289
160.69	**113**	79.47	779.1	196.24	**138**	97.05	951.5	231.79	**163**	114.63	1.124	267.34	**188**	132.21	1.296
162.11	**114**	80.17	786.0	197.66	**139**	97.75	958.4	233.21	**164**	115.33	1.131	268.76	**189**	132.91	1.303
163.53	**115**	80.87	792.9	199.08	**140**	98.45	965.3	234.63	**165**	116.03	1.138	270.18	**190**	133.61	1.310
164.95	**116**	81.58	799.8	200.50	**141**	99.16	972.2	236.05	**166**	116.74	1.145	271.60	**191**	134.32	1.317
166.38	**117**	82.28	806.7	201.92	**142**	99.86	979.1	237.47	**167**	117.44	1.151	273.02	**192**	135.02	1.324
167.80	**118**	82.98	813.6	203.35	**143**	100.56	986.0	238.90	**168**	118.14	1.158	274.45	**193**	135.72	1.331
169.22	**119**	83.68	820.5	204.77	**144**	101.27	992.9	240.32	**169**	118.85	1.165	275.87	**194**	136.43	1.338
170.64	**120**	84.39	827.4	206.19	**145**	101.97	999.7	241.74	**170**	119.55	1.172	277.29	**195**	137.13	1.344
172.06	**121**	85.09	834.3	207.61	**146**	102.67	1.007	243.16	**171**	120.25	1.179	278.71	**196**	137.83	1.351
173.48	**122**	85.79	841.2	209.03	**147**	103.38	1.014	244.58	**172**	120.96	1.186	280.13	**197**	138.54	1.358
174.91	**123**	86.50	848.1	210.46	**148**	104.08	1.020	246.01	**173**	121.66	1.193	281.56	**198**	139.24	1.365
176.33	**124**	87.20	855.0	211.88	**149**	104.78	1.027	247.43	**174**	122.36	1.200	282.98	**199**	139.94	1.372
												284.40	**200**	140.65	1.379

APPROXIMATE EQUIVALENT HARDNESS NUMBERS AND TENSILE STRENGTHS FOR STEEL

Brinell Hardness No. 3000 kg Load, 10-mm ball	Vickers Hardness No.	Rockwell Hardness No. B Scale, 100-kg Load, 1/16-in. diam. ball	Rockwell Hardness No. C Scale, 150 kg Load, Brale Indenter	Knoop Hardness No., 500 g Load and Greater	Shore Sclero-Scope Hardness No.	Tensile Strength (Approx.) ksi	Tensile Strength (Approx.) MPa
(745)	840	–	65.3	852	91	–	–
(712)	783	–	63.4	808	–	–	–
(682)	737	–	61.7	768	84	–	–
(653)	697	–	60.0	732	81	–	–
627	667	–	58.7	703	79	347	2392
601	640	–	57.3	677	77	328	2261
578	615	–	56.0	652	75	313	2158
555	591	–	54.7	626	73	298	2055
534	569	–	53.5	604	71	288	1986
514	547	–	52.1	579	70	273	1882
–	539	–	51.6	571	–	269	1855
495	528	–	51.0	558	68	263	1818
–	516	–	50.3	545	–	257	1782
477	508	–	49.6	537	66	252	1737
–	495	–	48.8	523	–	244	1682
461	491	–	48.5	518	65	242	1669
–	474	–	47.2	499	–	231	1593
444	472	–	47.1	496	63	229	1579
429	455	–	45.7	476	61	220	1517
415	440	–	44.5	459	59	212	1462
401	425	–	43.1	441	58	202	1393
388	410	–	41.8	423	56	193	1331
375	396	–	40.4	407	54	184	1269
363	383	–	39.1	392	52	177	1220
352	372	–	37.9	379	51	172	1186
341	360	–	36.6	367	50	164	1131
331	350	–	35.5	356	48	159	1096
321	339	–	34.3	345	47	154	1062
311	328	–	33.1	336	46	149	1027
302	319	–	32.1	327	45	146	1007
293	309	–	30.9	318	43	142	979
285	301	–	29.9	310	42	138	952
277	292	–	28.8	302	41	134	924
269	284	–	27.6	294	40	131	903
262	276	–	26.6	286	39	127	876
255	269	–	25.4	279	38	123	848
248	261	–	24.2	272	37	120	827
241	253	100.0	22.8	265	36	116	800
235	247	99.0	21.7	259	35	114	786
229	241	98.2	20.5	253	34	111	765

(*Continued*)

APPROXIMATE EQUIVALENT HARDNESS NUMBERS AND TENSILE STRENGTHS FOR STEEL (*Continued*)

Brinell Hardness No. 3000 kg Load, 10-mm ball	Vickers Hardness No.	Rockwell Hardness No. B Scale, 100-kg Load, 1/16-in. diam. ball	Rockwell Hardness No. C Scale, 150 kg Load, Brale Indenter	Knoop Hardness No., 500 g Load and Greater	Shore Sclero-Scope Hardness No.	Tensile Strength (Approx.) ksi	Tensile Strength (Approx.) MPa
223	234	97.3	–	247	–	107	738
217	228	96.4	–	242	33	105	724
212	222	95.5	–	237	32	102	703
207	218	94.6	–	232	31	100	690
201	212	93.7	–	227	–	98	676
197	207	92.8	–	222	30	95	655
192	202	91.9	–	217	29	93	641
187	196	90.9	–	212	–	90	621
183	192	90.0	–	207	28	89	614
179	188	89.0	–	202	27	87	600
174	182	88.0	–	198	–	85	586
170	178	87.0	–	194	26	83	572
167	175	86.0	–	190	–	81	559
163	171	85.0	–	186	25	79	545
159	167	83.9	–	182	–	78	538
156	163	82.9	–	178	24	76	524
152	159	81.9	–	174	–	75	517
149	156	80.8	–	170	23	73	503
146	153	79.7	–	166	–	72	496
143	150	78.6	–	163	22	71	490
137	143	76.4	–	157	21	67	462
131	137	74.2	–	151	–	65	448
126	132	72.0	–	145	20	63	434
121	127	69.8	–	140	19	60	414
116	122	67.6	–	135	18	58	400
111	117	65.4	–	131	17	56	386

Source: *Metals Handbook*, Desk Edition, pp. 1–61, ASM, 1985. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

COMMON GAGE SERIES USED FOR SHEET THICKNESS

Name	Acronym	Identical with
American Wire Gage	AWG	B&S
Birmingham Wire Gage	BWG	Stubs Iron Wire Gage[1]
Brown and Sharp	B&S	AWG
Galvanized Iron	GSG	
Standard Wire Gage (British)	SWG	Imperial St., British Std.
Manufacture's Standard (U.S.)	MSG	
U.S. Standard Plate	USG	
Zinc (American Zinc Gage)	AZG	

[1] But Not Stubs Steel Wire Gage.

SHEET GAGE – THICKNESS CONVERSIONS (INCHES)

Gage No.	Al (U.S.) Copper Brass B&S AWG	Galv. Iron GSG	Al (U.K.) SWG	Sheet MSG	Stainless Steel Strip USG	Zinc BWG	AZG
1	0.289		0.300		0.281		
2	0.258		0.276		0.266		
3	0.229		0.252	0.239	0.250		0.006
4	0.204		0.232	0.224	0.234		0.008
5	0.182		0.212	0.209	0.219		0.010
6	0.162		0.192	0.194	0.203		0.012
7	0.144		0.176	0.179	0.188	0.180	0.014
8	0.128	0.168	0.160	0.164	0.172	0.165	0.016
9	0.114	0.153	0.144	0.149	0.156	0.148	0.018
10	0.102	0.138	0.128	0.134	0.141	0.134	0.020
11	0.091	0.125	0.116	0.120	0.125	0.120	0.024
12	0.081	0.110	0.104	0.105	0.109	0.109	0.028
13	0.072	0.095	0.092	0.090	0.094	0.095	0.032
14	0.064	0.080	0.080	0.075	0.078	0.083	0.036
15	0.057	0.071	0.072	0.067	0.070	0.072	0.040
16	0.051	0.064	0.064	0.060	0.062	0.065	0.045
17	0.045	0.058	0.056	0.054	0.056	0.058	0.050
18	0.040	0.052	0.048	0.048	0.050	0.049	0.055
19	0.036	0.046	0.040	0.042	0.044	0.042	0.060
20	0.032	0.040	0.036	0.036	0.038	0.035	0.070
21	0.028	0.037	0.032	0.033	0.034	0.032	0.080
22	0.025	0.034	0.028	0.030	0.031	0.028	0.090
23	0.023	0.031	0.024	0.027	0.028	0.025	0.100
24	0.020	0.028	0.022	0.024	0.025	0.022	0.125
25	0.018	0.025	0.020	0.021	0.022	0.020	0.250

Source: *Materials Performance*, Vol. 14, No. 12, p. 75 (1975).

SHEET GAGE – THICKNESS CONVERSIONS (mm)

Gage No.	Al (U.S.) Copper Brass B&S AWG	Galv. Iron GSG	Al (U.K.) SWG	Steel MSG	Stainless Steel Sheet USG	Stainless Steel Strip BWG	Zinc AZG
1	7.34		7.62		7.14		
2	6.55		7.71		6.75		
3	5.82		6.40	6.07	6.35		0.15
4	5.18		5.89	5.69	5.95		0.20
5	4.62		5.38	5.31	5.56		0.25
6	4.11		4.88	4.93	5.16		0.30
7	3.66		4.47	4.55	4.76	4.57	0.36
8	3.25	4.27	4.06	4.17	4.37	4.19	0.41
9	2.90	3.89	3.66	3.78	3.97	3.76	0.46
10	2.59	3.50	3.25	3.40	3.57	3.40	0.51
11	2.31	3.18	2.95	3.05	3.18	3.05	0.61
12	2.06	2.79	2.64	2.67	2.78	2.77	0.71
13	1.83	2.41	2.34	2.29	2.38	2.41	0.81
14	1.63	2.03	2.03	1.90	1.98	2.11	0.91
15	1.45	1.80	1.83	1.70	1.79	1.83	1.02
16	1.30	1.63	1.63	1.52	1.59	1.65	1.14
17	1.14	1.47	1.42	1.37	1.42	1.47	1.27
18	1.02	1.32	1.22	1.22	1.27	1.24	1.40
19	0.91	1.17	1.02	1.07	1.11	1.07	1.52
20	0.81	1.02	0.91	0.91	0.95	0.89	1.78
21	0.71	0.94	0.81	0.84	0.87	0.81	2.03
22	0.64	0.86	0.71	0.76	0.79	0.71	2.29
23	0.58	0.79	0.61	0.69	0.71	0.64	2.54
24	0.51	0.71	0.56	0.61	0.64	0.56	3.18
25	0.46	0.64	0.51	0.53	0.56	0.51	6.35

Source: *Materials Performance*, Vol. 14, No. 12, p. 75 (1975).

PHYSICAL PROPERTIES OF GASES AND LIQUIDS

Name	Formula	Molecular Weight	Density g/L	Melting Point °C	Boiling Point °C	Auto-Ignition Point °C	Explosive Limits Percent by Vol. in Air Lower	Upper
Acetylene	C_2H_2	26.04	1.173	−81	−83.6 subl.	335	2.5	80.0
Air			1.2929					
Ammonia	NH_3	17.03	0.7710	−77.7	−33.4	780	16.0	27.0
Argon	Ar	39.94	1.784	−189.2	−185.7			
Butane-n	C_4H_{10}	58.12	0.601	−138	−0.6	430	1.6	8.5
Butane-i	C_4H_{10}	58.12	0.601	−159	−11.7			
Butylene-n	C_4H_8	56.10	0.595	−185	−6.3		1.7	9.0
Carbon dioxide	CO_2	44.01	1.977	−57 5 atm.	−78.5 subl.			
Carbon monoxide	CO	28.01	1.250	−207	−191	650	12.5	74.2
Chlorine	Cl_2	70.91	3.214	−101	−34			
Ethane	C_2H_6	30.07	0.572	−172	−88.6	510	3.1	15.0
Ethylene	C_2H_4	28.05	0.384	−169	−103.7	543	3.0	34.0
Helium	He	4.003	0.1785	−272	−268.9			
Heptane-n	C_7H_{16}	100.20	0.684 g/cm^3	−90.6	98.4	233	1.0	6.0
Hexane-n	C_6H_{14}	86.17	0.6594 g/cm^3	−95.3	68.7	248	1.2	6.9
Hydrogen	H_2	2.016	0.0899	−259.2	−252.8	580	4.1	74.2
Hydrogen chloride	HCl	36.47	1.639	−112	−84			
Hydrogen fluoride	HF	20.01	0.921	−92.3	19.5			
Hydrogen sulfide	H_2S	34.08	1.539	−84	−62		4.3	45.5
Methane	CH_4	16.04	0.7168	−182.5	−161.5	538	5.3	13.9
Nitrogen	N_2	28.016	1.2506	−209.9	−195.8			
Octane-n	C_8H_{18}	114.23	0.7025 g/cm^3	−56.8	125.7	232	0.8	3.2
Oxygen	O_2	32.00	1.4290	−218.4	−183.0			
Pentane-n	C_5H_{12}	72.15	0.625 g/cm^3	−131	36.2	310	1.4	8.0
Propane	C_3H_8	44.09	0.501	−189	−44.5	465	2.4	9.5
Propylene	C_3H_6	42.05	0.519	−184	−48	458	2.0	11.1
Sulfur dioxide	SO_2	64.06	2.926	−75.7	−10.0			

Density of gases in g/L at 0°C and 760 mm Hg.
Density of liquids in g/cm^3 at 20°/4°C.

PHYSICAL PROPERTIES OF ELEMENTS

	Symbol	Atomic Weight	Density g/cm^3 20°C	Valencies	Melting Point °C	Crystal Structure ***
Aluminum	Al	26.98	2.70	3	660	1
Antimony	Sb	121.75	6.68	3/5	630	5
Argon	A	39.948	1.784*	0	−189.2	1
Arsenic	As	74.92	5.73	3/5	814	5
Barium	Ba	137.34	3.5	2	725	2
Beryllium	Be	9.01	1.85	2	1280	3
Bismuth	Bi	208.98	9.80	3/5	271	5
Boron	B	10.81	2.3	3	2300	–
Bromine	Br	79.91	3.12	1/3/5/7	−7.2	6
Cadmium	Cd	112.40	8.65	2	321	3
Calcium	Ca	40.08	1.55	2	842	1
Carbon	C	12.01	2.25	2/3/4	3550	4
Chlorine	Cl	35.45	1.56**	1/3/5/7	−103	7
Chromium	Cr	52.00	7.2	2/3/6	1890	2
Cobalt	Co	58.93	8.9	2/3	1495	3
Copper	Cu	63.54	8.92	1/2	1083	1
Fluorine	F	19.00	1.69*	1	223	–
Gold	Au	196.97	19.32	1/3	1063	1
Helium	He	4.003	0.177*	0	−272.2	–
Hydrogen	H	1.008	0.090*	1	−259.2	4
Iodine	I	126.90	4.93	1/3/5/7	113.5	6
Iron	Fe	55.85	7.87	2/3/6	1535	2
Lead	Pb	207.19	11.35	2/4	327.4	1
Lithium	Li	6.94	0.53	1	186	2
Magnesium	Mg	24.31	1.74	2	651	3
Manganese	Mn	54.94	7.2	2/3/4/6/7	1260	10
Mercury	Hg	200.59	13.55	1/2	−38.9	5
Molybdenum	Mo	95.94	10.2	2/3/4/5/6	2620	2
Nickel	Ni	58.71	8.90	2/3	1455	1
Niobium	Nb	92.91	8.55	3/5	2500	2
Nitrogen	N	14.007	1.25*	3/5	−209.9	4
Oxygen	O	15.9994	1.429*	2	−218.4	10
Phosphorus	P	30.98	1.82	3/5	44.1	10
Platinum	Pt	195.09	21.37	2/4	1773	1
Potassium	K	39.10	0.87	1	62.3	2
Rhodium	Rh	102.91	12.5	1/2/3/4	1966	1
Selenium	Se	78.96	4.8	2/4/6	220	4
Silicon	Si	28.09	2.42	4	1420	8
Silver	Ag	107.87	10.50	1	960.5	1
Sodium	Na	22.99	0.97	1	97.5	2
Sulfur	S	32.06	2.07	2/4/6	119	9
Tantalum	Ta	180.95	16.6	3/5	2996	2
Tin	Sn	118.69	7.31	2/4	231.9	7

(*Continued*)

PHYSICAL PROPERTIES OF ELEMENTS (*Continued*)

	Symbol	Atomic Weight	Density g/cm^3 20°C	Valencies	Melting Point °C	Crystal Structure ***
Titanium	Ti	47.90	4.5	2/3/4	1800	3
Tungsten	W	183.85	19.3	2/4/5/6	3370	2
Vandium	V	50.94	5.96	2/3/4/5	1710	2
Zinc	Zn	65.73	7.14	2	419.5	3
Zirconium	Zr	91.22	6.4	4	1857	3

*g/L (0°C and 760 mm Hg)
**Liquid at boiling point −37°C
***at 20°C

Crystal structures:

1 Face-centered cubic
2 Body-centered cubic
3 Close packed hexagonal
4 Hexagonal
5 Rhombohedral
6 Orthorhombic
7 Tetragonal
8 Diamond cubic
9 Face-centered orthorhombic
10 Cubic (complex)

PHYSICAL PROPERTIES OF WATER

Temperature	Density[1]	Specific Volume[1]	Vapor Pressure[2]	Viscosity[3]	Dielectric Constant[4]
t °C	*d* g/ml	*v* ml/g	*p* mm Hg*	η centipose	ϵ
0**	0.99987	1.00013	4.580	1.787	87.74
5	.99999	1.00001	6.538	1.517	85.76
10	.99973	1.00027	9.203	1.306	83.83
15	.99913	1.00087	12.782	1.138	81.95
18	.99862	1.00138	15.471	1.053	80.84
20	.99823	1.00177	17.529	1.002	80.10
25	.99707	1.00293	23.753	0.8903	78.30
30	.99567	1.00434	31.824	.7974	76.55
35	.99406	1.00598	42.180	.7194	74.83
38	.99299	1.00706	49.702	.6783	73.82
40	.99224	1.00782	55.338	.6531	73.15
45	.99025	1.00985	71.90	.5963	71.51
50	.98807	1.01207	92.56	.5471	69.91
55	.98573	1.01448	118.11	.5044	68.34
60	.98324	1.01705	149.47	.4669	66.81
65	.98059	1.01979	187.65	.4338	65.32
70	.97781	1.02270	233.81	.4044	63.86
75	.97489	1.02576	289.22	.3782	62.43
80	.97183	1.02899	355.31	.3547	61.03
85	.96865	1.03237	433.64	.3340	59.66
90	.96534	1.03590	525.92	.3149	58.32
95	.96192	1.03959	634.04	.2976	57.01
100***	.95838	1.04343	760.00	.2822	55.72

[1] M. Thiesen, Wiss. Abh. der Physikalisch-Technischen Reichsanstalt 4, No. 1, 1904; International Critical Tables 3, 25 (1928).

[2] F. G. Keyes, J. Chem. Phys., 15, 602 (1947).

[3] J. F. Swindells, J. R. Coe, and T. B. Godfrey, J. Research Nat. Bur. Standards, 48, 1 (1952); R. C. Hardy and R. L. Cottington, *ibid*, 42, 573 (1949); J. R. Coe and T. B. Godfrey, J. App. Phys., 15, 625 (1944).

[4] C. G. Malmberg and A. A. Maryott, J. Research Nat. Bur. Standards, 56, 1 (1956).

* 760 mm Hg = 1 atmosphere = 1,013,250 dyn cm^{-2} = 101,325 newtons m^{-2}; on the Système International d'Unites, adopted in a resolution, 11th General Conference on Weights and Measures, Paris, October 1960, the international unit of pressure is the newton per square meter.

**The freezing point is zero degrees Celsius, exactly; the triple point of water is 0.001°C or 273.16°K.

***The boiling point.

PROPERTIES OF DRY SATURATED STEAM (English Units)

Temp. °F	Pressure psia	Pressure psig	Specific Volume $ft^3/lb.$	Specific Enthaipy Btu/lb.
32	0.08859	–	3305	1075.5
35	0.09991	–	2948	1076.8
40	0.12163	–	2446	1079.0
45	0.14744	–	2037.8	1081.2
50	0.17796	–	1704.8	1083.4
60	0.2561	–	1207.6	1087.7
70	0.3629	–	868.4	1092.1
80	0.5068	–	633.3	1096.4
90	0.6981	–	468.1	1100.8
100	0.9492	–	350.4	1105.1
110	1.2750	–	265.4	1109.3
120	1.6927	–	203.26	1113.6
130	2.2230	–	157.33	1117.8
140	2.8892	–	123.00	1122.0
150	3.718	–	97.07	1126.1
160	4.741	–	77.29	1130.2
170	5.993	–	62.06	1134.2
180	7.511	–	50.22	1138.2
190	9.340	–	40.96	1142.1
200	11.526	–	33.64	1146.0
210	14.123	–	27.82	1149.7
212	14.696	0.000	26.80	1150.5
220	17.186	2.490	23.15	1153.4
230	20.779	6.083	19.381	1157.1
240	24.968	10.272	16.321	1160.6
250	29.825	15.129	13.819	1164.0
260	35.427	20.731	11.762	1167.4
270	41.856	27.160	10.060	1170.6
280	49.200	34.524	8.644	1173.8
290	57.550	42.854	7.460	1176.8
300	67.005	52.309	6.466	1179.7
310	77.67	62.97	5.626	1182.5
320	89.64	74.94	4.914	1185.2
340	117.99	103.29	3.788	1190.1
360	153.01	138.31	2.957	1194.4
380	195.73	181.03	2.335	1198.0
400	247.26	232.56	1.8630	1201.0
420	308.78	294.08	1.4997	1203.1
440	381.54	366.84	1.2169	1204.4
460	466.9	452.2	0.9942	1204.8
480	566.2	551.5	0.8172	1204.1
500	680.9	666.2	0.6749	1202.2
520	812.5	797.8	0.5596	1199.0
540	962.8	948.1	0.4651	1194.3
560	1133.4	1118.7	0.3871	1187.7
580	1326.2	1311.5	0.3222	1179.0
600	1543.2	1528.5	0.2675	1167.7
620	1786.9	1772.2	0.2208	1153.2
640	2059.9	2045.2	0.1802	1133.7
660	2365.7	2351.0	0.1443	1107.0
680	2708.6	2693.9	0.1112	1068.5
700	3094.3	3079.6	0.0752	995.2
705.5	3208.2	3193.5	0.0508	906.0

Source: Babcock and Wilcox, *Steam*, pp. 2–3. Reprinted by permission of ASME International.

PROPERTIES OF DRY SATURATED STEAM (SI UNITS)

Abs. Pressure bar	Temp. °C	Specific Volume dm^3/kg	Specific Enthalpy kJ/kg
0.01	7.0	129,209	2514
0.025	21.1	54,256	2540
0.05	32.9	28,194	2562
0.075	40.3	19,239	2575
0.10	45.8	14,675	2585
0.15	54.0	10,023	2599
0.20	60.1	7,650	2610
0.25	65.0	6,205	2618
0.30	69.1	5,229	2625
0.40	75.9	3,993	2637
0.50	81.3	3,240	2646
0.75	91.8	2,217	2663
1.0	99.6	1,694	2675
1.5	111.4	1,159	2693
2.0	120.2	885	2706
2.5	127.4	718	2716
3.0	133.5	606	2725
3.5	138.9	524	2732
4.0	143.6	462	2738
5.0	151.8	375	2748
6.0	158.8	315	2756
7.0	164.9	273	2762
8.0	170.4	240	2768
9.0	175.4	215	2772
10.0	179.9	194.3	2776
12.5	189.8	156.9	2784
15.0	198.3	131.7	2790
17.5	205.7	113.4	2794
20.0	212.4	99.5	2797
22.5	218.4	88.7	2799
25.0	223.9	79.9	2801
27.5	229.0	72.7	2802
30.0	233.8	66.6	2802
32.5	238.3	61.5	2802
35.0	242.5	57.0	2802
37.5	246.5	53.2	2801
40.0	250.3	49.7	2800
45.0	257.4	44.0	2798
50.0	263.9	39.4	2794
55.0	269.9	35.6	2790

(*Continued*)

PROPERTIES OF DRY SATURATED STEAM (SI UNITS) (*Continued*)

Abs. Pressure bar	Temp. °C	Specific Volume dm^3/kg	Specific Enthalpy kJ/kg
60.0	275.6	32.4	2785
65.0	280.8	29.7	2780
70.0	285.8	27.4	2774
75.0	290.5	25.3	2767
80.0	295.0	23.5	2760
85.0	299.2	21.9	2753
90.0	303.2	20.5	2745
95.0	307.2	19.21	2736
100.0	311.0	18.04	2728
110.0	318.0	16.01	2709
120.0	324.6	14.28	2689
130.0	330.8	12.80	2667
140.0	336.6	11.50	2642
150.0	342.1	10.34	2615
160.0	347.3	9.31	2585
170.0	352.3	8.37	2552
180.0	357.0	7.50	2514
190.0	361.4	6.68	2471
200.0	365.7	5.88	2418
210.0	369.8	5.02	2348
220.0	373.7	3.73	2196
221.2	374.2	3.17	2107

Source: A. Parrish, *Mechanical Engineers Handbook*, pp. 2-86 and 2-93. Reprinted by permission of ASME International.

VAPOR PRESSURE OF WATER BELOW 100°C

Temperature		Pressure		Temperature		Pressure	
° C	° F	mm Hg	Millibar	° C	° F	mm Hg	Millibar
−15	5	1.4	1.9	43	109	64.8	86.4
−14	7	1.6	2.1	44	111	68.3	91.0
−13	9	1.7	2.3	45	113	71.9	95.8
−12	10	1.8	2.4	46	115	75.7	101.
−11	12	2.0	2.7	47	117	79.6	106.
−10	14	2.1	2.8	48	118	83.7	112.
−9	16	2.3	3.1	49	120	88.0	117.
−8	18	2.5	3.3	50	122	92.5	123.
−7	19	2.7	3.6	51	124	97.2	130.
−6	21	2.9	3.9	52	126	102.	136.
−5	23	3.2	4.3	53	127	107.	143.
−4	25	3.4	4.5	54	129	113.	151.
−3	27	3.7	4.9	55	131	118.	157.
−2	28	4.0	5.3	56	133	124.	165.
−1	30	4.3	5.7	57	135	130.	173.
0	32	4.6	6.1	58	136	136.	181.
1	34	4.9	6.5	59	138	143.	191.
2	36	5.3	7.1	60	140	149.	199
3	37	5.7	7.6	61	142	156.	208.
4	39	6.1	8.1	62	144	164.	219.
5	41	6.5	8.7	63	145	171.	228.
6	43	7.0	9.3	64	147	179.	239.
7	45	7.5	10.0	65	149	187.	249.
8	46	8.0	10.7	66	151	196.	261.
9	48	8.6	11.5	67	153	205.	273.
10	50	9.2	12.3	68	154	214.	285.
11	52	9.8	13.1	69	156	224.	299.
12	54	10.5	14.0	70	158	234.	312.
13	55	11.2	14.9	71	160	244.	325.
14	57	12.0	16.0	72	162	255.	340.
15	59	12.8	17.1	73	163	266.	355.
16	61	13.6	18.1	74	165	277.	369.
17	63	14.5	19.3	75	167	289.	385.
18	64	15.5	20.7	76	169	301.	401.
19	66	16.5	22.0	77	171	314.	419.
20	68	17.5	23.3	78	172	327.	436.
21	70	18.6	24.8	79	174	341.	455.
22	72	19.8	26.4	80	176	355.	473.
23	73	21.1	28.1	81	178	370.	493.
24	75	22.4	29.9	82	180	385.	513.
25	77	23.8	31.7	83	181	401.	535.
26	79	25.2	33.6	84	183	417.	556.
27	81	26.7	35.6	85	185	434.	579.
28	82	28.3	37.7	86	187	451.	601.
29	84	30.0	40.0	87	189	469.	625.
30	86	31.8	42.4	88	190	487.	649.
31	88	33.7	44.9	89	192	506.	674.
32	90	35.7	47.6	90	194	526.	701.
33	91	37.7	50.3	91	196	546.	728.
34	93	39.9	53.2	92	198	567.	756.
35	95	42.2	56.3	93	199	589.	785.
36	97	44.6	59.5	94	201	617.	822.
37	99	47.1	62.8	95	203	634.	845.
38	100	49.7	66.3	96	205	658.	877.
39	102	52.4	69.8	97	207	682.	909.
40	104	55.3	73.7	98	208	707.	942.
41	106	58.3	77.7	99	210	733.	977.
42	108	61.5	81.2	100	212	760.	1013.

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DEW POINT OF MOIST AIR

The temperature drop required for condensation to occur at a specified air temperature and relative humidity is given in the table below. The temperature drops are mean values for the indicated air temperature ranges.

	Air Temperature °C			Air Temperature °F	
RH %	**0–20**	**20–35**	**RH%**	**32–68**	**68–95**
55	9	10	55	16	18
60	7	9	60	13	15
65	6	7	65	11	13
70	5	6	70	9	11
75	4	5	75	8	9
80	3	4	80	6	7
85	2	3	85	4	5
90	1.6	1.8	90	3	3
92	1.2	1.4	92	2.2	2.5
95	0.8	0.9	95	1.4	1.6
98	0.3	0.3	98	0.5	0.5

Example: At 30°C (86°F) and 80% RH, a temperature drop of 4°C (7°F) would result in condensation.

Dew point temperatures of moist air as a function of air temperature and relative humidity are tabulated on the following four pages.

DEW POINT OF MOIST AIR (°C)
Air Temperature °C

RH%	0	2	4	6	8	10	12	14	16	18	20	22	24
1	−50	−49	−47	−46	−45	−44	−42	−41	−40	−39	−38	−36	−35
3	−40	−39	−37	−36	−34	−33	−32	−30	−29	−28	−26	−25	−24
5	−35	−34	−32	−31	−29	−28	−26	−25	−24	−22	−21	−19	−18
7	−32	−30	−29	−27	−26	−24	−23	−21	−20	−18	−17	−15	−14
9	−29	−27	−26	−24	−23	−21	−20	−18	−17	−15	−14	−12	−11
11	−27	−25	−24	−22	−21	−19	−17	−16	−14	−13	−11	−10	−8
13	−25	−23	−22	−20	−19	−17	−15	−14	−12	−11	−9	−8	−6
15	−23	−22	−20	−19	−17	−15	−14	−12	−11	−9	−7	−6	−4
17	−22	−20	−19	−17	−15	−14	−12	−11	−9	−7	−6	−4	−2
19	−21	−19	−17	−16	−14	−12	−11	−9	−8	−6	−4	−3	−1
21	−20	−18	−16	−15	−13	−11	−10	−8	−6	−5	−3	−1	0
23	−19	−17	−15	−14	−12	−10	−8	−7	−5	−3	−2	0	2
25	−18	−16	−14	−13	−11	−9	−7	−6	−4	−2	−1	1	3
27	−17	−15	−13	−12	−10	−8	−6	−5	−3	−1	1	2	4
29	−16	−14	−12	−11	−9	−7	−5	−4	−2	0	2	3	5
31	−15	−13	−12	−10	−8	−6	−5	−3	−1	1	2	4	6
33	−14	−13	−11	−9	−7	−6	−4	−2	0	2	3	5	7
35	−14	−12	−10	−8	−7	−5	−3	−1	1	2	4	6	8
37	−13	−11	−9	−8	−6	−4	−2	0	1	3	5	7	9
39	−12	−10	−9	−7	−5	−3	−1	0	2	4	6	8	9
41	−12	−10	−8	−6	−4	−3	−1	1	3	5	6	8	10
43	−11	−9	−7	−6	−4	−2	0	2	4	5	7	9	11
45	−11	−9	−7	−5	−3	−1	1	2	4	6	8	10	11
47	−10	−8	−6	−5	−3	−1	1	3	5	7	8	10	12
49	−9	−8	−6	−4	−2	0	2	4	5	7	9	11	13
51	−9	−7	−5	−3	−1	0	2	4	6	8	10	12	13
53	−8	−7	−5	−3	−1	1	3	5	7	8	10	12	14
55	−8	−6	−4	−2	−1	1	3	5	7	9	11	13	14
57	−7	−6	−4	−2	0	2	4	6	8	9	11	13	15
59	−7	−5	−3	−1	1	2	4	6	8	10	12	14	16
61	−7	−5	−3	−1	1	3	5	7	9	11	12	14	16
63	−6	−4	−2	0	2	3	5	7	9	11	13	15	17
65	−6	−4	−2	0	2	4	6	8	10	11	13	15	17
67	−5	−3	−2	0	2	4	6	8	10	12	14	16	18
69	−5	−3	−1	1	3	5	7	8	10	12	14	16	18
71	−5	−3	−1	1	3	5	7	9	11	13	15	17	19
73	−4	−2	0	2	4	6	7	9	11	13	15	17	19
75	−4	−2	0	2	4	6	8	10	12	14	15	17	19
77	−4	−2	0	2	4	6	8	10	12	14	16	18	20
79	−3	−1	1	3	5	7	8	10	12	14	16	18	20
81	−3	−1	1	3	5	7	9	11	13	15	17	19	21
83	−3	−1	1	3	5	7	9	11	13	15	17	19	21
85	−2	0	2	4	6	8	10	12	14	16	18	19	21
87	−2	0	2	4	6	8	10	12	14	16	18	20	22
89	−2	0	2	4	6	8	10	12	14	16	18	20	22
91	−1	1	3	5	7	9	11	13	15	17	19	21	23
93	−1	1	3	5	7	9	11	13	15	17	19	21	23
95	−1	1	3	5	7	9	11	13	15	17	19	21	23
97	0	2	4	6	8	10	12	14	16	18	20	22	24
99	0	2	4	6	8	10	12	14	16	18	20	22	24

(*Continued*)

DEW POINT OF MOIST AIR (°C) (*Continued*)
Air Temperature °C

RH%	26	28	30	32	34	36	38	40	42	44	46	48	50
1	−34	−33	−32	−30	−29	−28	−27	−26	−25	−24	−22	−21	−20
3	−22	−21	−20	−18	−17	−16	−14	−13	−12	−11	−9	−8	−7
5	−16	−15	−14	−12	−11	−10	−8	−7	−5	−4	−3	−1	0
7	−12	−11	−9	−8	−7	−5	−4	−2	−1	1	2	4	5
9	−9	−8	−6	−5	−3	−2	0	1	3	4	6	7	9
11	−7	−5	−4	−2	−1	1	3	4	6	7	9	10	12
13	−4	−3	−1	0	2	3	5	6	8	10	11	13	14
15	−3	−1	1	2	4	5	7	9	10	12	13	15	16
17	−1	1	2	4	6	7	9	10	12	14	15	17	18
19	1	2	4	6	7	9	10	12	14	15	17	19	20
21	2	4	5	7	9	10	12	14	15	17	19	20	22
23	3	5	7	8	10	12	13	15	17	18	20	22	23
25	5	6	8	10	11	13	15	16	18	20	21	23	25
27	6	7	9	11	12	14	16	18	19	21	23	24	26
29	7	8	10	12	14	15	17	19	20	22	24	25	27
31	8	9	11	13	15	16	18	20	21	23	25	27	28
33	9	10	12	14	16	17	19	21	22	24	26	28	29
35	9	11	13	15	16	18	20	22	23	25	27	29	30
37	10	12	14	16	17	19	21	23	24	26	28	30	31
39	11	13	15	16	18	20	22	24	25	27	29	31	32
41	12	14	15	17	19	21	23	24	26	28	30	31	33
43	13	14	16	18	20	22	23	25	27	29	31	32	34
45	13	15	17	19	20	22	24	26	28	29	31	33	35
47	14	16	17	19	21	23	25	27	28	30	32	34	36
49	15	16	18	20	22	24	26	27	29	31	33	35	36
51	15	17	19	21	23	24	26	28	30	32	34	35	37
53	16	18	20	21	23	25	27	29	31	32	34	36	38
55	16	18	20	22	24	26	27	29	31	33	35	37	38
57	17	19	21	23	24	26	28	30	32	34	36	37	39
59	17	19	21	23	25	27	29	30	32	34	36	38	40
61	18	20	22	24	26	27	29	31	33	35	37	39	41
63	19	20	22	24	26	28	30	32	34	35	37	39	41
65	19	21	23	25	27	28	30	32	34	36	38	40	42
67	19	21	23	25	27	29	31	33	35	37	38	40	42
69	20	22	24	26	28	30	31	33	35	37	39	41	43
71	20	22	24	26	28	30	32	34	36	38	40	42	43
73	21	23	25	27	29	31	32	34	36	38	40	42	44
75	21	23	25	27	29	31	33	35	37	39	41	42	44
77	22	24	26	28	29	31	33	35	37	39	41	43	45
79	22	24	26	28	30	32	34	36	38	40	41	43	45
81	23	25	26	28	30	32	34	36	38	40	42	44	46
83	23	25	27	29	31	33	35	37	39	40	42	44	46
85	23	25	27	29	31	33	35	37	39	41	43	45	47
87	24	26	28	30	32	34	36	37	39	41	43	45	47
89	24	26	28	30	32	34	36	38	40	42	44	46	48
91	25	27	29	31	32	34	36	38	40	42	44	46	48
93	25	27	29	31	33	35	37	39	41	43	45	47	49
95	25	27	29	31	33	35	37	39	41	43	45	47	49
97	26	28	30	32	34	36	38	40	42	44	46	48	50
99	26	28	30	32	34	36	38	40	42	44	46	48	50

DEW POINT OF MOIST AIR (°F)
Air Temperature °F

RH%	32	35	38	41	44	47	50	53	56	59	62	65	68	71	74
1	−57	−56	−54	−52	−50	−48	−46	−45	−43	−41	−39	−37	−36	−34	−32
3	−40	−38	−36	−34	−32	−30	−28	−25	−23	−21	−19	−17	−15	−13	−11
5	−31	−29	−27	−25	−22	−20	−18	−16	−14	−12	−9	−7	−5	−3	−1
7	−25	−23	−20	−18	−16	−14	−11	−9	−7	−5	−2	0	2	4	6
9	−20	−18	−15	−13	−11	−9	−6	−4	−2	1	3	5	7	10	12
11	−16	−14	−12	−9	−7	−5	−2	0	2	5	7	9	12	14	16
13	−13	−11	−8	−6	−3	−1	1	4	6	8	11	13	16	18	20
15	−10	−8	−5	−3	0	2	4	7	9	12	14	16	19	21	24
17	−8	−5	−3	0	2	5	7	10	12	15	17	19	22	24	27
19	−5	−3	0	2	5	7	10	12	15	17	19	22	24	27	29
21	−3	−1	2	4	7	9	12	14	17	19	22	24	27	29	32
23	−1	1	4	6	9	11	14	16	19	21	24	26	29	31	34
25	0	3	5	8	11	13	16	18	21	23	26	28	31	33	36
27	2	5	7	10	12	15	17	20	23	25	28	30	33	35	38
29	4	6	9	11	14	17	19	22	24	27	29	32	35	37	40
31	5	8	10	13	16	18	21	23	26	29	31	34	36	39	42
33	6	9	12	14	17	20	22	25	27	30	33	35	38	41	43
35	8	10	13	16	18	21	24	26	29	31	34	37	39	42	45
37	9	12	14	17	20	22	25	28	30	33	36	38	41	44	46
39	10	13	15	18	21	23	26	29	32	34	37	40	42	45	48
41	11	14	17	19	22	25	27	30	33	35	38	41	44	46	49
43	12	15	18	20	23	26	29	31	34	37	39	42	45	48	50
45	13	16	19	21	24	27	29	32	35	38	40	43	46	49	51
47	14	17	20	22	25	28	31	33	36	39	42	44	47	50	52
49	15	18	21	24	26	29	32	35	37	40	43	46	48	51	54
51	16	19	22	24	27	30	33	36	38	41	44	47	49	52	55
53	17	20	23	25	28	31	34	37	39	42	45	48	50	53	56
55	18	21	23	26	29	32	35	37	40	43	46	48	51	54	57
57	19	21	24	27	30	33	35	38	41	44	47	50	52	55	58
59	19	22	25	28	31	33	36	39	42	45	48	50	53	56	59
61	20	23	26	29	32	34	37	40	43	46	49	51	54	57	60
63	21	24	27	29	32	35	38	41	44	47	49	52	55	58	61
65	22	25	27	30	33	36	39	42	44	47	50	53	56	59	62
67	22	25	28	31	34	37	40	42	45	48	51	54	57	60	62
69	23	26	29	32	35	37	40	43	46	49	52	55	58	60	63
71	24	27	30	32	35	38	41	44	47	50	53	55	58	61	64
73	24	27	30	33	36	39	42	45	48	51	53	56	59	62	65
75	25	28	31	34	37	39	42	45	48	51	54	57	60	63	66
77	26	29	32	34	37	40	43	46	49	52	55	58	61	64	66
79	26	29	32	35	38	41	44	47	50	52	55	58	61	64	67
81	27	30	33	36	39	42	44	47	50	53	56	59	62	65	68
83	27	30	33	36	39	42	45	48	51	54	57	60	63	66	68
85	28	31	34	37	40	43	46	49	52	55	58	60	64	66	69
87	29	32	34	37	40	43	46	49	52	55	58	61	64	67	70
89	29	32	35	38	41	44	47	50	53	56	59	62	65	68	71
91	30	33	36	39	42	45	48	51	54	56	60	62	65	68	71
93	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72
95	31	34	37	40	43	46	49	52	55	58	61	64	67	70	73
97	31	34	37	40	43	46	49	52	55	58	61	64	67	70	73
99	32	35	38	41	44	47	50	53	56	59	62	65	68	71	74

(*Continued*)

DEW POINT OF MOIST AIR (°F) (*Continued*)

Air Temperature °F

RH%	77	80	83	86	89	92	95	98	101	104	107	110	113	116	119	122
1	−30	−28	27	−25	−23	−21	−20	−18	−16	−14	−13	−11	−9	−7	−6	−4
3	−9	−7	−5	−3	−1	1	2	4	6	8	10	12	14	16	18	20
5	1	3	5	8	10	12	14	16	18	20	22	24	26	28	30	32
7	8	11	13	15	17	19	22	24	26	28	30	32	35	37	39	41
9	14	16	19	21	23	25	28	30	32	34	36	39	41	43	45	47
11	19	21	23	26	28	30	32	35	37	39	41	44	46	48	50	53
13	23	25	27	30	32	34	37	39	41	44	46	48	51	53	55	57
15	26	28	31	33	35	38	40	43	45	47	50	52	54	57	59	61
17	29	31	34	36	39	41	44	46	48	51	53	55	58	60	63	65
19	32	34	37	39	42	44	46	49	51	54	56	59	61	63	66	68
21	34	37	39	42	44	47	49	52	54	56	59	61	64	66	69	71
23	37	39	42	44	47	49	51	54	56	59	61	64	66	69	71	74
25	38	41	44	46	49	51	54	56	59	61	64	66	69	71	74	76
27	41	43	46	48	51	53	56	58	61	64	66	68	71	74	76	79
29	42	45	48	50	53	55	58	60	63	65	68	71	73	76	78	81
31	44	47	49	52	55	57	60	62	65	67	70	73	75	78	80	83
33	46	48	51	54	56	59	61	64	67	69	72	74	77	80	82	85
35	47	50	53	55	58	60	63	66	68	71	74	76	79	81	84	87
37	49	52	54	57	60	62	65	67	70	73	75	78	81	83	86	89
39	50	53	56	58	61	64	66	69	72	74	77	80	82	85	87	90
41	52	54	57	60	62	65	68	70	73	76	78	81	84	86	89	92
43	53	56	58	61	64	66	69	72	75	77	80	83	85	88	91	93
45	54	57	60	62	65	58	70	73	76	78	81	84	87	89	92	95
47	55	58	61	63	66	69	72	74	77	80	82	85	88	91	93	96
49	56	59	62	65	68	70	73	76	78	81	84	87	89	92	95	98
51	58	60	63	66	69	71	74	77	80	82	85	88	91	93	96	99
53	59	62	64	67	70	73	75	78	81	84	86	89	92	95	97	100
55	60	62	65	68	71	73	76	79	82	85	87	90	93	96	98	101
57	61	64	66	69	72	75	78	80	83	86	89	91	94	97	100	103
59	62	64	67	70	73	76	78	81	84	87	90	92	95	98	101	104
61	63	66	68	71	74	77	80	82	85	88	91	94	96	99	102	105
63	64	66	69	72	75	78	81	83	86	89	92	95	98	100	103	106
65	64	67	70	73	76	79	82	84	87	90	93	96	98	101	104	107
67	65	68	71	74	77	80	82	85	88	91	94	97	100	102	105	108
69	66	69	72	75	78	80	83	86	89	92	95	98	100	103	106	109
71	67	70	73	76	79	81	84	87	90	93	96	99	101	104	107	110
73	68	71	74	76	79	82	85	88	91	94	97	100	102	105	108	111
75	69	71	74	77	80	83	86	89	92	94	97	100	103	106	109	112
77	69	72	75	78	81	84	87	90	93	96	98	101	104	107	110	113
79	70	73	76	79	82	84	87	90	93	96	99	102	105	108	111	114
81	71	74	77	80	82	85	88	91	94	97	100	103	106	109	112	115
83	71	74	77	80	83	86	89	92	95	98	101	104	107	109	112	115
85	72	75	78	81	84	87	90	93	96	99	102	105	108	110	113	116
87	73	76	79	82	85	88	91	94	96	99	102	105	108	111	114	117
89	73	76	79	82	85	88	91	94	97	100	103	106	109	112	115	118
91	74	77	80	83	86	89	92	95	98	101	104	107	110	113	116	119
93	75	78	81	84	87	90	93	96	99	102	105	108	111	114	117	120
95	76	79	82	85	87	90	93	96	99	102	105	108	111	114	117	120
97	76	79	82	85	88	91	94	97	100	103	106	109	112	115	118	121
99	77	80	83	86	89	92	95	98	101	104	107	110	113	116	119	122

PERCENT RELATIVE HUMIDITY ABOVE WHICH MOISTURE WILL CONDENSE ON METAL SURFACES NOT INSULATED

	Surrounding Air Temperature °F																
Metal Surface Temp.	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**
35°F	60	33	11														
40		69	39	20	8												
45			69	45	27	14											
50				71	49	32	20	11									
55					73	53	38	26	17	9							
60						75	56	41	30	21	14	9					
65							78	59	45	34	25	18	13				
70								79	61	48	37	29	22	16	13		
75									80	64	50	40	32	25	20	15	
80										81	66	53	43	35	29	22	16
85											81	68	55	46	37	30	25
90												82	69	58	49	40	32
95	% of Relative Humidity												83	70	58	50	40
100														84	70	61	50
105															85	71	61
110																85	72
115																	86
120																	

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 468, NACE, 1999.

ABSOLUTE ATMOSPHERIC HUMIDITIES AT DIFFERENT TEMPERATURES AND DIFFERENT RELATIVE HUMIDITIES (EXPRESSED AS GRAMS WATER VAPOR/M^3)

Temperature °C	Relative Humidity (%)									
	10	20	30	40	50	60	70	80	90	100
0	0.49	0.98	1.47	1.96	2.45	2.94	3.43	3.92	4.4	4.9
1	0.52	1.04	1.56	2.08	2.60	3.12	3.64	4.16	4.7	5.2
2	0.56	1.12	1.68	2.24	2.80	3.36	2.92	4.48	5.0	5.6
3	0.60	1.20	1.80	2.40	3.00	3.60	4.20	4.80	5.4	6.0
4	0.64	1.28	1.91	2.56	3.20	3.84	4.48	5.12	5.8	6.4
5	0.68	1.36	2.04	2.72	3.40	4.08	4.76	5.44	6.1	6.8
6	0.73	1.46	2.19	2.92	3.63	4.38	5.11	5.84	6.6	7.3
7	0.77	1.54	2.31	3.08	3.85	4.62	5.39	6.16	6.9	7.7
8	0.83	1.66	2.49	3.32	4.15	4.98	5.81	6.64	7.5	8.3
9	0.88	1.76	2.64	3.52	4.40	5.28	6.16	7.04	7.9	8.8
10	0.94	1.87	2.82	3.76	4.70	5.64	6.58	7.52	8.5	9.4
11	0.99	1.99	2.98	3.98	4.97	5.97	6.96	7.96	8.9	9.9
12	1.06	2.12	3.18	4.24	5.30	6.36	7.42	8.48	9.5	10.6
13	1.13	2.26	3.39	4.52	5.65	6.78	7.91	9.04	10.2	11.3
14	1.20	2.40	3.60	4.80	6.00	7.30	8.40	9.60	10.8	12.0
15	1.28	2.56	3.84	5.12	6.40	7.68	8.96	10.20	11.5	12.8
16	1.35	2.72	4.08	5.44	6.80	8.16	9.52	10.90	12.2	13.6
17	1.45	2.89	4.33	5.78	7.22	8.67	10.10	11.60	13.0	14.5
18	1.54	3.07	4.61	6.14	7.68	9.22	10.80	12.30	13.8	15.4
19	1.63	3.25	4.88	6.51	8.13	9.76	11.40	13.00	14.6	16.3
20	1.72	3.44	5.16	6.88	8.60	10.30	12.00	13.80	15.5	17.2
21	1.82	3.65	5.48	7.30	9.13	11.00	12.80	14.60	16.4	18.2
22	1.93	3.87	5.80	7.44	9.67	11.60	13.50	15.50	17.4	19.3
23	2.05	4.10	6.15	8.20	10.25	12.30	14.30	16.40	18.4	20.5
24	2.17	4.34	6.51	8.68	10.85	13.00	15.20	17.40	19.5	21.7
25	2.29	4.58	6.87	9.16	11.45	13.20	16.00	18.30	20.6	22.9
26	2.42	4.84	7.26	9.68	12.10	14.00	16.90	19.40	21.8	24.2
27	2.56	5.12	7.68	10.25	12.80	15.40	17.90	20.50	23.0	25.6
28	2.71	5.42	8.15	10.85	13.50	16.30	19.00	21.70	24.4	27.5
29	2.86	5.72	8.58	11.44	14.30	17.20	20.00	22.90	25.7	28.6
30	3.02	6.04	9.05	12.10	15.10	18.10	21.10	24.10	27.2	30.2

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 36, NACE, 1999.

VAPOR PRESSURE VS TEMPERATURE FOR VOLATILE COMPOUNDS

Temperature		Propane		Butane		Isobutane		Pentane		Carbon Dioxide		Hydrogen Sulfide		Sulfur Dioxide		Ammonia	
°F	°C	psia	bar	psia	bar	psia	bar	psia	bar	psia	bar	psia	bar	psia	bar	psia	bar
−70	−56.7	7.4	0.51														
−60	−51.1	9.7	0.67													5.5	0.38
−50	−45.6	12.6	0.87													7.7	0.53
−40	−40.0	16.2	1.12											3.1	0.21	10.4	0.72
−30	−34.4	20.3	1.40											4.3	0.30	13.9	0.96
−20	−29.9	25.4	1.75			7.5	0.52			221.	15.24			5.9	0.41	18.3	1.26
−10	−23.3	31.4	2.17			9.3	0.64			262.	18.07			7.9	0.54	23.7	1.63
0	−17.8	38.2	2.63	7.3	0.50	11.6	0.80			309.	21.3			10.4	0.72	30.4	2.10
+10	−12.2	46.0	3.17	9.2	0.63	14.6	1.01			362.	25.0			13.4	0.92	38.5	2.66
20	−6.7	55.5	3.83	11.6	0.80	18.2	1.26			422.	29.1			17.2	1.19	48.2	3.32
30	−1.1	66.3	4.57	14.4	0.99	22.3	1.54			489.	33.7			21.7	1.50	59.7	4.12
40	+4.4	78.0	5.38	17.7	1.22	26.9	1.86			565.	39.0			27.1	1.87	73.3	5.06
50	10.0	91.8	6.33	21.6	1.49	32.5	2.24			650.	44.8	197.	13.6	33.5	2.31	89.2	6.15
60	15.6	107.1	7.39	26.3	1.81	38.7	2.67			744.	51.3	233.	16.0	40.9	2.82	107.6	7.42
70	21.1	124.0	8.55	31.6	2.18	45.8	3.16			849.	58.6	268.	18.5	49.6	3.42	128.8	8.88
80	26.7	142.8	9.85	37.6	2.59	53.9	3.72			964.	66.5	303.	20.9	59.7	4.12	153.0	10.55
90	32.2	164.0	11.31	44.5	3.07	63.3	4.37					349.	24.1	71.2	4.91	180.6	12.46
100	37.8	187.0	12.90	52.2	3.60	73.7	5.08	15.7	1.08			394.	27.2	84.5	5.83	211.9	14.61
110	43.3	213.0	14.19	60.8	4.19	85.1	5.87	19.1	1.32			448.	30.9			247.0	17.03
120	48.9	240.0	16.55	70.8	4.88	98.0	6.76	22.4	1.54			502.	34.6			286.4	19.75
130	54.4			81.4	5.61	112.0	7.72	25.8	1.78			564.	38.9				
140	60.0			92.6	6.39	126.8	8.74	31.5	2.17			630.	43.5				

Source: Reprinted by permission of *CRC Handbook*, 55th Edition, pp. E-27–E-31. Copyright CRC Press, Boca Raton, Florida.

APPROXIMATE pH VALUES AT 25°C

Solution	Concentration N	g/L	pH	Solution	Concentration N	g/L	pH
Acids				Bases			
Hydrochloric	1	36.5	0.1	Sodium hydroxide	1	40.01	14.0
	0.1	3.65	1.1		0.1	4.00	13.0
	0.01	0.365	2.0		0.01	0.40	12.0
Sulfuric	1	49.0	0.3	Potassium hydroxide	1	56.1	14.0
	0.1	4.9	1.2		0.1	5.61	13.0
	0.01	0.49	2.1		0.01	0.56	12.0
Sulfurous	0.1	4.1	1.5	Sodium carbonate	0.1	5.3	11.6
Ortho-phosphoric	0.1	3.27	1.5	Sodium bicarbonate	0.1	4.2	8.4
Formic	0.1	4.60	2.3	Trisodium phosphate	0.1	5.47	12.0
Acetic	1	60.05	2.4	Ammonia	1	17.03	11.6
	0.1	6.01	2.9		0.1	1.7	11.1
	0.01	0.60	3.4		0.01	0.17	10.6
Carbonic (saturated)			3.8	Calcium carbonate (saturated)			9.4
Hydrogen sulfide	0.1	3.41	4.1	Calcium hydroxide (saturated)			12.4
Hydrocyanic	0.1	2.70	5.1				

BOILING POINTS VS CONCENTRATION OF COMMON CORROSIVE MEDIA

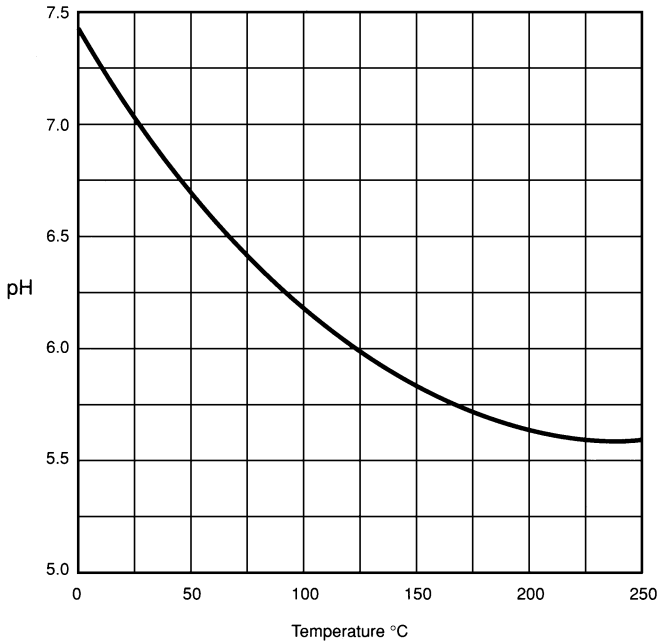
BOILING POINT

Concentration, Percent	Hydrochloric Acid		Sulfuric Acid		Nitric Acid		Phosphoric Acid		Acetic Acid		Formic Acid		Sodium Hydroxide	
By Weight	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
10	219	104	215	102	217	103	212	100	213	101	214	101	218	103
20	230*	110*	219	104	222	106	–		–		215	102	226	108
30	–		226	108	228	109	215	102	–		216	102	241	116
40	–		237	114	234	112	–		–		218	103	262	128
50	–		253	123	242	117	226	108	217	103	–		–	
60	–		284	140	249	121	–		–		222	106	–	
65	–		304	151	251	122	–		–		–		–	
70	–		329	165	250	121	–		–		–		–	
80	–		395	202	–		–		–		–		–	
85	–		437	225	–		316	158	–		222	106	–	
90	–		491	255	–		–		–		–		–	
96	–		554	290	–		–		–		–		–	
98	–		626	330	–		–		–		–		–	
99	–		–		–		–		243	117	–		–	

*Constant Boiling Point Mixture at 20.2 percent concentration.

Source: Cabot Corp., *Corrosion Resistance of Hastelloy Alloys*.

pH VALUES OF PURE WATER AT DIFFERENT TEMPERATURES



SOLUBILITY OF GASES IN WATER (Partial pressure of the gas = 760 mm Hg)

Temperature		CO_2		H_2S		O_2	
°C	°F	cm^3/L	g/L	cm^3/L	g/L	cm^3/L	g/L
0	32	1713	3.36	4670	7.09	48.9	0.070
10	50	1194	2.35	3399	5.16	38.0	0.054
20	68	878	1.72	2582	3.92	31.0	0.044
30	86	665	1.31	2037	3.09	26.1	0.037
40	104	530	1.04	1660	2.52	23.1	0.033
50	122	436	0.86	1392	2.11	20.9	0.030
60	140	359	0.71	1190	1.81	19.5	0.028
70	158	–		1022	1.55	18.3	0.026
80	176	–		917	1.39	17.6	0.025
90	194	–		840	1.28	17.2	0.025
100	212	–		810	1.23	17.0	0.024

SOLUBILITY OF AIR IN WATER AND SOLVENTS

(Air Pressure = 1 Atmosphere)

Temperature		Distilled Water			Sea Water[a]		Ethanol		Iso-Octane	
		Air	O_2		O_2		O_2		O_2	
°C	°F	cm^3/L	cm^3/L	ppm	cm^3/L	ppm	cm^3/L	ppm	cm^3/L	ppm
0	32.0	29.2	10.2	14.6	7.9	11.0	–		–	
1	33.8	28.4	9.9	14.1	–		–		–	
2	35.6	27.7	9.6	13.7	–		–		–	
3	37.4	27.0	9.4	13.4	–		–		–	
4	39.2	26.3	9.1	13.0	–		–		–	
5	41.0	25.7	8.9	12.7	7.0	9.7	–		–	
6	42.8	25.1	8.7	12.4	–		–		–	
7	44.6	24.5	8.5	12.1	–		–		–	
8	46.4	23.9	8.3	11.9	–		–		–	
9	48.2	23.4	8.1	11.6	–		–		–	
10	50.0	22.8	7.9	11.3	6.3	8.7	–		–	
11	51.8	22.3	7.7	11.0	–		–		–	
12	53.6	21.9	7.5	10.7	–		–		–	
13	55.4	21.4	7.4	10.5	–		–		–	
14	57.2	21.0	7.2	10.3	–		–		–	
15	59.0	20.6	7.0	10.1	5.7	7.9	–		–	
16	60.8	20.1	6.9	9.9	–		–		–	
17	62.6	19.8	6.8	9.7	–		–		–	
18	64.4	19.4	6.6	9.5	–		–		–	
19	66.2	19.0	6.5	9.3	–		–		–	
20	68.0	18.7	6.4	9.1	5.2	7.2	44.	79.	62.	126.
21	69.8	18.3	6.2	8.9	–		–		–	
22	71.6	18.0	6.1	8.7	–		–		–	
23	73.4	17.7	6.0	8.6	–		–		–	
24	75.2	17.4	5.9	8.4	–		–		–	
25	77.0	17.1	5.8	8.3	4.7	6.6	–		–	
26	78.8	16.8	5.7	8.1	–		–		–	
27	80.6	16.5	5.6	8.0	–		–		–	
28	82.4	16.2	5.5	7.9	–		–		–	
29	84.2	15.9	5.4	7.7	–		–		–	
30	86.0	15.6	5.3	7.6	3.9	5.4	–		–	

[a] Chlorinity = 20.

SOLUBILITY OF WATER IN HYDROCARBONS

			Solubility	
Hydrocarbon	**°C**	**°F**	**mg/100g**	**Gal/1000 Bbl**
n-Butane	20	68	6.5	1.6
Isobutane	19	66	6.9	1.7
n-Pentane	15	59	6.1	1.6
	25	77	12.0	3.2
Isopentane	20	68	9.4	2.4
n-Hexane	20	68	11.1	3.1
Cyclohexane	20	68	10.0	3.3
n-Heptane	20	68	12.6	3.6
n-Octane	20	68	14.2	4.2
Benzene	20	68	43.5	16.1
Heptene-1	21	70	104.7	30.8
Butene-1	20	68	39.7	11.1
Gasoline	4	40	6.	1.8
	10	50	7.2	2.1
	16	60	8.2	2.4
	21	70	9.2	2.7
	27	80	10.2	3.0
	32	90	11.3	3.3
	38	100	12.3	3.6
	43	110	13.6	4.0

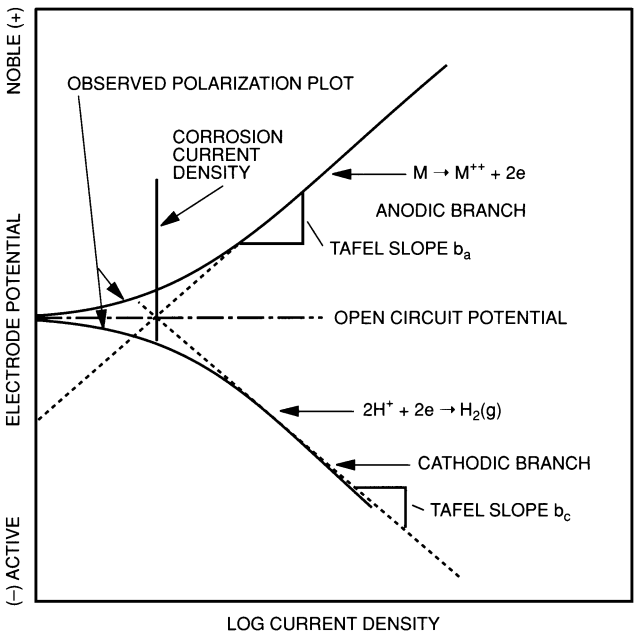
Source: *Corrosion Inhibitors*, p. 89, NACE, 1973.

THERMOCOUPLE DATA

Thermo-Couple	**Cu-Const.**	**Fe-Const.**	**Ni Cr-Ni**	**Pt Rh-Pt**
+ pole	Copper	Iron	Nickel-Chromium	Platinum-10% Rhodium
− pole	Constantan		Nickel	Platinum
Measuring Temp. °C	**Approximate Thermocouple Voltage in mV**			
−200	−5.70	−8.15		
−100	−3.40	−4.60		
0	0	0	0	0
100	4.25	5.37	4.04	0.64
200	9.20	10.95	8.14	1.44
300	14.89	16.55	12.24	2.32
400	20.99	22.15	16.38	3.26
500	27.40	27.84	20.64	4.22
600	34.30	33.66	24.94	5.23
700		39.72	29.15	6.27
800		46.23	33.27	7.34
900		53.15	37.32	8.45
1000			41.32	9.60
1100			45.22	10.77
1200			49.02	11.97
1300				13.17
1400				14.38
1500				15.58
1600				16.76

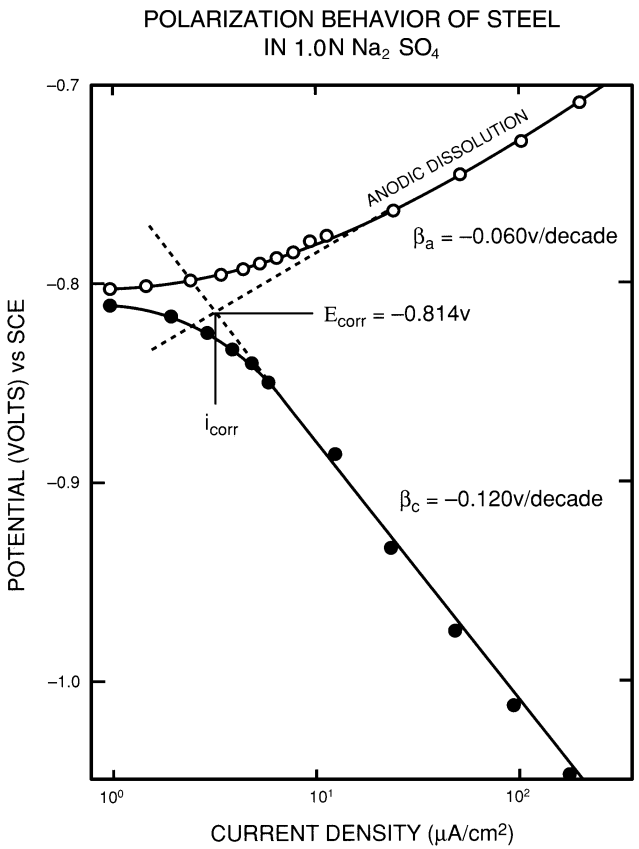
	TEMP. LIMITS	
THERMOCOUPLE	**Average °C**	**Intermittent °C**
Copper/Constantan	400	600
Iron/Constantan	750	1000
Nickel-Chromium/Nickel	1000	1300
Platinum-Rhodium/Platinum	1450	1700

HYPOTHETICAL CATHODIC AND ANODIC POLARIZATION DIAGRAM



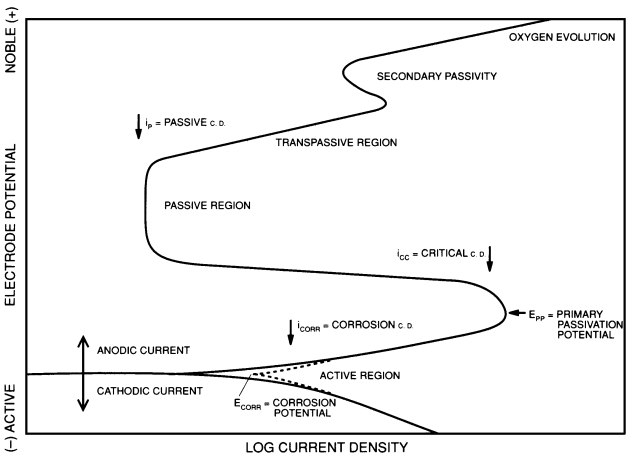
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TYPICAL CATHODIC AND ANODIC POLARIZATION DIAGRAM



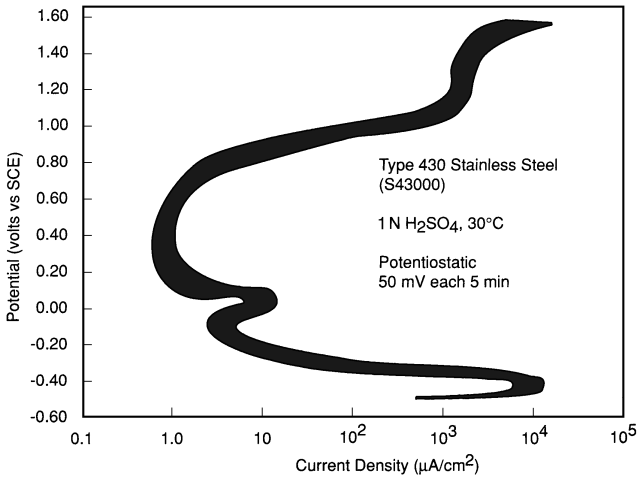
Source: R. Baboian.

HYPOTHETICAL CATHODIC AND ANODIC POLARIZATION PLOTS FOR A PASSIVE ANODE



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TYPICAL STANDARD POTENTIOSTATIC ANODIC POLARIZATION PLOT



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DATA FOR TAFEL EQUATION CALCULATIONS

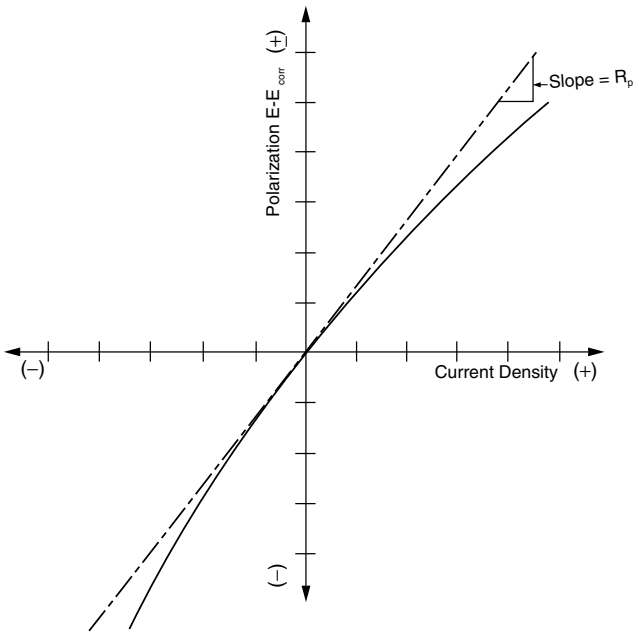
$$\eta = \beta \log \frac{i}{i_o}$$

Metal	Temperature °C	Solution	β volts	i_o A/m^2	η [1 mA/cm^2 (V)]*
		Hydrogen Overvoltage			
Pt (smooth)	20	1N HCl	0.03	10	0.00
	25	0.1N NaOH	0.11	0.68	0.13
Pd	20	0.6N HCl	0.03	2	0.02
Mo	20	1N HCl	0.04	10^{-2}	0.12
Au	20	1N HCl	0.05	10^{-2}	0.15
Ta	20	1N HCl	0.08	10^{-1}	0.16
W	20	5N HCl	0.11	10^{-1}	0.22
Ag	20	0.1N HCl	0.09	5×10^{-3}	0.30
Ni	20	0.1N HCl	0.10	8×10^{-3}	0.31
	20	0.12N NaOH	0.10	4×10^{-3}	0.34
Bi	20	1N HCl	0.10	10^{-3}	0.40
Nb	20	1N HCl	0.10	10^{-3}	0.40
Fe	16	1N HCl	0.15	10^{-2}	0.45
	25	4% NaCl pH 1-4	0.10	10^{-3}	0.40 (Stern)
Cu	20	0.1N HCl	0.12	2×10^{-3}	0.44
	20	0.15N NaOH	0.12	1×10^{-2}	0.36
Sb	20	2N H_2SO_4	0.10	10^{-5}	0.60
Al	20	2N H_2SO_4	0.10	10^{-6}	0.70
Be	20	1N HCl	0.12	10^{-5}	0.72
Sn	20	1N HCl	0.15	10^{-4}	0.75
Cd	16	1N HCl	0.20	10^{-3}	0.80
Zn	20	1N H_2SO_4	0.12	1.6×10^{-7}	0.94
Hg	20	0.1N HCl	0.12	7×10^{-9}	1.10
	20	0.1N H_2SO_4	0.12	2×10^{-9}	1.16
	20	0.1N NaOH	0.10	3×10^{-11}	1.15
Pb	20	0.01-8N HCl	0.12	2×10^{-9}	1.16
		Oxygen Overvoltage			
Pt (smooth)	20	0.1N H_2SO_4	0.10	9×10^{-8}	0.81
	20	0.1N NaOH	0.05	4×10^{-9}	0.47
Au	20	0.1N NaOH	0.05	5×10^{-9}	0.47
		Metal Overvoltage (*deposition*)			
Zn	25	1M $ZnSO_4$	0.12	0.2	0.20 (Bockris)
Cu	25	1M $CuSO_4$	0.12	0.2	0.20 (Bockris)
Fe	25	1M $FeSO_4$	0.12	10^{-4}	0.60 (Bockris)
Ni	25	1M $NiSO_4$	0.12	2×10^{-5}	0.68 (Bockris)

*1 mA/cm^2 = 10 A/m^2

Source: H. H. Uhlig, *Corrosion and Corrosion Control*, 3rd ed., p. 44, John Wiley & Sons. Copyright ©1985. This material is used by permission of John Wiley & Sons, Inc.

HYPOTHETICAL POLARIZATION RESISTANCE PLOT



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POLARIZATION RESISTANCE METHOD FOR DETERMINING CORROSION RATES

Defining the polarization resistance R_p as

$$R_p = \left(\frac{\partial \Phi}{\partial I}\right)_{\Phi_{corr}}$$

and combining the constants as

$$B = \frac{b_a b_c}{2.303(b_a + b_c)}$$

the corrosion current I_{corr} can be calculated as

$$I_{corr} = \frac{b_a b_c}{2.303(b_a + b_c)} \left(\frac{\partial I}{\partial \Phi}\right)_{\Phi_{corr}} = \frac{B}{R_p}$$

The dimension of R_p as determined from a potential-current plot is ohms (Ω). In order to obtain a value of R_p, which is independent of the electrode surface and which can be converted into corrosion rates, polarization resistance values should be reported in $\Omega \cdot cm^2$ (e.g., $mV/mA/cm^2$).

See following page for typical values for constant B.

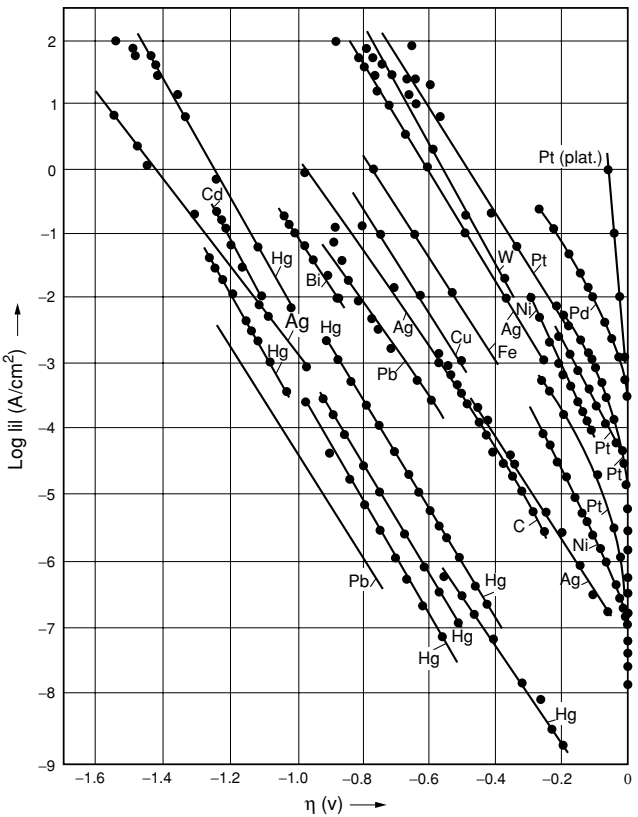
Source: F. Mansfield in *Electrochemical Techniques for Corrosion*, R. Baboian, Editor, NACE, pp. 18–26, 1977.

VALUES OF THE CONSTANT B FOR THE POLARIZATION RESISTANCE METHOD

Corroding System	b_a, mV	b_c, mV	B, mV
Theoretical	30	30	6.5
(Values of B calculated from arbitrary	30	60	9
b_a and b_c values using formula on	30	120	10
previous page; b_a and b_c values	30	180	11
can be interchanged.)	30	∞	13
	60	60	13
	60	90	16
	60	120	17
	60	180	20
	60	∞	26
	90	90	20
	90	120	22
	90	180	26
	90	∞	39
	120	120	26
	120	∞	52
	180	180	39
	180	∞	78
Iron, 4% NaCl, pH 1.5	–	–	17
Iron, 0.5N H_2SO_4, 30 C	–	–	17
Iron, 1N H_2SO_4	–	–	10–20
Iron, 1N HCl	–	–	18–23
Iron, 0.02M citric acid, pH 2.6. 35 C	–	–	12
Carbon steel, seawater	57	∞	25
Carbon steel, 1N Na_2SO_4, H_2, pH 6.3, 30 C	–	–	19
304L SS, 1N H_2SO_4, O_2	inf.	50	22
304 SS, lithiated water, 288 C	85	160	24
304 SS, 3% NaCl, 90 C	inf.	50	22
430 SS, 1N H_2SO_4, H_2, 30 C	–	–	20
600 alloy, lithiated water, 288 C	82	160	24
Al 1199, 1N NaCl, pH 2, 30 C	–	–	44
Aluminum, seawater	45	600	18
Zircaloy 2, lithiated water, 288 C	inf.	186	81
OFHC Copper, 1N NaCl, H_2, pH 6.2, 30 C	–	–	26

Source: Adapted from a collection of literature values compiled by Florian Mansfeld, *Electrochemical Techniques for Corrosion*, R. Baboian, Editor, NACE, pp. 18, 26, 1977.

HYDROGEN OVERVOLTAGE ON VARIOUS ELECTRODE MATERIALS



Source: C. A. Hampel.

STANDARD REFERENCE POTENTIALS AND CONVERSION TABLE

REFERENCE POTENTIALS

Electrode	Potential (V) @ 25°C		Thermal Temperature Coefficient[a] (mV/°C)
	E′[b]	E″[c]	
(Pt)/H_2 ($\alpha = 1$)/H + ($\alpha = 1$) (SHE)	0.000	•••	+0.87
Ag/AgCl/1M KCl	+0.235	•••	+0.25
Ag/AgCl/0.6M Cl^- (seawater)	+0.25	•••	•••
Ag/AgCl/0.1M Cl^-	+0.288	•••	+0.22
Hg/Hg_2Cl_2/sat KCl (SCE)	+0.241	+0.244	+0.22
Hg/Hg_2Cl_2/1M KCl	+0.280	+0.283	+0.59
Hg/Hg_2Cl_2/0.1M KCl	+0.334	+0.336	+0.79
Cu/$CuSO_4$sat	+0.30	•••	+0.90
Hg/Hg_2SO_4/H_2SO_4	+0.616	•••	+0.09

[a] To convert from thermal to isothermal temperature coefficients, subtract 0.87 mV/°C. Thus the isothermal temperature coefficient for Ag/AgCl/1M KCl is −0.62 mV/°C.
[b] E′ is the standard potential for the half cell corrected for the concentration of the ions.
[c] E″ also includes the liquid junction potentials for a saturated KCl salt bridge.

CONVERSION FACTORS[d]

From (E′)	To SHE Scale	To SCE Scale (E′)
H_2/H^+	•••	−0.241
Ag/AgCl/1M KCl	+0.235	−0.006
Ag/AgCl/0.6M Cl^- (seawater)	+0.25	+0.009
Ag/AgCl/0.1M Cl^-	+0.288	+0.047
Hg/Hg_2Cl_2/sat KCl (SCE)	+0.241	•••
Hg/Hg_2Cl_2/1M KCl	+0.280	+0.039
Hg/Hg_2Cl_2/0.1M KCl	+0.334	+0.093
Cu/$CuSO_4$ sat	+0.30	+0.06
Hg/Hg_2SO_4/H_2SO_4	+0.616	•••

[d] To convert from one scale to another, add the value indicated.

Example:
An electrode potential of +1.000V versus SCE would be $(1.000 + 0.241) = +1.241$V versus SHE. An electrode potential of −1.000V versus SCE would give $(-1.000 + 0.241) = -0.759$V versus SHE.

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ELECTROCHEMICAL SERIES

REDUCTION REACTIONS HAVING E° VALUES MORE POSITIVE THAN THAT OF THE STANDARD HYDROGEN ELECTRODE

Reaction	E°, V
$2\,H^+ + 2\,e \rightleftarrows H_2$	0.00000
$CuI_2^- + e \rightleftarrows Cu + 2\,I^-$	0.00
$Ge^{4+} + 2\,e \rightleftarrows Ge^{2+}$	0.00
$NO_3^- + H_2O + 2\,e \rightleftarrows NO_2^- + 2\,HO^-$	0.01
$Tl_2O_3 + 3\,H_2O + 4\,e \rightleftarrows 2\,Tl^+ + 6\,OH^-$	0.02
$SeO_4^{2-} + H_2O + 2\,e \rightleftarrows SeO_3^{2-} + 2\,OH^-$	0.05
$UO_2^{2+} + e \rightleftarrows UO_2^+$	0.062
$Pd(OH)_2 + 2\,e \rightleftarrows Pd + 2\,OH^-$	0.07
$AgBr + e \rightleftarrows Ag + Br^-$	0.07133
$S_4O_6^{2-} + 2\,e \rightleftarrows 2\,S_2O_3^{2-}$	0.08
$AgSCN + e \rightleftarrows Ag + SCN^-$	0.8951
$N_2 + 2\,H_2O + 6\,H^+ + 6\,e \rightleftarrows 2\,NH_4OH$	0.092
$HgO + H_2O + 2\,e \rightleftarrows Hg + 2\,OH^-$	0.0977
$Ir_2O_3 + 3\,H_2O + 6\,e \rightleftarrows 2\,Ir + 6\,OH^-$	0.098
$2\,NO + 2\,e \rightleftarrows N_2O_2^{2-}$	0.10
$[Co(NH_3)_6]^{3+} + e \rightleftarrows [Co(NH_3)_6]^{2+}$	0.108
$Hg_2O + H_2O + 2\,e \rightleftarrows 2\,Hg + 2\,OH^-$	0.123
$Ge^{4+} + 4\,e \rightleftarrows Ge$	0.124
$Hg_2Br_2 + 2\,e \rightleftarrows 2\,Hg + 2\,Br^-$	0.13923
$Pt(OH)_2 + 2\,e \rightleftarrows Pt + 2\,OH^-$	0.14
$S + 2\,H^+ + 2\,e \rightleftarrows H_2S(aq)$	0.142
$Np^{4+} + e \rightleftarrows Np^{3+}$	0.147
$Ag_4[Fe(CN)_6] + 4\,e \rightleftarrows 4\,Ag + [Fe(CN)_6]^{4-}$	0.1478
$Mn(OH)_3 + e \rightleftarrows Mn(OH)_2 + OH^-$	0.15
$2\,NO_2^- + 3\,H_2O + 4\,e \rightleftarrows N_2O + 6\,OH^-$	0.15
$Sn^{4+} + 2\,e \rightleftarrows Sn^{2+}$	0.151
$Sb_2O_3 + 6\,H^+ + 6\,e \rightleftarrows 2\,Sb + 3\,H_2O$	0.152
$Cu^{2+} + e \rightleftarrows Cu^+$	0.153
$BiOCl + 2\,H^+ + 3\,e \rightleftarrows Bi + Cl^- + H_2O$	0.1583
$Bi(Cl)_4^- + 3\,e \rightleftarrows Bi + 4\,Cl^-$	0.16
$Co(OH)_3 + e \rightleftarrows Co(OH)_2 + OH^-$	0.17
$SO_4^{2-} + 4\,H^+ + 2\,e \rightleftarrows H_2SO_3 + H_2O$	0.172
$SbO^+ + 2\,H^+ + 3\,e \rightleftarrows Sb + 2\,H_2O$	0.212
$AgCl + e \rightleftarrows Ag + Cl^-$	0.22233
$As^2O_3 + 6\,H^+ + 6\,e \rightleftarrows 2\,As + 3\,H_2O$	0.234
Calomel electrode, saturated NaCl (SSCE)	0.2360
$Ge^{2+} + 2\,e \rightleftarrows Ge$	0.24
Calomel electrode, saturated KCl	0.2412
$PbO_2 + H_2O + 2\,e \rightleftarrows PbO + 2\,OH^-$	0.247
$HAsO_2 + 3\,H^+ + 3_c \rightleftarrows As + 2\,H_2O$	0.248
$Ru^{3+} + e \rightleftarrows Ru^{2+}$	0.2487
$ReO_2 + 4\,H^+ + 4\,e \rightleftarrows Re + 2\,H_2O$	0.2513
$IO_3^- + 3\,H_2O + 6\,e \rightleftarrows I^- + OH^-$	0.26
$Hg_2Cl_2 + 2\,e \rightleftarrows 2\,Hg + 2\,Cl^-$	0.26808
Calomel electrode, molal KCl	0.2800
Calomel electrode, 1 mol/1 KCl (NCE)	0.2801
$Re^{3+} + 3\,e \rightleftarrows Re$	0.300
$BiO^+ + 2\,H^+ + 3\,e \rightleftarrows Bi + H_2O$	0.320
$UO_2^{2+} + 4\,H^+ + 2\,e \rightleftarrows U^{4+} + 2\,H_2O$	0.327
$ClO_3^- + H_2O + 2\,e \rightleftarrows ClO_2^- + 2\,OH^-$	0.33
$2\,HCNO + 2\,H^+ + 2\,e \rightleftarrows (CN)_2 + 2\,H_2O$	0.330
Calomel electrode, 0.1 mol/l KCl	0.3337
$VO^{2+} + 2\,H^+ + e \rightleftarrows V^{3+} + H_2O$	0.337
$Cu^{2+} + 2\,e \rightleftarrows Cu$	0.3419
$Ag_2O + H_2O + 2\,e \rightleftarrows 2\,Ag + 2\,OH^-$	0.342
$Cu^{2+} + 2\,e \rightleftarrows Cu(Hg)$	0.345

Reaction	E°, V
$AgIO_3 + e \rightleftarrows Ag + IO_3^-$	0.354
$[Fe(CN)_6]^{3-} + e \rightleftarrows [Fe(CN)_6]^{4-}$	0.358
$ClO_4^- + H_2O + 2\,e \rightleftarrows ClO_3^- + 2\,OH^-$	0.36
$Ag_2SeO_3 + 2\,e \rightleftarrows 2\,Ag + SeO_3^{2-}$	0.3629
$ReO_4^- + 8\,H^+ + 7\,e \rightleftarrows Re + 4\,H_2O$	0.368
$(CN)_2 + 2\,H^+ + 2\,e \rightleftarrows 2\,HCN$	0.373
$[Ferricinium]^+ + e \rightleftarrows ferrocene$	0.400
$Tc^{2+} + 2\,e \rightleftarrows Tc$	0.400
$O_2 + 2\,H_2O + 4\,e \rightleftarrows 4\,OH^-$	0.401
$AgOCN + e \rightleftarrows Ag + OCN^-$	0.41
$[RhCl_6]^{3-} + 3\,e \rightleftarrows Rh + 6\,Cl^-$	0.431
$Ag_2CrO_4 + 2\,e \rightleftarrows 2\,Ag + CrO_4^{2-}$	0.4470
$H_2SO_3 + 4\,H^+ + 4\,e \rightleftarrows S + 3\,H_2O$	0.449
$Ru^{2+} + 2\,e \rightleftarrows Ru$	0.455
$Ag_2MoO_4 + 2\,e \rightleftarrows 2\,Ag + MoO_4^{2-}$	0.4573
$Ag_2C_2O_4 + 2\,e \rightleftarrows 2\,Ag + C_2O_4^{2-}$	0.4647
$Ag_2WO_4 + 2\,e \rightleftarrows 2\,Ag + WO_4^{2-}$	0.4660
$Ag_2CO_3 + 2\,e \rightleftarrows 2\,Ag + CO_3^{2-}$	0.47
$TeO_4^- + 8\,H^+ + 7\,e \rightleftarrows Te + 4\,H_2O$	0.472
$IO^- + H_2O + 2\,e \rightleftarrows I^- + 2\,OH^-$	0.485
$ReO_4^- + 4\,H^+ + 3\,e \rightleftarrows ReO_2 + 2\,H_2O$	0.510
$Hg_2(ac)_2 + 2\,e \rightleftarrows 2\,Hg + 2\,(ac)^-$	0.51163
$Cu^+ + e \rightleftarrows Cu$	0.521
$I_2 + 2\,e \rightleftarrows 2\,I^-$	0.5355
$I^3 + 2\,e \rightleftarrows 3\,I^-$	0.536
$AgBrO_3 + e \rightleftarrows Ag + BrO_3^-$	0.546
$MnO_4^- + e \rightleftarrows MnO_4^{2-}$	0.558
$H_3AsO_4 + 2\,H^+ + 2\,e^- \rightleftarrows HAsO_2 + 2\,H_2O$	0.560
$IO_3^- + 2\,H_2O + 4\,e \rightleftarrows IO^- + 4\,OH^-$	0.56
$S_2O_6^{2-} + 4\,H^+ + 2\,e \rightleftarrows 2\,H_2SO_3$	0.564
$AgNO_2 + e \rightleftarrows Ag + NO_2^-$	0.564
$Te^{4+} + 4\,e \rightleftarrows Te$	0.568
$Sb_2O_5 + 6\,H^+ + 4\,e \rightleftarrows 2\,SbO^+ + 3\,H_2O$	0.581
$RuO_4^- + e \rightleftarrows RuO_4^{2-}$	0.59
$[PdCl_4]^{2-} + 2\,e \rightleftarrows Pd + 4\,Cl^-$	0.591
$TeO_2 + 4\,H^+ + 4\,e \rightleftarrows Te + 2\,H_2O$	0.593
$MnO_4^- + 2\,H_2O + 3\,e \rightleftarrows MnO_2 + 4\,OH^-$	0.595
$Rh^{2+} + 2\,e \rightleftarrows Rh$	0.600
$Rh^+ + e \rightleftarrows Rh$	0.600
$MnO_4^{2-} + 2\,H_2O + 2\,e \rightleftarrows MnO_2 + 4\,OH^-$	0.60
$2\,AgO + H_2O + 2\,e \rightleftarrows Ag_2O + 2\,OH^-$	0.607
$BrO_3^- + 3\,H_2O + 6\,e \rightleftarrows Br^- + 6\,OH^-$	0.61
$UO_2^+ + 4\,H^+ + e \rightleftarrows U^{4+} + 2\,H_2O$	0.612
$Hg_2SO_4 + 2\,e \rightleftarrows 2\,Hg + SO_4^{2-}$	0.6125
$ClO_3^- + 3\,H_2O + 6\,e \rightleftarrows Cl^- + 6\,OH^-$	0.62
$Hg_2HPO_4 + 2\,e \rightleftarrows 2\,Hg + HPO_4^{2-}$	0.6359
$Ag(ac) + e \rightleftarrows Ag + (ac)^-$	0.643
Sb_2O_5 (valentinite) $+ 4\,H^+ + 4\,e \rightleftarrows Sb_2O_3 + 2\,H_2O$	0.649
$Ag_2SO_4 + 2\,e \rightleftarrows 2\,Ag + SO_4^{2-}$	0.654
$ClO_2^- + H_2O + 2\,e \rightleftarrows ClO^- + 2\,OH^-$	0.66
Sb_2O_5 (senarmontite) $+ 4\,H^+ + 4\,e \rightleftarrows Sb_2O_3 + 2\,H_2O$	0.671
$[PtCl_6]^{2-} + 2\,e \rightleftarrows [PtCl_4]^{2-} + 2\,Cl^-$	0.68
$O_2 + 2\,H^+ + 2\,e \rightleftarrows H_2O_2$	0.695
p-benzoquinone $+ 2\,H^+ + 2\,e \rightleftarrows$ hydroquinone	0.6992
$H_3IO_6 + 2\,e \rightleftarrows IO_3^- + 3\,OH^-$	0.7
$Ag_2O_3 + H_2O + 2\,e \rightleftarrows 2\,AgO + 2\,OH^-$	0.739
$[PtCl_4]^{2-} + 2\,e \rightleftarrows Pt + 4\,Cl^-$	0.755
$Rh^{3+} + 3\,e \rightleftarrows Rh$	0.758
$ClO_2^- + 2\,H_2O + 4\,e \rightleftarrows Cl^- + 4\,OH^-$	0.76
$2\,NO + H_2O + 2\,e \rightleftarrows N_2O + 2\,OH^-$	0.76
$BrO^- + H_2O + 2\,e \rightleftarrows Br^- + 2\,OH^-$	0.761
$ReO_4^- + 2\,H^+ + e \rightleftarrows ReO_3 + H_2O$	0.768
$(CNS)_2 + 2\,e \rightleftarrows 2\,CNS^-$	0.77
$[IrCl_6]^{3-} + 3e \rightleftarrows Ir + 6\,Cl^-$	0.77
$Fe^{3+} + e \rightleftarrows Fe^{2+}$	0.771
$Ag(F) + e \rightleftarrows Ag + F^-$	0.779
$TcO_4^- + 4\,H^+ + 3\,e \rightleftarrows TcO_2 + 2\,H_2O$	0.782
$Hg_2^{2+} + 2\,e \rightleftarrows 2\,Hg$	0.7973
$Ag^+ + e \rightleftarrows Ag$	0.7996
$2\,NO_3^- + 4\,H^+ + 2\,e \rightleftarrows N_2O_4 + 2\,H_2O$	0.803
$ClO^- + H_2O + 2\,e \rightleftarrows Cl^- + 2\,OH^-$	0.841
$OsO_4 + 8\,H^+ + 8\,e \rightleftarrows Os + 4\,H_2O$	0.85

(*Continued*)

ELECTROCHEMICAL SERIES (*Continued*)

Reaction	E°, V
$Hg^{2+} + 2\,e \rightleftarrows Hg$	0.851
$AuBr_4^- + 3\,e \rightleftarrows Au + 4\,Br^-$	0.854
SiO_2 (quartz) $+ 4\,H^+ + 4\,e \rightleftarrows Si + 2\,H_2O$	0.857
$2\,HNO_2 + 4\,H^+ + 4\,e \rightleftarrows H_2N_2O_2 + H_2O$	0.86
$[IrCl_6]^{2-} + e \rightleftarrows [IrCl_6]^{3-}$	0.8665
$N_2O_4 + 2\,e \rightleftarrows 2\,NO_2^-$	0.867
$HO_2^- + H_2O + 2\,e \rightleftarrows 3\,OH^-$	0.878
$2\,Hg^{2+} + 2\,e \rightleftarrows Hg_2^{2+}$	0.920
$NO_3^- + 3\,H^+ + 2\,e \rightleftarrows HNO_2 + H_2O$	0.934
$Pd^{2+} + 2\,e \rightleftarrows Pd$	0.951
ClO_2 (aq) $+ e \rightleftarrows ClO_2^-$	0.954
$NO_3^- + 4\,H^+ + 3\,e \rightleftarrows NO + 2\,H_2O$	0.957
$AuBr_2^- + e \rightleftarrows Au + 2\,Br^-$	0.959
$HNO_2 + H^+ + e \rightleftarrows NO + H_2O$	0.983
$HIO + H^+ + 2\,e \rightleftarrows I^- + H_2O$	0.987
$VO_2^+ + 2\,H^+ + e \rightleftarrows VO^{2+} + H_2O$	0.991
$RuO_4 + e \rightleftarrows RuO_4^-$	1.00
$V(OH)_4^+ + 2\,H^+ + e \rightleftarrows VO^{2+} + 3\,H_2O$	1.00
$AuCl_4^- + 3\,e \rightleftarrows Au + 4\,Cl^-$	1.002
$Pu^{4+} + e \rightleftarrows Pu^{3+}$	1.006
$H_6TeO_6 + 2\,H^+ + 2\,e \rightleftarrows TeO_2 + 4\,H_2O$	1.02
$N_2O_4 + 4\,H^+ + 4\,e \rightleftarrows 2\,NO + 2\,H_2O$	1.035
$[Fe(phen)_3]^{3+} + e \rightleftarrows [Fe(phen)_3]^{2+}$ (1 (mol// H_2SO_4)	1.06
$PuO_2(OH)_2 + H^+ + e \rightleftarrows PuO_2OH + H_2O$	1.062
$N_2O_4 + 2\,H^+ + 2\,e \rightleftarrows 2\,HNO_2$	1.065
$Br_2(l) + 2\,e \rightleftarrows 2\,Br^-$	1.066
$IO_3^- + 6\,H^+ + 6\,e \rightleftarrows I^- + 3\,H_2O$	1.085
Br_2(aq) $+ 2\,e \rightleftarrows 2\,Br^-$	1.0873
$Pu^{5+} + e \rightleftarrows Pu^{4+}$	1.099
$Cu^{2+} + 2\,CN^- + e \rightleftarrows [Cu(CN)2]^-\ Pt^{2+} + 2\,e \rightleftarrows Pt$	1.118
$RuO_2 + 4\,H^+ + 2\,e \rightleftarrows Ru^{2+} + 2\,H_2O$	1.120
$[Fe(phenanthroline)_3]^{3+} + e \rightleftarrows [Fe(phen)_3]^{2+}$	1.147
$SeO_4^{2-} + 4\,H^+ + 2\,e \rightleftarrows H_2SeO_3 + H_2O$	1.151
$ClO_3^- + 2\,H^+ + e \rightleftarrows ClO_2 + H_2O$	1.152
$Ir^{3+} + 3\,e \rightleftarrows Ir$	1.156
$ClO_4^- + 2\,H^+ + 2\,e \rightleftarrows ClO_3^- + H_2O$	1.189
$2\,IO_3^- + 12\,H^+ + 10\,e \rightleftarrows I_2\ 6\,H_2O$	1.195
$ClO_3^- + 3\,H^+ + 2\,e \rightleftarrows HClO_2 + H_2O$	1.214
$MnO_2 + 4\,H^+ + 2\,e \rightleftarrows Mn^{2+} + 2\,H_2O$	1.224
$O_2 + 4\,H^+ + 4\,e \rightleftarrows 2\,H_2O$	1.229
$Cr_2O_7^{2-} + 14\,H^+ + 6\,e \rightleftarrows 2\,Cr^{3-} + 7\,H_2O$	1.232
$O_3 + H_2O + 2\,e \rightleftarrows O_2 + 2\,OH^-$	1.24
$Tl^{3+} + 2\,e \rightleftarrows Tl^+$	1.252
$N_2H_5^+ + 3\,H^+ + 2\,e \rightleftarrows 2\,NH_4^+$	1.275
$ClO_2 + H^+ + e \rightleftarrows HClO_2$	1.227
$[PdCl_6]^{2-} + 2\,e \rightleftarrows [PdCl_4]^{2-} + 2\,Cl^-$	1.288
$2\,HNO_2 + 4\,H^+ + 4\,e \rightleftarrows N_2O + 3\,H_2O$	1.297
$PuO_2(OH)_2 + 2\,H^+ + 2\,e \rightleftarrows Pu(OH)_4$	1.325
$HBrO + H^+ + 2\,e \rightleftarrows Br^- + H_2O$	1.331
$HCrO_4^- + 7\,H^+ + 3\,e \rightleftarrows Cr^{3+} + 4\,H_2O$	1.350
$Cl_2(g) + 2\,e \rightleftarrows Cl^-$	1.35827
$ClO_4^- + 8\,H^+ + 8\,e \rightleftarrows Cl^- + 4\,H_2O$	1.389
$ClO_4^- + 8\,H^+ + 7\,e \rightleftarrows 1/2\ Cl_2 + 4\,H_2O$	1.39
$Au^{3+} + 2\,e \rightleftarrows Au^+$	1.401
$2\,NH_3OH^+ + H^+ + 2\,e \rightleftarrows N_2H_5^+ + 2\,H_2O$	1.42
$BrO_3^- + 6\,H^+ + 6\,e \rightleftarrows Br^- + 3\,H_2O$	1.423
$2\,HIO + 2\,H^+ + 2\,e \rightleftarrows I_2 + 2\,H_2O$	1.439
$Au(OH)_3 + 3\,H^+ + 3\,e \rightleftarrows Au^- + 3\,H_2O$	1.45
$3IO_3^- + 6\,H^+ + 6\,e \rightleftarrows Cl^- + 3\,H_2O$	1.451
$PbO_2 + 4\,H^- + 2\,e \rightleftarrows Pb^{2+} + 2\,H_2O$	1.455
$ClO_3^- + 6\,H^+ + 5\,e \rightleftarrows 1/2\ Cl_2 + 3\,H_2O$	1.47
$BrO_3^- + 6\,H^+ + 5\,e \rightleftarrows 1/2\ Br_2 + 3\,H_2O$	1.482
$HClO + H^+ + 2\,e \rightleftarrows Cl^- + H_2O$	1.482
$HO_2 + H^+ + e \rightleftarrows H_2O_2$	1.495
$Au^{3+} + 3\,e \rightleftarrows Au$	1.498
$MnO_4^- + 8\,H^+ + 5\,e \rightleftarrows Mn^{2+} + 4\,H_2O$	1.507
$Mn^{3+} + e \rightleftarrows Mn^{2+}$	1.5415
$HClO_2 + 3\,H^+ + 4\,e \rightleftarrows Cl^- + 2\,H_2O$	1.570
$HBrO + H^+ + e \rightleftarrows 1/2\ Br_2$(aq) $+ H_2O$	1.574
$2\,NO + 2\,H^+ + 2\,e \rightleftarrows N_2O + H_2O$	1.591
$Bi_2O_4 + 4\,H^+ + 2\,e \rightleftarrows 2\,BiO^+ + 2\,H_2O$	1.593
$HBrO + H^+ + e \rightleftarrows 1/2\ Br_2(l) + H_2O$	1.596

Reaction	E°, V	Reaction	E°, V
$H_5IO_6 + H^+ + 2\,e \rightleftarrows IO_3^- + 3\,H_2O$	1.601	$Co^{3+} + e \rightleftarrows Co^{2+}$ (2 mol// H_2SO_4)	1.83
$Ce^{4+} + e \rightleftarrows Ce^{3+}$	1.61	$Ag^{2+} + e \rightleftarrows Ag^+$	1.980
$HClO + H^+ + e \rightleftarrows 1/2\,Cl_2 + H_2O$	1.611	$S_2O_8^{2-} + 2\,e \rightleftarrows 2\,SO_4^{2-}$	2.010
$HClO_2 + 3\,H^+ + 3\,e \rightleftarrows 1/2\,Cl_2 + 2\,H_2O$	1.628	$OH + e \rightleftarrows OH^-$	2.02
$HClO_2 + 2\,H^+ + 2\,e \rightleftarrows HClO + H_2O$	1.645	$O_3 + 2\,H^+ + 2\,e \rightleftarrows O_2 + H_2O$	2.076
$NiO_2 + 4\,H^+ + 2\,e \rightleftarrows Ni^{2+} + 2\,H_2O$	1.678	$S_2O_8^{2-} + 2\,H^+ + 2\,e \rightleftarrows 2\,HSO_4^{2-}$	2.123
$MnO_4^- + 4\,H^+ + 3\,e \rightleftarrows MnO_2 + 2\,H_2O$	1.679	$F_2O + 2\,H^+ + 4\,e \rightleftarrows H_2O + 2\,F^-$	2.153
$PbO_2 + SO_4^{2-} + 4\,H^+ + 2\,e \rightleftarrows PbSO_4 + 2\,H_2O$	1.6913	$FeO_4^{2-} + 8\,H^+ + 3\,e \rightleftarrows Fe^{3+} + 4\,H_2O$	2.20
$Au^+ + e \rightleftarrows Au$	1.692	$O(g) + 2\,H^+ + 2\,e \rightleftarrows H_2O$	2.421
$CeOH^{3+} + H^+ + e \rightleftarrows Ce^{3+} + H_2O$	1.715	$H_2N_2O_2 + 2\,H^+ + 2\,e \rightleftarrows N_2 + 2\,H_2O$	2.65
$N_2O + 2\,H^+ + 2\,e \rightleftarrows N_2 + H_2O$	1.766	$F_2 + 2\,e \rightleftarrows 2\,F^-$	2.866
$H_2O_2 + 2\,H^+ + 2\,e \rightleftarrows 2\,H_2O$	1.776	$F_2 + 2\,H^+ + 2\,e \rightleftarrows 2\,HF$	3.053

REDUCTION REACTIONS HAVING E° VALUES MORE NEGATIVE THAN THAT OF THE STANDARD HYDROGEN ELECTRODE

Reaction	E°, V	Reaction	E°, V
$2\,H^+ + 2\,e \rightleftarrows H_2$	–0.00000	$WO_2 + 4\,H^+ + 4\,e \rightleftarrows W + 2\,H_2O$	–0.119
$AgCN + e \rightleftarrows Ag + CN^-$	–0.017	$Pb^{2+} + 2\,e \rightleftarrows Pb(Hg)$	–0.1205
$2\,WO_3 + 2\,H^+ + 2\,e \rightleftarrows W_2O_5 + H_2O$	–0.029	$Pb^{2+} + 2\,e \rightleftarrows Pb$	–0.1262
$W_2O_5 + 2\,H^+ + 2\,e \rightleftarrows 2\,WO_2 + H_2O$	–0.031	$CrO_4^{2-} + 4\,H_2O + 3\,e \rightleftarrows Cr(OH)_3 + 5\,OH^-$	–0.13
$D^+ + e \rightleftarrows 1/2\,D_2$	–0.0034	$Sn^{2-} + 2\,e \rightleftarrows Sn$	–0.1375
$Ag_2S + 2\,H^+ + 2\,e \rightleftarrows Ag + H_2S$	–0.0366	$In^+ + e \rightleftarrows In$	–0.14
$Fe^{3+} + 3\,e \rightleftarrows Fe$	–0.037	$O_2 + 2\,H_2O + 2\,e \rightleftarrows H_2O_2 + 2\,OH^-$	–0.146
$Hg_2I_2 + 2\,e \rightleftarrows 2\,Hg + 2\,I^-$	–0.0405	$AgI + e \rightleftarrows Ag + I^-$	–0.15224
$2\,D^+ + 2\,e \rightleftarrows D_2$	–0.044	$2\,NO_2^- + 2\,H_2O + 4\,e \rightleftarrows N_2O_2^{2-} + 4\,OH^-$	–0.18
$Tl(OH)_3 + 2\,e \rightleftarrows TlOH + 2\,OH^-$	–0.05	$H_2GeO_3 + 4\,H^+ + 4\,e \rightleftarrows Ge + 3\,H_2O$	–0.182
$TiOH^{3+} + H^+ + e \rightleftarrows Ti^{3+} + H_2O$	–0.055	$Co_2 + 2\,H^+ + 2\,e \rightleftarrows HCOOH$	–0.199
$2\,H_2SO_3 + H^+ + 2\,e \rightleftarrows HS_2O_4^- + 2\,H_2O$	–0.056	$Mo^{3+} + 3\,e \rightleftarrows Mo$	–0.200
$P(white) + 3\,H^+ + 3\,e \rightleftarrows PH_3(g)$	–0.063	$2\,SO_2^{2-} + 4\,H^+ + 2\,e \rightleftarrows S_2O_6^{2-} + H_2O$	–0.22
$O_2^- + H_2O + 2\,e \rightleftarrows HO_2^- + OH^-$	–0.076	$Cu(OH)_2 + 2\,e \rightleftarrows Cu + 2\,OH^-$	–0.222
$2\,Cu(OH)_2 + 2\,e \rightleftarrows Cu_2O + 2\,OH^- + H_2O$	–0.080	$CdSO_4 + 2\,e \rightleftarrows Cd + SO_4^{2-}$	–0.246
$WO_3 + 6\,H^+ + 6\,e \rightleftarrows W + 3\,H_2O$	–0.090	$V(OH)_4^+ + 4\,H^+ + 5\,e \rightleftarrows V + 4\,H_2O$	–0.254
$P(red) + 3\,H^+ + 3\,e \rightleftarrows PH_3(g)$	–0.111	$V^{3+} + e \rightleftarrows V^{2+}$	–0.255
$GeO_2 + 2\,H^+ + 2\,e \rightleftarrows GeO + H_2O$	–0.118	$Ni^{2+} + 2\,e \rightleftarrows Ni$	–0.257

(*Continued*)

ELECTROCHEMICAL SERIES (*Continued*)

Reaction	E°, V
$PbCl_2 + 2\,e \rightleftarrows Pb + 2\,Cl^-$	−0.2675
$H_3PO_4 + 2\,H^+ + 2\,e \rightleftarrows H_3PO_3 + H_2O$	−0.276
$Co^{2+} + 2\,e \rightleftarrows Co$	−0.28
$PbBr_2 + 2\,e \rightleftarrows Pb + 2\,Br^-$	−0.284
$Tl^+ + e \rightleftarrows Tl(Hg)$	−0.3338
$Tl^+ + e \rightleftarrows Tl$	−0.336
$In^{3+} + 3\,e \rightleftarrows In$	−0.3382
$TlOH + e \rightleftarrows Tl + OH^-$	−0.34
$PbF_2 + 2\,e \rightleftarrows Pb + 2\,F^-$	−0.3444
$PbSO_4 + 2\,e \rightleftarrows Pb(Hg) + SO_4^{2-}$	−0.3505
$Cd^{2+} + 2\,e \rightleftarrows Cd(Hg)$	−0.3521
$PbSO_4 + 2\,e \rightleftarrows Pb + SO_4^{2-}$	−0.3588
$Cu_2O + H_2O + 2\,e \rightleftarrows 2\,Cu + 2\,OH^-$	−0.360
$Eu^{3+} + e \rightleftarrows Eu^{2+}$	−0.36
$PbI_2 + 2\,e \rightleftarrows Pb + 2\,I^-$	−0.365
$Se_3^{2-} + 3\,H_2O + 4\,e \rightleftarrows Se + 6\,OH^-$	−0.366
$Ti^{3+} + e \rightleftarrows Ti^{2+}$	−0.368
$Se + 2\,H^+ + 2\,e \rightleftarrows H_2Se(aq)$	−0.399
$In^{2+} + e \rightleftarrows In^+$	−0.40
$Cd^{2+} + 2\,e \rightleftarrows Cd$	−0.4030
$Cr^3 + e \rightleftarrows Cr^{2+}$	−0.407
$2\,S + 2\,e \rightleftarrows S_2^{2-}$	−0.42836
$Tl_2SO_4 + 2\,e \rightleftarrows Tl + SO_4^{2-}$	−0.4360
$In^{3+} + 2\,e \rightleftarrows In^+$	−0.443
$Fe^{2+} + 2\,e \rightleftarrows Fe$	−0.447
$H_3PO_3 + 3\,H^+ + 3\,e \rightleftarrows P + 3\,H_2O$	−0.454
$Bi_2O_3 + 3\,H_2O + 6\,e \rightleftarrows 2\,Bi + 6\,OH^-$	−0.46
$NO_2^- + H_2O + e \rightleftarrows NO + 2\,OH$	−0.46
$PbHPO_4 + 2\,e \rightleftarrows Pb + HPO_4^{2-}$	−0.465
$S + 2\,e \rightleftarrows S^{2-}$	−0.47627
$S + H_2O + 2\,e \rightleftarrows HS^- + OH^-$	−0.478
$NiO_2 + 2\,H_2O + 2\,e \rightleftarrows Ni(OH)_2 + 2\,OH^-$	−0.490
$In^{3+} + e \rightleftarrows In^{2+}$	−0.49
$H_3PO_3 + 2\,H^+ + 2\,e \rightleftarrows H_3PO_2 + H_2O$	−0.499
$TiO_2 + 4\,H^+ + 2\,e \rightleftarrows Ti^{2+} + 2\,H_2O$	−0.502
$H_3PO_2 + H^+ + e \rightleftarrows P + 2\,H_2O$	−0.508
$Sb + 3\,H^+ + 3\,e \rightleftarrows SbH_3$	−0.510
$HPbO_2^- + H_2O + 2\,e \rightleftarrows Pb + 3\,OH^-$	−0.537
$TlCl + e \rightleftarrows Tl + Cl^-$	−0.5568
$Ga^{3+} + 3\,e \rightleftarrows Ga$	−0.560
$Fe(OH)_3 + e \rightleftarrows Fe(OH)_2 + OH^-$	−0.56
$TeO_3^{2-} + 3\,H_2O + 4\,e \rightleftarrows Te + 6\,OH^-$	−0.57
$2\,SO_3^{2-} + 3\,H_2O + 4\,e \rightleftarrows S_2O_3^{2-} + 6\,OH^-$	−0.571
$PbO + H_2O + 2\,e \rightleftarrows Pb + 2\,OH^-$	−0.580
$ReO_2^- + 4\,H_2O + 7\,e \rightleftarrows Re + 8\,OH^-$	−0.584
$SbO_3^- + H_2O + 2\,e \rightleftarrows SbO_2^- + 2\,OH^-$	−0.59
$U^{4+} + e \rightleftarrows U^{3+}$	+0.607
$As + 3\,H^+ + 3\,e \rightleftarrows AsH_3$	−0.608
$Nb_2O_5 + 10\,H^+ + 10\,e \rightleftarrows 2\,Nb + 5\,H_2O$	−0.644
$TlBr + e \rightleftarrows Tl + Br^-$	−0.658
$SbO_2^- + 2\,H_2O + 3\,e \rightleftarrows Sb + 4\,OH^-$	−0.66
$AsO_2^- + 2\,H_2O + 3\,e \rightleftarrows As + 4\,OH^-$	−0.68
$Ag_2S + 2\,e \rightleftarrows 2\,Ag + S^{2-}$	−0.691
$AsO_4^{3-} + 2\,H_2O + 2\,e \rightleftarrows AsO_2^- + 4\,OH^-$	−0.71
$Ni(OH)_2 + 2\,e \rightleftarrows Ni + 2\,OH^-$	−0.72
$Co(OH)_2 + 2\,e \rightleftarrows Co + 2\,OH^-$	−0.73
$H_2SeO_3 + 4\,H^+ + 4\,e \rightleftarrows Se + 3\,H_2O$	−0.74
$Cr^{3+} + 3\,e \rightleftarrows Cr$	−0.744
$Ta_2O_5 + 10\,H^+ + 10\,e \rightleftarrows 2\,Ta + 5\,H_2O$	−0.750
$TlI + e \rightleftarrows Tl + I^-$	−0.752
$Zn^{2+} + 2\,e \rightleftarrows Zn$	−0.7618
$Zn^{2+} + 2\,e \rightleftarrows Zn(Hg)$	−0.7628
$Te + 2\,H^+ + 2\,e \rightleftarrows H_2Te$	−0.793
$ZnSO_4 \cdot 7H_2O + 2\,e \rightleftarrows Zn(Hg) + SO_4^{2-}$ (Sat'd $ZnSO_4$)	−0.7993
$Cd(OH)_2 + 2\,e \rightleftarrows Cd(Hg) + 2\,OH^-$	−0.809
$2\,H_2O + 2\,e \rightleftarrows H_2 + 2\,OH^-$	−0.8277
$2\,NO_3^- + 2\,H_2O + 2\,e \rightleftarrows N_2O_4 + 4\,OH^-$	−0.85
$H_3BO_3 + 3\,H^+ + 3\,e \rightleftarrows B + 3\,H_2^+O$	−0.8698
$P + 3\,H_2O + 3\,e \rightleftarrows PH_3(g) + 3\,OH^-$	−0.87
$HSnO_2^- + H_2O + 2\,e \rightleftarrows Sn + 3\,OH^-$	−0.909
$Cr^{2+} + 2\,e \rightleftarrows Cr$	−0.913
$Se + 2\,e \rightleftarrows Se^{2-}$	−0.924

Reaction	E°, V
$SO_4^{2-} + H_2O + 2\,e \rightleftarrows SO_3^{2-} + 2\,OH^-$	−0.93
$Sn(OH)_6^{2-} + 2\,e \rightleftarrows HSNO_2^- + 3\,OH^- + H_2O$	−0.93
$NpO_2 + H_2O + H^+ + e \rightleftarrows Np(OH)_3$	−0.962
$PO_4^{3-} + 2\,H_2O + 2\,e \rightleftarrows HPO_3^{2-} + 3\,OH^-$	−1.05
$Nb^{3+} + 3\,e \rightleftarrows Nb$	−1.099
$2\,SO_3^{2-} + 2\,H_2O + 2\,e \rightleftarrows S_2O_4^{2-} + 4\,OH^-$	−1.12
$Te + 2\,e \rightleftarrows Te^{2-}$	−1.143
$V^{2+} + 2\,e \rightleftarrows V$	−1.175
$Mn^{2+} + 2\,e \rightleftarrows Mn$	−1.185
$CrO_2^- + 2\,H_2O + 3\,e \rightleftarrows Cr + 4\,OH^-$	−1.2
$ZnO_2^{2-} + 2\,H_2O + 2\,e \rightleftarrows Zn + 4\,OH^-$	−1.215
$H_2GaO_3^- + H_2O + 3\,e \rightleftarrows Ga + 4\,OH^-$	−1.219
$H_2BO_3^- + 5\,H_2O + 8\,e \rightleftarrows BH_4^- + 8\,OH^-$	−1.24
$SiF_6^{2-} + 4\,e \rightleftarrows Si + 6\,F^-$	−1.24
$Ce^{3+} + 3\,e \rightleftarrows Ce(Hg)$	−1.4373
$UO_2^{2+} + 4\,H^+ + 6\,e \rightleftarrows U + 2\,H_2O$	−1.444
$Cr(OH)_3 + 3\,e \rightleftarrows Cr + 3\,OH^-$	−1.48
$HfO_2 + 4\,H^+ + 4\,e \rightleftarrows Hf + 2\,H_2O$	−1.505
$ZrO_2 + 4\,H^+ + 4\,e \rightleftarrows Zr + 2\,H_2O$	−1.553
$Mn(OH)_2 + 2\,e \rightleftarrows Mn + 2\,OH^-$	−1.56
$Ba^{2+} + 2\,e \rightleftarrows Ba(Hg)$	−1.570
$Ti^{2+} + 2\,e \rightleftarrows Ti$	−1.630
$HPO_3^{2-} + 2\,H_2O + 2\,e \rightleftarrows H_2PO_2^- + OH^-$	−1.65
$Al^{3+} + 3\,e \rightleftarrows Al$	−1.662
$SiO_3^{2-} + H_2O + 4\,e \rightleftarrows Si + 6\,OH^-$	−1.697
$HPO_3^{2-} + 2\,H_2O + 3\,e \rightleftarrows P + 5\,OH^-$	−1.71
$HfO^{2+} + 2\,H^+ + 4\,e \rightleftarrows Hf + H_2O$	−1.724
$ThO_2 + 4\,H^- + 4\,e \rightleftarrows Th + 2\,H_2O$	−1.789
$H_2BO_3^- + H_2O + 3\,e \rightleftarrows B + 4\,OH^-$	−1.79
$Sr^{2+} + 2\,e \rightleftarrows Sr(Hg)$	−1.793
$U^{3+} + 3\,e \rightleftarrows U$	−1.798
$H_2PO_2^- + e \rightleftarrows P + 2\,OH^-$	−1.82
$Be^{2+} + 2\,e \rightleftarrows Be$	−1.847
$Np^{3+} + 3\,e \rightleftarrows Np$	−1.856

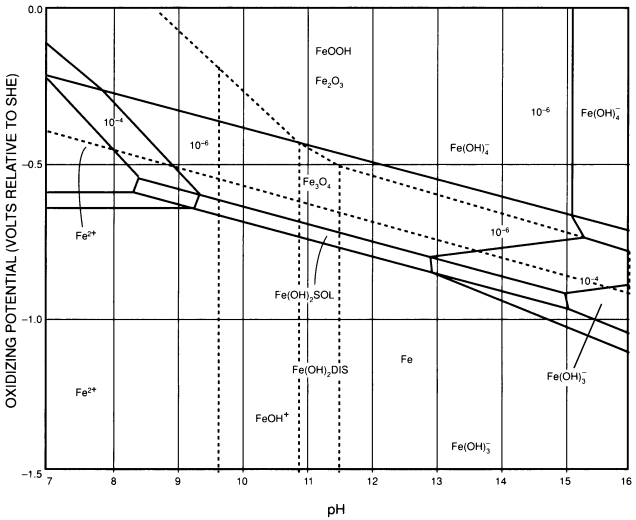
Reaction	E°, V
$Th^{4+} + 4\,e \rightleftarrows Th$	−1.899
$Pu^{3+} + 3\,e \rightleftarrows Pu$	−2.031
$AlF_6^{3-} + 3\,e \rightleftarrows Al + 6\,F^-$	−2.069
$Sc^{3+} + 3\,e \rightleftarrows Sc$	−2.077
$H_2 + 2\,e \rightleftarrows 2\,H^-$	−2.23
$H_2AlO_3^- + H_2O + 3\,e \rightleftarrows Al + 4\,OH^-$	−2.33
$ZrO(OH)_2 + H_2O + 4\,e \rightleftarrows Zr + 4\,OH^-$	−2.36
$Mg^{2+} + 2\,e \rightleftarrows Mg$	−2.372
$Y^{3+} + 3\,e \rightleftarrows Y$	−2.372
$Eu^{3+} + 3\,e \rightleftarrows Eu$	−2.407
$Nd^{3+} + 3\,e \rightleftarrows Nd$	−2.431
$Th(OH)_4 + 4\,e \rightleftarrows Th + 4\,OH^-$	− 2.48
$Ce^{3+} + 3\,e \rightleftarrows Ce$	−2.483
$HfO(OH)_2 + H_2O + 4\,e \rightleftarrows Hf + 4\,OH^-$	−2.50
$La^{3+} + 3\,e \rightleftarrows La$	−2.522
$Be_2O_3^{2-} + 3\,H_2O + 4\,e \rightleftarrows 2\,Be + 6\,OH^-$	−2.63
$Mg(OH)_2 + 2\,e \rightleftarrows Mg + 2\,OH^-$	−2.690
$Mg^+ + e \rightleftarrows Mg$	−2.70
$Na^+ + e \rightleftarrows Na$	−2.71
$Ca^{2+} + 2\,e \rightleftarrows Ca$	−2.868
$Sr(OH)_2 + 2\,e \rightleftarrows Sr + 2\,OH^-$	−2.88
$Sr^{2+} + 2\,e \rightleftarrows Sr$	−2.89
$La(OH)_3 + 3\,e \rightleftarrows La + 3\,OH^-$	−2.90
$Ba^{2+} + 2\,e \rightleftarrows Ba$	−2.912
$Cs^+ + e \rightleftarrows Cs$	−2.92
$K^+ + e \rightleftarrows K$	−2.931
$Rb^- + e \rightleftarrows Rb$	−2.98
$Ba(OH)_2 + 2\,e \rightleftarrows Ba + 2\,OH^-$	−2.99
$Ca(OH)_2 + 2\,e \rightleftarrows Ca + 2\,OH^-$	−3.02
$Li^+ + e \rightleftarrows Li$	−3.0401
$3\,N_2 + 2\,H^+ + 2\,e \rightleftarrows 2\,NH_3$	−3.09
$Eu^{2+} + 2\,e \rightleftarrows Eu$	−3.395
$Ca^+ + e \rightleftarrows Ca$	−3.80
$Sr^+ + e \rightleftarrows Sr$	−4.10

EMF SERIES FOR METALS

Electrode Reaction	Standard Potential at 25°C (77°F), Volts versus SHE
$Au^{3+} + 3e^- \rightarrow Au$	1.50
$Pd^{2+} + 2e^- \rightarrow Pd$	0.987
$Hg^{2+} + 2e^- \rightarrow Hg$	0.854
$Ag^+ + e^- \rightarrow Ag$	0.800
$Hg_2^{2+} + 2e^- \rightarrow 2\,Hg$	0.789
$Cu^+ + e^- \rightarrow Cu$	0.521
$Cu^{2+} + 2e^- \rightarrow Cu$	0.337
$2\,H^+ + 2e^- \rightarrow H_2$	(Reference) 0.000
$Pb^{2+} + 2e^- \rightarrow Pb$	−0.126
$Sn_2 + 2e^- \rightarrow Sn$	−0.136
$Ni^{2+} + 2e^- \rightarrow Ni$	−0.250
$Co^{2+} + 2e^- \rightarrow Ni$	−0.277
$Tl^+ + e^- \rightarrow Tl$	−0.336
$In^{3+} + 3e^- \rightarrow In$	−0.342
$Cd^{2+} + 2e^- \rightarrow Cd$	−0.403
$Fe^{2+} + 2e^- \rightarrow Fe$	−0.440
$Ga^{3+} + 3e^- \rightarrow Ga$	−0.53
$Cr^{3+} + 3e^- \rightarrow Cr$	−0.74
$Cr^{2+} + 2e^- \rightarrow Cr$	−0.91
$Zn^{2+} + 2e^- \rightarrow Zn$	−0.763
$Mn^{2+} + 2e^- \rightarrow Mn$	−1.18
$Zr^{4+} + 4e^- \rightarrow Zr$	−1.53
$Ti^{2+} + 2e^- \rightarrow Ti$	−1.63
$Al^{3+} + 3e^- \rightarrow Al$	−1.66
$Hf^{4+} + 4e^- \rightarrow Hf$	−1.70
$U^{3+} + 3e^- \rightarrow U$	−1.80
$Be^{2+} + 2e^- \rightarrow Be$	−1.85
$Mg^{2+} + 2e^- \rightarrow Mg$	−2.37
$Na^+ + e^- \rightarrow Na$	−2.71
$Ca^{2+} + 2e^- \rightarrow Ca$	−2.87
$K^+ + e^- \rightarrow K$	−2.93
$Li^+ + e^- \rightarrow Li$	−3.05

Source: *Metals Handbook*, 9th ed., Vol. 13, p. 20, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

TYPICAL POTENTIAL-pH (POURBAIX) DIAGRAM IRON IN WATER AT 25°C



IONIC SPECIES ARE AT ACTIVITIES OF 10^{-4} AND 10^{-6}

Source: M. Pourbaix, *Atlas of Electrochemical Equlibria in Aqueous Solutions*, NACE, p. 313, 1974.

STANDARD ENVIRONMENTS FOR ENVIRONMENTAL CRACKING TESTS

Standard	Environment	Temperature °C	Materials
NACE TM0177	5.0% NaCl + 0.5% Acetic acid, saturated with H_2S (1 atm.)	21–27	All metals
ASTM G 35	Polythionic acid solution	22–25	Stainless steels Related nickel-chromium-iron alloys
ASTM G 36	45% $MgCl_2$ (boiling)	154–156	Stainless steels Related alloys
ASTM G 37	Mattsson's Solution. pH 7.2 ($CuSO_4 + (NH_4)_2SO_4 + NH_4OH$)	18–24	Copper-zinc base alloys
ASTM G 41	NaCl or other salts or synthetic seawater	230–450	All metals
ASTM G 44, G 47	3.5% NaCl (alt. immersion)	26–28	Aluminum alloys Ferrous alloys
ASTM G 103	6% NaCl	Boiling	Al-Zn-Mg alloys
ASTM G 123	25% NaCl, pH 1.5 with phosphoric acid	Boiling	Stainless steels
ISO 9591	3.5% NaCl, (alt.immersion)	25	Aluminum alloys
ISO 9591	2.0% NaCl 0.5% Na_2CrO_4 pH = 3.0	25	Aluminum alloys
ISO 15324	0.1 M NaCl Dripped on 300°C specimen	20–26	Stainless steels Nickel based alloys

SPECIMEN TYPES USED IN ENVIRONMENTAL CRACKING TESTS

Loading System	Specimen Type	Standard	Product Form					Used to Determine				
			Sheet	Bar	Plate	Tube	Wire	T_f	σ_{th}	K_{Iscc}	da/dt	I_{cc}
Constant Load	Bent Beam	–		X	X			X	X			
	Notched beam	–		X	X			X	X	X		
	Direct tension	ASTM G 49		X	X	X		X	X			
Constant Strain	U-bend	ASTM G 30	X					X				
	Cup	–	X			X						
	C-ring	ASTM G 38		X	X	X		X	X			
	Bent beam	ASTM G 39	X	X	X	X		X	X			
	Direct tension	ASTM G 49		X	X	X		X	X			
	Tuning fork	–		X	X			X				
	Weld bead	–	X		X			X				
	Rough ground	–	X					X				
	Hairpin	–					X	X				
Slow Strain Rate	Round tensile	–		X	X	X			X			X
	Tube	–				X						X
Sustained-Loading Crack-Growth	DCB	–			X	X				X	X	

T_f time to failure.
σ_{th} threshold stress.
K_{Iscc} threshold stress intensity.
da/dt crack growth rate.
I_{ICC} index of susceptibility.

Source: See ISO 7539, Parts 2 through 8 and NACE TM0177.

TYPICAL HIGH TEMPERATURE/HIGH PRESSURE TEST CONDITIONS

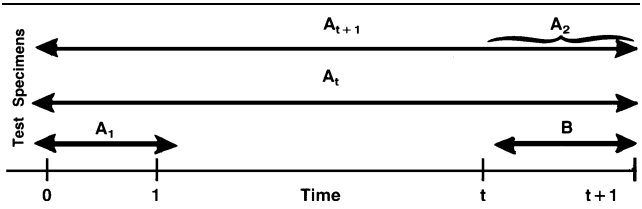
No.	Application	Environment	Temp, C	Pressure, MPa (bar)
1	Nuclear Power	high-purity water/steam/H_2	280 to 500	≤17 (170)
2	Fluidized Bed Combustion	air, gas, coal	600 to 750	1 (10)
3	Deep Sea	seawater	0 to 70*	< 5 (50)
4	Oil and Gas Production	brine, H_2S, CO_2, S°	20 to 250	≤130 (1300)
5	Aerospace Propulsion	hydrogen	−200 to 900	0.1 to 67 (1 to 670)
		oxygen	−200 to 480	≤8 (80)
6	Petroleum Refining	H_2, H_2S, hydrocarbons	350 to 650	≤10 (100)
7	Compressed Natural Gas Storage	methane w/trace H_2S	0 to 100	≤8 (80)
8	Ammonia Storage	NH_3, H_2O	0 to 70	≤4 (40)
9	Thermodynamic Power Generation	NH_3, H_2O	100 to 650	1.5 to 11 (15 to 110)
10	Exhaust Gas Processing	H_2, N_2, CO, CO_2	≤70	≤35 (350)
11	Natural Gas Pipeline	CH_4 w/trace $H_2S/CO_2/O_2$	≤60	≤13 (130)
12	Geothermal Power	brine, steam, H_2S	≤370	≤17 (170)
13	Steam Boiler	water/steam	≤300	≤9 (90)

*Pipeline surface temperature.

Source: Manual 20, p. 106, ASTM, 1995. Reprinted, with permission, copyright ASTM.

PLANNED INTERVAL CORROSION TEST

Used to Evaluate Effect of Time on Corrosion Rate and to Determine if the Time Effect is Due to Changes in Environment Corrosiveness or in Metal Corrodibility



Identical specimens all placed in the same corrosive fluid. Imposed conditions of the test kept constant for entire time t + 1. Letters A_1, A_t, A_{t+1}, B, represent corrosion damage experienced by each test specimen. A_2 is calculated by subtracting A_t from A_{t+1}.

	Occurrences During Corrosion Test	Criteria
Liquid corrosiveness	unchanged	$A_1 = B$
	decreased	$B < A_1$
	increased	$A_1 < B$
Metal corrodibility	unchanged	$A_2 = B$
	decreased	$A_2 < B$
	increased	$B < A_2$

Liquid Corrosiveness	Combinations of Situations Metal Corrodibility	Criteria
1. unchanged	unchanged	$A_1 = A_2 = B$
2. unchanged	decreased	$A_2 < A_1 = B$
3. unchanged	increased	$A_1 = B < A_2$
4. decreased	unchanged	$A_2 = B < A_1$
5. decreased	decreased	$A_2 < B < A_1$
6. decreased	increased	$A_1 > B < A_2$
7. increased	unchanged	$A_1 < A_2 = B$
8. increased	decreased	$A_1 < B > A_2$
9. increased	increased	$A_1 < B < A_2$

Example

Interval, Days	Wt. Loss, mg	Penetration, mils	Apparent Corrosion Rate, mils/yr.
A_1.....0-1	1080	1.69	620
A_t.....0-3	1430	2.24	270
A_{t+1}.....0-4	1460	2.29	210
B.....3-4	70	0.11	40
A_2.....calc. 3-4	30	0.05	18

$$A_2 < B < A_1$$
$$0.05 < 0.11 < 1.69$$

Therefore, liquid markedly decreased in corrosiveness during test, and formation of partially protective scale on the steel was indicated.

Source: A. Wachtner and R. S. Treseder, "Corrosion Testing—Evaluation of Metals for Process Equipment," *Chemical Engineering Progress*, Vol. 43, p. 318, 1947. Reprinted by permission of American Institute of Chemical Engineers.

CORROSION RATE CONVERSION FACTORS

$$\textbf{Mils/year (mpy)} = \textbf{C} \times \frac{\textbf{weight loss}}{\textbf{area} \times \textbf{time}} \times \textbf{K}$$

$$\textbf{Millimetres/year (mm/y)} = \textbf{0.0254 mpy}$$

Weight Loss	Area	C Factors				
		Hour	Day	Week	Month	Year
mg	cm^2	437	18.2	2.59	0.598	0.0498
	dm^2	4.37	0.182	0.0259	5.98×10^{-3}	4.98×10^{-4}
	m^2	0.0437	1.82×10^{-3}	2.59×10^{-4}	5.98×10^{-5}	4.98×10^{-6}
	in^2	67.7	2.82	0.402	0.0927	7.72×10^{-3}
	ft^2	0.470	0.0196	2.79×10^{-3}	6.44×10^{-4}	5.36×10^{-5}
g	cm^2	437×10^3	182×10^2	2590	598	49.8
	dm^2	4370	182	25.9	5.98	0.498
	m^2	43.7	1.82	0.259	0.0598	4.98×10^{-3}
	in^2	677×10^2	2820	402	92.7	7.72
	ft^2	470	19.6	2.79	0.644	0.0536
lb	cm^2	198×10^6	825×10^4	118×10^4	271×10^3	226×10^2
	dm^2	198×10^4	825×10^2	118×10^2	2710	226
	m^2	198×10^2	825	118	27.1	2.26
	in^2	307×10^5	128×10^4	182×10^3	420×10^2	3500
	ft^2	213×10^3	8880	1270	292	24.3

EXAMPLE: A 5.0 square inch specimen of copper has a weight loss of 218 mg in a 40 hour corrosion test.

$$\text{mpy} = 67.7 \times \frac{218.}{5.0 \times 40} \times 0.88 = 65$$

$$\text{mm/y} = 0.0254 \times 65 = 1.65$$

K is a density factor.
K = 1.000 for carbon steel.
K factors for other alloys are given on the next page.

Source: Courtesy Aaron Wachter.

DENSITIES OF COMMON ALLOYS

(K = ratio of carbon steel density to that of alloy)

UNS	Common Name	Density g/cm^3	K	UNS	Common Name	Density g/cm^3	K
A91100	Al 1100	2.72	2.89	N06007	G Alloy	8.34	0.94
A93003	Al 3003	2.74	2.87	N06022	C-22 Alloy	8.69	0.90
A95052	Al 5052	2.68	2.93	N06030	G-30 Alloy	8.22	0.96
A96061	Al 6061	2.70	2.91	N06455	C-4 Alloy	8.64	0.91
A97075	Al 7075	2.80	2.81	N06600	600 Alloy	8.47	0.93
C11000	ETP Copper	8.94	0.88	N06601	601 Alloy	8.11	0.97
C22000	Commercial Bronze	8.89	0.88	N06625	625 Alloy	8.44	0.93
C23000	Red Brass	8.75	0.90	N06985	G-3 Alloy	8.30	0.95
C26000	Cartridge Brass	8.53	0.92	N07001	Waspaloy	8.19	0.96
C27000	Yellow Brass	8.39	0.94	N07041	Rene 41	8.25	0.95
C28000	Muntz Metal	8.39	0.94	N07718	718 Alloy	8.19	0.96
C44300	Admiralty brass. As	8.52	0.92	N07750	X-750 Alloy	8.28	0.95
C46500	Naval Brass. As	8.41	0.93	N08020	20Cb-3	8.08	0.97
C51000	Phosphor Bronze A	8.86	0.89	N08024	20Mo-4	8.11	0.97
C52400	Phosphor Bronze D	8.78	0.90	N08026	20Mo-6	8.13	0.97
C61300	Aluminum Bronze, 7%	7.89	1.00	N08028	Sanicro 28	8.0	0.98
C61400	Aluminum Bronze D	7.78	1.01	N08366	AL-6X	8.0	0.98
C63000	Ni-Al Bronze	7.58	1.04	N08800	800 Alloy	7.94	0.99
C65500	High-Silicon Bronze	8.52	0.92	N08825	825 Alloy	8.14	0.97
C67500	Manganese Bronze A	8.36	0.94	N08904	904L Alloy	8.0	0.98
C68700	Aluminum Brass, As	8.33	0.94	N08925	25-6Mo	8.1	0.97
C70600	9-10 Copper-Nickel	8.94	0.88	N09925	925 Alloy	8.05	0.98
C71500	70-30 Copper-Nickel	8.94	0.88	N10003	N Alloy	8.79	0.89
C75200	Nickel Silver	8.73	0.90	N10004	W Alloy	9.03	0.87
C83600	Ounce Metal	8.80	0.89	N10276	C-276 Alloy	8.89	0.88
C86500	Manganese Bronze	8.3	0.95	N10665	B-2 Alloy	9.22	0.85
C90500	Gun Metal	8.72	0.90	R03600	Molybdenum	10.22	0.77
C92200	M Bronze	8.64	0.91	R04210	Niobium	8.57	0.92
C95700	Cast Mn-Ni-Al Bronze	7.53	1.04	R05200	Tantalum	16.60	0.47
C95800	Cast Ni-Al Bronze	7.64	1.03	R50250	Titanium, Gr 1	4.54	1.73
F10006	Gray Cast Iron	7.20	1.09	R50400	Titanium, Gr 2	4.54	1.73
F20000	Malleable Cast Iron	7.27	1.08	R53400	Titanium, Gr 12	4.52	1.74
F32800	Ductile Iron	7.1	1.11	R56400	Titanium, Gr 5	4.43	1.77
F41002	Ni-Resist Type 2	7.3	1.08	R60702	Zr 702	6.53	1.20
F43006	Ductile Ni-Resist, D5	7.68	1.02	S20100	201 SS	7.94	0.99
F47003	Duriron	7.0	1.12	S20200	202 SS	7.94	0.99
G10200	1020 Carbon Steel	7.86	1.00	S30400	304 SS	7.94	0.99
G41300	4130 Steel	7.86	1.00	S30403	304L SS	7.94	0.99
J91150	CA-15 Cast SS	7.61	1.03	S30900	309 SS	7.98	0.98
J91151	CA-15M Cast SS	7.61	1.03	S31000	310 SS	7.98	0.98
J91540	CA-6NM Cast SS	7.7	1.02	S31254	254 SMO	8.0	0.98
J92600	CF-8 Cast SS	7.75	1.01	S31500	3RE60	7.75	1.01
J92800	CF-3MN Cast SS	7.75	1.01	S31600	316 SS	7.98	0.98
J92900	CF-8M Cast SS	7.75	1.01	S31603	316L SS	7.98	0.98
J94204	HK-40 Cast SS	7.75	1.01	S31700	317 SS	7.98	0.98
J95150	CN-7M Cast SS	8.00	0.98	S32100	321 SS	7.94	0.99
K11597	1.25Cr-0.5Mo Steel	7.85	1.00	S32550	Ferralium 255	7.81	1.01
K81340	9Ni Steel	7.86	1.00	S32950	7 Mo Plus	7.75	1.01
L51120	Chemical Lead	11.3	0.70	S34700	347 SS	8.03	0.98
M11311	Mg AZ31B	1.77	4.44	S41000	410 SS	7.70	1.02
N02200	Nickel 200	8.89	0.88	S43000	430 SS	7.72	1.02
N04400	400 Alloy	8.80	0.89	S44600	446 SS	7.65	1.03
N05500	K-500 Alloy	8.44	0.93	S50100	5Cr-0.5Mo Steel	7.82	1.01
N06002	X Alloy	8.23	0.96	S50400	9Cr-1Mo Steel	7.67	1.02

DENSITY OF MATERIALS

Material	Density (g/cm^3)	Density ($lb/in.^3$)	Material	Density (g/cm^3)	Density ($lb/in.^3$)
Iridium	22.65	0.82	Nickel iron superalloy	7.86	0.28
Osmium	22.61	0.82	Chromium steel	7.83	0.28
Platinum	21.45	0.77	Nonresulfurized carbon steel	7.83	0.28
Rhenium	21.00	0.76	Stainless steel (17Cr-4Ni)	7.81	0.28
Tungsten	19.40	0.70	Hot work tool steel	7.75	0.28
Gold	19.30	0.70	Aluminum bronze	7.64	0.28
Uranium	19.07	0.69	Babbitt	7.50	0.27
Tungsten carbide	17.20	0.62	Samarium	7.49	0.27
Tantalum	16.60	0.60	Manganese	7.43	0.27
Tantalum carbide (TaC)	14.53	0.52	Indium	7.31	0.26
Hafnium	13.10	0.47	Niobium nitride	7.30	0.26
Ruthenium	12.45	0.45	Tin	7.30	0.26
Rhodium	12.41	0.45	Cerium dioxide	7.28	0.26
Palladium	12.02	0.43	Austempered ductile iron	7.20	0.26
Thallium	11.85	0.43	Pewter (Sn, Sb, Cu)	7.20	0.26
Thorium	11.50	0.42	Chromium	7.19	0.26
Lead	11.34	0.41	Zinc	7.13	0.26
Silver	10.49	0.38	Neodymium	7.00	0.25
Molybdenum	10.20	0.37	Praseodymium	6.77	0.24
Bismuth	9.80	0.35	Cerium	6.77	0.24
Thulium	9.31	0.34	Chromium carbide	6.70	0.24
Cast high leaded tin bronze	9.29	0.34	Antimony	6.65	0.24
Nickel-moly (Hastelloy B-2)	9.20	0.33	Zirconium	6.49	0.23
Copper	8.96	0.32	Lanthanum	6.15	0.22
Nickel	8.90	0.32	Vanadium	6.11	0.22
Copper nickel (64Cu-14Ni-22Zn)	8.85	0.32	Nickel aluminide (NiAl)	6.05	0.22
Cobalt	8.85	0.32	Gallium	5.91	0.21
Nickel silver	8.70	0.31	Zirconia (partially stabilized)	5.70	0.21
Brass (61.5Cu-3Pb-35.5Zn)	8.70	0.31	Germanium	5.32	0.19
Bronze (57Cu, 40Zn, 3Pb)	8.70	0.31	Titanium nitride	5.29	0.19
Cadmium	8.65	0.31	Titanium carbide	4.94	0.18
Niobium (Columbium)	8.57	0.31	Titanium diboride	4.52	0.16
Nickel chromium cobalt alloy	8.21	0.30	Titanium	4.51	0.16
Nickel-chromium (Inconel 718)	8.20	0.30	Ti-6Al-4V	4.50	0.16
Copper zinc alloy	8.19	0.30	Titanium dioxide	4.25	0.15
Maraging steel	8.02	0.29	Aluminum oxide	3.98	0.14
Austenitic stainless steel	8.00	0.29	Spinel ($MgO{\cdot}Al_3O_3$)	3.57	0.13
Iron-nickel (Invar)	8.00	0.29	Aluminum nitride	3.26	0.12
Iron	7.87	0.28	Sialon	3.20	0.12

(*Continued*)

DENSITY OF MATERIALS (*Continued*)

Material	Density (g/cm^3)	Density ($lb/in.^3$)	Material	Density (g/cm^3)	Density ($lb/in.^3$)
Silicon nitride	3.19	0.12	Magnesium	1.74	0.06
Mullite ($3Al_2O_3$-$2SiO_2$)	3.16	0.11	PPS (polyphenylene sulfide)	1.67	0.06
Silicon carbide	3.10	0.11	Nylon 6	1.64	0.06
Hydroxyapatite	3.10	0.00	Acetal resin	1.57	0.06
Aluminum carbide	2.99	0.11	Epoxy resin	1.56	0.06
Wollastonite	2.90	0.10	Calcium	1.55	0.06
Aluminum copper alloy	2.84	0.10	Rubidium	1.53	0.06
Aluminum zinc alloy	2.78	0.10	Polycarbonate	1.53	0.06
Aluminum	2.70	0.10	Aramid fiber	1.45	0.05
Cordierite	2.65	0.10	Aromatic polyamide	1.44	0.05
E-glass fiber	2.62	0.10	Bismaleimide resin	1.36	0.05
Pyrex glass	2.52	0.09	Silicone	1.35	0.05
Boron carbide	2.52	0.09	PEEK (polyetheretherketone)	1.32	0.05
Boron	2.40	0.09	Cellulose acetate	1.30	0.05
Silicon	2.33	0.08	Human Bone	1.30	0.05
PTFE (polytetrafluoroethylene)	2.30	0.08	Polyurethane	1.27	0.05
Graphite	2.26	0.08	ABS (acrylonitrile butadiene styrene)	1.26	0.05
Boron nitride	2.25	0.08	Polysulfone	1.24	0.04
Sulfur	2.07	0.07	Acrylic	1.19	0.04
Unsaturated polyester	2.00	0.07	Polypropylene	1.05	0.04
Polyimide thermoset	2.00	0.07	Sodium	0.97	0.04
Phenolic resin	1.99	0.07	PE (polyethylene)	0.95	0.03
Beryllium	1.85	0.07	UHMWPE (ultrahigh molecular weight PE)	0.93	0.03
Phosphorus	1.83	0.07	Potassium	0.86	0.03
Carbon fiber	1.74	0.06	Lithium	0.53	0.19

Source: GEM 2001, p. 35, ASM, 2000. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

EQUIVALENT WEIGHT VALUES FOR METALS AND ALLOYS

Common Designation	UNS	Elements w/Constant Valence	Lowest		Second		Third		Fourth	
			Variable Valence	Equivalent Weight	Variable Valance	Equivalent Weight	Element/ Valence	Equivalent Weight	Element/ Valence	Equivalent Weight
Aluminum Alloys										
AA1100	A91100	Al/3		8.99						
AA2024	A92024	Al/3, Mg/2	Cu/1	9.38	Cu/2	9.32				
AA2219	A92219	Al/3	Cu/1	9.51	Cu/2	9.42				
AA3003	A93003	Al/3	Mn/2	9.07	Mn/4	9.03	Mn 7	8.98		
AA3004	A93004	Al/3, Mg/2	Mn/2	9.09	Mn/4	9.06	Mn 7	9.00		
AA5005	A95005	Al/3, Mg/2		9.01						
AA5050	A95050	Al/3, Mg/2		9.03						
AA5052	A95052	Al/3, Mg/2		9.05						
AA5083	A95083	Al/3, Mg/2		9.09						
AA5086	A95086	Al/3, Mg/2		9.09						
AA5154	A95154	Al/3, Mg/2		9.08						
AA5454	A95454	Al/3, Mg/2		9.06						
AA5456	A95456	Al/3, Mg/2		9.11						
AA6061	A96061	Al/3, Mg/2		9.01						
AA6070	A96070	Al/3, Mg/2, Si/4		8.98						
AA6101	A96161	Al/3		8.99						
AA7072	A97072	Al/3, Zn/2		9.06						
AA7075	A97075	Al/3, Zn/2, Mg/2	Cu/1	9.58	Cu/2	9.55				
AA7079	A97079	Al/3, Zn/2, Mg/2		9.37						
AA7178	A97178	Al/3, Zn/2, Mg/2	Cu/1	9.71	Cu/2	9.68				
Copper Alloys										
CDA110	C11000		Cu/1	63.55	Cu/2	31.77				
CDA220	C22000	Zn/2	Cu/1	58.07	Cu/2	31.86				
CDA230	C23000	Zn/2	Cu/1	55.65	Cu/2	31.91				

Common Designation	UNS	Elements w/Constant Valence	Lowest Variable Valence	Lowest Equivalent Weight	Second Variable Valance	Second Equivalent Weight	Third Element/ Valence	Third Equivalent Weight	Fourth Element/ Valence	Fourth Equivalent Weight
CDA260	C26000	Zn/2	Cu/1	49.51	Cu/2	32.04				
CDA280	C28000	Zn/2	Cu/1	46.44	Cu/2	32.11				
CDA444	C44300	Zn/2	Cu/1, Sn/2	50.42	Cu/1, Sn/4	50.00	Cu/2, Sn/4	32.00		
CDA687	C68700	Zn/2, Al/3	Cu/1	48.03	Cu/2	30.29				
CDA608	C60800	Al/3	Cu/1	47.114	Cu/2	27.76				
CDA510	C51000		Cu/1, Sn/2	63.32	Cu/1, Sn/4	60.11	Cu/2, Sn/4	31.66		
CDA524	C52400		Cu/1, Sn/2	63.10	Cu/1, Sn/4	57.04	Cu/2, Sn/4	31.55		
CDA655	C65500	Si/4	Cu/1	50.21	Cu/2	28.51				
CDA706	C70600	Ni/2	Cu/1	56.92	Cu/2	31.51				
CDA715	C71500	Ni/2	Cu/1	46.69	Cu/2	30.98				
CDA752	C75200	Ni/2, Zn/2	Cu/1	46.38	Cu/2	31.46				
Stainless Steels										
304	S30400	Ni/2	Fe/2, Cr/3	25.12	Fe/3, Cr/3	18.99	Fe/3, Cr/6	15.72		
321	S32100	Ni/2	Fe/2, Cr/3	25.13	Fe/3, Cr/3	19.08	Fe/3, Cr/6	15.78		
309	S30900	Ni/2	Fe/2, Cr/3	24.62	Fe/3, Cr/3	19.24	Fe/3, Cr/6	15.33		
310	S31000	Ni/2	Fe/2, Cr/3	24.44	Fe/3, Cr/3	19.73	Fe/3, Cr/6	15.36		
316	S31600	Ni/2	Fe/2, Cr/3, Mo/3	25.50	Fe/3, Cr/3, Mo/4	25.33	Fe/3, Cr/6, Mo/6	19.14	Fe/3, Cr/6, Mo/6	16.111
317	S31700	Ni/2	Fe/2, Cr/3, Mo/3	25.26	Fe/3, Cr/3, Mo/4	25.03	Fe/3, Cr/6, Mo/6	19.15	Fe/3, Cr/6, Mo/6	15.82
410	S41000		Fe/2, Cr/3	25.94	Fe/3, Cr/3	18.45	Fe/3, Cr/6	16.28		
430	S43000		Fe/2, Cr/3	25.30	Fe/3, Cr/3	18.38	Fe/3, Cr/6	15.58		
446	S44600		Fe/2, Cr/3	24.22	Fe/3, Cr/3	18.28	Fe/3, Cr/6	14.46		
20CB3[a]	N08020	Ni/2	Fe/2, Cr/3, Mo/3, Cu/1	23.98	Fe/2, Cr/3, Mo/4, Cu/1	23.83	Fe/3, Cr/3, Mo/6, Cu/2	18.88	Fe/3, Cr/6, Mo/6, Cu/2	15.50
Nickel Alloys										
200	N02200		Ni/2	29.36	Ni/3	19.57				
400	N04400	Ni/2	Cu/1	35.82	Cu/2	30.12				
600	N06600	Ni/2	Fe/2, Cr/3	26.41	Fe/3, Cr/3	25.44	Fe/3, Cr/6	20.73		
800	N08800	Ni/2	Fe/2, Cr/3	25.10	Fe/3, Cr/3	20.76	Fe/3, Cr/6	16.59		
825	N08825	Ni/2	Fe/2, Cr/3, Mo/3, Cu/1	25.52	Fe/3, Cr/3, Mo/4, Cu/1	25.32	Fe/3, Cr/3, Mo/6, Cu/2	21.70	Fe/3, Cr/6, Mo/6, Cu/2	17.10
B	N10001	Ni/2	Mo/3, Fe/2	30.05	Mo/4, Fe/2	27.50	Mo/6, Fe/2	23.52	Mo/6, Fe/3	23.23
C-22[b]	N06022	Ni/2	Fe/2, Cr/3, Mo/3, W/4	26.04	Fe/2, Cr/3, Mo/4, W/4	25.12	Fe/2, Cr/3, Mo/6, W/6	23.28	Fe/3, Cr/6, Mo/6, W/6	17.88

(*Continued*)

EQUIVALENT WEIGHT VALUES FOR METALS AND ALLOYS (*Continued*)

Common Designation	UNS	Elements w/Constant Valence	Lowest		Second		Third		Fourth	
			Variable Valence	Equivalent Weight	Variable Valance	Equivalent Weight	Element/ Valence	Equivalent Weight	Element/ Valence	Equivalent Weight
C-276	N10276	Ni/2	Fe/2, Cr/3, Mo/3, W/4	27.09	Cr/3, Mo/4	25.90	Fe/2, Cr/3, Mo/6, W/6	23.63	Fe/3, Cr/6, Mo/6, W/6	19.14
G	N06007	Ni/2	(1)	25.46	(2)	22.22	(3)	22.04	(4)	17.03
Carbon Steel			Fe/2	27.92	Fe/3	18.62				
(1) = Fe/2, Cr/3, Mo/3, Cu/1, Nb/4, Mn/2			(3) = Fe/3, Cr/3, Mo/6, Cu/2, Nb/5, Mn/2							
(2) = Fe/2, Cr/3, Mo/4, Cu/2, Nb/5, Mn/2			(4) = Fe/3, Cr/6, Mo/6, Cu/2, Nb/5, Mn/4							
Other Metals										
Mg	M14142	Mg/2		12.15						
Mo	R03600		Mo/3	31.98	Mo/4	23.98	Mo/6	15.99		
Ag	P07016		Ag/1	107.87	Ag/2	53.93				
Ta	R05210	Ta/5		36.19						
Sn	L13002		Sn/2	59.34	Sn/4	29.67				
Ti	R50400		Ti/2	23.95	Ti/3	15.97	Ti/4	11.98		
Zn	Z19001	Zn/2		32.68						
Zr	R60701	Zr/4		22.80						
Pb	L50045		Pb/2	103.59	Pb/4	51.80				

[a]Registered trademark Carpenter Technology.
[b]Registered trademark Haynes International.
Note 1: Alloying elements at concentrations below 1% by mass were not included in the calculation, for example, they were considered part of the basis metal.
Note 2: Midrange values were assumed for concentrations of alloying elements.
Note 3: Only consistent valence groupings were used.
Note 4: Equation 4 in ASTM G 102 was used to make these calculations.

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CORROSION RATE CALCULATION FROM MASS LOSS

$$\text{Corrosion rate} = \frac{(K \times W)}{(A \times T \times D)}$$

where

$K =$ a constant (see below),
$T =$ time of exposure in hours to the nearest 0.01 h,
$A =$ area in cm^2 to the nearest 0.01 cm^2,
$W =$ mass loss in g, to nearest 1 mg (corrected for any loss during cleaning (see 9.4)), and
$D =$ density in g/cm^3,

Many different units are used to express corrosion rates. Using the above units for T, A, W, and D, the corrosion rate can be calculated in a variety of units with the following appropriate value of K:

Corrosion Rate Units Desired	**Constant (K) in Corrosion Rate Equation**
mils per year (mpy)	3.45×10^6
inches per year (ipy)	3.45×10^3
inches per month (ipm)	2.87×10^2
millimetres per year (mm/y)	8.76×10^4
micrometres per year (μm/y)	8.76×10^7
picometres per second (pm/s)	2.78×10^6
grams per square metre per hour ($g/m^2 \cdot h$)	$1.00 \times 10^4 \times D^a$
milligrams per square decimetre per day (mdd)	$2.40 \times 10^6 \times D^a$
micrograms per square metre per second ($\mu g/m^2 \cdot s$)	$2.78 \times 10^6 \times D^a$

[a]Density is not needed to calculate the corrosion rate in these units. The density in the constant K cancels out the density in the corrosion rate equation.

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VALUES OF CONSTANTS FOR USE IN FARADAY'S EQUATION

Calculation of Corrosion Rate—Faraday's Law can be used to calculate the corrosion rate, either in terms of penetration rate (*CR*) or mass loss rate (*MR*)

$$CR = K_1 \frac{i_{corr}}{\rho} EW$$
$$MR = K_2 \, i_{corr} \, EW$$

where

CR is given in mm/yr, i_{corr} in μA/cm^2,
$K_1 = 3.27 \times 10^{-3}$, mm g/$\mu$A cm yr,
ρ = density in g/cm^3,
$MR = g/m^2$d, and
$K_2 = 8.954 \times 10^{-3}$, g cm$^2/\mu$A m^2 d.
EW = Equivalent weight

Other values for K_1 and K_2 for different unit systems are given in the following table:

Rate

A

Penetration Rate Unit (CR)	I_{corr} Unit	ρ Unit	K_1	Units of K_1[a]
mpy	μA/cm^2	g/cm^3	0.1288	mpy g/μA cm
mm/yr[b]	A/m^{2b}	kg/m^{3b}	327.2	mm kg/A m y
mm/yr[b]	μA/cm^2	g/cm^3	3.27×10^{-3}	mm g/μA cm y

B

Mass Loss Rate Unit	I_{corr} Unit	K_2	Units of K_2[a]
g/m^{2}d[b]	A/m^{2b}	0.8953	g/Ad
mg/dm^{2}d (mdd)	μA/cm^2	0.0895	mg cm$^2/\mu$A dm^2 d
mg/dm^{2}d (mdd)	A/m^{2b}	8.953×10^{-3}	mg m^2/A dm^2 d

[a]EW is assumed to be dimensionless.

[b]SI unit.

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CHEMICAL CLEANING PROCEDURES FOR REMOVAL OF CORROSION PRODUCTS

Material	Solution	Time	Temperature	Remarks
Aluminum and Aluminum Alloys	50 mL phosphoric acid (H_3PO_4, sp gr 1.69) 20 g chromium trioxide (CrO_3) Reagent water to make 1000 mL	5 to 10 min	90°C to Boiling	If corrosion product films remain, rinse, then follow with nitric acid procedure (C.1.2).
	Nitric acid (HNO_3, sp gr 1.42)	1 to 5 min	20 to 25°C	Remove extraneous deposits and bulky corrosion products to avoid reactions that may result in excessive removal of base metal.
Copper and Copper Alloys	500 mL hydrochloric acid (HCl, sp gr 1.19) Reagent water to make 1000 mL	1 to 3 min	20 to 25°C	Deaeration of solution with purified nitrogen will minimize base metal removal.
	4.9 g sodium cyanide (NaCN) Reagent water to make 1000 mL	1 to 3 min	20 to 25°C	Removes copper sulfide corrosion products that may not be removed by hydrochloric acid treatment.
	100 mL sulfuric acid (H_2SO_4, sp gr 1.84) Reagent water to make 1000 mL	1 to 3 min	20 to 25°C	Remove bulky corrosion products before treatment to minimize copper redeposition on specimen surface.
	120 mL sulfuric acid (H_2SO_4, sp gr 1.84) 30 g sodium dichromate ($Na_2Cr_2O_7 \cdot 2H_2O$) Reagent water to make 1000 mL	5 to 10 s	20 to 25°C	Removes redeposited copper resulting from sulfuric acid treatment.
	54 mL sulfuric acid (H_2SO_4, sp gr 1.84) Reagent water to make 1000 mL	30 to 60 min	40 to 50°C	Deaerate solution with nitrogen. Brushing of test specimens to remove corrosion products followed by re-immersion for 3 to 4 s is recommended.
Iron and Steel	1000 mL hydrochloric acid (HCl, sp gr 1.19) 20 g antimony trioxide (Sb_2O_3) 50 g stannous chloride ($SnCl_2$)	1 to 25 min	20 to 25°C	Solution should be vigorously stirred or specimen should be brushed. Longer times may be required in certain instances.
	50 g sodium hydroxide (NaOH) 200 g granulated zinc or zinc chips Reagent water to make 1000 mL	30 to 40 min	80 to 90°C	Caution should be exercised in the use of any zinc dust since spontaneous ignition upon exposure to air can occur.
	200 g sodium hydroxide (NaOH) 20 g granulated zinc or zinc chips Reagent water to make 1000 mL	30 to 40 min	80 to 90°C	Caution should be exercised in the use of any zinc dust since spontaneous ignition upon exposure to air can occur.

(*Continued*)

CHEMICAL CLEANING PROCEDURES (*Continued*)

Material	Solution	Time	Temperature	Remarks
	200 g diammonium citrate ($(NH_4)_2HC_6H_5O_7$) Reagent water to make 1000 mL	20 min	75 to 90°C	Depending upon the composition of the corrosion product, attack of base metal may occur.
	500 mL hydrochloric acid (HCl, sp gr 1.19) 3.5 g hexamethylene tetramine Reagent water to make 1000 mL	10 min	20 to 25°C	Longer times may be required in certain instances.
	Molten caustic soda (NaOH) with 1.5–2.0% sodium hydride (NaH)	1 to 20 min	370°C	For details refer to Technical Information Bulletin SP29-370, "DuPont Sodium Hydride Descaling Process Operating Instructions."
Lead and Lead Alloys	10 mL acetic acid (CH_3COOH) Reagent water to make 1000 mL	5 min	Boiling	...
	50 g ammonium acetate (CH_3COONH_4) Reagent water to make 1000 mL	10 min	60 to 70°C	...
	250 g ammonium acetate (CH_3COONH_4) Reagent water to make 1000 mL	5 min	60 to 70°C	...
Magnesium and Magnesium Alloys	150 g chromium trioxide (CrO_3) 10 g silver chromate (Ag_2CrO_4) Reagent water to make 1000 mL	1 min	Boiling	The silver salt is present to precipitate chloride.
	200 g chromium trioxide (CrO_3) 10 g silver nitrate ($AgNO_3$) 20 g barium nitrate ($Ba(NO_3)_2$) Reagent water to make 1000 mL	1 min	20 to 25°C	The barium salt is present to precipitate sulfate.

Material	Solution	Time	Temperature	Remarks
Nickel and Nickel Alloys	150 mL hydrochloric acid (HCl, sp gr 1.19) Reagent water to make 1000 mL	1 to 3 min	20 to 25°C	...
	100 mL sulfuric acid (H_2SO_4, sp gr 1.84) Reagent water to make 1000 mL	1 to 3 min	20 to 25°C	...
Stainless Steels	100 mL nitric acid (HNO_3, sp gr 1.42) Reagent water to make 1000 mL	20 min	60°C	...
	150 g diammonium citrate ($(NH_4)_2HC_6H_5O_7$) Reagent water to make 1000 mL	10 to 60 min	70°C	...
	100 g citric acid ($C_6H_8O_7$) 50 mL sulfuric acid (H_2SO_4, sp gr 1.84) 2 g inhibitor (diorthotolyl thiourea or quinoline ethyliodide or betanaphthol quinoline) Reagent water to make 1000 mL	5 min	60°C	...
	200 g sodium hydroxide (NaOH) 30 g potassium permanganate ($KMnO_4$) Reagent water to make 1000 mL *followed by* 100 g diammonium citrate ($(NH_4)_2HC_6H_5O_7$) Reagent water to make 1000 mL	5 min	Boiling	...
	100 mL nitric acid (HNO_3, sp gr 1.42) 20 mL hydrofluoric acid (HF, sp gr 1.198–48%) Reagent water to make 1000 mL	5 to 20 min	20 to 25°C	...
	200 g sodium hydroxide (NaOH) 50 g zinc powder Reagent water to make 1000 mL	20 min	Boiling	Caution should be exercised in the use of any zinc dust since spontaneous ignition upon exposure to air can occur.

(*Continued*)

CHEMICAL CLEANING PROCEDURES (*Continued*)

Material	Solution	Time	Temperature	Remarks
Tin and Tin Alloys	150 g trisodium phosphate ($Na_3PO_4 \cdot 12H_2O$) Reagent water to make 1000 mL	10 min	Boiling	...
	50 mL hydrochloric acid (HCl, sp gr 1.19) Reagent water to make 1000 mL	10 min	20°C	...
Zinc and Zinc Alloys	150 mL ammonium hydroxide (NH_4OH, sp gr 0.90) Reagent water to make 1000 mL *followed by* 50 g chromium trioxide (CrO_3) 10 g silver nitrate ($AgNO_3$) Reagent water to make 1000 mL	5 min 15 to 20 s	20 to 25°C Boiling	... The silver nitrate should be dissolved in water and added to the boiling chromic acid to prevent excessive crystallization of silver chromate. The chromic acid must be sulfate free to avoid attack of the zinc base metal.
	100 g ammonium chloride (NH_4Cl) Reagent water to make 1000 mL	2 to 5 min	70°C	...
	200 g chromium trioxide (CrO_3) Reagent water to make 1000 mL	1 min	80°C	Chloride contamination of the chromic acid from corrosion products formed in salt environments should be avoided to prevent attack of the zinc base metal.
	85 mL hydriodic acid (HI, sp gr 1.5) Reagent water to make 1000 mL	15 s	20 to 25°C	Some zinc base metal may be removed. A control specimen (3.1.1) should be employed.
	100 g ammonium persulfate ($(NH_4)_2S_2O_8$) Reagent water to make 1000 mL	5 min	20 to 25°C	Particularly recommended for galvanized steel.
	100 g ammonium acetate (CH_3COONH_4) Reagent water to make 1000 mL	20 to 5 min	70°C	...

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ELECTROLYTIC CLEANING PROCEDURES FOR REMOVAL OF CORROSION PRODUCTS

Material	Solution	Time	Temperature	Remarks
Iron, Cast Iron, Steel	75 g sodium hydroxide (NaOH) 25 g sodium sulfate (Na_2SO_4) 75 g sodium carbonate (Na_2CO_3) Reagent water to make 1000 mL	20 to 40 min	20 to 25°C	Cathodic treatment with 100 to 200 A/m^2 current density. Use carbon, platinum or stainless steel anode.
	28 mL sulfuric acid (H_2SO_4, sp gr 1.84) 0.5 g inhibitor (diorthotolyl thiourea or quinoline ethyliodide or betanaphthol quinoline) Reagent water to make 1000 mL	3 min	75°C	Cathodic treatment with 2000 A/m^2 current density. Use carbon, or platinum or lead anode.
	100 g diammonium citrate ($(NH_4)_2HC_6H_5O_7$) Reagent water to make 1000 mL	5 min	20 to 25°C	Cathodic treatment with 100 A/m^2 current density. Use carbon or platinum anode.
Lead and Lead Alloys	28 mL sulfuric acid (H_2SO_4, sp gr 1.84) 0.5 g inhibitor (diorthotolyl thiourea or quinoline ethyliodide or betanaphthol quinoline) Reagent water to make 1000 mL	3 min	75°C	Cathodic treatment with 2000 A/m^2 current density. Use carbon, platinum or lead anode.
Copper and Copper Alloys	7.5 g potassium chloride (KCl) Reagent water to make 1000 mL	1 to 3	20 to 25°C	Cathodic treatment with 100 A/m^2 current density. Use carbon or platinum anode.
Zinc and Cadmium	50 g dibasic sodium phosphate (Na_2HPO_4) Reagent water to make 1000 mL	5 min	70°C	Cathodic treatment with 110 A/m^2 current density. Specimen must be energized prior to immersion. Use carbon, platinum or stainless steel anode.
	100 g sodium hydroxide (NaOH) Reagent water to make 1000 mL	1 to 2 min	20 to 25°C	Cathodic treatment with 100 A/m^2 current density. Specimen must be energized prior to immersion. Use carbon, platinum or stainless steel anode.
General (excluding Aluminum, Magnesium and Tin Alloys)	20 g sodium hydroxide (NaOH) Reagent water to make 1000 mL	5 to 10 min	20 to 25°C	Cathodic treatment with 300 A/m^2 current density. A S31600 stainless steel anode may be used.

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ETCHANTS FOR REVEALING MICROSTRUCTURES IN SELECTED ALLOYS

Alloy	Etchant	Uses
Aluminum and Al Alloys	0.5–25 g NaOH 1 g zinc chloride 100 mL water	General purpose etch. Grain boundary delineation. Immerse up to 2 min.
	1 mL HF (48%) 200 mL water	Outlines microconstituents. Immerse for 30–40 s.
	12.5 mL HNO_3 (conc.) 2.5 mL HF (48%) 85 mL water	General purpose etch. Grain boundary delineation. Immerse up to 1 min.
	2 mL HF (48%) 3 mL HCl (conc.) 20 mL HNO_3 (conc.) 175 mL water	Modified Keller's Rgnt. General purpose etch for Al & Al alloys. Immerse 10–60 s. Wash in warm water, blow dry.
Copper and Copper Alloys	10 mL NH_4OH 10 mL H_2O_2 (3%) Can dilute up to 20 mL water	General purpose etch. Grain boundary delineation. Use fresh, swab, or immerse up to 1 min.
	10 g $(NH_4)_2S_2O_8$ 90 mL water	General purpose etch. Grain boundary delineation. Immerse up to 1 min.
	10 g Cr_2O_3 4 drops HCl 75–100 mL water	Swab or immerse up to 30 s.
Nickel and Nickel Alloys	20 mL HNO_3 60 mL HCl	AquaRegia. Grain boundary, carbide, and σ contrast. Use fresh and under hood. Discard after use. Swab or immerse up to 1 min.
	3 parts glycerol 2–3 parts HCl 1 part HNO_3	Glyceregia. Popular etch. Use fresh and under hood. Discard after use. Swab or immerse up to 1 min.
	10 g $CuSO_4$ 50 mL HCl 50 mL water	Marble's Reagent. Grain boundary delineation. Swab or immerse up to 1 min. A few drops of H_2SO_4 increase etch activity.
Iron and Iron Alloys	2 mL HNO_3 98 mL Ethanol	Nital. Gives good pearlite-ferrite-grain boundary contrast in carbon and low alloy steels. Swab or immerse up to 1 min.
	4 g picric acid 100 mL Ethanol 4–5 drops of zephiran chloride (wetting agent)	Picral. Promotes good resolution of pearlite, bainite. martensite, and carbides. Swab or immerse up to 1 min.

(*Continued*)

ETCHANTS FOR REVEALING MICROSTRUCTURES IN SELECTED ALLOYS (*Continued*)

Alloy	Etchant	Uses
	100 mL Picric acid (sat.) 1 g tridecylbenzene	Reveals prior austenitic grain boundaries in martensitic steels.
Stainless Steel	1 part HNO_3 1 part HCl 1 part water	General purpose etch for stainless steels. Promotes grain boundary contrast. Immerse in a gently stirred solution.
	1 g picric acid 5 mL HCl 100 mL Ethanol	Vilella's Reagent. Outlines carbides, σ and δ. Immerse up to 1 min.
	1 part glycerol 3 parts HCl 1 part HNO_3	Glyceregia for SS's. Reveals grain structure. Outlines σ and carbides. Use fresh and under hood. Discard after use. Swab or Immerse up to 1 min.
	10 g oxalic acid 100 mL water	Electrolytic etch (sample is anode). Use at 1–6 V @ 0.1–1.0 A/cm^2. Resolves σ in 5–10 s. Resolves carbides in 15–30 s. Resolves grain boundaries in 45–60 s.

Source: Manual 20, p. 49, ASTM, 1995. Reprinted, with permission, copyright ASTM.

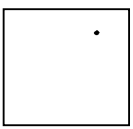
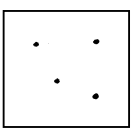
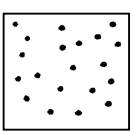
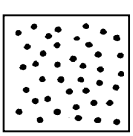
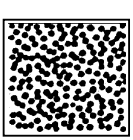
COMPARISON OF SURFACE ANALYSIS TECHNIQUES

Category Technique	Incident Particle	Analyzed Particle	Measured Quantity	Analysis Depth in Monolayers	Sample Damage	Sensitivity (Atomic Fraction)	Standardless Quantification
Auger	Electron	Auger Electron	Energy	2–10	No-Mod	10^{-3}	fair
XPS-ESCA	X-Ray	Photo-Electron	Energy	2–10	No-Min	10^{-3}	fair
Dynamic Sims	Ions	Sec Ions	Mass	10–20	Mod-Ext	10^{-7}	poor
Static Sims	Ions	Sec Ions	Mass	1–2	Mid-Mod	10^{-6}	poor
SNMS	Ions	Neutrals	Mass	5–10	Min-Ext	10^{-7}	fair
SALI	Ions	Neutrals	Mass	1–2	Min-Ext	10^{-7}	fair
RBS	Ions	Input Ions	Energy	many	Min-Mod	10^{-3}	good
ISS	Ions	Input Ions	Energy	1	No	10^{-3}	good

NOTES—NO: NONE; MOD: MODERATE; MED: MEDIUM; EXT: EXTENSIVE.

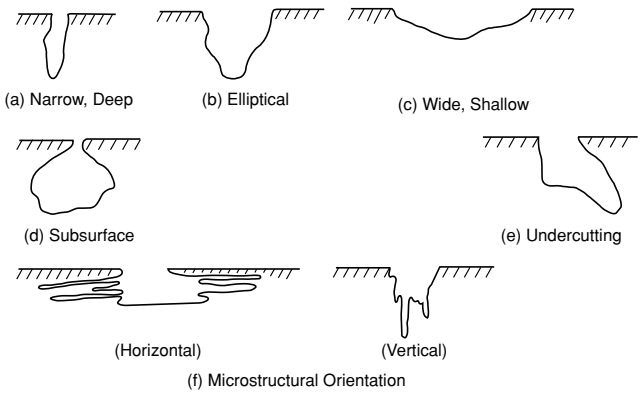
Source: Manual 20, p. 56, ASTM, 1995. Reprinted, with permission, copyright ASTM.

STANDARD RATING CHART FOR PITS

	A	B	C
	Density	**Size**	**Depth**
1			
	$2.5 \times 10^3/m^2$	0.5 mm^2	0.4 mm
2			
	$1 \times 10^4/m^2$	2.0 mm^2	0.8 mm
3			
	$5 \times 10^4/m^2$	8.0 mm^2	1.6 mm
4			
	$1 \times 10^5/m^2$	12.5 mm^2	3.2 mm
5			
	$5 \times 10^5/m^2$	24.5 mm^2	6.4 mm

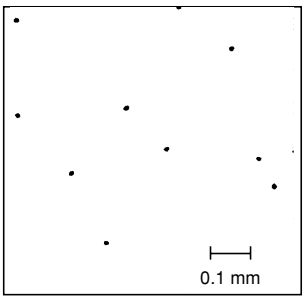
Source: ASTM, G 46, Fig. 2 (2000 Edition). Reprinted, with permission, copyright ASTM.

VARIATIONS IN THE CROSS-SECTIONAL SHAPE OF PITS

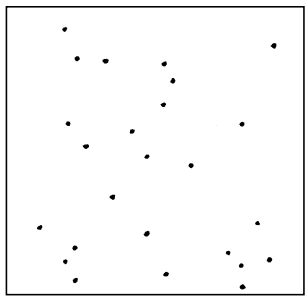


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STANDARD DOT PATTERNS FOR THE NUMBER OF CORROSION PITS (cm^2) OBSERVED AT 100X

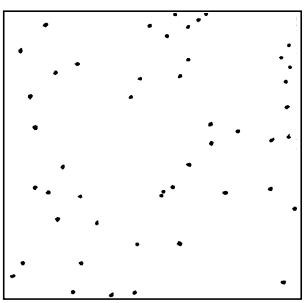


1000 pits/square cm at 100 ×

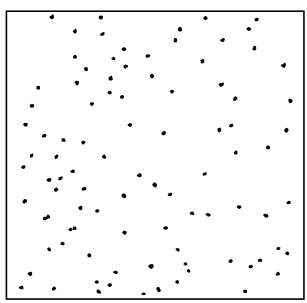


2500 pits/square cm at 100 ×

RANDOM DOT PATTERNS



5000 pits/square cm at 100 ×



10000 pits/square cm at 100 ×

Source: ASTM B 627, Fig. 6 (2000 Edition). Reprinted, with permission, copyright ASTM.

STANDARD COATING RATINGS SYSTEM

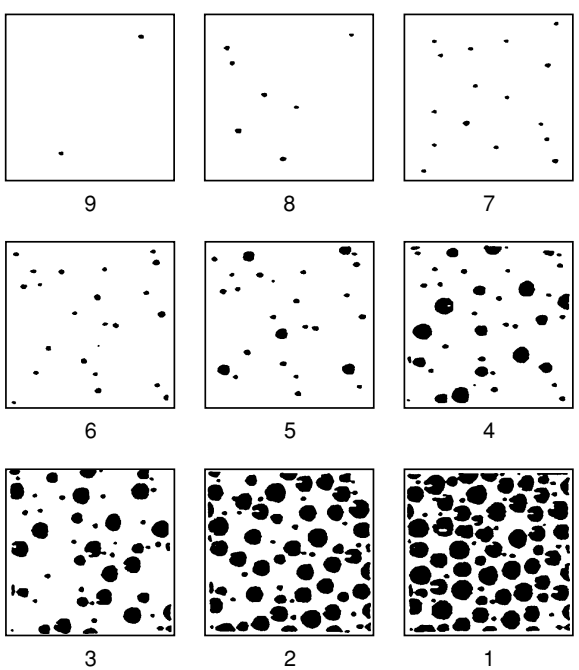
Standard	Scale	Description
ASTM D714-56, Evaluating the Degree of Blistering Paints	Size of Blister	
	10	No blister
	8	Pinpoint
	6	Pinpoint to $\frac{1}{16}$ in.
	4	$\frac{1}{8}$ in.
	2	$\frac{3}{8}$ in. or larger
	Frequency of Blisters	
	10	None
	8	Few
	6	Medium
	4	Medium-Dense
	2	Dense
ASTM D659-44, Evaluating Degree of Resistance to Chalking of Exterior Paints (wool cloth pressed on surface and turned 180 degrees)	10	No chalk or discolor on cloth
	8	Slight discoloration
	6	Light discoloration
	2	Completely opaque chalk
ASTM D660, Evaluating Degree of Resistance to Checking (checking is a break in the surface not penetrating to the substrate)	10	No checking
	9	Very minor checking
	8	Few checks
	6	Moderate
	4	Almost continuously checked
	2	Completely checked
ASTM D661, Evaluating the Degree of Resistance to Cracking of Exterior Paints (cracking extends through coating to substrate)	10	No cracking
	9	Very minor cracking
	8	Few cracks
	6	Moderate
	4	Almost continuously cracked
	2	Completely cracked
ASTM D772-47, Evaluating the Degree of Flaking (scaling) of Exterior Paint	10	No flaking
	8	Few flakes
	6	Moderate flaking
	4	20 to 25% of surface flaked
	2	40 to 50% of surface flaked

Source: C. G. Munger, *Repairing Protective Coatings: Effect of Coating Types, Plant Engineering*, Feb. 17, 1977.

RATING OF PAINTED SURFACE
ASTM-D610/SSPC-Vis 2

Scale and Description of Rust Grades

Rust Grades*	Description	ASTM-SSPC Photographic Standard
10	no rusting or less than 0.01 percent of surface rusted	unnecessary
9	minute rusting less than 0.03 percent of surface rusted	No. 9
8*	few isolated rust spots. less than 0.1 percent of surface rusted	No. 8
7	less than 0.3 percent of surface rusted	none
6*	extensive rust spots but less than 1 percent of surface rusted	No. 6
5	rusting to the extent of 3 percent of surface rusted	none
4*	rusting to the extent of 10 percent of surface rusted	No. 4
3*	approximately one sixth of the surface rusted	none
2	approximately one third of the surface rusted	none
1	approximately one half of the surface rusted	none
0*	approximately 100 percent of the surface rusted	unnecessary



Source: NACE Coating Inspector's Logbook, 3rd ed., NACE 1996.

ABBREVIATIONS DESCRIBING DEFECTS

Types of Failure

R = corrosion (rusting) of the basis metal. (Permanent or massive type of basis metal corrosion such as that in pinholes, bare, or flaked areas, or in craters of broken blisters.)

Rs = stain due to basis metal corrosion products, such as rust stain, which can be removed readily with a damp cloth or chamois and mild abrasive revealing a sound bright surface.

S = stains or spots other than that of *obvious* basis metal corrosion products.

Sp = surface pits. Corrosion pits probably not extending through to the basis metal—that is absence of *obvious* basis metal corrosion products bleeding therefrom.

F = flaking or peeling of deposit.

B = blistering.

C = cracking.

Z = crazing.

W = crow's feet.

Degree or Extent of Pinhole Rusting, Staining, Surface Pitting, Flaking, Etc.

vs = very slight amount.

s = slight amount.

i = intermediate or moderate amount.

x = excessive amount.

Description of Blisters

s = less than about 0.5 mm in diameter.

i = about 0.5 to 2.0 mm in diameter.

x = greater than about 2.0 mm in diameter.

vf = 5 or fewer.

f = 5+ to 10.

i = 10+ to 25.

m = 25+ to 50.

ym = over 50.

Description of Location of Defects

e = edge.

g = general.

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GALVANIC SERIES OF METALS EXPOSED TO SEAWATER

ACTIVE END	Magnesium
(–)	Magnesium Alloys
↑	Zinc
|	Galvanized Steel
|	Aluminum 1100
|	Aluminum 6053
|	Alclad
|	Cadmium
|	Aluminum 2024 (4.5 Cu, 1.5 Mg, 0.6 Mn)
|	Mild Steel
|	Wrought Iron
|	Cast Iron
|	13% Chromium Stainless Steel
|	Type 410 (Active)
|	18-8 Stainless Steel
|	Type 304 (Active)
|	18-12-3 Stainless Steel
|	Type 316 (Active)
|	Lead-Tin Solders
|	Lead
|	Tin
|	Muntz Metal
|	Manganese Bronze
|	Naval Brass
|	Nickel (Active)
|	76 Ni-16 Cr-7 Fe alloy (Active)
|	60 Ni-30 Mo-6 Fe-1 Mn
|	Yellow Brass
|	Admirality Brass
|	Aluminum Brass
|	Red Brass
|	Copper
|	Silicon Bronze
|	70:30 Cupro Nickel
|	G-Bronze
|	M-Bronze
|	Silver Solder
|	Nickel (Passive)
|	76 Ni-16 Cr-7 Fe
|	Alloy (Passive)
|	67 Ni-33 Cu Alloy (Monel)
|	13% Chromium Stainless Steel
|	Type 410 (Passive)
|	Titanium
|	18-8 Stainless Steel
|	Type 304 (Passive)
|	18-12-3 Stainless Steel
↓	Type 316 (Passive)
(+)	Silver
NOBLE or	Graphite
PASSIVE END	Gold
	Platinum

ENVIRONMENTAL POLLUTANTS CAUSING CORROSION

Pollutant	Sources	Susceptible Metals
Sulfur Dioxide (SO_2)	Fossil fuel combustion, petrochemical industries, pulp and paper industry, metal producing industry	Most metals
Nitrogen Dioxide (NO_2)	Auto & truck emissions, fossil fuel combustion, various industries	Copper, brass, synergistic with SO_2
Hydrogen Sulfide (H_2S)	Pulp & paper industries, chemical industry, sewage plants, garbage dumps, oil refineries, animal shelters, volcanic activity, swamp areas, marine tidal areas	All copper and silver based metals
Chlorine (Cl_2) but most important is chlorine containing gases.	Bleaching plants in industries, metal production, PVC plants, cleaning agents	Most metals synergistic with other pollutants
Ammonia and Its Salts (NH_3 and NH_4^+) Chloride (Cl^-) Soot (Carbon)	Fertilizer, animal and human activity, detergents Sea salt mist, road salt areas Combustion, auto & truck emissions, steel production	All copper based alloys, nickel, silver Most metals Synergistic with other pollutants; provides cathodic sites for most metals
Ozone	Formed in polluted areas, highest concentrations in smog	Strong oxidant to produce acids which attack most metals
Mineral Acids (H_2SO_4, HCl, HF, HNO_3)	Pickling industry, chemical industry, metals production, semiconductor industry	Most metals, glass, ceramics
Organic acids	Wood, packing material, animals, preservatives	Long-term effects on some metals

Source: Manual 20, p. 638, ASTM, 1995. Reprinted, with permission, copyright ASTM.

CATAGORIES OF CORROSIVITY OF THE ATMOSPHERES[(1)](C)

Category	Corrosivity
C1	Very low
C2	Low
C3	Medium
C4	High
C5	Very high

CLASSIFICATION OF TIME OF WETNESS[1]

Wetness Class	Time Wet, %	Hrs. Wet Per Yr.	Examples of Occurrence
T1	<0.1	<10	Indoor
T2	0.1–3	10–250	Indoor—Unheated
T3	3–30	250–2600	Shed Storage—Cold Climate
T4	30–60	2600–5200	Outdoor Temperate Climate
T5	>60	>5200	Tropical Outdoor or Surf

CLASSIFICATION OF POLLUTION BY SULPHUR-CONTAINING SUBSTANCES REPRESENTED BY[(1)](SO_2)

Category	Pollution (SO_2, $\mu g/m^2$)
P_0	<12
P_1	12–40
P_2	40–90
P_3	90–250

CLASSIFICATION OF POLLUTION BY AIRBORNE SALINITY[(1)]

Category	Chloride (mg/m^2-day)
S_0	<3
S_1	3–60
S_2	60–300
S_3	300–1500

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ATMOSPHERIC CORROSION RATES FOR CORROSION CLASS (μm/YEAR)

Corrosion Class	Steel		Copper		Zinc		Aluminum		Weathering Steel	
	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
1	<0.5	<0.1	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.1	<0.1
2	0.5–2	0.1–1.5	0.01–0.1	0.01–0.1	0.1–0.5	0.01–0.5	0.01–0.025	0.01–0.02	0.1–2	0.1–1
3	2–10	1.5–6	0.1–2	0.1–1.5	0.5–2	0.5–2	0.025–0.2	0.02–0.2	2–8	1–4
4	10–35	6–20	2–3	1.5–3	2–4	2–3.5	0.2–1.0	0.2–1.0	8–15	4–10
5	>35	>20	>3	>3	>4	>3.5	>1.0	>1.0	>15	>10

Note: ST = average corrosion rate during the first ten years of exposure; LT = steady state corrosion rate for long-term exposures.

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CORROSION CLASSES FOR ENVIRONMENTAL CLASSES

	T2			T3			T4			T5		
	S0-S1	**S2**	**S3**	**S0-1**	**S2**	**S3**	**S0-S1**	**S2**	**S3**	**S0-S1**	**S2**	**S3**
					Unalloyed Steels							
P0-P1	1	2	3–4	2–3	3–4	4	3	4	5	4	5	5
P2	1–2	3	3–4	3–4	3–4	4–5	4	4	5	5	5	5
P3	2	3–4	4	4	4–5	5	5	5	5	5	5	5
					Zinc and Copper							
P0-P1	1	1–2	3	3	3	3–4	3	4	5	4	5	5
P2	1–2	2	3	3	3–4	4	3–4	4	5	5	5	5
P3	2	3	3–4	3	3–4	4	4–5	5	5	5	5	5
					Aluminum							
P0-P1	1	2–3	4	3	3–4	4	3–4	3–4	5	4–5	5	5
P2	1–2	3–4	4	3	4	4–5	3–4	4	5	4–5	5	5
P3	2–4	4	4	3–4	4–5	5	4–5	5	5	5	5	5

Note: T = wetness class; P = SO_2 class; S = chloride class.

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CLASSIFICATION OF ATMOSPHERIC TEST SITES BY ENVIRONMENTAL CATEGORY (ACCORDING TO ISO 9223 ENVIRONMENTAL CRITERIA)

SO_2 Pollution (um/m^3)			Pollution by Airborne Salinity (mg/m^2 d)			Time of Wetness (h/year)		
Test Site	**Mean Value**	**Category**	**Test Site**	**Mean Value**	**Category**	**Test Site**	**Mean Value**	**Category**
Birkenes	1.2	P0	Svanvik	1.0	S0	Oymyakon	381	T3
Tananger	4.0	P0	Batumi	1.0	S0	San Juan	855	T3
Ahtari	4.1	P0	Bergisch Glad.	1.6	S0	Boucherville	1396	T3
El Pardo	4.9	P0	Oslo	2.1	S0	Madrid	2060	T3
Murmansk	5.0	P0	Otaniemi	2.5	S0	Tokyo	2173	T3
Kvarnvik	5.0	P0	Helsinki	3.7	S0	Kopisty	2444	T3
Kattesand	5.0	P0	Tokyo	4.4	S0	Svanvik	2605	T4
Oymyakon	5.0	P0	Picherande	6.5	S1	Oslo	2641	T4
Choshi	7.7	P0	Bergen	7.1	S1	Jubay-Antarct.	2693	T4
Bergen	8.6	P0	Fleet Hall	7.9	S1	Lagoas	2840	T4
Picherande	9.1	P0	Borregaard	8.2	S1	Praha	2991	T4
Kure Beach	9.6	P0	Stratford	15.1	S1	Ahtari	3105	T4
Buenos Aires	9.7	P0	Auby	16.0	S1	Paris	3189	T4
Stockholm Van	9.8	P0	Vladivostok	18.4	S1	Kasp Hory.	3206	T4
Okinawa	11.1	P0	Murmansk	19.9	S1	Batumi	3216	T4
Oslo	13.8	P1	Lagoas	21.2	S1	El Pardo	3223	T4
Fleet Hall	14.4	P1	St. Denis	27.8	S1	Murmansk	3227	T4
Tokyo	14.6	P1	Baracaldo	29.2	S1	Otaniemi	3256	T4
Otaniemi	15.3	P1	Camet	46.0	S1	Salin de Gir.	3311	T4
Boucherville	15.9	P1	Boucherville	59.0	S1	Borregaard	3339	T4
Svanik	16.7	P1	Choshi	66.8	S1	Helsinki	3578	T4
Kasper. Hory	17.1	P1	Kattesand	85.5	S1	Ponteau Mart.	3846	T4
Bergisch Glad.	18.0	P1	Okinawa	130.0	S2	Okinawa	3852	T4
Helsinki	18.9	P1	Ostende (B)	173.0	S2	Vladivostok	3920	T4
Stratford	19.9	P1	Salin de Gir.	184.0	S2	Los Angeles	4003	T4
Salin de Gir.	20.0	P1	Kure Beach	184.0	S2	Birkenes	4138	T4

SO_2 Pollution (um/m^3)			Pollution by Airborne Salinity (mg/m^2 d)			Time of Wetness (h/year)		
Test Site	**Mean Value**	**Category**	**Test Site**	**Mean Value**	**Category**	**Test Site**	**Mean Value**	**Category**
Los Angeles	20.0	P1	Biarritz	193.0	S2	Picherande	4171	T4
Rye	21.2	P1	Ponteau Mart.	241.0	S2	Bergisch Glad.	4267	T4
Ostende (B)	24.0	P1	Rye	300.0	S2	St. Denis	4268	T4
Batumi	25.8	P1	Tananger	321.0	S2	Kure Beach	4289	T4
Vladivostok	28.6	P1	St. Remy	378.0	S2	Baracaldo	4375	T4
St. Remy	30.3	P1	Panama CZ	619.0	S3	Bergen	4439	T4
Baracaldo	32.1	P1	Kvarnvik	667.0	S3	Auby	4571	T4
Borregaard	44.2	P2				Tananger	4583	T4
Madrid	44.2	P2	Res Triang Park		no data	Buenos Aires	4645	T4
Lagoas	48.7	P2	Point Reyes	M		Fleet Hall	4809	T4
St. Denis	49.6	P2	Birkenes			lugazu	5680	T5
Panama CZ	51.5	P2	Paris			Choshi	5704	T5
Paris	53.4	P2	Los Angeles			Stratford	5783	T5
Praha	67.5	P2	Newark	no data		Ostende (B)	6083	T5
Ponteau Mart.	87.0	P2	El Pardo			Camet	6088	T5
Kopisty	89.9	P2	Crowthorne			St. Remy	6310	T5
Auby	188.0	P3	Stockholm Vanad			Panama CZ	7598	T5
			Oymyakon					
Newark	no data		Madrid			Rye	no data	
Point Reyes			Kopisty			Point Reyes		
Res Triang Park			Ahtari			Newark		
Biarritz			lugazu			Crowthorne		
Crowthorne			Kasperske Hory			Kattesand		
San Juan			Praha			Stockholm Vanad		
lugazu			San Juan			Biarritz		
Camet			Jubay-Antarct.	M		Kvarnvik		
Jubay-Antarct.			Buenos Aires	M		Judgeford		
Judgeford			Judgeford	M		Res Triang Park		

Note: M = marine influence.

Source: W. W. Kirk and H. H. Lawson, eds., *Atmospheric Corrosion*, STP1239, ASTM, 1990. Reprinted, with permission, copyright ASTM.

ONE-YEAR CORROSION LOSS OF FLAT METAL SAMPLES AFTER ONE-YEAR EXPOSURE AT VARIOUS TEST SITES

Unalloyed Steel			Zinc			Copper			Aluminum		
Test Site	A	B	Test Site	A	B	Test Site	A	B	Test Site	A	B
Panama CZ	373.0	C 5*	Panama CZ	17.50	C 5*	Panama CZ	5.46	C 5	Auby	1.70	C
Auby	106.0	C 5	Auby	5.60	C 5	Biarritz	3.69		Ostende (B)	1.50	
Ostende (B)	99.3		Ostende (B)	5.10		Kopisty	3.30		Jubay-Antarctic	1.31	
Biarritz	87.2		Salin de Gir.	4.60		Salin de Gir.	3.20		St. Denis	1.20	
Okinawa	75.2	C 4	Biarritz	4.30		Ostende (B)	3.10		Biarritz	1.20	
Salin de Gir.	73.0		Borregaard	3.80	C 4	Kure Beach	2.85		Ponteau Mart	1.00	
Ponteau Mart.	72.4		Kopisty	3.50		Kvarnvik	2.80		Paris	0.90	
Kopisty	70.7		Okinawa	3.40		Ponteau Mart	2.70	C 4	Murmansk	0.80	
Borregaard	61.7		Tananger	3.00		Res Triang Park	2.43		Salin de Gir.	0.70	
Kvarnvik	61.6		Paris	3.00		Point Reyes	2.42		Kopisty	0.70	
Tananger	59.6		Praha	2.80		Camet	2.23		St. Remy	0.70	
Rye	58.5		Ponteau Mart	2.60		Okinawa	2.10		Tananger	0.60	
Praha	47.4	C 3	Rye	2.54		Jubay-Antarctic	2.04		Praha	0.60	
St. Remy	44.1		Vladivostok	2.30		Batumi	2.00		Kvarnvik	0.60	
Baracaldo	43.9		Birkenes	2.30		Kasperske Hory	2.00		Borregaard	0.60	
Choshi	43.3		Bergen	2.10		Tananger	1.90		Panama CZ	0.57	C
Paris	41.7		Kure Beach	2.01	C 3	Auby	1.90		Los Angeles	0.56	
Point Reyes	40.1		Newark	1.96		Rye	1.86		Tokyo	0.54	
Tokyo	39.5		Kasperske Hory	1.90		St. Remy	1.80		Kasperske Hory	0.50	
Fleet Hall	39.0	C 3	Jubay-Antarctic	1.87	C 3	Kattesand	1.70	C 4	Rye	0.42	C
Stratford	38.7		Kvarnvik	1.80		Murmansk	1.70		Boucherville	0.40	
Kure Beach	37.9		Point Reyes	1.73		Vladivostok	1.40		Kattesand	0.40	
Crowthorne	37.4		Stratford	1.67		Paris	1.40		Fleet Hall	0.36	
St. Denis	37.2		Iugazu	1.62		Picherande	1.40		Choshi	0.33	
Camet	36.8		Bergisch Glad.	1.60		Borregaard	1.40		Picherande	0.30	
Jubay-Antarctic	36.6		Batumi	1.60		Newark	1.39		Vladivostok	0.30	

Unalloyed Steel			Zinc			Copper			Aluminum		
Test Site	A	B	Test Site	A	B	Test Site	A	B	Test Site	A	B
Bergisch Glad.	36.2		Kattesand	1.50		Judgeford	1.36		Helsinki	0.30	
Kattesand	35.2		St. Remy	1.50		Choshi	1.35		Bergisch Glad.	0.30	
Helsinki	33.3		St. Denis	1.50		Praha	1.30		Stratford	0.29	
Murmansk	30.8		Tokyo	1.50		Birkenes	1.30		Kure Beach	0.29	
Batumi	28.7		Boucherville	1.40		Baracaldo	1.20	C 3	Newark	0.28	
Bergen	27.9		Choshi	1.40		St. Denis	1.20		Okinawa	0.26	
Madrid	27.7		Fleet Hall	1.34		Los Angeles	1.16		Point Reyes	0.22	
Lagoas	26.9		Helsinki	1.30		Stratford	1.13		Stockholm Vana	0.20	
Newark	26.4		Oslo	1.30		Crowthorne	1.10		Oslo	0.20	
Kasperske Hory	26.0		Camet	1.26		El Pardo	1.10		Lagoas	0.20	
Vladivostok	25.9		Baracaldo	1.20		Boucherville	1.10		Baracaldo	0.20	
Otaniemi	25.6	C 3	Crowthorne	1.10	C 3	Bergen	1.00	C 3	Camet	0.19	C
Oslo	25.2		Murmansk	1.10		Lagoas	1.00		Crowthorne	0.12	
Stockholm Vana	24.4	C 2	Los Angeles	1.09		Fleet Hall	0.93		Res Triang Park	0.11	
Boucherville	23.2		Buenos Aires	1.01		Iugazu	0.80		Birkenes	0.10	C
Res Triang Park	23.1		Lagoas	1.00		Otaniemi	0.80		Ahtari	0.10	
Los Angeles	21.4		Otaniemi	0.90		Svanvik	0.80		Batumi	0.10	
Svanvik	20.2		Picherande	0.90		Helsinki	0.70		Otaniemi	0.10	
Birkenes	19.7		Res Triang Park	0.84		Ahtari	0.70		Bergen	0.10	
Judgeford	19.3		Svanvik	0.80		Tokyo	0.66		Svanvik	0.10	
Buenos Aires	16.2		Ahtari	0.70	C 2	Buenos Aires	0.64		Madrid	0.07	
Picherande	16.1		Judgeford	0.66		Bergisch Glad.	0.60	C 2	Oymyakon	0.07	
El Pardo	15.5		Stockholm Vana	0.60		Stockholm Vana	0.60		Judgeford	0.06	
Ahtari	12.8		Madrid	0.60		Oslo	0.60		Iugazu	0.05	
Iugazu	5.8		El Pardo	0.50		Madrid	0.50		Buenos Aires	0.05	
San Juan	4.6		Oymyakon	0.40		San Juan	0.18		El Pardo	0.05	
Oymyakon	0.8	C 1	San Juan	0.18		Oymyakon	0.09	C 1	San Juan	0.03	

Note:
A = corrosion loss (um/a).
B = corrosivity categories (ISO 9223).
* = corrosion rate exceeding the upper limit in C5.

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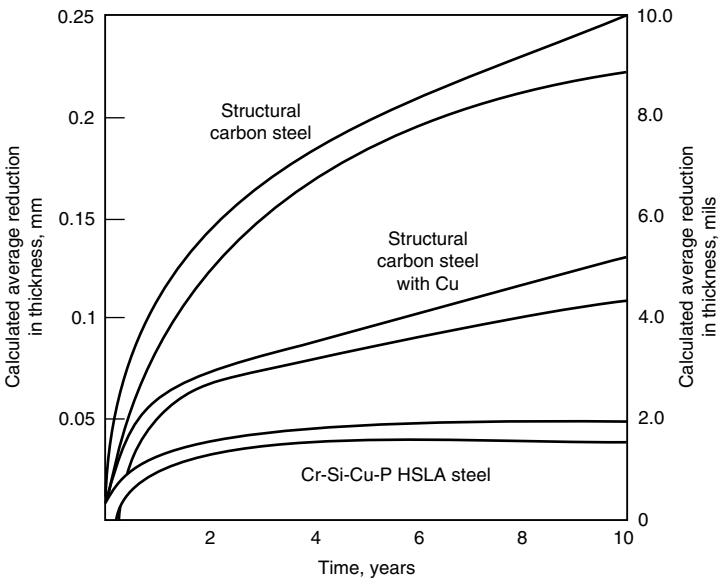
ATMOSPHERIC CORROSIVITY RANKING OF STEEL AND ZINC AT VARIOUS TEST SITES TWO-YEAR EXPOSURE

Ranking			Weight Loss (g)		Loss Ratio
Steel	Zinc	Location	Steel	Zinc	Steel/Zinc
1	1	Norman Wells, NWT, Canada	0.73	0.07	10.3
2	2	Phoenix, AR	2.23	0.13	17.0
3	3	Saskatoon, SK, Canada	2.77	0.13	21.0
4	4	Esquimalt, Vancouver Island, BC, Canada	6.50	0.21	31.0
5	15	Detroit, MI	7.03	0.58	12.2
6	5	Fort Amidor Pier, Panama, C.Z.	7.10	0.28	25.2
7	11	Morenci, MI	9.53	0.53	18.0
8	7	Ottawa, ON, Canada	9.60	0.49	19.5
9	13	Potter County, PA	10.00	0.55	18.3
10	31	Waterbury, CT	11.00	1.12	9.8
11	10	State College, PA	11.17	0.51	22.0
12	28	Montreal, PQ, Canada	11.44	1.05	10.9
13	6	Melbourne, Australia	12.70	0.34	37.4
14	20	Halifax (York Redoubt), NS, Canada	12.97	0.70	18.5
15	19	Durham, NH	13.30	0.70	19.0
16	12	Middletown, OH	14.00	0.54	26.0
17	30	Pittsburgh, PA	14.90	1.14	13.1
18	27	Columbus, OH	16.00	0.95	16.8
19	21	South Bend, PA	16.20	0.78	20.8
20	18	Trail, BC, Canada	16.90	0.70	24.2
21	14	Bethlehem, PA	18.3	0.57	32.4
22	33	Cleveland, OH	19.0	1.21	15.7
23	8	Miraflores, Panama, C.Z.	20.9	0.50	41.8
24	29	London (Battersea), England	23.0	1.07	21.6
25	24	Monroeville, PA	23.8	0.84	28.4
26	35	Newark, NJ	24.7	1.63	15.1
27	16	Manila, Philippine Islands	26.2	0.66	39.8
28	32	Limon Bay, Panama, C.Z.	30.3	1.17	25.9
29	39	Bayonne, NJ	37.7	2.11	17.9
30	22	East Chicago, IN	41.1	0.79	52.1
31	9	Cape Kennedy, FL (1/2 mile from ocean)	42.0	0.50	84.0
32	23	Brazos River, TX	45.4	0.81	56.0
33	40	Pilsey Island, England	50.0	2.50	20.0
34	42	London (Stratford), England	54.3	3.06	17.8
35	43	Halifax (Federal Building), NS, Canada	55.3	3.27	17.0
36	38	Cape Kennedy, FL (60 yards from ocean, 60-ft. elevation)	64.0	1.94	33.0
37	26	Kure Beach, NC (800-ft. lot)	71.0	0.89	80.0
38	36	Cape Kennedy, FL (60 yards from ocean, 30-ft. elevation)	80.2	1.77	45.5
39	25	Daytona Beach, FL	144.0	0.88	164.0
40	44	Widness, England	174.0	4.48	39.0
41	37	Cape Kennedy, FL (60 yards from ocean, ground level)	215.0	1.83	117.0
42	34	Dungeness, England	238.0	1.60	148.0
43	17	Point Reyes, CA	244.0	0.67	364.0
44	41	Kure Beach, NC (80-ft. lot)	260.0	2.80	93.0
45	45	Galeta Point Beach, Panama, CZ	336.0	6.80	49.4

[a]Specimen size 150 × 100 mm (6 × 4 in.)

Source: W. W. Kirk and H. H. Lawson, eds., *Atmospheric Corrosion*, STP1239, ASTM, 1990. Reprinted, with permission, copyright ASTM.

ATMOSPHERIC CORROSION OF STEEL VS TIME IN AN INDUSTRIAL ATMOSPHERE



Source: *Metals Handbook*, 9th ed., Vol. 13, p. 1304, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

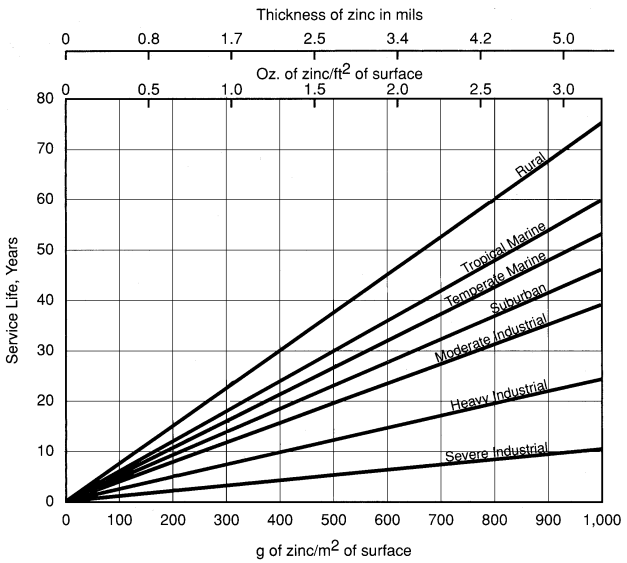
CORROSION OF STRUCTURAL STEEL IN VARIOUS ENVIRONMENTS

Type of Atmosphere	Time, Yr.	Average Reduction in Thickness, Mils[a] Structural Carbon Steel	Structural Copper Steel	UNS K11510[b]	UNS K11430[c]	UNS K11630[d]	UNS K11576[e]
Industrial	3.5	3.3	2.6	1.3	1.8	1.4	2.2
(Netwark, NJ)	7.5	4.1	3.2	1.5	2.1	1.7	–
	15.5	5.3	4.0	1.8	–	2.1	–
Semi-industrial	1.5	2.2	1.7	1.1	1.4	1.2	1.6
(Monroeville, PA)	3.5	3.7	2.5	1.2	2.1	1.4	2.4
	7.5	5.1	3.2	1.4	2.4	1.7	–
	15.5	7.3	4.7	1.8	–	1.8	–
Semi-industrial	1.5	1.8	1.4	1.0	1.3	1.0	1.5
(South Bend, PA)	3.5	2.9	2.2	1.3	1.9	1.5	2.4
	7.5	4.6	3.2	1.8	2.7	1.9	–
	15.5	7.0	4.8	2.2	–	2.5	–
Rural	2.5	–	1.3	0.8	1.2	–	–
(Potter County, PA)	3.5	2.0	1.7	1.1	1.4	1.2	1.8
	7.5	3.0	2.5	1.3	1.5	1.5	–
	15.5	4.7	3.8	1.4	–	2.0	–
Moderate marine	0.5	0.9	0.8	0.6	0.8	0.7	1.0
(Kure Beach, NC,	1.5	2.3	1.9	1.1	1.7	1.2	1.7
800 ft from ocean)	3.5	4.9	3.3	1.8	2.5	1.9	2.2
	7.5	5.6	4.5	2.5	3.7	2.9	–
Severe marine	0.5	7.2	4.3	2.2	3.8	1.1	0.7
(Kure Beach, NC,	2.0	36.0	19.0	3.3	12.2	–	2.1
80 ft from ocean)	3.5	57.0	38.0	–	28.7	3.9	3.9
	5.0	f	f	19.4	38.8	5.0	–

a) To obtain equivalent values in μm, multiply listed value by 25. b) ASTM A242 (type 1). c) ASTM A588 (grade A). d) ASTM A514 (type B) and A517 (grade B). e) ASTM A514 (type F) and A517 (grade F). f) Specimen corroded completely away.

Source: *Metals Handbook*, 9th ed., Vol. 1, p. 723, ASM, 1978. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

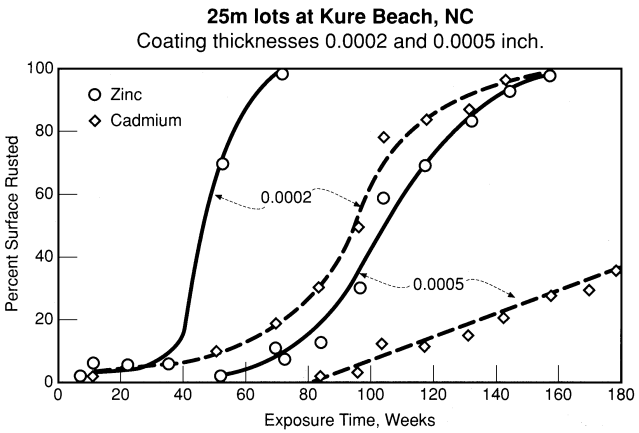
EFFECT OF AMOUNT OF ZINC ON SERVICE LIFE OF GALVANIZED SHEET IN VARIOUS ENVIRONMENTS



Surface life is measured in years to the appearance of first significant rusting.

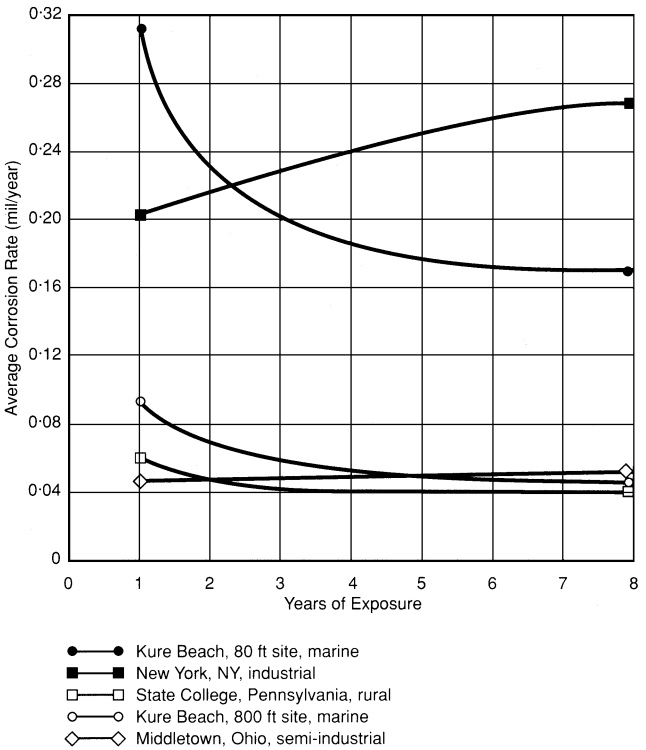
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DEVELOPMENT OF RUST ON ZINC AND CADMIUM-PLATED STEELS IN A MARINE ATMOSPHERE



Source: F. W. Fink, et al., *Corrosion of Metals in Marine Environments*, Battelle Memorial Institute DMIC Report 254, NTIS AD-712 5B5-S, pp. 7, 13, 1970. Reprinted by permission of Battelle Memorial Institute.

ATMOSPHERIC CORROSION OF ZINC IN VARIOUS LOCATIONS AS A FUNCTION OF TIME



Source: *Zinc, Its Corrosion Resistance*, 2nd ed., p. 42, International Lead Zinc Research Organization, 1983. Reprinted by permission of International Lead Zinc Research Organization.

LIFETIMES OF HOT DIP ZINC AND ZINC-ALLOY COATINGS

	Years to First Rust			
Environment	**Zn**	**Zn-4Al**	**Zn-7Al**	**Zn-55Al**
Severe marine				
25 m from ocean, Kure Beach, NC	4	9	9	15
Moderate marine				
250 m from ocean, Kure Beach, NC	16	15	14	>25
Rural				
Saylorsburg, PA	14	14	14	>25
Industrial				
Bethlehem, PA	10	10	9	>25

Source: H. Townsend.

ATMOSPHERIC CORROSION OF VARIOUS METALS AND ALLOYS

10-Year Exposure Times Corrosion Rates are Given in mits/yr (1 mil/yr = 0.025 mm/yr).

	New York, NY (urban-industrial)	La Jolla, CA (marine)	State College, P, (rural)
Aluminum	0.032	0.028	0.001
Copper	0.047	0.052	0.023
Lead	0.017	0.016	0.019
Tin	0.047	0.091	0.018
Nickel	0.128	0.004	0.006
Ni-Cu Alloy 400	0.053	0.007	0.005
Zinc (99.9%)	0.202	0.063	0.034
Zinc (99.0%)	0.193	0.069	0.042
0.2% C Steel (a) (0.02% P, 0.05% S, 0.05% Cu, 0.02% Ni, 0.02% Cr)	0.48	–	–
Low-alloy steel (a) (0.1% C, 0.2% P, 0.04% S, 0.03% Ni, 1.1% Cr, 0.4% Cu)	0.09	–	–

Source: *Metals Handbook*, 9th ed., Vol. 13, p. 82, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

CORROSION OF COPPER ALLOYS IN MARINE ATMOSPHERES

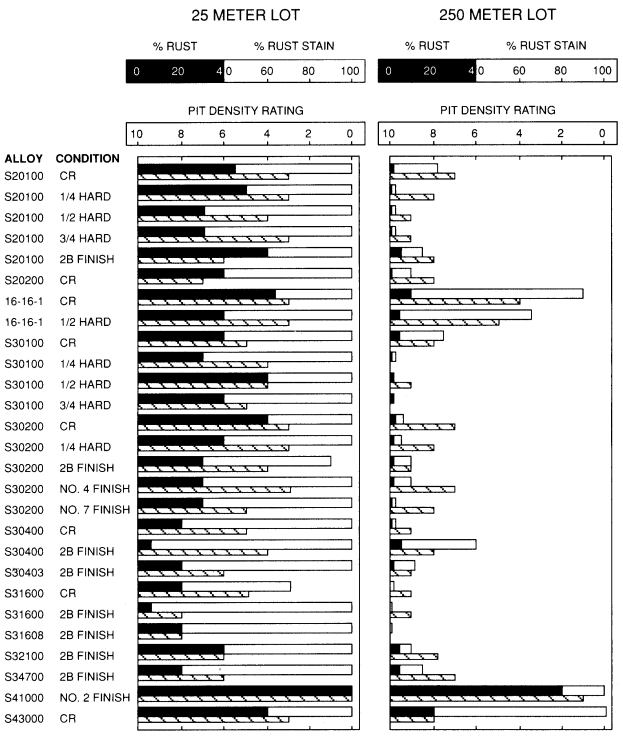
7 Year Exposure of Specimens at 25 Meter Lot at Kure Beach, NC (KB) or Point Reyes, CA (PR). Corrosion Rates by Weight Loss

UNS	Comman Name	Mils/Year		Appearance (KB)
		KB	PR	
C11000	ETP Copper	0.065	0.025	Brown film, smooth, slight patina near edges
C23000	Red Brass	0.033	0.026	Brown-maroon film, smooth
C26000	Cartridge Brass	0.030	0.017	Brown-maroon film, smooth, very slight patina
C42000	Tin Brass	0.024	–	Dark maroon, smooth
C50500	Phos. Bronze E (1.25% Sn)	0.069	0.017	“Mink brown”, slight patina
C51000	Phos. Bronze. A (5% Sn)	0.099	–	Maroon film, heavy etch
–	Alum. Bronze (7.5% Al)	0.013	–	Light tan film, smooth
C70400	Copper-Nickel (5% Ni)	0.033	–	Dark brown, plus patina streaks on panel face
C70700	Copper-Nickel (10% Ni)	0.038	–	Uniform maroon with patina at edges
C71100	Copper-Nickel (22% Ni)	0.031	–	Greenish brown, green near edges, slight etch
C74500	Nickel Silver (10% Ni)	0.024	0.010	Brown with slight patina film in center, green near edges, smooth
C75200	Nickel Silver (18% Ni)	0.021	–	Brown film in center, green near edges, smooth

Source: F. W. Fink et al., *Corrosion of Metals in Marine Environments*, Battelle Memorial Institute DMIC Report 254, NTIS AD-712 5B5-S, pp. 7, 13, 1970. Reprinted by permission of Battelle Memorial Institute.

RELATIVE PERFORMANCE OF STAINLESS STEELS EXPOSED IN A MARINE ATMOSPHERE

KURE BEACH – 26 YEARS



PIT DENSITY RATING

10 = No pits
9 = 0 to 0.1% coverage
8 = 0.1 to 0.25% coverage
7 = 0.25 to 0.5% coverage
6 = 0.5 to 1.0% coverage
5 = 1.0 to 2.5% coverage
4 = 2.5 to 5.0% coverage
3 = 5.0 to 10.0% coverage
2 = 10.0 to 25.0% coverage
1 = 25.0 to 50.0% coverage
0 = > 50% coverage

Source: Baker and Lee, ASTM Special Publication 965, p. 62, 1986. Reprinted, with permission, copyright ASTM.

THE MAJOR CONSTITUENTS OF SEAWATER

Chlorinity = 19%

Anions	Parts Per Million	Milliequivalents Per Litre
Chloride	18980	535.3
Sulfate	2649	55.2
Bicarbonate	142	2.3
Bromide	65	0.8
Fluoride	1.4	0.07
Borate	24.9	0.58
		594.25
Cations		
Sodium	10561	459.4
Potassium	380	9.7
Magnesium	1272	104.4
Calcium	400	20.0
Strontium	13	0.3
		593.8

Notes:
(1) The above composition shows slight difference between anions and cations, expressed as milliequivalents per litre because of the presence of traces of other components not listed in the above composition.
(2) Chlorinity is the total amount of chlorine, bromine and iodine in grams contained in one kilogram of seawater assuming that the bromine and iodine have been expressed as chlorine.
(3) Salinity is the total solid material in grams contained in one kilogram of sea water when all carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all organic matter is completely oxidized. In the open sea the salinity varies between 32 and 36.

$$\text{salinity} = 1.807 \times \text{chlorinity}$$

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CHEMICAL COMPOSITION OF SUBSTITUTE SEAWATER[(a)]

Compound	Concentration (g/L)
NaCl	24.53
$MgCl_2$	5.20
Na_2SO_4	4.09
$CaCl_2$	1.16
KCl	0.695
$NaHCO_3$	0.201
KBr	0.101
H_3BO_3	0.027
$SrCl_2$	0.025
NaF	0.003
$Ba(NO_3)_2$	0.0000994
$Mn(NO_3)_2$	0.000034
$Cu(NO_3)_2$	0.0000308
$Zn(NO_3)_2$	0.0000096
$Pb(NO_3)_2$	0.0000066
$AgNO_3$	0.00000049

[(a)]Chlorinity = 19.38. Adjust pH to 8.2 with 0.1 N NaOH.

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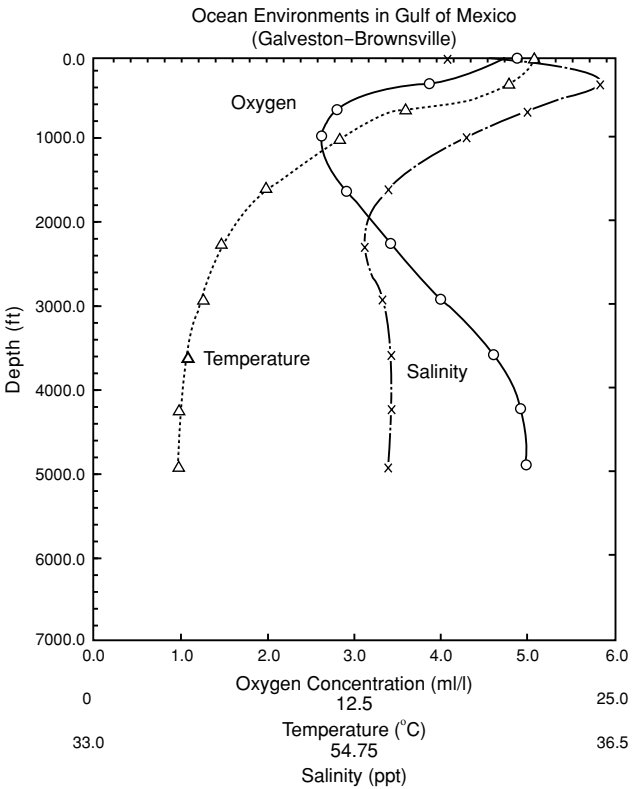
WORLDWIDE SEAWATER EXPOSURE SITES: TYPICAL SEAWATER CHARACTERISTICS

		Range of Environmental Constituents[a]			
Site	Rack Location	Dissolved Oxygen, ppm	Salinity	Temperature °C	pH
Ocean City, NJ	from raft 0.3 m below surface	5.2–11.7	31–34	1–29	7.5–8.2
Wrightsville Beach, NC Banks Channel	from wharf in channel	5.0–9.6	31.8–37.6	7–30	7.9 to 8.2
Key West, FL Fleming Key	under pier	4–8	33–39	16–31	8.0–8.2
Freeport, TX	intake flume	1.5–6.0	11.7–19.4[b]	15–27	7.5–8.6
Port Hueneme, CA Port Hueneme Harbor	from bulkhead	3.6–5.3	33	14–21	7.9–8.1
Talara, Peru	from pier 180 m from shore	5–6	19.8[b]	18–22	8.2
KeAhole, Kona, Hawaii	45 m from shore on pipe	6–14	34.6–35	24–28	8–8.3
Australia, Innisfail North Barnard Islands	from raft	5.1–6.5	31.7–37.2	23–30	8–8.5
Japan Sakata Harbor	off docking pier	7.1–13	16.8–18.3[b]	2–28	8.4
Italy Genoa Harbor	from raft	4.5–6.0	35	11–25	8.1
Denmark, Sjaelland Kyndby Isefjord	from raft in Fjord	NA[c]	18–28	0–18	7.5–8.0
Sweden					
Studsvik (Baltic Sea)	from wooden bulkhead	6–10	7.8–8.1	2–20	7.4–7.6
Bohus-Malmon (North Sea)	from raft	6–10	21–28	2–20	8.0–8.2
England, Isle of Wight Langstone Harbour	from raft	88–118[d]	34–34.6	5–22	7.8–8.4

[a] compiled from information provided by participants
[b] chlorinity, g/L
[c] NA = not available
[d] reported as % saturation

Source: R. Kain and W. Young, eds., *Corrosion Testing in Natural Waters,* Vol. 2, p. 37, STP1300, ASTM, 1997. Reprinted, with permission, copyright ASTM.

ENVIRONMENT/DEPTH PROFILE IN THE GULF OF MEXICO



Source: S. Milligan.

SPECIFIC CONDUCTANCE OF SEAWATER AS A FUNCTION OF TEMPERATURE AND CHLORINITY

Conductance: $\Omega^{-1} \cdot cm^{-1}$

Chlorinity, %	Temperature, °C (°F)					
	0 (32)	5 (40)	10 (50)	15 (60)	20 (70)	25 (75)
1	0.001839	0.002134	0.002439	0.002763	0.003091	0.003431
2	0.003556	0.004125	0.004714	0.005338	0.005971	0.006628
3	0.005187	0.006016	0.006872	0.007778	0.008702	0.009658
4	0.006758	0.007845	0.008958	0.010133	0.011337	0.012583
5	0.008327	0.009653	0.011019	0.012459	0.013939	0.015471
6	0.009878	0.011444	0.013063	0.014758	0.016512	0.018324
7	0.011404	0.013203	0.015069	0.017015	0.019035	0.021121
8	0.012905	0.014934	0.017042	0.019235	0.021514	0.023868
9	0.014388	0.016641	0.018986	0.021423	0.023957	0.026573
10	0.015852	0.018329	0.020906	0.023584	0.026367	0.029242
11	0.017304	0.020000	0.022804	0.025722	0.028749	0.031879
12	0.018741	0.021655	0.024684	0.027841	0.031109	0.034489
13	0.020167	0.023297	0.026548	0.029940	0.033447	0.037075
14	0.021585	0.024929	0.028397	0.032024	0.035765	0.039638
15	0.022993	0.026548	0.030231	0.034090	0.038065	0.042180
16	0.024393	0.028156	0.032050	0.036138	0.040345	0.044701
17	0.025783	0.029753	0.033855	0.038168	0.042606	0.047201
18	0.027162	0.031336	0.035644	0.040176	0.044844	0.049677
19	0.028530	0.032903	0.037415	0.042158	0.047058	0.052127
20	0.029885	0.034454	0.039167	0.044114	0.049248	0.054551
21	0.031227	0.035989	0.040900	0.046044	0.051414	0.056949
22	0.032556	0.037508	0.042614	0.047948	0.053556	0.059321

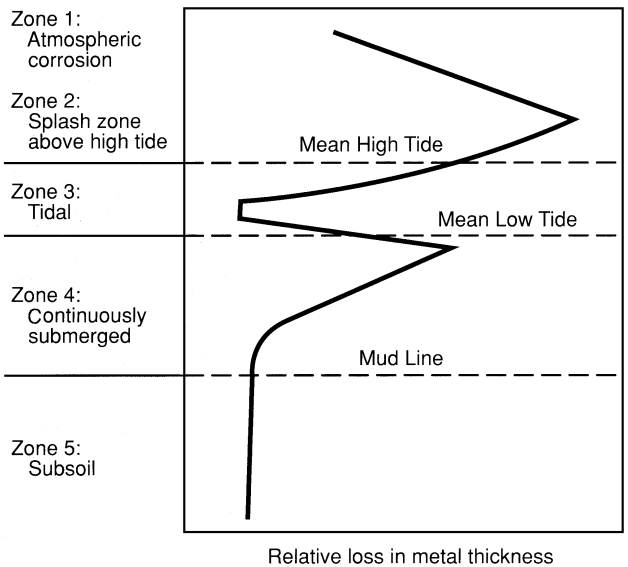
Source: *Metals Handbook*, 9th ed., Vol. 13, p. 896, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

CORROSION FACTORS FOR CARBON STEEL IN SEAWATER

Factor in Seawater	Effect on Iron and Steel
Chloride Ion	Highly corrosive to ferrous metals. Carbon steel and common ferrous metals cannot be passivated. (Sea salt is about 55% chloride.)
Electrical Conductivity	High conductivity makes it possible for anodes and cathodes to operate over long distances, thus corrosion possibilities are increased and the total attack may be much greater than that for the same structure in fresh water.
Oxygen	Steel corrosion, for the most part, is cathodically controlled. Oxygen, by depolarizing the cathode, facilitates the attack; thus a high oxygen content increases corrosivity.
Velocity	Corrosion rate is increased, especially in turbulent flow. Moving seawater may: (1) destroy rust barrier, and (2) provide more oxygen. Impingement attack tends to promote rapid penetration. Cavitation damage exposes the fresh steel surface to further corrosion.
Temperature	Increasing ambient temperature tends to accelerate attack. Heated seawater may deposit protective scale or lose its oxygen; either or both actions tend to reduce attack.
Biofouling	Hard-shell animal fouling tends to reduce attack by restricting access of oxygen. Bacteria can take part in the corrosion reaction in some cases.
Stress	Cyclic stress sometimes accelerates failure of a corroding steel member. Tensile stresses near yield also promote failure in special situations.
Pollution	Sulfides, which normally are present in polluted seawater, greatly accelerate attack on steel. However, the low oxygen content of polluted waters could favor reduced corrosion.
Silt and Suspended Sediment	Erosion of the steel surface by suspended matter in the flowing seawater greatly increases the tendency to corrode.
Film Formation	A coating of rust, or rust and mineral scale (calcium and magnesium salts), will interfere with the diffusion of oxygen to the cathode surface, thus slowing the attack.

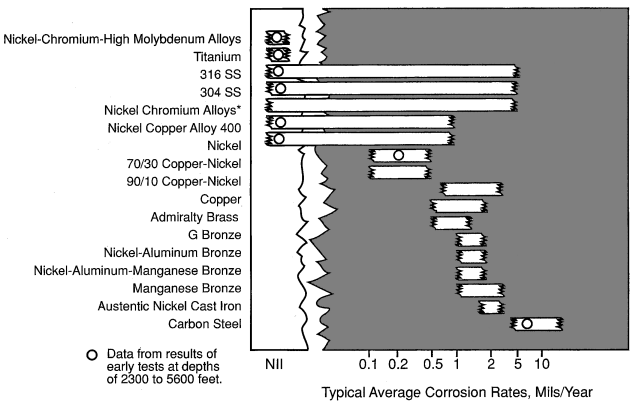
Source: F. W. Fink, et al., *The Corrosion of Metals in Marine Environment*, Battelle Memorial Inst., DMIC Report 254, Distributed by NTIS, AD-712 5B5-S, pp. 7, 13, 1970. Reprinted by permission of Battelle Memorial Institute.

ZONES OF CORROSION FOR STEEL PILING IN SEAWATER



Source: F. L. LaQue, *Marine Corrosion Cause and Prevention*, p. 116, John Wiley & Sons, 1975. Reproduced by permission of The Electrochemical Society.

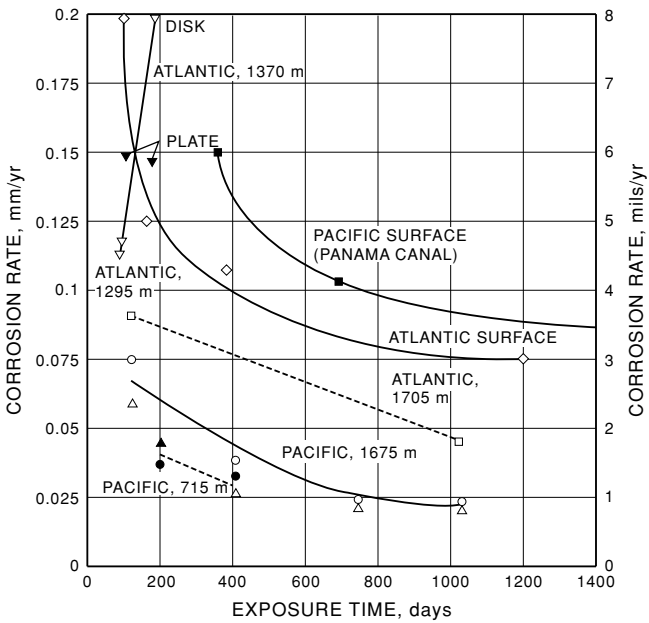
RATES OF GENERAL WASTAGE OF METALS IN QUIET SEAWATER



*Nickel chromium alloys designate a family of nickel base alloys with substantial chromium contents with or without alloying elements all of which, except those with high molybdenum contents, have related seawater corrosion characterstics.

Source: F. L. LaQue, *Marine Corrosion Causes and Prevention*, p. 146, John Wiley & Sons, 1975. Reproduced by permission of The Electrochemical Society.

CORROSION RATES OF LOW CARBON STEEL AT VARYING DEPTHS OF SEAWATER



Source: Manual 20, p. 309, ASTM, 1995. Reprinted, with permission, copyright ASTM.

SUGGESTED VELOCITY LIMITS FOR CONDENSER TUBE ALLOYS IN SEAWATER

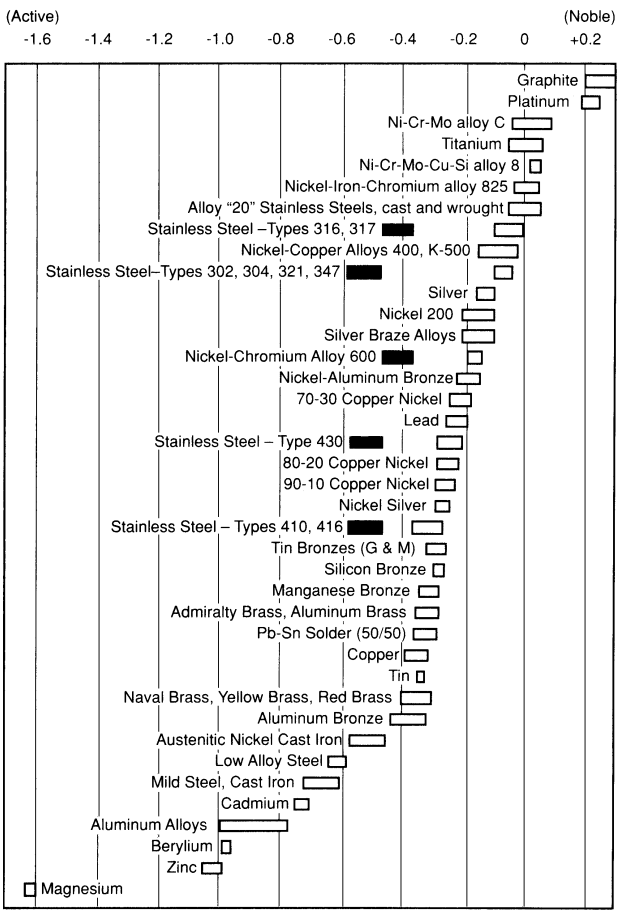
Alloy	Design Velocity That Should Not Be Exceeded (ft/s)	(m/s)
Copper	3[a]	0.9[a]
Silicon bronze	3[a]	0.9[a]
Admiralty brass	5[a]	1.5[a]
Aluminum brass	8[a]	2.4[a]
90-10 copper nickel	10[a]	3.0[a]
70-30 copper nickel	12[a]	3.7[a]
Ni-Cu alloy 400	No maximum velocity limit[b]	
Type 316 stainless steel	No maximum velocity limit[b]	
Ni-Cr-Fe-Mo alloys 825 and 20Cb3	No maximum velocity limit[b]	
Ni-Cr-Mo alloys 625 and C-276	No velocity limits	
Titanium	No velocity limits	

[a] In deaerated brines encountered in the heat recovery heat exchangers in desalination plants the critical velocities can be increased from 1 to 2 ft/sec. (0.3 to 0.6 m/s).
[b] Minimum velocity 5 ft/sec. (1.5 m/s).

Source: F. L. LaQue. Marine Corrosion Causes and Prevention, p. 267, John Wiley & Sons, 1975. Reproduced by permission of The Electrochemical Society.

GALVANIC SERIES IN SEAWATER

Flowing Seawater at 2.4 to 4.0 m/s for 5 to 15 days at 5 to 30°C



Note: Dark boxes indicate active behavior of active-passive alloys.

Source: ASTM, G82-98. Reprinted, with permission, copyright ASTM.

PRACTICAL GALVANIC SERIES

Open Circuit Potential Values Compared to Copper Alloy C11000 Test Medium: 5% NaCl at 25 C, 2.5-4 m/s

UNS	Name	Condition	Voltage	UNS	Name	Condition	Voltage
M11311	AZ31B Mg		−1.344	C11000	ETP Copper		0.000 (ref.)
M11912	AZ91B Mg		−1.314	S34700	347 SS	active	+0.006
Z33250	AG40A Zn		−0.786	–	Molybdenum		+0.006
–	Berylium		−0.780	C71500	Cu-Ni, 70-30		+0.012
A92014	2014 Al	T3	−0.639	S20200	202 SS	active	
A91160	1160 Al	H4	−0.609			(dull)	+0.014
A97075	7075 Al	T6	−0.604	–	Niobium		+0.018
A97079	7079 Al		−0.584	C53400	Phosphor Bronze		+0.034
M08990	Uranium		−0.556	S20200	202 SS	active	
A95052	5052 Al	H12	−0.545			(bright)	+0.051
A95052	5052 Al	0	−0.534	N44000	400 Ni-Cu alloy		+0.051
A95083	5083 Al		−0.524	S34700	347 SS	passive	+0.058
A96151	6151 Al	T6	−0.520	N02200	Nickel 200		+0.064
–	Cadmium		−0.519	S20100	201 SS	active	+0.070
A95456	5456 Al		−0.514	N08020	20Cb-3	active	+0.074
A95456	5456 Al	H343	−0.507	S32100	321 SS	active	+0.077
A94043	4043 Al	H14	−0.507	S31600	316 SS	active	+0.082
A95052	5052 Al	H32	−0.502	S30400	304 SS	passive	+0.098
A91100	1100 Al	0	−0.499	S17700	17-7PH	passive	+0.098
A93003	3003 Al	H25	−0.496	S30900	309 SS	active	+0.108
A96061	6061 Al	T6	−0.493	S31000	310 SS	passive	+0.109
A97071	7071 Al	T6	−0.484	S30100	301 SS	passive	+0.112
A13800	1380 Al	Cast	−0.444	S32100	321 SS	passive	+0.116
A92014	2014 Al	0	−0.444	S20100	201 SS	passive	+0.129
A92024	2024 Al	T4	−0.370	S35500	AM 355	active	+0.167
A95056	5056 Al	H16	−0.369	S66286	A286	active	+0.156
S43000	430 SS	active	−0.324	S31603	316L SS	passive	+0.156
–	Lead		−0.316	S20200	202 SS	passive	
G10100	1010 steel		−0.297			(dull)	+0.159
–	Tin		−0.281	S35500	Am 355	active	+0.167
S41000	410 SS	active	−0.297	S20200	202 SS	passive	
–	Tantalum		−0.166			(bright)	+0.183
S35000	AM 350	active	−0.149	N08020	20Cb-3	passive	+0.186
R50255	Ta-W, 90-10		−0.124	S35500	Am 355	passive	+0.204
S31000	310 SS	active	−0.124	S66286	A286	passive	+0.311
S30100	301 SS	active	−0.120	R54521	Ti, 5Al-2.5Sn		+0.423
S30400	304 SS	active	−0.106	R50810	Ti, 13V-11Cr-3Al	ANN	
S43000	430 SS	passive	−0.094			(33.5 HRC)	+0.436
S17700	17-7PH	active	−0.076	R56401	Ti, 6Al-4V	STA	
–	Tungsten		−0.047			(41.5 HRC)	+0.455
–	Niobium, 1% Zr		−0.044	–	Graphite		+0.473
C26800	Yellow brass		−0.043	R56401	Ti, 6Al-4V	ANN	
–	Uranium, 8% Mo		−0.041			(36 HRC)	+0.481
C46400	Naval brass		−0.041	R56080	Ti, 8Mn		+0.493
C28000	Muntz metal		−0.034	R50810	Ti, 13V-11 Cr-3Al	STA	
C75200	Nickel silver		−0.022			(45.5 HRC)	+0.498
S31603	316L SS	active	−0013	R50700	Ti, Gr. 4 (75A)		+0.506
C22000	Bronze, 90%		−0.012	S35000	AM 350	passive	+0.666
C65500	Si Bronze A		−0.007				

Source: C. M. Forman and E. A. Verchot, U.S. Army Missile Command Report No. RS-TR-67-11 (1967).

CORROSION OF STEEL IN AERATED WATER

Oxygen Content (ml O_2/1000 ml H_2O)	Corrosion Rate (mpy)	Temperature (°F)	pH
0	0.00	77	7.0
2	4.93	77	7.0
6 (Air saturation)	9.86	77	7.0
10	11.87	77	7.0
13	12.42	77	7.0
15	10.59	77	7.0
17	5.48	77	7.0
20	2.19	77	7.0
25	1.46	77	7.0
6	9.86	77	7.0
6 (Closed system)	20.00	132	7.0
6 (Open system)	18.00	132	7.0
6 (Closed system)	30.00	187	7.0
6 (Open system)	10.00	187	7.0
6	9.86	77	7.0
6	9.86	77	4.0
6	15.00	77	3.0
6	+40.00	77	2.6
6	9.86	77	10.0
6	3.00	77	12.0
6	5.00	77	14.0
6	13.00	77	16.0

Source: H. H. Uhlig, *Corrosion and Corrosion Control*, 2nd, ed., pp. 94–95, 99, John Wiley & Sons, Inc., © 1971. This material is used by permission of John Wiley & Sons, Inc.

CALCULATION OF CALCIUM CARBONATE SATURATION INDEX (LANGELIER INDEX)

A			C		D	
Total Solids mg/L		A	Calcium Hardness mg/L $CaCO_3$	C	M.O. Alkalinity mg/L $CaCO_3$	D
50–300		0.1	10–11	0.6	10–11	1.0
400–1000		0.2	12–13	0.7	12–13	1.1
B			14–17	0.8	14–17	1.2
			18–22	0.9	18–22	1.3
Temperature			23–27	1.0	23–27	1.4
°C	°F	B	28–34	1.1	28–35	1.5
0–1	32–34	2.6	35–43	1.2	36–44	1.6
2–6	36–42	2.5	44–55	1.3	45–55	1.7
7–9	44–48	2.4	56–69	1.4	56–69	1.8
10–13	50–56	2.3	70–87	1.5	70–88	1.9
14–17	58–62	2.2	88–110	1.6	89–110	2.0
18–21	64–70	2.1	111–138	1.7	111–139	2.1
22–27	72–80	2.0	139–174	1.8	140–176	2.2
28–31	82–88	1.9	175–220	1.9	177–220	2.3
32–37	90–98	1.8	230–270	2.0	230–270	2.4
38–43	100–110	1.7	280–340	2.1	280–350	2.5
44–50	112–122	1.6	350–430	2.2	360–440	2.6
51–55	124–132	1.5	440–550	2.3	450–550	2.7
56–64	134–146	1.4	560–690	2.4	560–690	2.8
65–71	148–160	1.3	700–870	2.5	700–880	2.9
72–81	162–178	1.2	880–1000	2.6	890–1000	3.0

(1) Obtain values of A, B, C and D from above table.
(2) pHs = (9.3 + A + B) − (C + D).
(3) Saturation index = pH − pHs.
If index is 0, water is in chemical balance.
If index is a plus quantity, there is a tendency for calcium carbonate deposition.

If the index is a minus quantity, calcium carbonate does not precipitate, and the probability of corrosion (if dissolved oxygen is present) will increase with an increase in the negative value of the index.

To determine temperature at which scaling begins (i.e., pH = pHs), find the temperature equivalent to the following value of B:

$$B = pH + (C + D) - (9.3 + A)$$

Ryznar Stability index = 2 (pHs) − pH
With waters having a Stability Index of 6.0 or less, scaling increases and the tendency for corrosion decreases. When the Stability Index is above 7.0, a protective coating of calcium carbonate may not be developed.

WATER ANALYSIS CONVERSION FACTORS

	$CaCO_3$ ppm	$CaCO_3$ grains/US gal	English degree	French degree	German degree
$CaCO_3$, ppm	1.0	0.058	0.07	0.10	0.056
$CaCO_3$, grains/US gal	17.1	1.0	1.2	1.71	0.958
English degree	14.3	0.833	1.0	1.43	0.800
French degree	10.0	0.583	0.7	1.0	0.560
German degree	17.9	1.04	1.24	1.79	1.0

1 English degree = 1 grain $CaCO_3$/Imperial gallon.
1 French degree = 10 ppm $CaCO_3$.
1 German degree = 10 ppm CaO.

Source: Courtesy of H. P. Godard.

COMMON GROUPS OF ALGAE

	Temperature Range			
Group	°C	°F	pH Range	Examples
Green Algae	30–35	86–95	5.5–8.9	Chlorella—common unicellular Ulothrix(1)—filamentous Spirogyra—filamentous
Blue–Green Algae (Contain Blue Pigment)	35–40	95–104	6.0–8.9	Anacystis—unicellular slime former Phormidium—filamentous(1) Oscillatoria(2) causes the most severe problems
Diatoms (Brown Pigment and Silica in Cell Wall)	18–85	64–186	5.5–8.9	Fragilaria Cyclotella Diatoms(1)

(1) These algae may occur in cooling water with as much as 120 ppm chromate present.
(2) Oscillatoria will grow at 186°F and at pH 9.5.

COMMON TYPES OF BACTERIA CAUSING SLIME PROBLEMS

Type	Example	pH Range	Problems Caused
Aerobic Capsulated	Aerobacter aerogenes Flavobacterium Proteus vulgaris Pseudomonas aeroginosa Serratia Alcaligenes	4.0–8.0 Optimum pH 7.5	Major slime forming bacteria. May produce green, yellow, and pink slimes in addition to usual grey or brown slime.
Aerobic Spore-Forming	Bacilus mycoides (in other Bacillus) species	5.0–8.0	Add to slime problem. Spores are more difficult to destroy.
Iron Bacteria	Crenothrix Leptothrix Gallionella	7.4–9.5	Precipitate ferric hydroxide in sheath-like coating around cell-forms bulking slime deposits.

NOTE: All of the above bacteria live in a temperature range of 68 to 104°F, with some species growing at 40 to 158°F.

Source: NACE, *Cooling Water Treatment Manual*, 1971.

MICROORGANISMS COMMONLY IMPLICATED IN BIOLOGICAL CORROSION

Genus or Species	pH Range	Temperature Range °C	Oxygen Requirement	Metals Affected	Action
Bacteria					
Desulfovibrio					
Best known: *D. desulfuricans*	4–8	10–40	Anaerobic	Iron and steel, stainless steels, aluminum zinc, copper alloys	Utilize hydrogen in reducing SO_4^{2-} to S^{2-} and H_2S; promote formation of sulfide films
Desulfotomaculum					
Best known: *D. nigrificans* (also known as *Clostridium*)	6–8	10–40 (some 45–75)	Anaerobic	Iron and steel, stainless steels	Reduce SO_4^{2-} to S^{2-} and H_2S (spore formers)
Desulfomonas	...	10–40	Anaerobic	Iron and steel	Reduce SO_4^{2-} to S^{2-} and H_2S
Thiobacillus thiooxidans	0.5–8	10–40	Aerobic	Iron and steel, copper alloys, concrete	Oxidizes sulfur and sulfides to form H_2SO_4: damages protective coatings corrodes concrete in sewers
Thiobacillus ferrooxidans	1–7	10–40	Aerobic	Iron and steel	Oxidizes ferrous to ferric
Gallionella	7–10	20–40	Aerobic	Iron and steel, stainless steels	Oxidizes ferrous (and manganous) to ferric (and manganic): promotes tubercule formation
Sphaerotilus	7–10	20–40	Aerobic	Iron and steel, stainless steels	Oxidizes ferrous (and manganous) to ferric (and manganic): promotes tubercule formation
S. natans	...	...	...	Aluminum alloys	
Pseudomonas	4–9	20–40	Aerobic	Iron and steel, stainless steels	Some strains can reduce ferric to ferrous
P. aeruginosa	4–8	20–40	Aerobic	Aluminum alloys	
Fungi					
Cladosporium resinae	3–7	10–45 (best at 30–35)	...	Aluminum alloys	Produces organic acids in metabolizing certain fuel constituents

Source: *Metals Handbook*, 9th ed., Vol. 13, p. 118, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

MICROBIOCIDES USED IN COOLING WATER SYSTEMS

Microbiocide	Effectiveness[a]			Comments
	Bacteria	Fungi	Algae	
Chlorine	E	S	E	Oxidizing: reacts with $-NH_2$ groups; effective at neutral pH; loses effectiveness at high pH. Use concentration: 0.1−0.2 mg/L continuous free residual; 0.5–1.0 mg/L intermittent free residual
Chlorine dioxide	E	G	G	Oxidizing; pH insensitive; can be used in presence of $-NH_2$ groups. Use concentration: 0.1–1 mg/L. intermittent free residual
Bromine	E	S	E	Oxidizing; substitute for Cl_2 and ClO_2; effective over broad pH range. Use concentration: 0.05−0.1 mg/L continuous free residual; 0.2 to 0.4 mg/L intermittent free residual
Organo-bromide (DBNPA)	E	NA	S	Nonoxidizing; pH range 6-8.5. Use concentration: 0.5–24 mg/L intermittent feed
Methylene bisthiocyanate	E	S	S	Nonoxidizing; hydrolyzes above pH 8. Use concentration: 1.5-8 mg/L intermittent feed
Isothiazolinone	E	G	E	Nonoxidizing; pH insensitive; deactivated by HS^- and $-NH_2$ groups. Use concentration: 0.9–13 mg/L intermittent feed
Quaternary ammonium salts	E	G	E	Nonoxidizing; tendency to foam; surface active; ineffective in highly oil- or organic-fouled systems. Use concentration: 8–35 mg/L intermittent feed
Organo-tin/ quaternary ammonium salts	E	G	E	Nonoxidizing; tendency to foam; functions best in alkaline pH. Use concentration: 7–50 mg/L
Glutaraldehyde	E	E	E	Nonoxidizing; deactivated by -NH_2 groups; effective over broad pH range. Use concentration: 10–75 mg/L intermittent feed

[a]E. excellent; G. good; S. slight; NA. not applicable

Source: *Metals Handbook*, 9th ed., Vol. 13. p. 493, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

CRITERIA FOR CATHODIC PROTECTION

(Criteria listed below are general guidelines resulting from engineering experience and are not always applicable. The reader should use criteria based on the specific application)

1. Steel and Cast Iron

A negative potential of at least 850 mV to a saturated copper–copper sulfate reference electrode (CSE) with the cathodic protection current applied. Voltage drops other than those across the structure to electrolyte boundary must be considered.

A negative polarized potential of at least 850 mV with respect to CSE.

A minimum of 100 mV of cathodic polarization between the structure and a stable reference electrode. This criterion also applies to steel in concrete.

2. Aluminum

A minimum of 100 mV of cathodic polarization between the structure and a stable reference electrode. Precautions must be taken to prevent overprotection of aluminum.

3. Copper

A minimum of 100 mV of cathodic polarization between the structure and a stable reference electrode.

APPROXIMATE CURRENT REQUIREMENTS FOR CATHODIC PROTECTION OF STEEL

Environmental Conditions	Current Density	
	mA/m^2	mA/ft^2
Immersed in Seawater[a]		
Stationary		
Well coated	1 to 2	0.1 to 0.2
Poor or old coating	2 to 20	0.2 to 2
Uncoated	20 to 30	2 to 3
Low velocity[b]		
Well coated	2 to 5	0.2 to 0.5
Poor coating	5 to 20	0.5 to 2
Uncoated	50 to 150	5 to 15
Medium velocity[c]		
Well coated	5 to 7	0.5 to 0.7
Poor coating	10 to 30	1 to 3
Uncoated	150 to 300	15 to 30
High velocity[d]		
Poor coating or uncoated	250 to 1000	25 to 100
Buried Underground[e]		
Soil resistivity		
0.5 to 5Ω·m	1 to 2	0.1 to 0.2
5 to 15Ω·m	0.5 to 1	0.05 to 0.1
15 to 40Ω·m	0.1 to 0.5	0.01 to 0.05

[a] Structures or vessels.
[b] 0.3 to 1 m/s (1 to 3 ft/s).
[c] 1 to 2 m/s (3 to 7 ft/s).
[d] Turbulent flow.
[e] Pipelines or structures, coated or wrapped.

Source: *Metals Handbook*, 9th ed., Vol. 1, p. 758, 1978. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

DESIGN CRITERIA FOR OFFSHORE CATHODIC PROTECTION SYSTEMS

Production Area	Water Resistivity[B] (ohm-cm)	Water Temp. (°C)	Environmental Factors[A]		Typical Design Current Density[C] mA/M² (mA/ft²)		
			Turbulence Factor (Wave Action)	Lateral Water Flow	Initial[E]	Mean[F]	Final[G]
Gulf of Mexico	20	22	Moderate	Moderate	110 (10)	55 (5)	75 (7)
US West Coast	24	15	Moderate	Moderate	150 (14)	90 (8)	100 (9)
Cook Inlet	50	2	Low	High	430 (40)	380 (35)	380 (35)
Northern North Sea	26–33	0–12	High	Moderate	180 (17)	90 (8)	120 (11)
Southern North Sea	26–33	0–12	High	Moderate	150 (14)	90 (8)	100 (9)
Arabian Gulf	15	30	Moderate	Low	130 (12)	65 (6)	90 (8)
Australia	23–30	12–18	High	Moderate	130 (12)	90 (8)	90 (8)
Brazil	20	15–20	Moderate	High	180 (17)	65 (6)	90 (8)
West Africa	20–30	5–21			130 (12)	65 (6)	90 (8)
Indonesia	19	24	Moderate	Moderate	110 (10)	55 (5)	75 (7)

(A) Typical values and ratings based on average conditions, remote from river discharge

(B) Water resistivities are a function of both chlorinity and temperature. In the *Corrosion Handbook* by H. H. Uhlig (New York, NY: John Wiley and Sons, Inc., 1948), the following resistivities are given for chlorinities of 19 and 20 parts per thousand:

	Resistivities (ohm-cm)		Temperature (°C)			
Chlorinity (ppt)	0	5	10	15	20	25
19	35.1	30.4	26.7	23.7	21.3	19.2
20	33.5	29.0	25.5	22.7	20.3	18.3

(C) In ordinary seawater, a current density less than the design value suffices to hold the platform at protective potential once polarization has been accomplished and calcareous coatings are built up by the design current density. CAUTION: Depolarization can result from storm action.

(D) Conditions in the North Sea can vary greatly from the northern to the southern area, winter to summer, and storm periods.

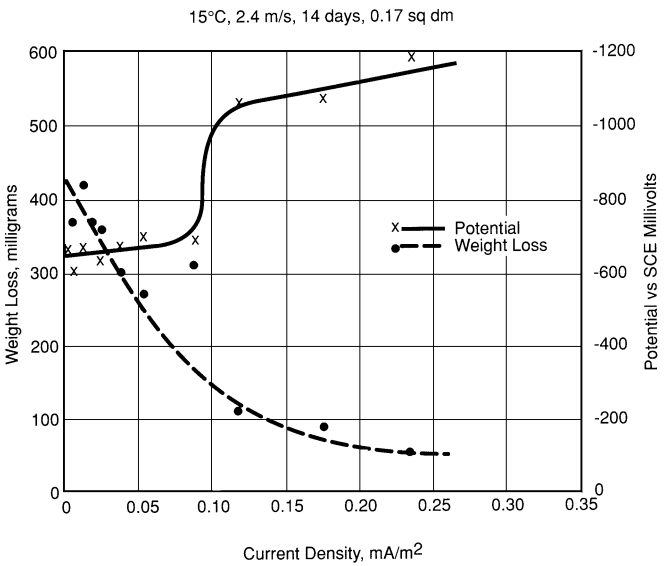
(E) Initial current densities are calculated using Ohm's Law and a resistance equation such as Dwight's or Crennell's (McCoyr's) equation with the original dimensions of the anode. An example of this calculation is given in Appendix D, using an assumed cathode potential of −0.80 V ($Ag/AgCl^{[sw]}$).

(F) Mean current densities are used to calculate the total weight of anodes required to maintain the protective current to the platform over the design life. An example of this calculation is given in Appendix D.

(G) Final current densities are calculated in a manner similar to the initial current density, except that the depleted anode dimensions are used. An example of this calculation is given in Appendix D.

Source: H. P. Hack, ed., *Designing Cathodic Protection Systems for Marine Structures and Vehicles*, STP 1370, ASTM, 2000. Reprinted, with permission, copyright ASTM.

EFFECT OF APPLIED CATHODIC CURRENT ON CORROSION AND POTENTIAL OF STEEL IN FLOWING SEAWATER



Source: F. L. LaQue, *Marine Corrosion Causes and Prevention*, p. 74, John Wiley & Sons, 1975. Reproduced by permission of the Electrochemical Society.

SYSTEMS FOR COASTAL AND HARBOR STRUCTURES

Installation	Coating	Splash Zone (m^2)	Current Density ($mA\ m^{-2}$)	Type of Anode	No. of Anodes	Anode Weight (t)	Rectifier Output (A)	Life (years)
Loading pier, Liberia	Tar pitch	5400	25→6.5	Zn	190	14	–	25
Loading pier, San Salvador	Tar pitch	27,000	70	C	120	–	7 × 300	15
Tanker pier, North Sea	Tar pitch	39,000	30	FeSi-Mo	210	–	65 × 20	15
Ore pier, Malaysia	Tar pitch-epoxy	35,000	15→5	PtTi	30	–	4 × 100	>10
Steel piling, Elbe	Tar pitch-epoxy	25,000	16	FeSi-Cr	380	4	20 × 100	>20
Drawbridge, Wilhelmshaven	Tar pitch-epoxy	22,000	10	FeSi-Mo	160	8	18 × 150	>25
Loading quay, Lomé-Togo	Tar pitch-epoxy	70,000	18	PtTi	71	–	2 × 250 2 × 150	>25
Ferry harbor, Puttgarden	None	8500 and ca. 5500 steel-reinforced concrete	160	PtTi	360	–	20 × 100	>10
Tonasa II Indonesia	None	11,250 and 5140 soil	70→30	PtTi	45	–	1 × 600 2 × 120	>20

Source: W. von Baeckman, W. Schwenk, and W. Prinz, eds., *Cathodic Corrosion Protection*, p. 381, Gulf Publishing, 2000. Reprinted by permission of Butterworth-Heinemann/Gulf Professional Publishing.

CATHODIC PROTECTION OF METALS AND ALLOYS PROTECTION POTENTIALS AND RANGES

System Material	System Medium	Protection Potential/Region (in volts) U_H	Protection Potential/Region (in volts) $U_{Cu-CuSO_4}$	Notes/References
Plain carbon and low-alloy ferrous materials	Neutral waters, saline and soil solutions (25°C)	<−0.53	<−0.85	Protection against weight loss corrosion (with film formation U_s is more positive)
	Boiling neutral waters	<−0.63	<−0.95	
	Weak acidic waters and anaerobic media (25°C)	<−0.63	<−0.95	
	High-resistance sandy soils	<−0.43 (−0.33)	<−0.75 (−0.65)	
High-alloy steels with >16% Cr (e.g. 1.4301, AISI 304)	Neutral waters and soils (25°C)	<0.2	<−0.1	Protection against pitting and crevice corrosion
	Boiling neutral waters	<0.0	<−0.3	Heating surfaces are more susceptible than cooling surfaces
CrNiMo stainless steels and Cr-rich special alloys	Seawater (25°C) Cl^- containing media	<0.0 (in general more positive; U_{PC} values determine)	<−0.3	U_s becomes more negative with increasing Cl^- concentration and temperature
CrNi stainless steels	Cl^- containing hot water	About < 0.0	About <−0.3	Protection against stress corrosion
Plain carbon and low-alloy steels	Warm solutions of			Protection against stress corrosion
	Nitrates	<−0.15	<−0.47	
	Caustic soda	<−0.98	<−1.30	
	Na_2CO_3	<−0.68	<−1.00	Strain induced
	$NaHCO_3$	<−0.43	<−0.75	
	$(NH_4)_2CO_3$	<−0.35	<−0.67	
Cu, CuNi alloys	Neutral waters and soils (25°C)	<+0.14	<−0.18	Protection against weight loss corrosion
Sn	Neutral waters (25°C)	<−0.33	<−0.65	
Plain carbon and low-alloy ferrous materials	Seawater	−0.53/−0.78	−0.85/−1.10	Protection for thin films and against stress corrosion at fluctuating loads
	Cement, concrete	−0.43/−0.98	−0.75/−1.3	
High-alloy heat-treated Cr steels (R_m > 1200 N mm^{-2})	Seawater (25°C)	−0.5/−0.0	−0.82/−0.32	Protection against H-induced stress corrosion and pitting corrosion

System Material	System Medium	Protection Potential/Region (in volts) U_H	Protection Potential/Region (in volts) $U_{Cu-CuSO_4}$	Notes/References
Pb	Neutral waters and soils (25°C)	−1.4/−0.33	−1.7/−0.65	Protection against hydride formation and weight loss corrosion
Zn	Neutral Waters and soils (25°C)	−1.3/−0.96	−1.6/−1.3	
Al, Al alloys	Cold water			Protection against weight loss corrosion and pitting corrosion
Al Zn 4.5 Mg 1	Fresh Water	−1.0/−0.3	−1.3/−0.62	
	Seawater	−1.0/−0.5	−1.3/−0.82	U_s' becomes more negative with decreasing Na^+ cocentration
	Seawater	−1.0/−0.7	−1.3/−1.02	
Ti, Ti alloys	Halide-free acids	>0.0	>−0.32	Protectioin against weight loss corrosion
	Increased concentration and temperature	U_s becomes more positive		
Plain carbon and low-alloy steels (R_p < 600) hardened region				Protection against stress corrosion and weight loss corrosion.
	Warm caustic soda	−0.6/+0.2	−0.9/−0.1	
	(R_m>1000 N mm^{-2})	−0.4/+0.2	−0.7/−0.1	
	Warm Na_2CO_3 soln.	−0.6/?	−0.9/?	Strain induced
	$NaHCO_3$ soln.	−0.3/?	−0.6/?	
	$(NH_4)_2CO_3$ soln.	−0.25/?	−0.57/?	
Fe, plain carbon steels	0.5 M H_2SO_4 (25°C)	0.8/1.6	0.5/1.3	Protection against active and transpassive corrosion
High-alloy steels with >16%Cr	Halide-free cold acids	0.2/1.1	−0.1/0.8	Protection against active and transpassive corrosion
	Boiling conc. H_2SO_4	1.2/1.6	0.9/1.3	
	Cl^- and NO_3^- containing water (25°C)	0.5/1.1	0.2/0.8	Protection against pitting corrosion and transpassive corrosion

Source: W. von Baeckman, W. Schwenk, and W. Prinz, eds., *Cathodic Corrosion Protection*, pp. 72–73, Gulf Publishing, 2000. Reprinted by permission of Butterworth-Heinemann/Gulf Professional Publishing.

APPLICATIONS AND DATA FOR CATHODIC PROTECTION REFERENCE ELECTRODES

Reference Electrode	Me/Me$^+$ System	Electrolyte	Potential U_H at 25°C (V)	Temperature Dependence (mV/°C)	Application
Cu-$CuSO_4$	Cu/Cu^{2+}	Sat. $CuSO_4$	+0.32	0.97	Soils, water
Ag-AgCl	Ag/Ag^+	Sat. KCl	+0.20	1.0	Saline and fresh water
Sat. calomel	Hg/Hg_2^{2+}	Sat. KCl	+0.24	0.65	Water, laboratory
1 *M* calomel	Hg/Hg_2^{2+}	1 *M* KCl	+0.29	0.24	Laboratory
Hg_2SO_4	Hg/Hg_2^{2+}	Sat. K_2SO_4	+0.71		Chloride-free water
Mercuric oxide	Hg/Hg_2^{2+}	0.1 *M* NaOH	+0.17		Dilute caustic soda
Mercuric oxide	Hg/Hg_2^{2+}	35% NaOH	+0.05		Concentrated caustic soda
Thalamid	Tl/Tl^+	3.5 *M* KCl	−0.57	< 0.1	Warm media
Ag-saline	Ag	–	+0.25		Seawater[a]
Pb-H_2SO_4	Pb/Pb^{2+}	–	−2.8		Concentrated sulfuric acid
Zn-saline	Rest potential	–	−0.79[b] −0.77 ± 0.01		Seawater and brine
Zn-soil	Rest potential	–	−0.8 ± 0.1		Soil
Fe-soil	Rest potential	–	−0.4 ± 0.1		Soil
Stainless steel-soil	Rest potential	–	About −0.4 to +0.4		Soil

[a] The reference potential for other solutions containing Cl^- ions must be determined.
[b] Activated with Hg.

Source: W. von Baeckman, W. Schwenk, and W. Prinz, eds., *Cathodic Corrosion Protection*, p. 80, Gulf Publishing, 2000. Reprinted by permission of Butterworth-Heinemann/Gulf Professional Publishing.

COMPOSITION AND PROPERTIES OF SOLID IMPRESSED CURRENT ANODES (WITHOUT COKE BACKFILL)

Type	Composition (wt.%)	Density ($g\ cm^{-3}$)	Anode Current Density ($A\ m^{-2}$) max.	Anode Current Density ($A\ m^{-2}$) avg.	Anode Consumption ($g\ A^{-1}\ a^{-1}$)
Graphite	100°C	1.6 to 2.1	50 to 150	10 to 50	300 to 1000
Magnetite	Fe_3O_4+ additions	5.2	–	90 to 100	1.5 to 2.5
High-silicon iron	14 Si, 1 C remainder Fe (5 Cr or 1 Mn or 1 to 3 Mo)	7.0 to 7.2	300	10 to 50	90 to 250
Lead-silver Alloy 1	1 Ag, 6 Sb, remainder Pb	11.0 to 11.2	300	50 to 200	45 to 90
Alloy 2	1 Ag, 5 Sb, 1 Sn, remainder Pb	11.0 to 11.2	300	100 to 250	30 to 80
Lead-platinum	Lead + Pt pins	11.0 to 11.2	300	100 to 250	2 to 60

Source: W. von Baeckman, W. Schwenk, and W. Prinz, eds., *Cathodic Corrosion Protection*, p. 212, Gulf Publishing, 2000. Reprinted by permission of Butterworth-Heinemann/Gulf Professional Publishing.

PROPERTIES OF METALS USED IN PLATINUM TYPE IMPRESSED CURRENT ANODES

Property	Pt	Ta	Nb	Ti
Atomic weight	195.09	180.95	92.91	47.90
Crystal structure	FCC	BCC	BCC	CPH
Density, g/cm^2, 20°C	21.45	16.6	8.57	4.54
Melting point, °C	1,769	2,996	2,468	1,668
Boiling point, °C	4,530	5,425	3,300	3,260
Specific heat, cal/gm	0.032	0.036	0.065	0.126
Thermal conductivity $cal/cm^2/cm/sec/°C$	0.17	0.13	0.12	0.04
Electrical resistivity $\mu\Omega$/cm	10.6	12.4	13.1	42
Linear coefficient of thermal expansion ($\times 10^4$) in./in./°C	9.1	6.5	7.1	8.5
Tensile strength psi ($\times 10^{-4}$), annealed	18–24	50	50	78.7
Elongation in 2 in., % annealed	30–40	40	30	25

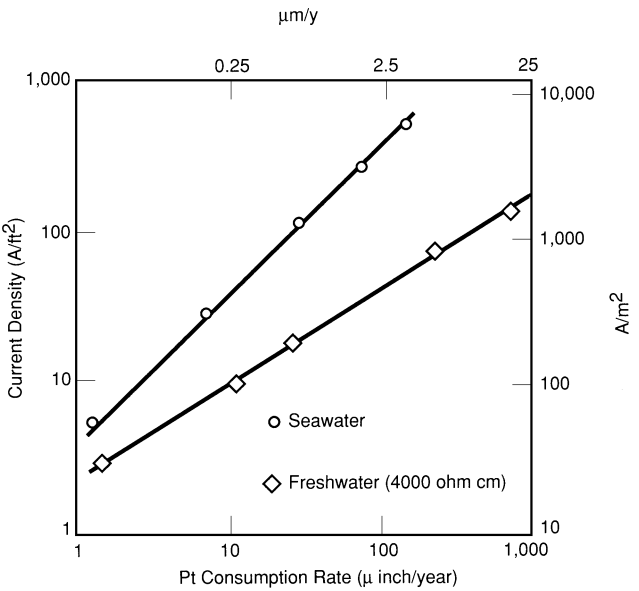
Source: R. Baboian.

COMPOSITION AND PROPERTIES OF NOBLE METAL ANODES

Substrate Metal	Density ($g\ cm^{-3}$)	Coating	Density ($g\ cm^{-3}$)	Coating Thickness (μm)	Anode Current Density ($A\ m^{-2}$)		Allowable Maximum Driving Voltage (max/V)	Loss ($mg\ A^{-1}\ a^{-1}$)
					max.	avg.		
Platinum	21.45	Platinum	21.45	Solid	$>10^4$			<2
Titanium	4.5	–		–			12 to 14	
Niobium	8.4	–		–			about 50 (<100)	
Tantalum	16.6	–		–			>100	
Ti, Nb, Ta		Platinum	21.45	2.5 to 10	$>10^3$	600 to 800		4 to 10
Ti, Nb, Ta		Lithium-ferrite	6 to 12	<25	$>10^3$	100 to 600		<1 to 6
Ti		Mixed Metal Oxide	15		$>10^3$	500		10

Source: W. von Baeckman, W. Schwenk, and W. Prinz, eds., *Cathodic Corrosion Protection*, p. 214, Gulf Publishing, 2000. Reprinted by permission of Butterworth-Heinemann/Gulf Professional Publishing.

PLATINUM CONSUMPTION RATES FOR CATHODIC PROTECTION ANODES



Source: R. Baboian.

PROPERTIES OF IMPRESSED CURRENT ANODES FOR SOILS

Anode Material	Iron		High-Silicon Iron			Graphite			Magnetite	Lithium Ferrite on Titanium
Length (m)	1 m NP 30 double T girder	1 m rail	0.5	1.2	1.5	1	1.2	1.5	0.9	0.5
Diameter (m)	ht. 0.3, br. 0.13	0.14, 0.13	0.04	0.06	0.075	0.06	0.06	0.08	0.04	0.016
Weight (kg)	56	43	16	26	43	5	6	8	6	0.2
Density (g cm^{-3})	7.8	7.8	7	7	7	2.1	2.1	2.1	5.18	6 to 12
Practical loss without coke backfill (kg A^{-1} a^{-1})	10	10		0.2–0.3		1	1	1	0.002	0.001
Practical loss with coke backfill (kg A^{-1} a^{-1})	5	5		ca. 0.1			ca. 0.2–0.5		–	< 0.001
Life at 1 A per anode without coke backfill (yrs)	5	4	50	80	140	5	6	8	200	120
Life at 1 A per anode with coke backfill (yrs)	10	8	160	260	430	10	12	16	–	> 120
Danger of fracture	None		Moderate			High			Moderate	None
Recommended installation site	Extended anode installation with coke backfill in poorly conducting soils, very economical		Mostly used for impressed current anodes with long life, also without coke backfill			Aggressive soils and aqueous solutions also without coke backfill; relatively economical			Soils Seawater	Deep anodes Seawater

Source: W. von Baeckman, W. Schwenk, and W. Prinz, eds., *Cathodic Corrosion Protection*, p. 209, Gulf Publishing, 2000. Reprinted by permission of Butterworth-Heinemann/Gulf Professional Publishing.

PROPERTIES OF GALVANIC ANODES

Anode Material	Density Kilograms Per Cubic m	Current Efficiency %	Consumption Rate Actual (Kg/Amp.-Yr.)	Potential to $CuSO_4$ Electrode (Volts)
Magnesium:	1936	50	7.9	
Standard Alloy				−1.55
High Potential Alloy				−1.80
Aluminum	2720	95	3.1	−1.1
Zinc	7040	90–95	11.8	−1.1

Source: H. P. Hack, ed., *Designing Cathodic Protection Systems for Marine Structures and Vehicles*, p. 56, STP 1370, ASTM, 2000. Reprinted, with permission, copyright ASTM.

COMPOSITION (WT. %) AND PROPERTIES OF ALUMINUM ALLOYS FOR ANODES

Type	Hg-Zn (X-Meral)	In-Zn (Galvalum III)	Sn-Zn
Zinc	2.0 to 2.2	3.0	5.5
Mercury	0.045 to 0.055	–	–
Indium	–	0.015	–
Tin	–	–	0.1
Iron	< 0.1	–	< 0.1
Copper	< 0.02	–	< 0.005
Silicon	< 0.05	0.1	< 0.1
Manganese	0.25 to 0.3	–	< 0.005
Titanium	0.02 to 0.03	–	< 0.04
Magnesium	0.04 to 0.05	–	< 0.005
Rest Potential in Seawater			
U_H/V	−0.8/−1.0	∼ −0.85	∼ −0.86

Source: W. von Baeckman, W. Schwenk, and W. Prinz, eds., *Cathodic Corrosion Protection*, p. 189, Gulf Publishing, 2000. Reprinted by permission of Butterworth-Heinemann/Gulf Professional Publishing.

COMPOSITION AND PROPERTIES OF MAGNESIUM ANODES[1]

Specific Gravity	1.94
Pounds per Cubic Foot	121
Theoretical Amp Hours per Pound	1000
Theoretical Pounds per Amp per Year	8.7
Current Efficiency—Percent	50[2]
Actual Amp Hours per Pound	500[2]
Actual Pounds per Amp per Year	17.4[2]
Solution Potential—Volts to CSE	
Standard H-1 Alloy	−1.50 to −1.55[3]
High Potential Alloy	−1.75 to −1.77[4]
Driving Potential to Pipeline	
Polarized to −0.90 Volt to $CuSO_4$	
Standard Alloy—Volts	0.55[5]
High Potential Alloy—Volts	0.80[5]

[1] Anodes installed in suitable chemical backfill.

[2] Current efficiency varies with current density. Efficiency given (which results in actual amp hr per pound and actual pounds per amp per year shown) is at approximately 30 milliamps per sq ft of anode surface. Efficiencies are higher at higher current densities, lower at lower current densities.

[3] Alloy with nominal composition % 6 Al, 3 Zn, 0.2 Mn and balance Mg.

[4] Proprietary alloy–manganese principal alloying element.

[5] Driving potentials allow for anode polarization in service of approximately 0.10 volt which reduces the solution potential by this amount. Driving potential in volts for pipeline polarized to any specific potential (P) in volts = solution potential of magnesium type used minus 0.10 volts minus P.

STANDARD H-1 ALLOY CHEMICAL COMPOSITION

	Weight Content %		
Element	**Grade A**	**Grade B**	**Grade C**
Al	5.3–6.7	5.3–6.7	5.0–7.0
Mn	0.15 min	0.15 min	0.15 min
Zn	2.5–3.5	2.5–3.5	2.0–4.0
Si	0.10 max	0.30 max	0.30 max
Cu	0.02 max	0.05 max	0.10 max
Ni	0.002 max	0.003 max	0.003 max
Fe	0.003 max	0.003 max	0.003 max
Other	0.30 max	0.30 max	0.30 max
Magnesium	Remainder	Remainder	Remainder

HIGH POTENTIAL ALLOY CHEMICAL COMPOSITION

Element	**Weight Content %**
Al	0.010
Mn	0.50 to 1.30
Cu	0.02 Max
Ni	0.001 Max
Fe	0.03 Max
Other	0.05 each or 0.3 Max Total
Magnesium	Remainder

Source: A. W. Peabody and R. L. Bianchetti, eds., *Peabody's Control of Pipeline Corrosion*, 2nd ed., p. 181, NACE, 2001.

COMPOSITION AND PROPERTIES OF ZINC ANODES[1]

Specific Gravity	7
Pounds per Cubic Foot	440
Theoretical Amp Hours per Pound	372[2]
Theoretical Pounds per Amp per Year	23.5
Current Efficiency—Percent	90[3]
Actual Amp Hours per Pound	335
Actual Pounds per Amp per Year	26
Solution Potential—Volts to CSE	−1.1
Driving Potential to Pipeline	
Polarized to—0.90 Volt to $CuSO_4$	0.2[4]

[1] Anodes installed in suitable chemical backfill.
[2] Zinc used for soil anodes should be high purity zinc such as "Special High Grade" classification which is at least 99.99 percent pure zinc.
[3] Current efficiency of zinc is reasonably constant from low to very high current outputs in terms of milliamperes per sq ft of anode surface. This applies when the high purity anode grade zinc is used. The 90 percent efficiency is conservative.
[4] Zinc not subject to significant anodic polarization when used in suitable backfill. Driving potential is zinc solution potential minus polarized potential of protected structure.

CHEMICAL COMPOSITION

Element	Weight Content %	
	MIL-A-18001 (ASTM B-418 Type I)	ASTM B-418 Type II
Al	0.1–0.5	0.005 max
Cd	0.02–0.07	0.003 max
Fe	0.005 max	0.0014 max
Pb	0.006 max	0.003 max
Cu	0.005 max	0.002 max
Zinc	Remainder	Remainder

Source: A. W. Peabody and R. L. Bianchetti, eds., *Peabody's Control of Pipeline Corrosion*, 2nd ed., p. 184, NACE, 2001.

COMPARISON OF ZINC AND MAGNESIUM ANODES FOR SOILS

Soil Resistivity in ohm-cm	Anode Type	Driving Potential in volts with Pipeline Polarized to −0.85V	Maximum Permissible Circuit Resistance in ohms, for 75 mA	Max Permissible Resistance of Anodes and Leads, in ohms, with 2 ohms Pipe-to-Earth Resistance	Number, Size (in inches) and Weight (Each) of Anodes Selected	Resistance of Anode Array Selected in ohms	Actual Total Circuit Resistance in ohms	Actual Current in mA with Pipeline Polarized to −1.05 V with zinc or to −1.20 V with Mg	Indicated Anode Life in Years	Max Current, mA, with Pipe-to-Earth Resistance Dropped to 0.50 ohm and with −0.85 V Polarized	Regulation as Ratio of Maximum Current to that Under Initial Conditions	Indicated Anode Life in Years Under Maximum Current Conditions
300	Mag	0.6	8.0	6.0	One 3×3×60, 40-Pound	1.44	3.44	72.8	27.2	403	5.55	4.9
	Zinc	0.25	3.3	1.3	Two 1.4×1.4×60, 30-Pound	0.76	2.76	18.1	107	198	11.0	9.8
500	Mag	0.6	8.0	6.0	One 3×3×60, 40-Pound	2.0	4.0	62.5	31.5	240	3.85	8.2
	Zinc	0.25	3.3	1.3	Two 1.4×1.4×60, 30-Pound	1.07	3.07	16.2	120	159.5	9.85	12.2
1500	Mag	0.6	8.0	6.0	One 2×2×60, 20-Pound	4.81	6.81	36.6	26.9	113	3.08	8.7
	Zinc	0.25	3.3	1.3	Five 1.4×1.4×60, 30-Pound	1.24	3.24	15.4	315	144	9.35	33.6
3000	Mag	0.6	8.0	6.0	Two 2×2×60, 20-Pound	4.86	6.86	36.4	55.2	112	3.08	17.6
	Zinc	0.25	3.3	1.3	Eleven 1.4×1.4×60, 30-Pound	1.3	3.3	15.2	745	139	9.15	83

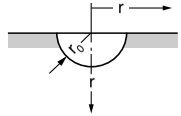
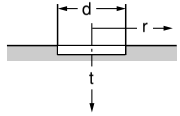
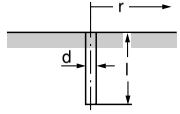
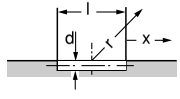
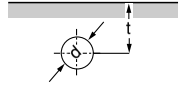
Source: A. W. Peabody, R. L. Bianchetti, ed., Peabody's Control of Pipeline Corrosion, 2nd ed., p. 192, NACE 2001.

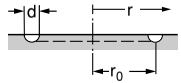
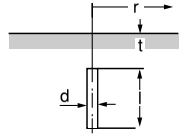
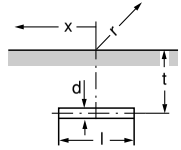
RESISTANCE OF GALVANIC ANODES–DWIGHT'S EQUATION

One vertical ground rod: length L, radius a	$R = \frac{\rho}{2\pi L}\left(\log_n \frac{4L}{a} - 1\right)$
Two vertical ground rods separation s, s > L	$R = \frac{\rho}{4\pi L}\left(\log_n \frac{4L}{a} - 1\right) + \frac{\rho}{4\pi s}\left(1 - \frac{L^2}{3s^2} + \frac{2}{5}\cdot\frac{L^4}{s^4}\cdots\right)$
s < L	$R = \frac{\rho}{4\pi L}\left(\log_n \frac{4L}{a} + \log_n \frac{4L}{s} - 2 + \frac{s}{2L} - \frac{s^2}{16L^2} + \frac{s^4}{512L^4}\cdots\right)$
Buried horizontal wire, length 2L, depth s/2	$R = \frac{\rho}{4\pi L}\left(\log_n \frac{4L}{a} + \log_n \frac{4L}{s} - 2 + \frac{s}{2L} - \frac{s^2}{16L^2} + \frac{s^4}{512L^4}\cdots\right)$
Right-angle turn of wire: length of arm L, depth s/2	$R = \frac{\rho}{4\pi L}\left(\log_n \frac{2L}{a} + \log_n \frac{2L}{s} - 0.24 + 0.2\frac{s}{L}\cdots\right)$
Three-point star	$R = \frac{\rho}{6\pi L}\left(\log_n \frac{2L}{a} + \log_n \frac{2L}{s} + 1.1 - 0.2\frac{s}{L}\cdots\right)$
Four-point star	$R = \frac{\rho}{8\pi L}\left(\log_n \frac{2L}{a} + \log_n \frac{2L}{s} + 3 - \frac{s}{L}\cdots\right)$
Six-point star	$R = \frac{\rho}{12\pi L}\left(\log_n \frac{2L}{a} + \log_n \frac{2L}{s} + 6.9 - \frac{3s}{L}\cdots\right)$
Eight-point star	$R = \frac{\rho}{16\pi L}\left(\log_n \frac{2L}{a} + \log_n \frac{2L}{s} + 11 - 5.5\frac{s}{L}\cdots\right)$
Ring of wire, Diameter D of ring, diameter of wire, a depth s/2	$R = \frac{\rho}{2\pi^2 D}\left(\log_n \frac{8D}{d} + \log_n \frac{4D}{s}\right)$
Buried horizontal strip: length 2L, section a by b depth s/2, b < a/8	$R = \frac{\rho}{4\pi L}\left(\log_n \frac{4L}{a} + \frac{a^2 - \pi ab}{2(a+b)^2} + \log_n \frac{4L}{s} - 1 + \frac{s}{2L} - \frac{s^2}{16L^2}\right)$
Buried horizontal round plate radius a, depth s/2	$R = \frac{\rho}{8a} + \frac{\rho}{4\pi s}\left(1 - \frac{7a^2}{12s^2} + \frac{33a^4}{40s^4}\cdots\right)$
Buried vertical round plate	$R = \frac{\rho}{8a} + \frac{\rho}{4\pi s}\left(1 + \frac{7a^2}{24s^2} + \frac{99a^4}{320s^4}\cdots\right)$

Source: John H. Morgan, *Cathodic Protection*, 2nd ed., p. 104, NACE, 1987.

CALCULATION FORMULAS FOR SIMPLE ANODES (ANODE VOLTAGE $U_0 = IR$)

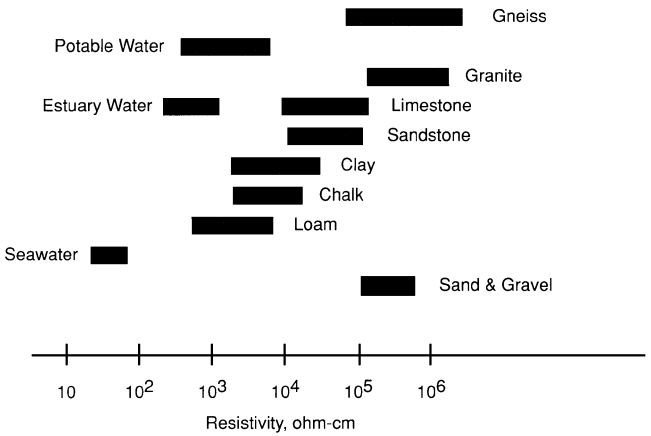
Anode Shape	Anode Arrangement	Grounding Resistance	Remarks	Voltage Cone
Hemisphere, radius r_0, diameter d		$R = \frac{\rho}{\pi d}$	Spherical field	$U_r = U_0 \frac{r_0}{r} = \frac{I\rho}{2\pi r}$
Circular plate, diameter d, radius r_0		$R = \frac{\rho}{2d\pi}$	Surface Depth	$U_r = \frac{2}{\pi} U_0 \arcsin\left(\frac{r_0}{r}\right)$ $U_r = \frac{2}{\pi} U_0 \arctan\left(\frac{r_0}{t}\right)$
Rod anode, length l, diameter d		$R = \frac{\rho}{2\pi l} \ln \frac{4l}{d}$	$l \gg d$	$U_r = \frac{I\rho}{2\pi l} \ln\left(\frac{l + \sqrt{l^2 + r^2}}{r}\right)$
Horizontal anode, length l, diameter d		$R = \frac{\rho}{\pi l} \ln \frac{2l}{d}$	$l \gg d$	$U_r = \frac{I\rho}{\pi l} \ln\left(\frac{l}{2r} + \sqrt{1 + \left(\frac{l}{2r}\right)}\right) \approx \frac{I\rho}{2\pi r}$ $U_x = \frac{I\rho}{2\pi l} \ln\left(\frac{2x + l}{2x - l}\right) \approx \frac{I\rho}{2\pi x}$ [the approximation holds for $(r, x) \gg 1$]
Sphere, diameter d, depth below surface t		$R = \frac{\rho}{2\pi}\left(\frac{1}{d} + \frac{1}{4t}\right)$	$t \gg d$	$U_r = \frac{I\rho}{2\pi\sqrt{t^2 + r^2}}$

Anode Shape	Anode Arrangement	Grounding Resistance	Remarks	Voltage Cone
Ring-shaped ground, band width b, radius r_0		$R = \frac{\rho}{2\pi^2 r_0} \ln\left(\frac{16 r_0}{d}\right)$	$d = \frac{b}{2}$	$U_r = \frac{I\rho}{\pi^2 (r_0 + r)} F\left(\frac{2\sqrt{r_0 r}}{r_0 + r}\right)^{a}$
Vertical anode, length l, diameter d, depth below surface t		$R = \frac{\rho}{2\pi l} \ln\left(\frac{2l}{d}\sqrt{\frac{4t+3l}{4t+l}}\right)$	$t \gg d$ $d \ll l$	$U_r = \frac{I\rho}{2\pi l} \ln\left(\frac{t + l + \sqrt{r^2 + (t+l)^2}}{t + \sqrt{r^2 + t^2}}\right)$
Vertical anode		$R = \frac{\rho}{2\pi l} \ln\left(\frac{2l}{d}\right)$	$t \gg l$	$U_r = \frac{I\rho}{2\pi l} \ln \frac{\sqrt{t^2 + r^2 + \left(\frac{l}{2}\right)^2} + \frac{l}{2}}{\sqrt{t^2 + r^2 + \left(\frac{l}{2}\right)^2} - \frac{l}{2}}$
Horizontal anode, length l, diameter d, depth below surface t		$R = \frac{\rho}{2\pi l} \ln\left(\frac{l^2}{td}\right)$	$d \ll l$ $t \ll l$	$U_x = \frac{I\rho}{2\pi l} \ln \frac{\sqrt{t^2 + \left(x + \frac{l}{2}\right)^2} + x + \frac{l}{2}}{\sqrt{t^2 + \left(x - \frac{l}{2}\right)^2} + x - \frac{l}{2}}$
Horizontal anode		$R = \frac{\rho}{2\pi l} \ln\left(\frac{2l}{d}\right)$	$t \gg l$	

[a] F is an elliptical integral

Source: W. von Baeckman, W. Schwenk, and W. Prinz, eds., *Cathodic Corrosion Protection*, pp. 538, 539 Gulf Publishing, 2000. Reprinted by permission of Butterworth-Heinemann/Gulf Professional Publishing.

TYPICAL RESISTIVITIES OF SOME WATERS AND SOIL MATERIALS



Source: John H. Morgan, *Cathodic Protection*, 2nd ed., NACE, 1987.

RESISTIVITY OF VARIOUS MINERALS AND SOILS

Minerals and Soils	Resistivity, Ω-cm
Minerals	
Pyrite	0.1
Magnetite	0.6 to 1.0
Graphite	0.03
Rock Salt (impure)	3000 to 500 000
Serpentine	20 000
Sederite	7 000
Igneous Rocks	
Granite	500 000 to 100 000 000
Diorite	1 000 000
Gabbro	10 000 000 to 1 400 000 000
Diabase	310 000
Metamorphic Rocks	
Garnet gneiss	20 000 000
Mica chist	130 000
Biotite gneiss	100 000 000 to 600 000 000
Slate	64 000 to 6 500 000
Sedimentary Rocks	
Chattanooga shale	2000 to 130 000
Michigan shale	200 000
Calumet and hecla conglomerates	200 000 to 1 300 000
Muschelkalk sandstone	7 000
Ferruginous sandstone	18 000
Muschelkalk limestone	18 000
Marl	7 000
Glacial till	50 000
Oil sand	400 to 22 000

Source: Manual 20, p. 326, ASTM, 1995. Reprinted, with permission, copyright of ASTM.

COMPOSITION OF PETROLEUM AND METALLURGICAL COKE BACKFILL

Element	Content %
Petroleum Coke Backfill	
Fixed Carbon	99.77
Ash	0.1
Moisture	0.0
Volatile Matter	0.0
Metallurgical Grade	
Fixed Carbon	85.89
Ash	8–10
Moisture	6–9
Sulfur	0.8
Volatile Matter	0.5

Source: A. W. Peabody and R. L. Bianchetti, eds., *Peabody's Control of Pipeline Corrosion*, 2nd ed., p. 174, NACE, 2001.

WEIGHTS OF CARBONACEOUS BACKFILL

Material	Lb/Ft^3
Coal coke breeze.....	40 to 50
Calcined petroleum coke breeze....	45 to 70
Natural graphite particle.....	70 to 80
Crushed man-made graphite.....	70

Source: A. W. Peabody and R. L. Bianchetti, eds., *Peabody's Control of Pipeline Corrosion*, 2nd ed., p. 175, NACE, 2001.

COMPOSITION OF BACKFILL FOR ZINC AND MAGNESIUM ANODES

	Backfill						
	for Mg Anodes				for Zn Anodes		
Specific Soil Resistivity in Ω m	Gypsum	Bentonite	Kieselguhr	Na_2SO_4	Gypsum	Bentonite	Na_2SO_4
Up To 20	65	15	15	5	75	25	–
	75	25	–	–	50	45	5
20–100	70	10	15	5	75	20	5
	75	20	–	5	–	–	–
	50	40	–	10	–	–	–
Above 100	65	10	10	15	–	–	–
	50	25	–	25	–	–	–

Source: W. von Baeckman, W. Schwenk, and W. Prinz, eds., *Cathodic Corrosion Protection*, p. 197, Gulf Publishing, 2000. Reprinted by permission of Butterworth-Heinemann/Gulf Professional Publishing.

PROPERTIES OF CONCENTRIC STRANDED COPPER SINGLE CONDUCTORS

DIRECT BURIAL SERVICE, SUITABLY INSULATED

Size AWG	Overall Diameter Not Including Insulation (Inches)	Approx. Weight Not Including Insulation (lbs./M ft.)	Maximum Breaking Strength (lbs.)	Maximum D.C. Resistance @20°C Ohms/M ft.	Maximum Allowable D.C. Current Capacity (Amperes)
14	0.0726	12.68	130	2.5800	15
12	0.0915	20.16	207	1.6200	20
10	0.1160	32.06	329	1.0200	30
8	0.1460	50.97	525	0.6400	45
6	0.1840	81.05	832	0.4030	65
4	0.2320	128.90	1320	0.2540	85
3	0.2600	162.50	1670	0.2010	100
2	0.2920	204.90	2110	0.1590	115
1	0.3320	258.40	2660	0.1260	130
1/0	0.3730	325.80	3350	0.1000	150
2/0	0.4190	410.90	4230	0.0795	175
3/0	0.4700	518.10	5320	0.0631	200
4/0	0.5280	653.30	6453	0.0500	230
250 MCM	0.5750	771.90	7930	0.0423	255

Data Courtesy Rome Cable Division of ALCOA.

Source: W. T. Bryan. The Duriron Co., Inc.

TEMPERATURE CORRECTION FACTORS FOR RESISTANCE OF COPPER

Temperature		Multiply Resistance at 25°C by:
°C	°F	
−10	14	0.862
−5	23	0.882
0	32	0.901
5	41	0.921
10	50	0.941
15	59	0.961
20	68	0.980
30	86	1.020
35	95	1.040
40	104	1.059

Source: A. W. Peabody and R. L. Bianchetti, eds., *Peabody's Control of Pipeline Corrosion*, 2nd ed., NACE, 2001.

STEEL PIPE RESISTANCE

Pipe Size, Inches	Outside Diameter, Inches	Wall Thickness, Inches	Weight Per Foot, Pounds	Resistance	
				Micro ohms Per Foot	Micro ohms Per Meter
2	2.375	0.154	3.65	79.2	260.
4	4.5	0.237	10.8	26.8	87.9
6	6.625	0.280	19.0	15.2	49.9
8	8.625	0.322	28.6	10.1	33.1
10	10.75	0.365	40.5	7.13	23.4
12	12.75	0.375	49.6	5.82	19.1
14	14.00	0.375	54.6	5.29	17.4
16	16.00	0.375	62.6	4.61	15.1
18	18.00	0.375	70.6	4.09	13.4
20	20.00	0.375	78.6	3.68	12.1
22	22.00	0.375	86.6	3.34	11.0
24	24.00	0.375	94.6	3.06	10.0
26	26.00	0.375	102.6	2.82	9.25
28	28.00	0.375	110.6	2.62	8.60
30	30.00	0.375	118.7	2.44	8.0
32	32.00	0.375	126.6	2.28	7.48
34	34.00	0.375	134.6	2.15	7.05
36	36.00	0.375	142.6	2.03	6.66

Based on steel density of 489 pounds per cubic foot and steel resistivity of 18 microhm-cm.

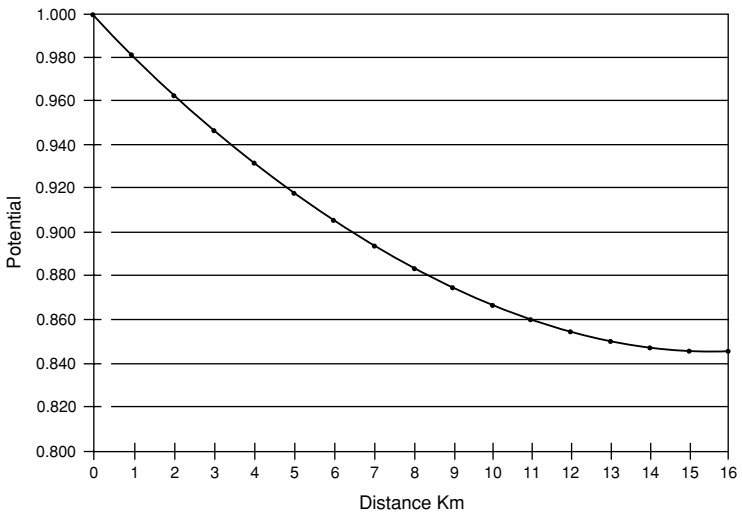
Source: A. W. Peabody and R. L. Bianchetti, eds., *Peabody's Control of Pipeline Corrosion*, 2nd ed., NACE, 2001.

ALLOY PIPE RESISTANCE

Resistance of alloy piping can be estimated using the factor below, which is the ratio of alloy resistivity to that of a typical carbon steel (18 microhm-cm):

304 SS	4.0
316 SS	4.1
410 SS	3.2
400 Alloy	3.1
Al 3003	0.19
OF Copper	0.09

TYPICAL ATTENUATION ON A PIPELINE



Typical attenuation on a pipeline.

Source: R. W. Revie, ed., Uhlig's Corrosion Handbook, 2nd ed., p. 1077, John Wiley & Sons, Inc., © 2000. This Material is used by permission of John Wiley & Sons, Inc.

CORROSION OF STEELS, COPPER, LEAD, AND ZINC IN SOILS

Maximum penetration in mils (1 mil = 0.001 in. = 0.025 mm) for total exposure period. Average corrosion rates in g m^{-2} d^{-1} (gmd).

	Open Hearth Iron		Wrought Iron		Bessemer Steel		Copper		Lead		Zinc	
	12-Year Exposure		12-Year Exposure		12-Year Exposure		8-Year Exposure		12-Year Exposure		11-Year Exposure	
Soil	gmd	mils	gmd	mils	gmd	mils	gmd	mils	gmd	mils	gmd	mils
Average of several soils	0.45 (44 soils)	70	0.47 (44 soils)	59	0.45 (44 soils)	61	0.07 (29 soils)	< 6	0.052 (21 soils)	> 32	0.3 (12 soils)	> 53
Tidal marsh, Elizabeth, New Jersey	1.08	90	1.16	80	1.95	100	0.53	< 6	0.02	13	0.19	36
Montezuma clay Adobe, San Diego, California	1.37	> 145	1.34	> 132	1.43	> 137	0.07	< 6	0.06 (9.6 years)	10	–	–
Merrimac gravelly sandy loam, Norwood, Massachusetts	0.09	28	0.10	23	0.10	21	0.02 (13.2 years)	< 6	0.013	19	–	–

Source: M. Romanoff, *Underground Corrosion*, NIST, 1957.

EFFECT OF CHLORIDES, SULFATES, AND pH ON CORROSION OF BURIED STEEL PIPELINES

Concentration (ppm)	Degree of Corrosivity
Chloride[1]	
> 5,000	Severe
1,500–5,000	Considerable
500–1,500	Corrosive
< 500	Threshold
Sulfate[1]	
> 10,000	Severe
1,500–10,000	Considerable
150–1,500	Positive
0-150	Negligible
pH[2]	
< 5.5	Severe
5.5–6.5	Moderate
6.5–7.5	Neutral
> 7.5	None (alkaline)

[1] Source: ACI-318 Building Code.
[2] Source: M. Romanoff, *Underground Corrosion,* NIST, 1957.

EFFECTS OF ENVIRONMENTAL FACTORS ON CORROSION OF STEEL IN SOILS[a]

Environmental Factor	Overall Corrosion Rate (mm/year)			Maximum Pitting Rate (mm/year)		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Resistivity (Ω·cm)						
< 1000	0.063	0.018	0.033	0.31	0.11	0.20
1000–5000	0.058	0.006	0.017	> 0.45[b]	0.05	0.14
5000–12000	0.033	0.005	0.018	0.23	0.06	0.14
> 12000	0.036	0.003	0.014	0.26	0.03	0.11
Drainage						
Very poor	0.058	0.038	0.046	> 0.45[b]	0.16	0.28
Poor	0.037	0.010	0.024	0.23	0.05	0.14
Fair	0.063	0.018	0.022	0.31	0.08	0.16
Good	0.022	0.003	0.010	0.18	0.03	0.11
Air-pore space (%)						
< 5	0.033	0.010	0.021	0.20	0.05	0.13
5–10	0.063	0.009	0.024	0.31	0.10	0.17
10-20	0.037	0.006	0.017	0.26	0.05	0.15
20-30	0.058	0.012	0.025	> 0.45[b]	0.10	0.20
> 30	0.038	0.004	0.013	0.23	0.03	0.09

[a] Original data are based on NBS field tests on open-hearth steel for 12 years at 44 locations in the United States.
[b] Perforated.

Source: M. Romanoff, *Underground Corrosion*, NIST, 1957.

CORROSION RATES OF ZINC COATING ON STEEL IN SOILS AT VARIOUS LOCATIONS

No.[a,b]	Soil Type	ρ(Ω-cm)	pH	*R* (μm/year)
1	Allis silt loam—Cleveland, OH	1,215	7.0	11.8
2	Bell clay—Dallas, TX	684	7.3	1.5
3	Cecil clay loam—Atlanta, GA	30,000	5.2	1.7
4	Chester loam—Jenkintown, PA	6,670	5.6	7.9
5	Dublin clay adobe—Oakland, CA	1,345	7.0	7.7
6	Everett gravelly sandy loam—Seattle, WA	45,100	5.9	0.5
7	Maddox silt loam—Cincinnati, OH	2,120	4.4	10.8
8	Fargo clay loam—Fargo, ND	350	7.6	3.2
9	Genesee silt loam—Sidney, OH	2,820	6.8	5.0
10	Gloucester sandy loam—Middleboro, MA	7,460	6.6	5.2
11	Hagerstown loam—Loch Raven, MD	11,000	5.3	3.7
12	Hanford fine sandy loam—Los Angeles, CA	3,190	7.1	2.2[c]
13	Hanford very fine sandy loam—Bakersfield, CA	290	9.5	3.7
14	Hempstead silt loam—St. Paul, MN	3,520	6.2	1.1
15	Houston black clay—San Antonio, TX	489	7.5	1.5
16	Kalmia fine sandy loam—Mobile, AL	8,290	4.4	4.2
17	Keyport loam—Alexandria, VA	5,980	4.5	14.8[d]
19	Lindley silt loam—Des Moines, IA	1,970	4.6	2.9
20	Mahoning silt loam—Cleveland, OH	2,870	7.5	4.9

[a] Average coating thickness, 121 microns.
[b] Original soil identification.
[c] Sheet specimens.
[d] Data includes corrosion of steel.

Source: M. Romanoff, *Underground Corrosion*, NIST 1957.

CORROSION OF GALVANIZED PIPE IN VARIOUS SOILS

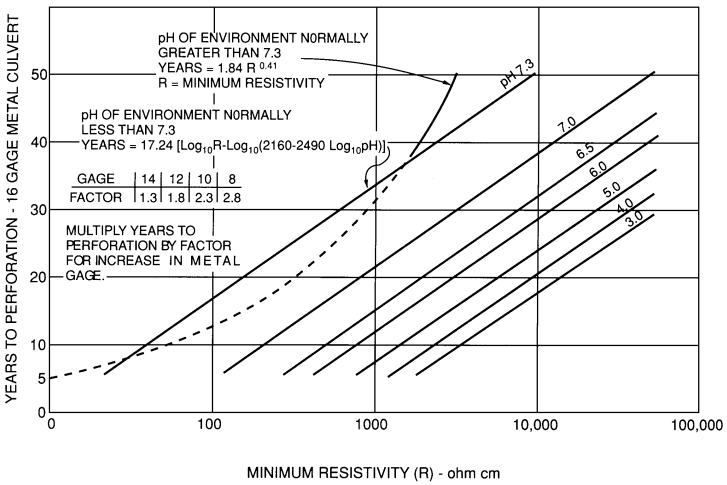
Weight loss (oz/ft^2) and maximum pit depth (mil) after burial period 12.7 years

	oz/ft^2	mil
Inorganic oxidizing acid soils		
Cecil clay loam	0.6	< 6
Hagerstown loam	0.6	< 6
Susquehanna clay	0.8	< 6
Inorganic oxidizing alkaline soils		
Chino silt loam	1.1	< 6
Mohave fine gravelly loam	1.1	< 6
Inorganic reducing acid soils		
Sharkey clay	1.1	6
Acadia clay	–	–
Inorganic reducing alkaline soils		
Docas clay	1.6	< 6
Merced silt loam	1.3	8
Lake Charles clay	13.8	66
Organic reducing acid soils		
Carlisle muck	3.4	< 6
Tidal marsh	4.8	52
Muck	10.7	76
Rifle peat	19.5	88
Cinders	11.9	48

Nominal weight of coating—3 oz/sq ft (915 g/m^2) of exposed area.

Source: *Zinc, Its Corrosion Resistance*, 2nd ed., p. 101, International Lead Zinc Research Organization, 1983. Reprinted by permission of International Lead Zinc Research Organization.

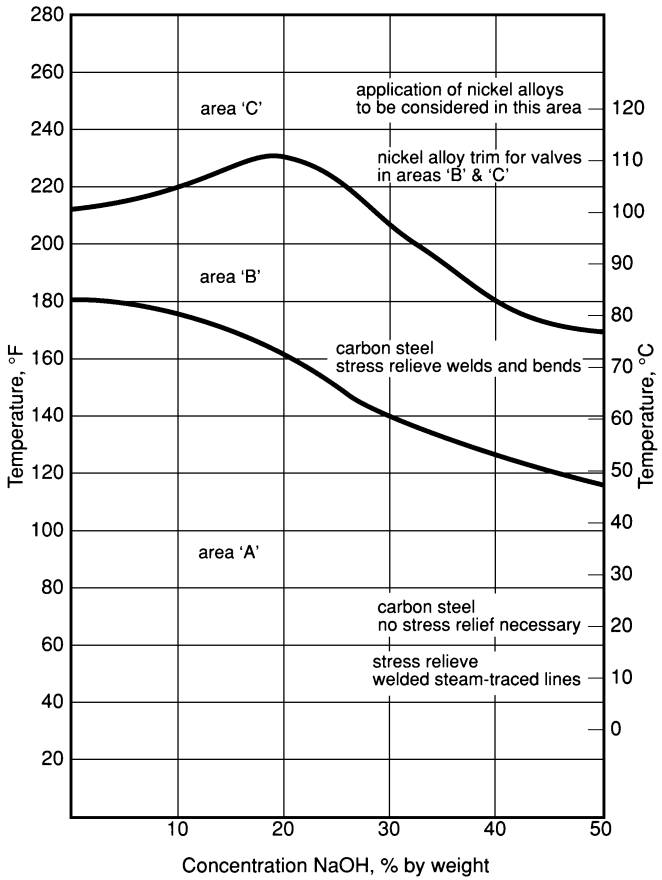
ESTIMATING SERVICE LIFE OF GALVANIZED STEEL IN SOILS



Method developed by the California Division of Highways for estimating services life of galvanized steel culverts, based on correlations involving pH and resistivity of soil. Base case is 16-gage galvanized steel pipe with a zinc coating thickness of 1.6 mm (0.064 in.).

Source: NACE-OSU Corrosion Cource.

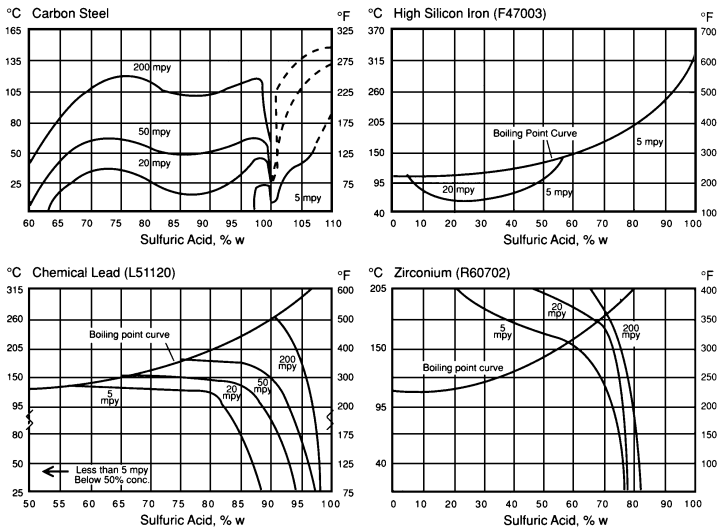
CAUSTIC SODA SERVICE CHART



Source: *Corrosion Data Survey*, NACE, 1985.

ALLOYS FOR SULFURIC ACID SERVICE

Isocorrosion Curves

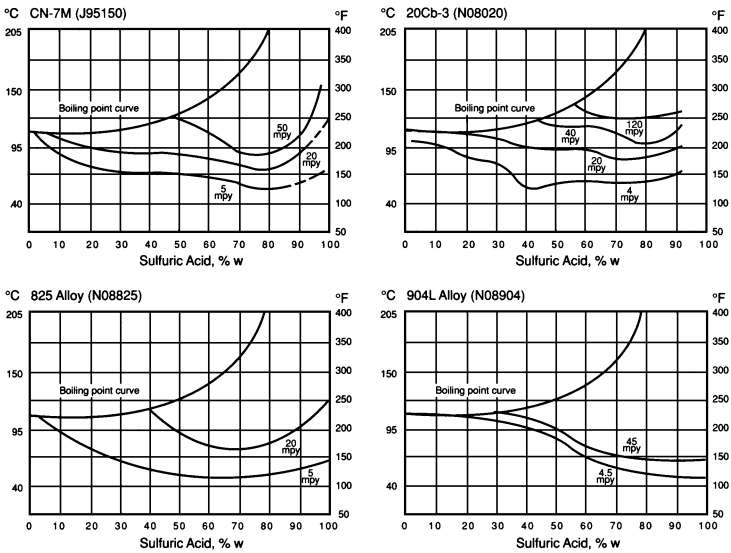


Note: These graphs are based on laboratory tests with pure acid, and should be used for general guidance only. For detailed information see *Process Industries Corrosion—The Theory and Practice* (NACE, 1986).

Sources: Mars G. Fontana, *Corrosion Engineering*, McGraw-Hill, 1986. R. T. Webster and T. L. Yau, *Materials Performance*, Vol. 25, No. 2, p. 15, 1986. [Zirconium]

ALLOYS FOR SULFURIC ACID SERVICE (*Continued*)

Isocorrosion Curves

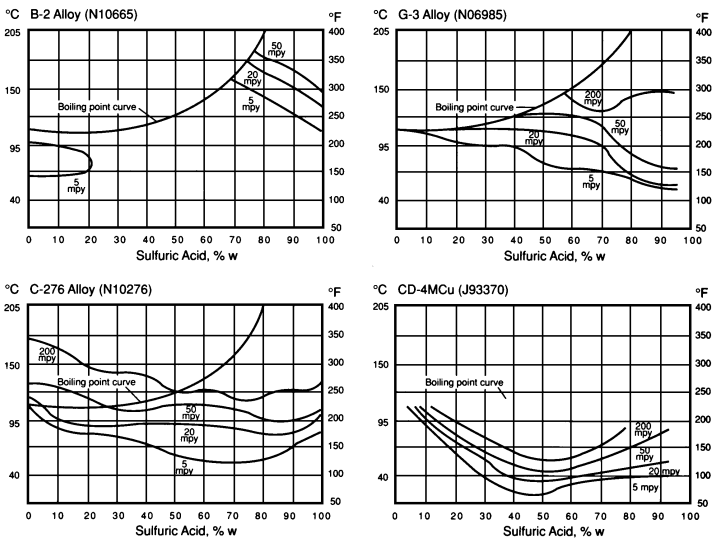


Note: These graphs are based on laboratory tests with pure acid, and should be used for general guidance only. For detailed information see *Process Industries Corrosion—The Theory and Practice* (NACE, 1986).

Source: Corrosion Engineering Bulletin 1, The International Nickel Company, 1983.

ALLOYS FOR SULFURIC ACID SERVICE (*Continued*)

Isocorrosion Curves



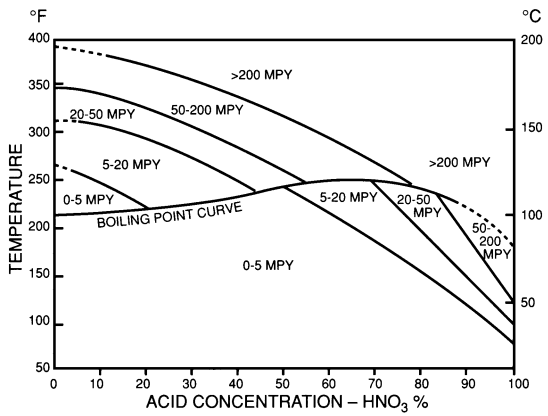
Note: These graphs are based on laboratory tests with pure acid, and should be used for general guidance only. For detailed information see *Process Industries Corrosion—The Theory and Practice* (NACE, 1986).

Sources: Corrosion Engineering Bulletin 1, The International Nickel Company, 1983. Hastelloy Alloy G-3 Booklet, Cabot Corp., 1983.

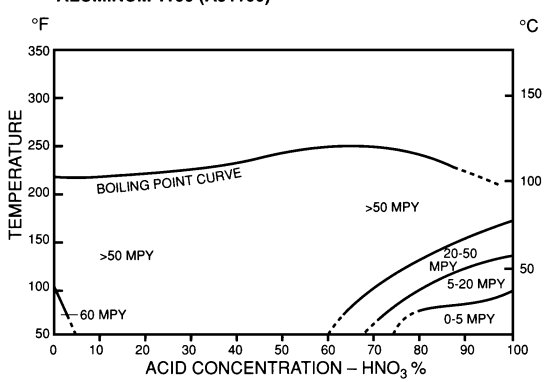
ALLOYS FOR NITRIC ACID SERVICE

Isocorrosion Curves

304 SS (S30400)



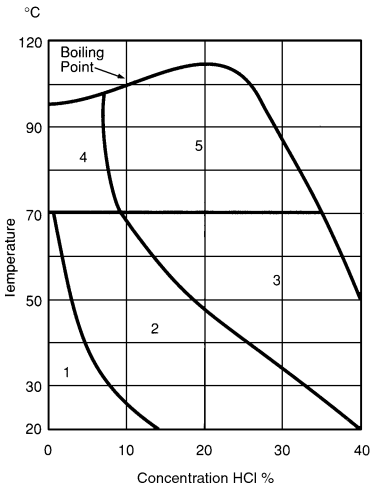
ALUMINUM 1100 (A91100)



Note: These graphs are based on laboratory tests with pure acid, and should be used for general guidance only. For detailed information see *Process Industries Corrosion—The Theory and Practice* (NACE, 1986).

Source: Mars G. Fontana, Corrosion Engineering,McGraw-Hill, 1986.

ALLOYS FOR HYDROCHLORIC ACID SERVICE



Note: These graph should be used for general guidance only. For more detailed information see *Process Industries Corrosion—The Theory and Practice*, NACE, 1986.

Source: *Corrosion Data Survey*, NACE, 1985. Modified by T. F. Degnan.

Materials in numbered zones have reported corrosion rates of <20 mpy

Zone 1

CN-7M	(1) (3) (6)
400 Alloy	(2) (3) (6)
Copper	(2) (3) (6)
Nickel 200	(2) (3) (6)
Silicon Bronze	(2) (3) (6)
Silicon Cast Iron	(7)
Tungsten	
Titanium (Gr. 7)	
Titanium (Gr. 2)	(4)

Zone 2

Silicon Bronze	(2) (6)
Silicon Cast Iron	(7)

Zone 3

Silicon Cast Iron	(7)

Zone 4

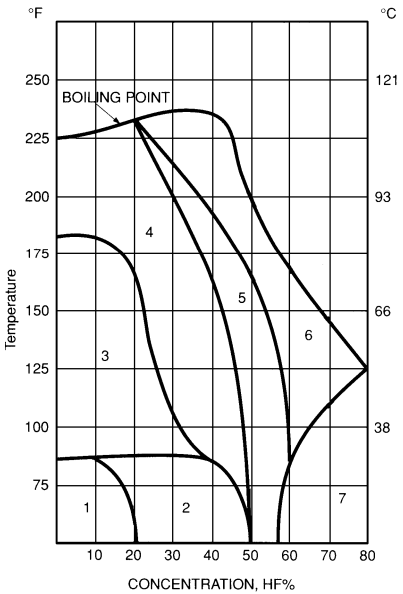
400 Alloy	(2) (3) (8)
Tungsten	
Titanium (Gr.7)	(5)

All Zones (including 5)

Platinum	
Tantalum	
Silver	(3) (6)
Zirconium	(3) (6)
B-2 Alloy	(3) (6)
Molybdenum	(3) (6)

Notes:
1. <2% at 25°C
2. No Air
3. No $FeCl_3$ or $CuCl_2$
4. <10% at 25°C
5. <5% at B.P.
6. No Chlorine
7. Cr-Mo Alloy
8. <0.05% Concentration

ALLOYS FOR HYDROFLUORIC ACID SERVICE



Materials in numbered zones have reported corrosion rates of <20 mpy

Zone 1

CN-7M
310 SS
70-30 Cu-Ni*
400 Alloy*
C Alloy
Copper*
Gold
Lead*
Nickel*
Nickel cast iron
Platinum
Silver

Zone 2

CN-7M
70-30 Cu-Ni*
400 Alloy*
C Alloy
Copper*
Gold
Lead*
Nickel*
Platinum
Silver

Zone 3

CN-7M
70-30 Cu-Ni*
400 Alloy*
C Alloy
Copper*
Gold
Lead*
Platinum
Silver

Zone 4

70-30 Cu-Ni*
400 Alloy*
C Alloy
Copper*
Gold
Lead*
Platinum
Silver

Zone 5

70-30 Cu-Ni*
400 Alloy*
C Alloy
Gold
Lead*
Platinum
Silver

Zone 6

400 Alloy*
C Alloy
Gold
Platinum
Silver

Zone 7

400 Alloy*
C Alloy
Carbon Steel
Gold
Platinum
Silver

*No Air

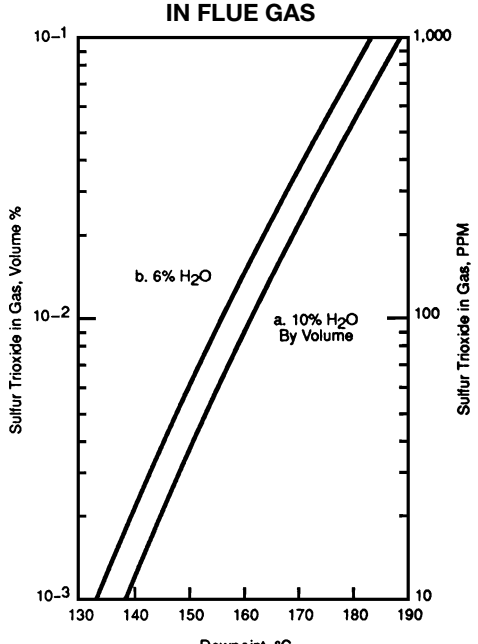
Note: These graph should be used for general guidance only. For more detailed information see *Process Industries Corrosion—The Theory and Practice*, NACE, 1986.

Source: *Corrosion Data Survey*, NACE, 1985.

ESTIMATE OF SULFUR TRIOXIDE IN COMBUSTION GAS

Sulfur in Fual (%)		**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**
Excess Air (%)	*Oxygen in Gas (%)*	*Sulfur Trioxide Expected in Gas (ppm)*					
		Oil Fired Units					
5	1	2	3	3	4	5	6
11	2	6	7	8	10	12	14
17	3	10	13	15	19	22	25
25	4	12	15	18	22	26	30
		Coal Fired Units					
25	4	3–7	7–14	14–28	20–40	27–54	33–66

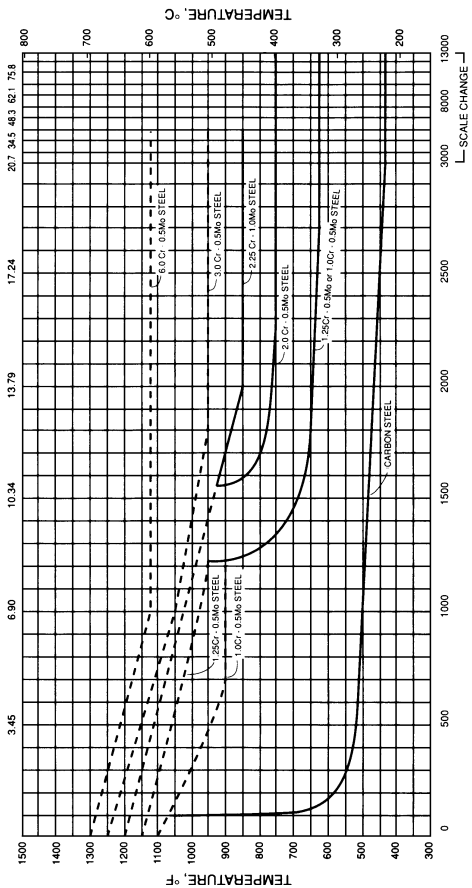
CALCULATED SULFURIC ACID DEWPOINT IN FLUE GAS



Calculated dewpoint vs sulfur trioxide concentration: (a) 10% H_2O from oil; and (b) 6% H_2O from coal.

Source: R. D. Terns and T. E. Mappes, *Materials Performance*, Vol. 21, No. 12, p. 26, 1982.

OPERATING LIMITS FOR STEELS IN HYDROGEN SERVICE TO AVOID DECARBURIZATION AND FISSURING



See current edition of API Publication 941 for detailed comments, including spcial comments regarding 0.5Mo Steel.

Source: Adapted from API Publication 941 (1990).

COMBINATIONS OF ALLOYS AND ENVIRONMENTS SUBJECT TO DEALLOYING

Alloy	Environment	Element Removed
Brasses	Many waters, especially under stagnant conditions	Zinc (dezincification)
Gray iron	Soils, many waters	Iron (graphitic corrosion)
Aluminum bronzes	Hydrofluoric acid, acids containing chloride ions	Aluminum (dealuminification)
Silicon bronzes	High-temperature steam and acidic species	Silicon (desiliconification)
Tin bronzes	Hot brine or steam	Tin (destannification)
Copper-nickel alloys	High heat flux and low water velocity (in refinery condenser tubes)	Nickel (denickelification)
Copper-gold single crystals	Ferric chloride	Copper
Nickel-copper	Hydrofluoric and other acids	Copper in some acids, and nickel in others
Gold alloys with copper or silver	Sulfide solutions, human saliva	Copper, silver
High-nickel alloys	Molten salts	Chromium, iron, molybdenum, and tungsten
Medium- and high-carbon steels	Oxidizing atmospheres, hydrogen at high temperatures	Carbon (decarburization)
Iron-chromium alloys	High-temperature oxidizing atmospheres	Chromium, which forms a protective film
Nickel-molybdenum alloys	Oxygen at high temperature	Molybdenum

Source: Metals Handbook, 9th ed., Vol. 13, p. 130, ASM, 1987. Reprinted by Permission of ASM International, Materials Park, OH 44073-0002.

LIQUID METAL CRACKING

Couples identified below are those combinations of solid metal and liquid metal that have resulted in embrittlement in tests with either the pure element or an alloy. This compilation is a summary of data from the indicated source.

Solid	Liquid
Aluminum	Hg Ga Na In Sn Bi Cd Pb Zn
Bismuth	Hg
Cadmium	Cs Ga Sn
Copper	Hg Ga Na In Li Sn Bi Pb
Germanium	Ga In Sn Bi Tl Cd Pb Sb
Iron	Hg Ga In Li Sn Cd Pb Zn Te Sb Cu
Magnesium	Na Zn
Nickel	Hg Li Sn Pb
Palladium	Li
Silver	Hg Ga Li
Tin	Hg Ga
Titanium	Hg Cd
Zinc	Hg Ga In Sn Pb

Source: *Metals Handbook*, 9th ed., Vol. 13, p. 182, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

STRESS CORROSION CRACKING SYSTEMS

Below is a partial listing of alloy/environment systems where stress corrosion cracking (anodic type) may occur. Whether cracking occurs in a specific system depends on temperature, environment composition, tensile stress level, alloy composition, and heat treatment.

Alloy	Environment
Aluminum alloys	Chloride solutions
Magnesium alloys	Chloride solutions
Copper alloys	Ammonia + oxygen + water Amines + oxygen + water Nitric acid vapor Steam
Carbon and low alloy steels	Nitrate solutions Caustic solutions Carbonate solutions Alkanolamines + carbon dioxide Carbon monoxide − carbon dioxide + water Anhydrous ammonia + air Hydrogen cyanide solutions
Austenitic stainless steels and some ferritic and duplex stainless steels	Chloride and bromide solutions Organic chlorides and bromides + water Caustic solutions H_2S solutions − chlorides or oxidants
Nickel alloys	Caustic solutions Fused caustic Hydrofluoric acid H_2S solutions − chlorides or oxidants
Titanium alloys	Aqueous salt systems Methanol plus halides Nitrogen tetroxide
Zirconium alloys	Aqueous salt systems Nitric acid
Sensitized austenitic stainless steels	Water − oxygen (high temperature) Chloride solutions Polythionic acid solutions Sulfurous acid

HYDROGEN STRESS CRACKING may occur with high strength alloys (carbon and low alloy steels, some stainless steels, and some nickel-base alloys) in a number of environments including:

Hydrogen sulfide solutions (SULFIDE STRESS CRACKING)

See following page for information on hydrogen degradation systems, and for H_2S concentration limit for SSC.

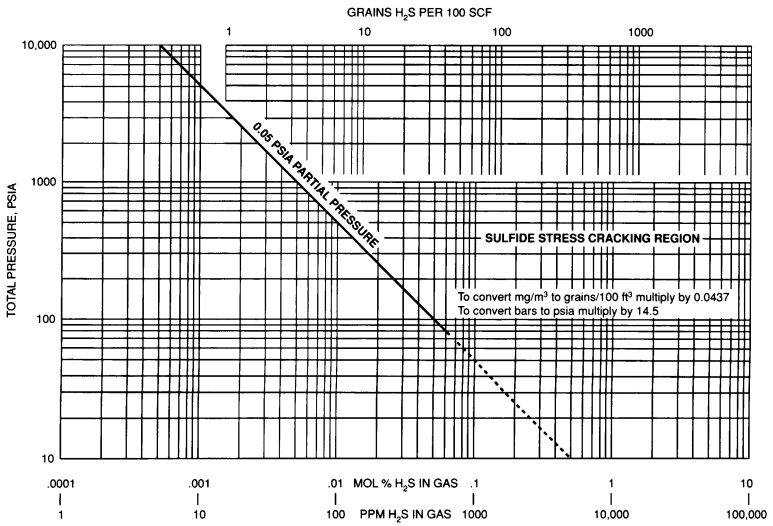
CLASSIFICATIONS OF PROCESSES OF HYDROGEN DEGRADATION OF METALS

	Hydrogen Embrittlement								
	Hydrogen Environment Embrittlement	**Hydrogen Stress Cracking**	**Loss in Tensile Ductility**	**Hydrogen Attack**	**Blistering**	**Shatter Cracks, Flakes, Fisheyes**	**Micro-Perforation**	**Degradation in Flow Properties**	**Metal Hydride Formation**
Typical materials...	Steels, nickel-base alloys, metastable stainless steel, titanium alloys	Carbon and low-alloy steels	Steels nickel-base alloys. Be-Cu bronze, aluminum alloys	Carbon and low-alloy steels	Steels, copper, aluminum	Steels (forgings and castings)	Steels (compressors)	Iron, steels, nickel-base alloys	V, Nb, Ta, Ti, Zr, U,
Usual source of hydrogen (not exclusive)...	Gaseous H_2	Thermal processing, electrolysis, corrosion	Gaseous hydrogen, internal hydrogen from electrochemical charging	Gaseous	Hydrogen sulfide corrosion electrolytic charging, gaseous	Water vapor reacting with molten steel	Gaseous hydrogen	Gaseous or internal hydrogen	Internal hydrogen from melt: corrosion, electrolytic charging, welding
Typical conditions...	10^{-6} to 10^{8} N/m^2 (10^{-10} to 10^{4} psi) gas pressure	0.1 to 10 ppm total hydrogen content	0.1 to 10 ppm total hydrogen content range of gas pressure exposure	Up to 10^{8} N/m^2 (15 ksi) at 200–595°C (400–1100°F)	Hydrogen activity equivalent to 0.2 to 1 $\times$ 10^{8} N/m^2 (3–15 ksi) at 0–150°C (30–300°F)	Precipitation of dissolved ingot cooling	2 to 8 $\times$ 10^{8} N/m^2 (30–125 ksi) at 20–100°C (70–200°F)	1–10 ppm hydrogen content (iron at 20 °C, or 70 °F) up to 10^{8} N/m^2 (15 ksi) gaseous hydrogen (various metals, T > 0.5 melting point)	10^{5} to 10^{8} N/m^2 (15–15 000 psi) gas pressure hydrogen activity must exceed solubility limit near 20 °C (70 °F)

	Hydrogen Embrittlement								
	Hydrogen Environment Embrittlement	Hydrogen Stress Cracking	Loss in Tensile Ductility	Hydrogen Attack	Blistering	Shatter Cracks, Flakes, Fisheyes	Micro-Perforation	Degradation in Flow Properties	Metal Hydride Formation
	Observed at −100 to 700 °C (−150 to 1290 °F); most severe near 20 °C (70 °F)	Observed at −100 to 100 °C (−150 to 212 °F); most severe near 20 °C (70 °F)	Observed at −100 to 700 °C (−150 to 1290 °F)	...	...	...	...	...	...
	Strain rate important; embrittlement more severe at low strain rate; generally more severe in notched or precracked specimens	Strain rate important; embrittlement more severe at low strain rate; always more severe in notched or precracked specimens	Occurs in absence of effect on yield stress; strain rate important	...	...	...	...	...	...
Failure initiation.....	Surface or internal initiation, incubation period not observed	Internal crack initiation ...	Surface and/or internal effect	Surface (decarburization); internal carbide interfaces (methane bubble formation)	Internal defect	Internal defect	Unknown	...	Internal defect
Mechanisms.....	Surface or subsurface processes	Internal diffusion to stress concentration	Surface or subsurface processes	Carbon diffusion (decarburization); hydrogen diffusion; nucleation and growth (bubble formation)	Hydrogen diffusion; nucleation and growth of bubble; steam formation	Hydrogen diffusion to voids	Unknown	Adsorption to dislocations; solid-solutions effects	Hydride precipitation

Source: J. P. Hirth and H. H. Johnson, *Corrosion*, Vol. 32, No. 1, p. 3, 1976.

POTENTIAL SULFIDE STRESS CRACKING REGION AS DEFINED BY THE 0.05 PSIA CRITERION



Source: NACE MRO175-2000.

MAXIMUM TEMPERATURE FOR CONTINUOUS SERVICE IN DRY HYDROGEN CHLORIDE AND DRY CHLORINE

Material	Hydrogen Chloride, °C	Hydrogen Chloride, °F	Chlorine °C	Chlorine °F
Platinum	1200	2200	260	500
Gold	870	1600	150	300
Nickel	510	950	540	1000
Ni-Cr alloy 600	480	900	540	1000
Ni-Mo alloy B	450	850	540	1000
Ni-Mo-Cr alloy C	450	850	540	950
Carbon steel	260	500	200	400
Ni-Cu alloy 400	230	450	430	800
Silver	230	450	65	150
Cast iron	200	400	180	350
304SS	400	750	310	600
316SS	400	750	340	650
Copper	93	200	200	400

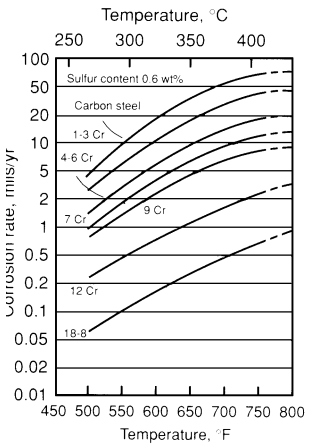
Source: Reprinted by permission of *Industrial Engineering Chemistry*, Vol. 39, p. 839, 1947. Copyright 1947, American Chemical Society.

MAXIMUM SERVICE TEMPERATURES IN AIR FOR STAINLESS STEELS AND ALLOY STEELS

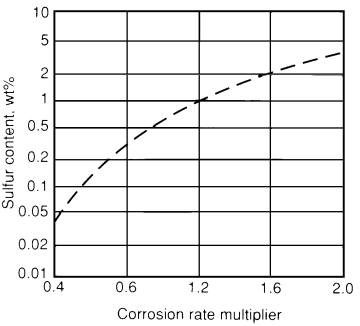
		Maximum Service Temperature			
		Intermittent Service		Continuous Service	
UNS	Common Name	°C	°F	°C	°F
S20100	201	815	1500	845	1550
S20200	202	815	1500	845	1550
S30100	301	840	1545	900	1650
S30200	302	870	1600	925	1700
S30400	304	870	1600	925	1700
S30800	308	925	1700	980	1795
S30900	309	980	1795	1095	2000
S31000	310	1035	1895	1150	2100
S31600	316	870	1600	925	1700
S31700	317	870	1600	925	1700
S32100	321	870	1600	925	1700
S33000	330	1035	1895	1150	2100
S34700	347	870	1600	925	1700
S40500	405	815	1500	705	1300
S43000	430	870	1600	815	1500
S44200	442	1035	1895	980	1795
S44600	446	1175	2145	1095	2000
S41000	410	815	1500	705	1300
S41600	416	760	1400	675	1250
S42000	420	735	1355	620	1150
S44000	440	815	1500	760	1400
	Carbon Steel	–	–	565	1050
K11522	1/2Mo Steel	–	–	565	1050
K11597	1Cr 1/2Mo Steel	–	–	595	1100
K21590	2-1/4Cr 1Mo Steel	–	–	620	1150
K41545	5Cr 1/2Mo Steel	–	–	650	1200
S50400	9Cr 1Mo Steel	–	–	705	1300

Source: Adapted from Metals Handbook, 9th ed., Vol. 13, p. 565, ASM, 1987.

HIGH-TEMPERATURE SULFIDIC CORROSION OF STEELS AND STAINLESS STEELS



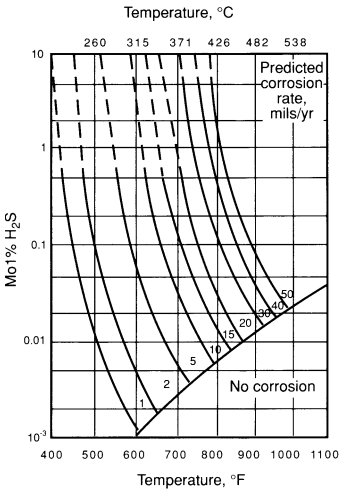
Modified McConomy curves showing the effect of temperature on high-temperature sulfidic corrosion of various steels and stainless steels.



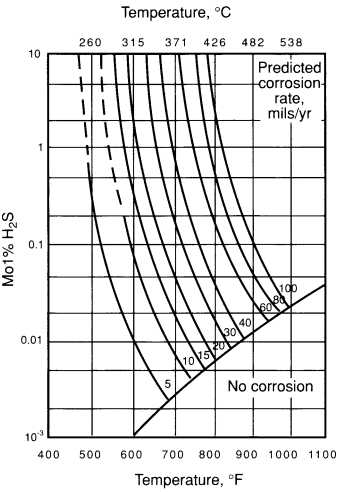
Effect of sulfur content on corrosion rates predicted by modified McConomy curves in 290 to 400°C (550 to 750°F) temperature range.

Source: J. Gutzeit, *Process Industries Corrosion—The Theory and the Practice*, NACE, 1986.

HIGH-TEMPERATURE H_2S/H_2 CORROSION OF 5Cr-0.5Mo STEEL



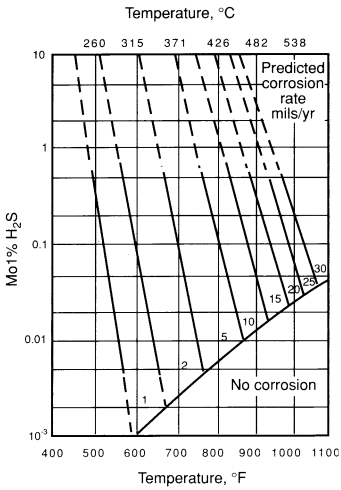
Effect of temperature and hydrogen sulfide content on high temperature H_2S/H_2 corrosion of 5Cr-0.5Mo steel (naphtha desulfurizers). 1 mil/yr = 0.025 mm/yr.



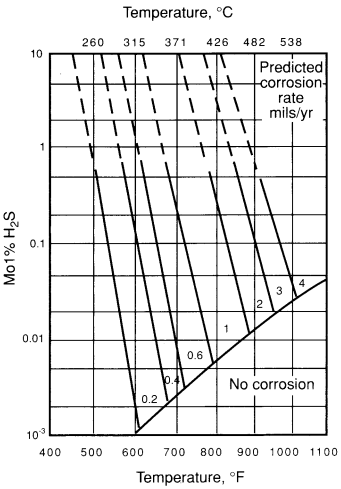
Effect of temperature and hydrogen sulfide content on high- temperature H_2S/H_2 corrosion of 5Cr-0.5Mo steel (gas oil desulfurizers). 1 mil/yr = 0.025 mm/yr.

Source: J. Gutzeit, *Process Industries Corrosion—The Theory and the Practice*, NACE, 1986.

HIGH-TEMPERATURE H_2S/H_2 CORROSION OF STAINLESS STEELS



Effect of temperature and hydrogen sulfide conter on high-temperature H_2S/H_2 corrosion of 12% Cr stainless steel. 1 mil/yr = 0.025 mm/yr.



Effect of temperature and hydrogen sulfide content on high-temperature H_2S/H_2 corrosion of 18Cr-8Ni austenitic stainless steel. 1 mil/yr = 0.025 mm/yr.

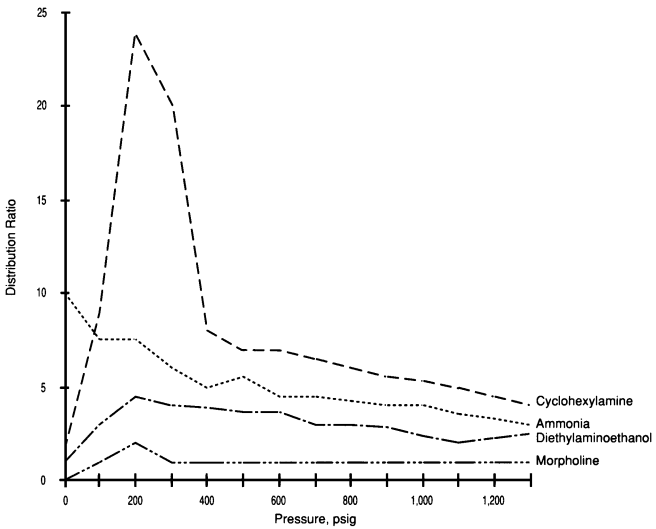
Source: J. Gutzeit, *Process Industries Corrosion—The Theory and the Practice*, NACE, 1986.

ASH FUSION TEMPERATURE OF SLAG-FORMING COMPOUNDS

Chemical Compound	Chemical Formula	Ash Fusion Temperature °C	Ash Fusion Temperature °F
Vanadium pentoxide	V_2O_5	690	1274
Sodium sulfate	Na_2SO_4	890	1630
Nickel sulfate	$NiSO_4$	840	1545
Sodium metavanadate	$Na_2O{\cdot}V_2O_5$	630	1165
Sodium pyrovanadate	$2Na_2O{\cdot}V_2O_5$	655	1210
Sodium orthovanadate	$3Na_2O{\cdot}V_2O_5$	865	1590
Nickel orthovanadate	$3NiO{\cdot}V_2O_5$	900	1650
Sodium vanadyl vanadate	$Na_2O{\cdot}V_2O_4{\cdot}5V_2O_5$	625	1155
Sodium iron trisulfate	$2Na_3Fe[SO_4]_3$	620	1150

Source: *Metals Handbook*, 9th ed., Vol. 13, p. 1273, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

DISTRIBUTION RATIO OF AMMONIA AND AMINES IN STEAM AND STEAM CONDENSATE



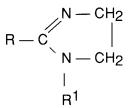
$$\text{Distribution Ratio} = \frac{\text{Concentration of amine in steam}}{\text{Concentration of amine in liquid}}$$

Source: *Oil and Gas Journal*, Nov. 9, 1987, p. 66. Reprinted by permission of *Oil and Gas Journal*.

OIL FIELD CORROSION INHIBITORS – CATIONIC MOLECULAR STRUCTURES

The letter R denotes fatty acids derived from such oils as soya, coconut, tallow, and tall oil.

Imidazolines



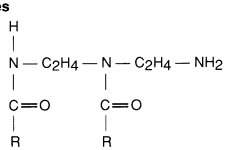
Primary Amine

$$R - NH_2$$

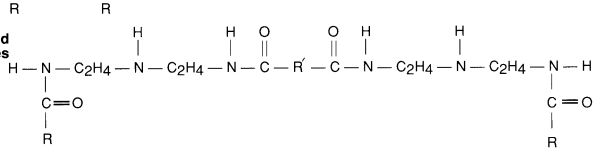
Diamines

$$R - NH - C_3H_6 - NH_2$$

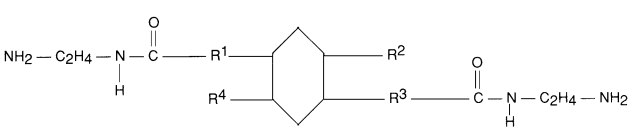
Amido-amines



Dimerized amido-amines



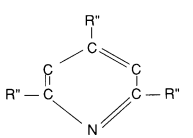
Dimer acid amido-amines



Oxyethylated primary amines

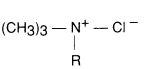
$$R - N - [(C_2H_4O)n - H]_2$$

Alkyl pyridine



R" may be CH_3 to C_3H_7 or higher

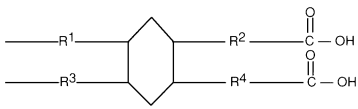
Quaternized amines



Source: *Metals Handbook*, 9th ed., Vol. 13, p. 479, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

OIL FIELD CORROSION INHIBITORS – ANIONIC MOLECULAR STRUCTURES

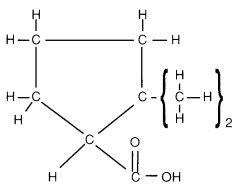
Dimer-trimer acids (C_{18} average)



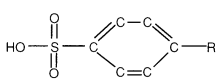
Fatty acids



Naphthenic acids



Dodecyl benzene sulfonic acid

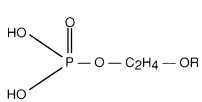


R= C_{12} branched or straight chained

Petroleum Oxidates

Petroleum-derived oxidates (from petrolatum, parrafin wax, lubricating oil, or fuel distillate) are complex mixtures composed primarily of organic acids and esters, but also contain alcohols, ketones, hydroxy and keto acids, estolides, lactides, and lactones.

Phosphate Esters of Ethoxylated alcohol



R= C_{10} to C_{16} (average C_{12})

Other Organic Acids

1. Acetic
2. Hydroxyacetic
3. Benzoic

Source: *Metals Handbook*, 9th ed., Vol. 13, p. 480, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

DESIGN DETAILS TO MINIMIZE CORROSION

On the opposite page are examples of how design and assembly can affect localized corrosion by creating crevices and traps where corrosive liquids can accumulate.

(a) Storage containers or vessels should allow complete drainage; otherwise, corrosive species can concentrate in bottom of vessel, and debris may accumulate if the vessel is open to the atmosphere.

(b) Structural members should be designed to avoid retention of liquids; L-shaped sections should be used with the open side down, and exposed seams should be avoided.

(c) Incorrect trimming or poor design of seals and gaskets can create crevice sites.

(d) Drain valves should be designed with sloping bottoms to avoid pitting of the base of the valve.

(e) Nonhorizontal tubing can leave pools of liquid at shutdown.

(f) to (i) Examples of poor assembly that can lead to premature corrosion problems.

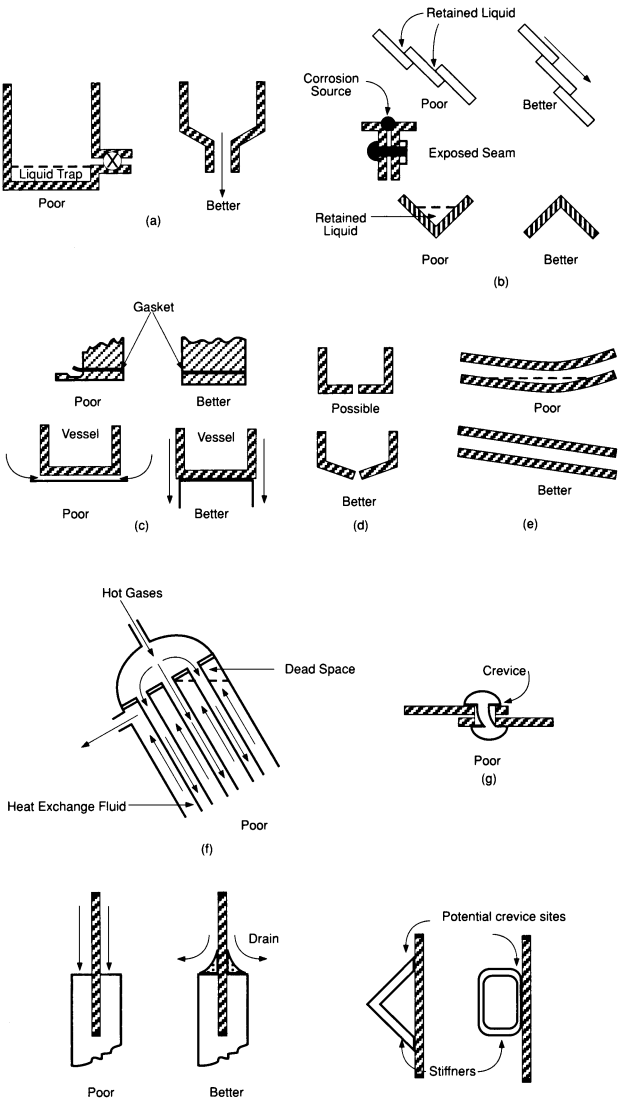
(f) Nonvertical assembly of heat exchanger permits a dead space that may result in overheating if very hot gases are involved.

(g) Nonaligned assembly distorts the fastener, which creates a crevice and may result in a loose fitting that can contribute to vibration, fretting, and wear.

(h) Structural supports should allow good drainage; use of a slope at the bottom of the member allows liquid to run off, rather than impinging directly on the concrete support.

(i) Continuous welding is necessary for horizontal stiffeners to prevent the formation of traps and crevices.

Source: *Metals Handbook*, 9th ed., Vol. 13, p. 339, ASM, 1987. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.


Liquid Trap
Poor
Better
(a)
Retained Liquid
Corrosion Source
Poor
Better
Exposed Seam
Retained Liquid
Poor
Better
(b)
Gasket
Poor
Better
Possible
Poor
Better
Vessel
Vessel
Poor
Better
(c)
(d)
(e)
Hot Gases
Dead Space
Heat Exchange Fluid
Poor
(f)
Crevice
Poor
(g)
Drain
Poor
Better
(h)
Potential crevice sites
Stiffners
(i)

COMMON TYPES OF SCALE-FORMING MINERALS

Scale	X-ray Analysis
Acmite - Sodium Iron Silicate	$NaFe(SiO_3)_2$
Barite - Barium Sulfate	$BaSO_4$
Anaicite - Sodium Aluminum Silicate	$NaAlSi_2O_5 \cdot H_2O$
Aragonite - (Rhombic Crystals)	$CaCO_3$
Calcium Carbonate - (Hexagonal Crystal)	$CaCO_3$
Calcium Sulfate - Anhydrite	$CaSO_4$
Hydromagnesite - Magnesium Carbonate and Hydroxide	$3MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O$
Hydroxyapatite - Calcium Phosphate	$Ca_{10}(OH)_2(PO_4)_6$
Iron Oxide	Alpha FeO (OH)
Iron Oxide - Magnetite	Fe_3O_4
Iron Oxide - Red	Fe_2O_3
Iron Chrome Spinels	$CrFe_2O_4$
Iron Sulfide - Troilite, Pyrrhotite	FeS
Magnesium Hydroxide - Bricite	$Mg(OH)_2$
Magnesium Oxide - Magnesia	MgO
Manganese Dioxide - Pyrolusite	MnO_2
Montmorillonite - Aluminum Silicate	$Al_2O_3 \cdot 4SiO_2 \cdot 4H_2O$
Noselite - Sodium Aluminum Silicate	$Na_8Al_6Si_6O_{24} \cdot SO_4$
Organic Deposits	
Pectolite - Calcium Sodium Silicate	$4CaO \cdot Na_2O \cdot 6SiO_2 \cdot H_2O$
Serpentine - Magnesium Silicate	$Mg_3Si_2O_7 \cdot 2H_2O$
Silica - Quartz	SiO_2
Sodalite - Sodium Aluminum Silicate	$Na_8Al_6Si_6O_{24} \cdot Cl_2$
Vermiculite - Magnesium Iron Aluminum Silicate	$(Mg \cdot Fe)_3(Si \cdot Al)_4O_{10}(OH)_2 \cdot 4H_2O$
Xonolite - Calcium Silicate	$5CaO \cdot 5SiO_2 \cdot H_2O$
The compounds listed below are usually found in industrial equipment which contains copper, brass, or bronze:	
Copper Iron Sulfide	CuFeS
Copper Sulfide - Covellite, Chalcocite	CuS and Cu_2S
Basic Copper Chloride	$CuCl_2 \cdot 3Cu(OH)_2$
Copper Oxide - Cuprite	Cu_2O
Chalcopyrite	$CuFeS_2$
Beta Zinc Sulfide - Sphalerite	ZnS
Green Basic Carbonate - Malachite	$CuCO_3Cu(OH)_2$

Source: Corrosion Testing of Chemical Cleaning Solvents Publication 3M182, NACE, 1982.

CHEMICAL CLEANING SOLUTIONS FOR SPECIFIC SCALES

Scale Component	Solvent*	Testing Conditions
Iron Oxide	5 to 15% HCl	150–175 F (66–80 C)
Fe_3O_4 magnetite or mill scale	2% Hydroxyacetic/1 Formic	180–220 F (82–104 C) circulating
	Monoammoniated Citric Acid	180–220 F (82–104 C) circulating
Fe_2O_3 red iron oxide or red rust	Ammonium EDTA	170–300 F (77–149 C) circulating
	EDTA organic acid mixtures	100–150 F (38–66 C) circulating
Copper	Copper complexor in HCl	150 F (66 C)
Copper Oxides	Ammoniacal Bromate	120–180 F (50–82 C)
	Monoammonlated Citric Acid	140–180 F (60–82), pH 9 to 11
	Ammonium Persulfate	below 100 F (38 C)
	Ammonium EDTA	150–180 F (66–82 C), pH 9 to 11
Calcium Carbonate $CaCO_3$	5 to 15% HCl	Preferable not above 150 F (66 C)
	7 to 10% Sulfamic Acid	Do not exceed 140 F (60 C)
	Sodium EDTA	Circulate at 150–300 F (66–149 C)
Calcium Sulfate $CaSO_4$	Sodium EDTA	Circulate at 150–300 F (66–149 C)
	1% NaOH · 5% HCl	Circulate at 120–150 F (49–66 C)
	EDTA organic acid mixtures	100–150 F (38–66 C) circulating
Hydroxyapatite or Phosphate Compounds $Ca_{10}(OH)_2\ (PO_4)_6$	5 to 10% HCl	Preferable not above 150 P (C6) C)
	Sodium EDTA	Undesirable to add Flouride
		Circulate 150–300 F (66–149 c)
	Sulfamic Acid 7 to 10%	Do not exceed 140 F (60 C)
Silicate Compounds Ex: Acmite, $NaFe(SiO_3)_2$ Analcite, $NaAlSi_2O_5 \cdot H_2O$	Prolonged treatment with 0·5 to 1% soda ash at 50 psi (345 kPa), follow with HCl containing fluoride	Alkaline preboil at 50 to 100 psi (345 to 690 kPa) for 12 to 16 hours
Pectolite, $4Ca \cdot Na_2O \cdot 6SiO_2 \cdot H_2O$ Serpentine, $Mg_3Si_2O_2 \cdot 2H_2O$	HCl containing Ammonium Bifluoride	150–175 F (66–80 C)
Sulfides, ferrous Trolite, FeS Pyrrhotite, FeS	HCl, inhibited	Heat slowly to avoid sudden release of toxic H_2S gas
Disulfides FeS_2, marcasite FeS_2 pyrite	Chromic Acid, CrO_3 followed by HCl	Boiling 7 to 10% ◦ chromic acid followed by HCl inhibited
Organic residues Organo · lignins Algae Some polymeric residues	Potassium Permanganate ($KMnO_4$) followed by HCl containing Oxalic Acid	Circulate at 212 F (100 C) a 1 to 2% $KMnO_4$ · solution. Oxalic acid added to HCl controls release of toxic chlorine gas

*The chemicals are to be considered possible solvents only. There are many alternative solvents for each deposit listed.

Source: Corrosion Testing of Chemical Cleaning Solvents Publication 3M182, NACE, 1982.

COMPONENTS OF BOILER DEPOSITS

Mineral	Formula	Nature of Deposit	Usual Location and Form
Acmite	$Na_2O{\cdot}Fe_2O_3{\cdot}4SiO_2$	Hard, adherent	Tube scale under hydroxyapatite or serpentine
Alpha quartz	SiO_2	Hard, adherent	Turbine blades, mud drum, tube scale
Amphibole	$MgO{\cdot}SiO_2$	Adherent binder	Tube scale and sludge
Analcite	$Na_2O{\cdot}Al_2O_3{\cdot}4SiO_2{\cdot}2H_2O$	Hard, adherent	Tube scale under hydroxyabatite or serpentine
Anhydrite	$CaSO_4$	Hard, adherent	Tube scale, generating tubes
Aragonite	$CaCO_3$	Hard, adherent	Tube scale, feed lines, sludge
Brucite	$Mg(OH)_2$	Flocculent	Sludge in mud drum and water wall headers
Copper	Cu	Electroplated layer	Boiler tubes and turbine blades
Cuprite	Cu_2O	Adherent layer	Turbine blades, boiler deposits
Gypsum	$CaSO_4{\cdot}2H_2O$	Hard, adherent	Tube scale, generating tubes
Hematite	Fe_2O_3	Binder	Throughout boiler
Hydroxyapatite	$Ca_{10}(PO_4)_5(OH)_2$	Flocculent	Mud drum, water walls, sludge
Magnesium phosphate	$Mg_3(PO_4)_2$	Adherent binder	Tubes, mud drum, water walls
Magnetites	Fe_2O_4	Protective film	All internal surfaces
Noselite	$4Na_2O{\cdot}3Al_2O_3{\cdot}6SiO_2{\cdot}SO_4$	Hard, adherent	Tube scale
Pectolite	$Na_2O{\cdot}4CaO{\cdot}6SiO_2{\cdot}H_2O$	Hard, adherent	Tube scale
Serpentine	$3MgO{\cdot}2SiO_2{\cdot}H_2O$	Flocculent	Sludge
Sodalite	$3Na_2O{\cdot}3Al_2O_2{\cdot}6SiO_2{\cdot}2NaCl$	Hard, adherent	Tube scale
Xonotlite	$5CaO{\cdot}5SiO_2{\cdot}H_2O$	Hard, adherent	Tube scale

Source: J. W. McCoy, *Industrial Chemical Cleaning*, Chemical Publishing Co., New York, 1984. Reprinted by permission of Chemical Publishing Company.

NONDESTRUCTIVE METHODS FOR EVALUATING MATERIALS

Method	Measures or Defects	Applications	Advantages	Limitations
Acoustic emission	Crack initiation and growth rate Internal cracking in welds during cooling Boiling or cavitation Friction or wear Plastic deformation Phase transformations	Pressure vessels Stressed structures Turbine or gear boxes Fracture mechanics research Weldments Sonic signature analysis	Remote and continuous surveillance Permanent record Dynamic (rather than static) detection of cracks Portable Triangulation techniques to locate flaws	Transducers must be placed on part surface Highly ductile materials yield low amplitude emissions Part must be stressed or operating Test system noise needs to be filtered out
Acoustic-impact (tapping)	Debonded areas or delaminations in metal or nonmetal composites or laminates Cracks in turbine wheels or turbine blades Loose rivets or fasteners Crushed core	Brazed or adhesive-bonded structures Bolted or riveted assemblies Turbine blades Turbine wheels Composite structures Honeycomb assemblies	Portable Easy to operate May be automated Permanent record or positive meter readout No couplant required	Part geometry and mass influences test results impactor and probe must be repositioned to fit geometry of part Reference standards required Pulser impact rate is critical for repeatability
Barkhausen noise analysis	Residual stresses in ferromagnetic steels	Jet engine components such as compressor blades, discs, diffuser cases	Nondestructive stress analysis Permanent record Fully automatic	Expensive Requires reference standard Need trained operator Not yet a production tool
Eddy current (100 Hz to 10 kHz)	Subsurface cracks around fastener holes in aircraft structure	Aluminum and titanium structure	Detect subsurface cracks not detectable by radiography	Part geometry Will not detect short cracks
Eddy current (10 kHz to 6 MHz)	Surface and subsurface cracks and seams Alloy content Heat treatment variations Wall thickness, coating thickness Crack depth Conductivity Permeability	Tubing Wire Ball bearings “Spot checks” on all types of surfaces Proximity gage Metal detector Metal sorting Measure conductivity in % IACS	No special operator skills required High speed, low cost Automation possible for symmetrical parts Permanent record capability for symmetrical parts No couplant or probe contact required	Conductive materials Shallow depth or penetration (thin walls only) Masked or false indications caused by sensitivity to variations, such as part geometry, lift-off Reference standards required Permeability variations
Eddy-sonic	Debonded areas in metal-core or metal-faced honey-comb structures Delaminations in metal laminates or composites Crushed core	Metal-core honey-comb Metal-faced honey-comb Conductive laminates such as boron or graphite fiber composites Bonded metal panels	Portable Simple to operate No couplant required May be automated	Specimen or part must contain conductive materials to establish eddy-current field Reference standards required Part geometry

(*Continued*)

NONDESTRUCTIVE METHODS FOR EVALUATING MATERIALS (*Continued*)

Method	Measures or Defects	Applications	Advantages	Limitations
Electric current (direct current conduction method)	Cracks Crack depth Resistivity Wall thickness Corrosion-induced wall-thinning	Metallic materials Electrically conductive materials Train rails Nuclear fuel elements Bars, plates,other shapes	Access to only one surface required Battery or dc source Portable	Edge effect Surface contamination Good surface contact required Difficult to automate Electrode spacing Reference standards required
Electrified particle	Surface defects in nonconducting material Through-to-metal pinholes on metal-backed material Tension, compression, cyclic cracks Brittle-coating stress cracks	Glass Porcelain enamel Nonhomogeneous materials such as plastic or asphalt coatings Glass-to-metal seals	Portable Useful on materials not practical for penetrant inspection	Poor resolution on thin coatings False indications from moisture streaks or lint Atmospheric conditions High voltage discharge
Exo-electron emission	Fatigue in metals	Metals	Access to only one surface required Permanent record Quantitative	No surface films or contamination Geometry limitations Skilled technician required
Filtered particle	Cracks Porosity Differential absorption	Porous materials such as clay, carbon, powedered metals, concrete Grinding wheels High-tension insulators Sanitary ware	Colored or fluorescent particles Leaves no residue after baking part over 400 F Quickly and easily applied Portable	Size and shape of particles must be selected before use Penetrating power of suspension medium is critical Particle concentration must be controlled Skin irritation
Fluoroscopy (Cinefluorography) (Kinefluorography)	Level of fill in containers Foreign objects Internal components Density variations Voids, thickness Spacing or position	Particles in liquid flow Presence of cavitation Operation of valves and switches Burning in small solid-propellant rocket motors	High-brightness images Real-time viewing Image magnification Permanent record Moving subject can be observed	Costly equipment Geometric unsharpness thick specimens Speed of event to be studied Viewing area
Holography (acoustical-liquid surface levitation)	Lack of bond Delaminations Voids Porosity Resin-rich or resin-starved areas Inclusions Density variations	Metals Plastics Composites Laminates Honeycomb structures Ceramics Biological specimens	No hologram film development required Real-time imaging provided Liquid-surface responds rapidly to ultrasonic energy	Through-transmission techniques only Object and reference beams must superimpose on special liquid surface Immersion test only Laser required

(*Continued*)

NONDESTRUCTIVE METHODS FOR EVALUATING MATERIALS (*Continued*)

Method	Measures or Defects	Applications	Advantages	Limitations
Holography interfero-metry)	Strain Plastic deformation Cracks Debonded areas Voids and inclusions Vibration	Bonded and composite structures Automotive or aircraft tires Three-dimensional imaging	Surface of test object can be uneven No special surface preparations or coatings required No physical contact with test specimen	Vibrationfree environment is required Heavy base to dampen vibrations Difficult to identify type of flaw detected
Holiday detector High voltage (spark)	Integrity of coatings or linings	Defects holidays in coatings of thickness >15 mils	Portable Easy to operate	Possible damage if dielectric strength exceeded
Holiday detector Low voltage	Integrity of coatings	Defects holidays in coatings of thickness <20 mills	Portable Easy to operate	Requires contact with substrate
Infrared (radiometers)	Lack of bond Hot spots Heat transfer Isotherms Temperature ranges	Brazed joints Adhesive-bonded joints Metallic platings or coatings; debonded areas or thickness Electrical assemblies Temperature monitoring	Sensitive to 1.5 F temperature variation Permanent record or thermal picture Quantitative Remote sensing; need not contact part Portable	Emissivity Liquid-nitrogen-cooled detector Critical time-temperature relationship Poor resolution for thick specimens Reference standards required
Leak testing	Leaks Helium Ammonia Smoke Water Air bubbles Radioactive gas Halogens	Joints: Welded Brazed Adhesive-bonded Sealed assemblies Pressure or vacuum chambers Fuel or gas tanks	High sensitivity to extremely small, tight separations not detectable by other NDT methods Sensitivity related to method selected	Accessibility to both surfaces of part required Smeared metal or contaminants may prevent detection Cost related to sensitivity
Magnetic field	Cracks Wall thickness Hardness Coercive force Magnetic anisotropy Magnetic field Nonmagnetic coating thickness on steel	Ferromagnetic materials Ship degaussing Liquid level control Treasure hunting Wall thickness of nonmetallic materials Material sorting	Measurement of magnetic material properties May be automated Easily detect magnetic objects in nonmagnetic material Portable	Permeability Reference standards required Edge-effect Probe lift-off
Magnetic particle	Surface and slightly subsurface defects; cracks, seams, porosity, inclusions Permeability variations Extremely sensitive for locating small tight cracks	Ferromagnetic materials; bar, forgings, weldments, extrusions, etc.	Advantage over penetrant in that it indicates subsurface defects, particularly inclusions Relatively fast and low cost May be portable	Alignment of magnetic field is critical Demagnetization of parts required after tests Parts must be cleaned before and after inspection Masking by surface coatings

(*Continued*)

NONDESTRUCTIVE METHODS FOR EVALUATING MATERIALS (*Continued*)

Method	Measures or Defects	Applications	Advantages	Limitations
Magnetic perturbation	Cracks Crack depth Broken strands in steel cables Permeability effects Nonmetallic inclusions Grinding burns and cracks under chromium plating	Ferromagnetic metals Broken steel cables in reinforced concrete	May be automated Easily detects magnetic objects in nonmagnetic materials Detects subsurface defects	Requires reference standard Need trained operator Part geometry Expensive equipment
Microwave (300 MHz-300 GHz)	Cracks, holes, debonded areas, etc. in nonmetallic parts Changes in composition, degree of cure, moisture content Thickness measurement Dielectric constant Loss tangent	Reinforced plastics Chemical products Ceramics Resins Rubber Liquids Polyurethane foam Radomes	Between radio waves and infrared in the electromagnetic spectrum Portable Contact with part surface not normally required Can be automated	Will not penetrate metals Reference standards required Horn to part spacing critical Part geometry Wave interference Vibration
Mossbauer effect	Nuclear magnetic resonance in materials, most common being iron-57 Polarization of magnetic domains in steel	Detect and identify iron in specimen or sample Detect iron films on stainless steel Measure retained austenite (2 to 35%) in steels Determine nitrided surfaces on steel Interaction of domains with dislocation in ferromagnetic materials	Provide unique information about the surroundings of the iron-57 nuclei	Radiation hazard Trained engineers or physicists required Nonportable Precision equipment for vibrating source and spectrum analysis
Neutron activation analysis (Reactor, accelerator, or radio-isotope)	Radiation emission resulting from neutron activation Oxygen in steel Nitrogen in food products Silicon in metals and ores	Metallurgical Prospecting Well logging Oceanography On-line process control of liquid or solid materials	Automatic systems Accurate (ppm range) Fast No contact with sample Sample preparation minimal	Radiation hazard Fast decay time Reference standard required Sensitivity varies with irradiation time
Penetrants (Dye or fluorescent)	Defects open to surface of parts: cracks, porosity, seams, laps, etc. Through-wall leaks	All parts with non-absorbing surfaces (forgings, weldments, castings, etc.) Note: Bleed-out from porous surfaces can mask indications of defects	Low cost Portable Indications may be further examined visually Results easily interpreted	Surface films, such as coatings, scale, and smeared metal may prevent detection of defects Parts must be cleaned before and after inspection Defect must be open to surface

(*Continued*)

NONDESTRUCTIVE METHODS FOR EVALUATING MATERIALS (*Continued*)

Method	Measures or Defects	Applications	Advantages	Limitations
Radiography (thermal neutrons from reactor, accelerator, or Californium 252)	Hydrogen contamination of litanium or zirconium alloys Defective or improperly loaded pyrotechnic devices Improper assembly of metal, nonmetal parts Corrosion products	Pyrotechnic devices Metallic, nonmetallic assemblies Biological specimens Nuclear reactor fuel elements and control rods Adhesive bonded structures	High neutron absorption by hydrogen, boron, lithium, cadmium, uranium, plutonium Low neutron absorption by most metals Complement to X-ray or gamma-ray radiography	Very costly equipment Nuclear reactor or accelerator required Trained physicists requlred Radiation hazard Nonportable Indium or gadolinium screens required
Radiography (gamma rays) Cobalt-60 Iridium-192	Internal defects and variations; porosity, inclusions, cracks, lack of fusion, geometry variations, corrosion thinning Density variations Thickness, gap and position	Usually where X-ray machines are not suitable because source cannot be placed in part with small openings and/or power source not available Panoramic imaging	Low initial cost Permanent records; film Small sources can be placed in parts with small openings Portable Low contrast	One energy level per source Source decay Radiation hazard Trained operators needed Lower image resolution Cost related to source size
Radiography (X-rays—film)	Internal defects and variations; porosity; inclusions; cracks; lack of fusion; geometry variations; corrosion thinning Density variations Thickness, gap and position Misassembly Misalignment	Castings Electrical assemblies Weldments Small, thin, complex wrought products Nonmetallics Solid propellant rocket motors Composites	Permanent records; film Ajustable energy levels (5 kv·25 mev) High sensitivity to density changes No couplant required Geometry variations do not effect direction of X-ray beam	High initial costs Orientation of linear defects in part may not be favorable Radiation hazard Depth of defect not indicated Sensitivity decreases with increase in scattered radiation
Radiometry (X-ray, gamma-ray, beta-ray) (Transmission or backscatter)	Wall thickness Plating thickness Variations in density or composition Fill level in cans or containers Inclusions or voids	Sheet, plate, foil, strip, tubing Nuclear reactor fuel rods Cans or containers Plated parts Composites	Fully automatic Fast Extremely accurate In-line process control Portable	Radiation hazard Beta-ray useful for ultrathin coatings only Source decay Reference standards required
Sonic (Less than 0.1 MHz)	Debonded areas or delaminations in metal or nonmetal composites or laminales Cohesive bond strength under controlled conditions Crushed or fractured core Bond integrity of metal insert fasteners	Metal or nonmetal composite or laminates brazed or adhesive-bonded Plywood Rocket motor nozzles Honeycomb	Portable Easy to operate Locates far-side debonded areas May be automated Access to only one surface required	Surface geometry influences test results Reference standards required Adhesive or core thickness variations influence results

(*Continued*)

NONDESTRUCTIVE METHODS FOR EVALUATING MATERIALS (*Continued*)

Method	Measures or Defects	Applications	Advantages	Limitations
Thermal (thermo-chromic paint, liquid crystals)	Lack of bond Hot spots Heat transfer Isotherms Temperature ranges Blockage in coolant passages	Brazed joints Adhesive-bonded joints Metallic platings or coatings Electrical assemblies Temperature monitoring	Very low initial cost Can be readily applied to surfaces which may be difficult to inspect by other methods No special operator skills	Thin-walled surfaces only Critical time-temperature relationship Image retentivity effected by humidity Reference standards required
Thermo-electric probe	Thermoelectric potential Coating thickness Physical properties Thompson effect P-N junctions in semiconductors	Metal sorting Ceramic coating thickness on metals Semiconductors	Portable Simple to operate Access to only one surface required	Hot probe Difficult to automate Reference standards required Surface contaminants Conductive coatings
Tomography	Boundaries Surface reconstruction Crack size, location, and orientation	Metals research Medicine	Pinpoint defect location Image display is computer controlled	Very expensive Need highly trained operator
Ultrasonic (0.1-25 MHz)	Internal defects and variations; cracks, lack of fusion, porosity, inclusions, delaminations, lack of bond, texturing Thickness or velocity Poisson's ratio, elastic modulus	Wrought metals Welds Brazed joints Adhesive-bonded joints Nonmetallics In-service parts	Most sensitive to cracks Test results know immediately Automating and permanent record capability Portable High penetration capability	Couplant required Small, thin, complex parts may be difficult to check Reference standards required Trained operator for manual inspection Special probes
Ultrasonic angle reflectivity	Elastic properties acoustic attenuation in solids Near-surface metallic property gradients, e.g. carburization in steel Metallic grain structure and size	Metals Nonmetals	Access to only one surface required Permanent record Quantitative No physical contact of sample required Sample preparation minimal	Test parts must be immersed Geometry limitations: test part must have a flat, smooth area Goniometer device required Skilled technician required

Source: *Metals Progress Databook*, pp. 127–131 with additions, ASM, Mid-June 1985. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

DIMENSIONS OF SEAMLESS AND WELDED WROUGHT STEEL PIPE

(All dimensions are in inches)

NPS Designator	Outside Diameter	Nominal Wall Thickness																
		Schedule 5S	Schedule 10S	Schedule 10	Schedule 20	Schedule 30	Schedule 40S	Standard Wall	Schedule 40	Schedule 60	Schedule 80S	Extra Strong	Schedule 80	Schedule 100	Schedule 120	Schedule 140	Schedule 160	Double Extra Strong
1/8	0.405	–	0.049	–	–	–	0.068	0.068	0.068	–	0.095	0.095	0.095	–	–	–	–	–
1/4	0.540	–	0.065	–	–	–	0.088	0.088	0.088	–	0.119	0.119	0.119	–	–	–	–	–
3/8	0.675	–	0.065	–	–	–	0.091	0.091	0.091	–	0.126	0.126	0.126	–	–	–	–	–
1/2	0.840	0.065	0.083	–	–	–	0.109	0.109	0.109	–	0.147	0.147	0.147	–	–	–	0.188	0.294†
3/4	1.060	0.065	0.083	–	–	–	0.113	0.113	0.113	–	0.154	0.154	0.154	–	–	–	0.219	0.308†
1	1.315	0.065	0.109	–	–	–	0.133	0.133	0.133	–	0.179	0.179	0.179	–	–	–	0.250	0.358†
1 1/4	1.660	0.065	0.109	–	–	–	0.140	0.140	0.140	–	0.191	0.191	0.191	–	–	–	0.250	0.382†
1 1/2	1.900	0.065	0.109	–	–	–	0.145	0.145	0.145	–	0.200	0.200	0.200	–	–	–	0.281	0.400†
2	2.375	0.065	0.109	–	–	–	0.154	0.154	0.154	–	0.218	0.218	0.218	–	–	–	0.344	0.436†
2 1/2	2.875	0.083	0.120	–	–	–	0.203	0.203	0.203	–	0.276	0.276	0.276	–	–	–	0.375	0.522†
3	3.500	0.083	0.120	–	–	–	0.216	0.216	0.216	–	0.300	0.300	0.300	–	–	–	0.438	0.600†
3 1/2	4.000	0.083	0.120	–	–	–	0.226	0.226	0.226	–	0.318	0.318	0.318	–	–	–	–	–
4	4.500	0.083	0.120	–	–	–	0.237	0.237	0.237	–	0.337	0.337	0.337	–	0.438	–	0.531	0.674†
5	5.563	0.109	0.134	–	–	–	0.258	0.258	0.258	–	0.375	0.375	0.375	–	0.500	–	0.625	0.750†
6	6.625	0.109	0.134	–	–	–	0.280	0.280	0.280	–	0.432	0.432	0.432	–	0.562	–	0.719	0.864†
8	8.625	0.109	0.148	–	0.250	0.277	0.322	0.322	0.322	0.406	0.500	0.500	0.500	0.594	0.719	0.812	0.906	0.875†
10	10.750	0.134	0.165	–	0.250	0.307	0.365	0.365	0.365	0.500	0.500	0.500	0.594	0.719	0.844	1.000	1.125	1.000
12	12.750	0.156	0.180	–	0.250	0.330	0.375	0.375†	0.406	0.562	0.500	0.500†	0.688	0.844	1.000	1.125	1.312	1.000

NPS Designator	Outside Diameter	Nominal Wall Thickness																
		Schedule 5S	Schedule 10S	Schedule 10	Schedule 20	Schedule 30	Schedule 40S	Standard Wall	Schedule 40	Schedule 60	Schedule 80S	Extra Strong	Schedule 80	Schedule 100	Schedule 120	Schedule 140	Schedule 160	Double Extra Strong
14	14.000	0.156*	0.188*	0.250	0.312	0.375	–	0.375	0.438	0.594	–	0.500†	0.750	0.938	1.094	1.250	1.406	–
16	16.000	0.165*	0.188*	0.250	0.312	0.375	–	0.375	0.500	0.656	–	0.500	0.844	1.031	1.219	1.438	1.594	–
18	18.000	0.165*	0.188*	0.250	0.312	0.438	–	0.375†	0.562	0.750	–	0.500†	0.938	1.156	1.375	1.562	1.781	–
20	20.000	0.188*	0.218*	0.250	0.375	0.500	–	0.375	0.594	0.812	–	0.500	1.031	1.281	1.500	1.750	1.969	–
22	22.000	0.188*	0.218*	0.250	0.375	0.500	–	0.375	0.625	0.875	–	0.500	1.125	1.375	1.625	1.875	2.125	–
24	24.000	0.218*	0.250*	0.250	0.375	0.562	–	0.375	0.688	0.969	–	0.500†	1.219	1.531	1.812	2.062	2.344	–
26	26.000	–	–	0.312	0.500	–	–	0.375†	–	–	–	0.500	–	–	–	–	–	–
28	28.000	–	–	0.312	0.500	0.625	–	0.375†	–	–	–	0.500	–	–	–	–	–	–
30	30.000	–	–	0.312	0.500	0.625	–	0.375†	–	–	–	0.500	–	–	–	–	–	–
32	32.000	–	–	0.312	0.500	0.625	–	0.375†	0.688	–	–	0.500	–	–	–	–	–	–
34	34.000	–	–	0.312	0.500	0.625	–	0.375†	0.688	–	–	0.500	–	–	–	–	–	–
36	36.000	–	–	0.312	0.500	0.625	–	0.375†	0.750	–	–	0.500	–	–	–	–	–	–

For tolerances on outside diameter and wall thickness see appropriate specifications.
Schedule 5S, 10S, 40S and 80S apply to austenitic chromium-nickel steel pipe only.
Except when marked † Standard, Extra Strong and Double Extra Strong wall thicknesses have pipe of corresponding wall thickness listed under one of the schedule numbers. Dimensions in this table are abstracted from ASA Standard B36.10 and ASA Standard B36.19, except that wall thicknesses marked* do not appear in ASA Standard B36.19.

METRIC DIMENSIONS OF SEAMLESS AND WELDED WROUGHT STEEL PIPE

(Dimensions in mm)

NPS Designator	Outside Diameter	Nominal Wall Thickness																
		Schedule 5S	Schedule 10S	Schedule 10	Schedule 20	Schedule 30	Schedule 40S	Standard Wall	Schedule 40	Schedule 60	Schedule 80S	Extra Strong	Schedule 80	Schedule 100	Schedule 120	Schedule 140	Schedule 160	Double Extra Strong
1/8	10.3	–	1.24	–	–	–	1.73	1.73	1.73	–	2.41	2.41	2.41	–	–	–	–	–
1/4	13.7	–	1.65	–	–	–	2.24	2.24	2.24	–	3.02	3.02	3.02	–	–	–	–	–
3/8	17.1	–	1.65	–	–	–	2.31	2.31	2.31	–	3.2	3.2	3.2	–	–	–	–	–
1/2	21.3	1.65	2.11	–	–	–	2.77	2.77	2.77	–	3.73	3.73	3.73	–	–	–	4.78	7.47†
3/4	26.7	1.65	2.11	–	–	–	2.87	2.87	2.87	–	3.91	3.91	–	–	–	–	5.56	7.82†
1	33.4	1.65	2.77	–	–	–	3.38	3.38	3.38	–	4.55	4.55	4.55	–	–	–	6.35	9.09†
1 1/4	42.2	1.65	2.77	–	–	–	3.56	3.56	3.56	–	4.85	4.85	4.85	–	–	–	6.35	9.70†
1 1/2	48.3	1.65	2.77	–	–	–	3.68	3.68	3.68	–	5.08	5.08	5.08	–	–	–	7.14	10.16†
2	60.3	1.65	2.77	–	–	–	3.91	3.91	3.91	–	5.54	5.54	5.54	–	–	–	8.74	11.07†
2 1/2	73.0	2.11	3.05	–	–	–	5.16	5.16	5.16	–	7.01	7.01	7.01	–	–	–	9.52	14.02†
3	88.9	2.11	3.05	–	–	–	5.49	5.49	5.49	–	7.62	7.62	7.62	–	–	–	11.13	15.24†
3 1/2	101.6	2.11	3.05	–	–	–	5.74	5.74	5.74	–	8.08	8.08	8.08	–	–	–	–	–
4	114.3	2.11	3.05	–	–	–	6.02	6.02	6.02	–	8.56	8.56	8.56	–	11.13	–	13.49	17.12†
5	141.3	2.77	3.40	–	–	–	6.55	6.55	6.55	–	9.52	9.52	9.52	–	12.7	–	15.88	19.05†
6	168.3	2.77	3.40	–	–	–	7.11	7.11	7.11	–	10.97	10.97	10.97	–	14.27	–	18.26	21.95†

NPS Designator	Outside Diameter	Nominal Wall Thickness																
		Schedule 5S	Schedule 10S	Schedule 10	Schedule 20	Schedule 30	Schedule 40S	Standard Wall	Schedule 40	Schedule 60	Schedule 80S	Extra Strong	Schedule 80	Schedule 100	Schedule 120	Schedule 140	Schedule 160	Double Extra Strong
8	219.1	2.77	3.76	–	6.35	7.04	8.18	8.18	8.18	10.31	12.7	12.7	12.7	15.09	18.26	20.62	23.01	22.22†
10	273	3.40	4.19	–	6.35	7.8	9.27	9.27	9.27	12.7	12.7	12.7	15.09	18.26	21.44	25.40	28.58	25.40†
12	323.9	3.96*	4.57*	–	6.35	8.38	9.52	9.52†	10.31	14.27	12.7	12.7†	17.47	21.44	25.40	28.58	33.34	25.40†
14	355.6	3.96*	4.78*	6.35	7.92	9.52	–	9.52	11.13	15.09	–	12.7†	19.05	23.82	27.79	31.75	35.71	–
16	406.4	4.19*	4.78*	6.35	7.92	9.52	–	9.52	12.7	16.64	–	12.7	21.44	26.19	30.96	36.52	40.49	–
18	457.2	4.19*	4.78*	6.35	7.92	11.13	–	9.52†	14.27	19.05	–	12.7†	23.82	29.36	34.92	39.69	45.24	–
20	508	4.78*	5.54*	6.35	9.52	12.7	–	9.52	15.9	20.62	–	12.7†	26.19	32.54	38.10	44.45	50.01	–
22	558.8	4.78*	5.54*	6.35	9.52	12.7	–	9.52	15.88	22.22	–	12.7	28.58	34.92	41.28	47.62	53.98	–
24	609.6	5.54*	6.35*	6.35	9.52	14.27	–	9.52	17.48	24.61	–	12.7*	30.96	38.89	46.02	52.39	59.54	–
26	660.4	–	–	7.92	12.7	–	–	9.52†	–	–	–	12.7	–	–	–	–	–	–
28	711.2	–	–	7.92	12.7	15.88	–	9.52†	–	–	–	12.7	–	–	–	–	–	–
30	762	–	–	7.92	12.7	15.88	–	9.52†	–	–	–	12.7	–	–	–	–	–	–
32	812.8	–	–	7.92	12.7	15.88	–	9.52†	–	–	–	12.7	–	–	–	–	–	–
34	863.6	–	–	7.92	12.7	15.88	–	9.52†	–	–	–	12.7	–	–	–	–	–	–
36	914.4	–	–	7.92	12.7	15.88	–	9.52†	–	–	–	12.7	–	–	–	–	–	–

For tolerance on outside diameter and wall thickness see appropriate specifications.
Schedule 5S, 10S, and 40S and 80S apply to austentic chromium-nickel steel pipe only
Except when marked † Standard, Extra Strong and Double Extra Strong wall thicknesses have pipe of corresponding wall thickness listed under one of the schedule numbers.
Dimensions in this table are based on ASA Standard B36. 10 and ASA Standard B36.19, except that the thicknesses marked* do not appear in ASA Standard B36.19.

STANDARD WALL STEEL PIPE DIMENSIONS, CAPACITIES, AND WEIGHTS

NPS Designator	Outside Diameter in.	Wall Thickness in.	Inside Diameter in.	Cross Sectional Area of Metal $in.^2$	Circumference, ft or Surface Area ft^2/ft of length Outside	Inside	Capacity at 1 ft/s Velocity U.S. Gal. per min.	Weight of Pipe lb/ft
1/8	0.405	0.068	0.269	0.072	0.106	0.0705	0.179	0.25
1/4	0.540	0.088	0.364	0.125	0.141	0.0954	0.323	0.43
3/8	0.675	0.091	0.493	0.167	0.177	0.1293	0.596	0.57
1/2	0.840	0.109	0.622	0.250	0.220	0.1630	0.945	0.85
3/4	1.050	0.113	0.824	0.333	0.275	0.2158	1.665	1.13
1	1.315	0.133	1.049	0.494	0.344	0.2745	2.690	1.68
1 1/4	1.660	0.140	1.380	0.669	0.435	0.362	4.57	2.28
1 1/2	1.900	0.145	1.610	0.799	0.498	0.422	6.34	2.72
2	2.375	0.154	2.067	1.075	0.622	0.542	10.45	3.66
2 1/2	2.875	0.203	2.469	1.704	0.753	0.647	14.92	5.80
3	3.500	0.216	3.068	2.228	0.917	0.804	23.00	7.58
3 1/2	4.000	0.226	3.548	2.680	1.047	0.930	30.80	9.11
4	4.500	0.237	4.026	3.173	1.178	1.055	39.6	10.8
5	5.563	0.258	5.047	4.304	1.456	1.322	62.3	14.7
6	6.625	0.280	6.065	5.584	1.734	1.590	90.0	19.0
8	8.625	0.322	7.981	8.396	2.258	2.090	155.7	28.6
10	10.750	0.365	10.020	11.90	2.814	2.620	246.0	40.5
12	12.750	0.375	12.000	14.58	3.338	3.142	352.5	49.6
14	14.000	0.375	13.250	16.05	3.665	3.469	430.0	54.6
16	16.000	0.375	15.250	18.41	4.189	3.992	568.0	62.6
18	18.000	0.375	17.250	20.76	4.712	4.516	728.4	70.6
20	20.000	0.375	19.250	23.12	5.236	5.040	902.0	78.6
22	22.000	0.375	21.250	25.48	5.760	5.563	1105.	86.6
24	24.000	0.375	23.250	27.83	6.283	6.087	1325.	94.6
26	26.000	0.375	25.250	30.19	6.807	6.610	1561.	102.6
28	28.000	0.375	27.250	32.54	7.330	7.134	1818.	110.6
30	30.000	0.375	29.250	34.90	7.854	7.658	2094.	118.7
32	32.000	0.375	31.250	37.26	8.378	8.181	2391.	126.7
34	34.000	0.375	33.250	39.61	8.901	8.705	2706.	134.7
36	36.000	0.375	35.250	41.97	9.424	9.228	3042.	142.7
METRIC CONVERSION FACTORS								
–	×25.4 = mm	×25.4 = mm	×25.4 = mm	×645. = mm^2	×0.305 = m^2/m	×0.305 = m^2/m	×0.01242 = m^3/min. at 1 m/s	×1.488 = kg/m

UNIFIED NUMBERING SYSTEM FOR METALS AND ALLOYS

UNS Series	Metal
Nonferrous metals and alloys	
A00001-A99999	Aluminum and aluminum alloys
C00001-C99999	Copper and copper alloys
E00001-E99999	Rare earth and rare earth-like metals and alloys
L00001-L99999	Low melting metals and alloys
M00001-M99999	Miscellaneous nonferrous metals and alloys
N00001-N99999	Nickel and nickel alloys
P00001-P00999	Gold
P01001-P01999	Iridium
P02001-P02999	Osmium
P03001-P03999	Palladium
P04001-P04999	Platinum
P05001-P05999	Rhodium
P06001-P06999	Ruthenium
P07001-P07999	Silver
R01011-R01999	Boron
R02001-R02999	Hafnium
R03001-R03999	Molybdenum
R04001-R04999	Niobium (Columbium)
R05001-R05999	Tantalum
R06001-R06999	Thorium
R07001-R07999	Tungsten
R08001-R08999	Vanadium
R10001-R19999	Beryllium
R20001-R29999	Chromium
R30001-R39999	Cobalt
R40001-R49999	Rhenium
R50001-R59999	Titanium
R60001-R69999	Zirconium
Z00001-Z99999	Zinc and zinc alloys
Ferrous metals and alloys	
D00001-D99999	Specified mechanical properties steels
F00001-F99999	Cast irons
G00001-G99999	AISI and SAE carbon and alloys steels (except tool steels)
H00001-H99999	AISI H-steels
J00001-J99999	Cast steels (except tool steels)
K00001-K99999	Miscellaneous steels and ferrous alloys
S00001-S99999	Heat and corrosion resistant (stainless) steels
T00001-T99999	Tool steels
Welding filler metals, classified by weld deposit composition	
W00001-W09999	Carbon steel with no significant alloying elements
W10000-W19999	Manganese-molybdenum low alloy steels
W20000-W29999	Nickel low alloy steels
W30000-W39999	Austenitic stainless steels
W40000-W49999	Ferritic stainless steels
W50000-W59999	Chromium low alloy steels
W60000-W69999	Copper base alloys
W70000-W79999	Surfacing alloys
W80000-W89999	Nickel base alloys

The following tables on composition and mechanical properties of metallic materials were compiled from data given in the indicated API, ASTM, ASME, and UNS standards.

COMMON NAMES OF UNS ALLOYS—Nonferrous

A02420 Al 242.0	A02950 Al 295.0	A03560 Al 356.0
A05140 Al 514.0	A05200 Al 520.0	A24430 Al B443.0
A91060 Al 1060	A91100 Al 1100	A92014 Al 2014
A92024 Al 2024	A93003 Al 3003	A95052 Al 5052
A95083 Al 5083	A95086 Al 5086	A95154 Al 5154
A96061 Al 6061	A96063 Al 6063	A97075 Al 7075
C10200 OF Copper	C11000 ETP Copper	C12200 DHP Copper
C14200 DPA Copper	C22000 Commercial Bronze	C23000 Red Brass
C26000 Cartridge Brass	C27000 Yellow Brass	C28000 Muntz Metal
C44300 Admiralty Brass, As	C44400 Admiralty Brass, Sb	C44500 Admiralty Brass, P
C46500 Naval Brass, As	C51000 Phosphor Bronze A	C52400 Phosphor Bronze D
C60800 Aluminum Bronze, 6%	C61300 Aluminum Bronze, 7%	C61400 Aluminum Bronze D
C63000 Nickel Aluminum Bronze	C65500 High-Silicon Bronze	C67500 Manganese Bronze A
C68700 Aluminum Brass, As	C70800 90-10 Copper-Nickel	C71500 70-30 Copper-Nickel
C75200 Nickel Silver	C83600 Ounce Metal	C86500 Manganese Bronze
C90500 Gun Metal	C92200 M Bronze	C95700 Cast Mn-Ni-Al Bronze
C95800 Cast Ni-Al Bronze	C96400 Cast 70-30 Cu-Ni	
L50045 Common Lead	L51120 Chemical Lead	L55030 50/50 Solder
M11311 Mg AZ31B	M11914 Mg AZ91C	M12330 Mg EZ33A
M13310 Mg HK31A		
N02200 Nickel 200	N02201 Nickel 201	N02230 Nickel 230
N04400 400 Alloy	N04405 R-405 Alloy	N05500 K-500 Alloy
N05502 502 Alloy	N06002 X Alloy	N06007 G Alloy
N06022 C-22 Alloy	N06030 G-30 Alloy	N06110 Allcor
N06333 RA333 Alloy	N06455 C-4 Alloy	N06600 600 Alloy
N06601 601 Alloy	N06617 617 Alloy	N06625 625 Alloy
N06690 690 Alloy	N06975 2550 Alloy	N06985 G-3 Alloy
N07001 Waspaloy	N07031 31 Alloy	N07041 Rene 41
N07090 90 Alloy	N07716 625 Plus	N07718 718 Alloy
N07750 X-750 Alloy	N08020 20Cb-3	N08024 20Mo-4
N08026 20Mo-6	N08028 Sanicro 28	N08320 20 Mod
N08330 RA-330	N08366 AL-6X	N08367 AL-6XN
N08700 JS700	N08800 800 Alloy	N08801 801 Alloy
N08810 800H Alloy	N08811 800HT Alloy	N08825 825 Alloy
N08904 904L Alloy	N08925 25-6Mo	N09706 706 Alloy
N09925 925 Alloy	N10001 B Alloy	N10002 C Alloy
N10003 N Alloy	N10004 W Alloy	N10276 C-276 Alloy
N10665 B-2 Alloy		
R03600 Molybdenum	R03630 Molybdenum Alloy	R03650 Molybdenum, low C
R04210 Niobium (Columbium)	R05200 Tantalum	R07005 Tungsten
R30003 Elgiloy	R30004 Havar	R30006 Stellite 6
R30031 Stellite 31	R30035 MP35N	R30155 N-155
R30188 HS-188 Alloy	R30260 Duratherm 2602	R30556 HS-556
R30605 L-605 Alloy	R50250 Titanium, Gr 1	R50400 Titanium, Gr 2
R50550 Titanium, Gr 3	R50700 Titanium, Gr 4	R52250 Titanium, Gr 11
R52400 Titanium, Gr 7	R53400 Titanium, Gr 12	R54520 Titanium, Gr 6
R58260 Ti6Al6Mo2Sn4Zr	R56320 Titanium, Gr 9	R56400 Titanium, Gr 5
R58640 Beta-C	R60702 Zr 702	R60704 Zr 704
R60705 Zr 705		
Z13000 Zinc Anode Type II	Z32120 Zinc Anode Type I	Z32121 Zinc Anode Type III

COMMON NAMES OF UNS ALLOYS—Ferrous

F10006 Gray Cast Iron	F20000 Malleable Cast Iron	F32800 Ductile Iron 60-40-18
F41000 Ni-Resist Type 1	F41002 Ni-Resist Type 2	F41006 Ni-Resist Type 5
F43000 Ductile Ni-Resist D2	F43006 Ductile Ni-Resist D5	F47003 Duriron
G10200 1020 Carbon Steel	G41300 4130 Steel	G43400 4340 Steel
J91150 CA-15	J91151 CA-15M	J91153 CA-40
J91540 CA-6NM	J91803 CB-30	J92500 CF-3
J92600 CF-8	J92602 CF-20	J92603 HF
J92605 HC	J92615 CC-50	J92701 CF-16F
J92710 CF-8C	J92800 CF-3M	J92900 CF-8M
J93000 CG-8M	J93001 CG-12	J93005 HD
J93370 CD-4MCu	J93402 CH-20	J93423 CE-30
J93503 HH	J94003 HI	J94202 CK-20
J94203 HK-30	J94204 HK-40	J94213 HN
J94224 HK	N08604 HL	N08002 HT
N08007 CN-7M	N08004 HU	N08705 HP
K01800 A516-55	K02100 A516-60	K02403 A516-65
K02700 A516-70	K02801 A285-C	K03005 A53-B
K03006 A106-B	K11510 0.2Cu Steel	K11522 C-0.5Mo
K11576 HSLA Steel	K11597 1.25Cr-0.5Mo	K21590 2.25Cr-1Mo
K41545 5Cr-0.5Mo	K81340 9Ni Steel	K90941 9Cr-1Mo
K94610 KOVAR		
S13800 PH 13-8 Mo	S15500 15-5 PH	S15700 PH 15-7 Mo
S17400 17-4 PH	S17600 Stainless W	S17700 17-7 PH
S20100 201 SS	S20200 202 SS	S20910 22-13-5
S21400 Tenelon	S21600 216 SS	S21800 Nitronic 60
S21900 21-6-9	S24000 18-3 Mn	S28200 18-18 Plus
S30200 302 SS	S30300 303 SS	S30400 304 SS
S30403 304L SS	S30409 304H SS	S30451 304N SS
S30453 304LN SS	S30500 305 SS	S30800 308 SS
S30815 253MA	S30900 309 SS	S30908 309S SS
S31000 310 SS	S31008 310S SS	S31200 44LN
S31254 254 SMO	S31260 DP-3	S31400 314 SS
S31500 3RE60	S31600 316 SS	S31603 316L SS
S31609 316H SS	S31635 316Ti SS	S31640 316Cb SS
S31651 316N SS	S31653 316LN SS	S31700 317 SS
S31703 317L SS	S31725 317LM SS	S31726 317L4 SS
S31803 2205 Alloy	S32100 321 SS	S32109 321H SS
S32304 SAF 2304	S32404 Uranus 50	S32550 Ferralium 255
S32900 329 SS	S32950 7-Mo Plus	S34700 347 SS
S34709 347H SS	S34800 348 SS	S35000 AM 350
S35500 AM 355	S36200 Almar 362	S38100 18-18-2
S40300 403 SS	S40500 405 SS	S40900 409 SS
S41000 410 SS	S41400 414 SS	S41600 416 SS
S41800 Greek Ascoloy	S42000 420 SS	S42200 422 SS
S42400 F6NM	S42900 429 SS	S43000 430 SS
S43100 431 SS	S43400 434 SS	S43600 436 SS
S44002 440A SS	S44003 440B SS	S44004 440C SS
S44200 442 SS	S44400 18-2	S44600 446 SS
S44625 26-1	S44626 26-1 Ti	S44627 26-1 Cb
S44635 26-4-4	S44660 SC-1	S44700 29-4
S44735 29-4C	S44800 29-4-2	S45000 Custom 450
S45500 Custom 455	S50100 5Cr-0.5Mo	S50200 5Cr-0.5Mo
S50300 7Cr-0.5Mo	S50400 9Cr-1Mo	S66286 A286

COMPARABLE ALLOY DESIGNATIONS

UNS	Name	Germany DIN	U.K. BS	France AFNOR	UNS	Name	Germany DIN	U.K. BS	France AFNOR
C22000	Com. Bronze	2.0230	–	–	N08800	800 Alloy	1.4876	NA15	Z5NC35-20
C44300	Adm. Brass, As	2.0470	CZ111	–	N08825	825 Alloy	2.4858	NA16	NFe32C20DU
C61400	Al Bronze D	2.0932	CA106	–	N08904	904L Alloy	1.4539	–	–
C63000	Ni Al Bronze	2.0966	CA105	–	N08925	25-6Mo	1.4529	–	–
C68700	Al Brass, As	2.0460	CZ110	–	N10276	C-276 Alloy	2.4819	–	–
C70600	90-10 Cu-Ni	2.0872	CN102	–	N10665	B-2 Alloy	2.4617	–	–
C71500	70-30 Cu-Ni	2.0882	CN107	UZ30	R50250	Titanium Gr 1	3.7025	–	–
N02200	Nickel 200	2.4066	NA11	–	R50400	Titanium Gr 2	3.7035	–	–
N02201	Nickel 201	2.4068	NA12	–	R50550	Titanium Gr 3	3.7055	–	–
N04400	400 Alloy	2.4360	NA13	NU30	S15700	PH 15-7 Mo	1.4532	–	–
N05500	K-500 Alloy	2.4375	NA18	–	S17700	17-7 PH	14568	–	–
N06002	X Alloy	2.4665	HR204	NC22FeD	S30300	303 SS	1.4305	303S21	Z10CNF 1809
N06022	C-22 Alloy	2.4602	–	–	S30400	304 SS	1.4301	304S18	Z6CN18-9
N06030	G-30 Alloy	2.4603	–	–	S30403	304L SS	1.4306	304S14	Z2CN18-10
N06333	RA333 Alloy	2.4608	–	–	S30409	304H SS	1.4948	–	–
N06455	C-4 Alloy	2.4610	–	–	S30453	304LN SS	1.4311	–	–
N06600	600 Alloy	2.4816	NA14	NC15Fe	S30500	305 SS	1.4303	–	–
N06601	601 Alloy	2.4851	–	–	S30800	308 SS	1.4303	–	–
N06625	625 Alloy	2.4856	NA21	NC22DNb	S30900	309 SS	1.4828	–	–
N06985	G-3 Alloy	2.4619	–	–	S30908	309S SS	1.4833	–	Z15CN2413
N07718	718 Alloy	2.4668	–	NC19FeNb	S31000	310 SS	1.4841	310S24	Z12CNS2520
N07750	X-750 Alloy	2.4669	HR505	NC15Fe (Nb)	S31008	310S SS	1.4845	–	–
N08020	20Cb-3	2.4660	–	–	S31200	44LN	1.4460	–	–
N08028	Sanicro 28	1.4563	–	–	S31400	314 SS	1.4841	310S24	Z12CNS2520

UNS	Name	Germany DIN	U.K. BS	France AFNOR	UNS	Name	Germany DIN	U.K. BS	France AFNOR
S31500	3RE60	1.4417	–	–	S34709	347H SS	1.4550	347S59	–
S31600	316 SS	1.4401	316S16	Z6CND17-11	S34800	348 SS	1.4546	347S17	–
S31603	316L SS	1.4919	316S14	Z2CND17-12	S40500	405 SS	1.4002	405S17	Z6CA13
S31609	316H SS	1.4919	316S59	–	S41000	410 SS	1.4006	–	–
S31651	316N SS	1.4919	–	–	S43000	430 SS	1.4016	430S15	Z8C17
S31653	316LN SS	1.4406	–	–	S43100	431 SS	1.4057	431S29	–
S31700	317 SS	1.4449	–	–	S43400	434 SS	1.4113	434S19	Z8CD1701
S31703	317L SS	1.4438	317S12	Z2CND1915	S44003	440B SS	1.4112	–	–
S31803	2205 Alloy	1.4462	–	–	S44004	440C SS	1.4125	–	–
S32100	321 SS	1.4541	321S12	Z6CNT18-10	S44400	18-2 SS	1.4521	–	–
S32109	321H SS	1.4541	321S59	–	S66286	A286	1.4980	–	–
S34700	347 SS	1.4550	347S17	Z6CNNb18-10					

ASTM	UNS	Name	ASTM	UNS	Name	ASTM	UNS	Name
615	S41800	Greek Ascoloy	P1, T1	K11522	C-0.5Mo	XM-9	S36200	Almar 362
630	S17400	17-4 PH	P5, T5	K41545	5Cr-0.5Mo	XM-10	S21900	21-6-9
631	S17700	17-7 PH	P7, T7	S50300	7Cr-0.5Mo	XM-12	S15500	15-5 PH
632	S15700	PH 15-7 Mo	P9, T9	S50400	9Cr-1Mo	XM-13	S13800	PH 13-8 Mo
634	S35500	AM 355	P11, T11	K11597	1.25Cr-0.5Mo	XM-15	S38100	18-18-2
635	S17600	Stainless W	P22, T22	K21590	2.25Cr-1Mo	XM-16	S45500	Custom 455
660	S66286	A286 alloy				XM-17	S21600	216 SS
						XM-19	S20910	22-13-5
						XM-25	S45000	Custom 450
						XM-27	S44625	26-1
						XM-29	S24000	18-3 Mn
						XM-31	S21400	Tenelon
						XM-33	S44626	26-1 Ti

ALUMINUM ALLOYS—Composition, %

UNS	Common Name	Cr	Cu	Mg	Mn	Si	Zn	Other	UNS
A02420	Al 242.0	0.25 max	3.5–4.5	1.2–1.8	0.35 max	0.7 max	0.35 max	Ni 1.7–2.3	A02420
A02950	Al 295.0	–	4.5–5.0	0.03 max	0.35 max	0.7–1.5	0.35 max	–	A02950
A03560	Al 356.0	–	0.25 max	0.20–0.45	0.35 max	6.5–7.5	0.35 max	–	A03560
A05140	Al 514.0	–	0.15 max	3.5–4.5	0.35 max	0.35 max	0.15 max	–	A05140
A05200	Al 520.0	–	0.25 max	9.5–10.6	0.15 max	0.25 max	0.15 max	–	A05200
A24430	Al B443.0	–	0.15 max	0.05 max	0.35 max	4.5–6.0	0.35 max	–	A24430
A91060	Al 1060	–	0.05 max	0.03 max	0.03 max	0.25 max	0.05 max	Al 99.60 min	A91060
A91100	Al 1100	–	0.05-0.20	–	0.05 max	–	0.10 max	Al 99.00 min	A91100
A92014	Al 2014	0.10 max	3.9–5.0	0.20–0.8	0.40–1.2	0.50–1.2	0.25 max	–	A92014
A92024	Al 2024	0.10 max	3.8–4.9	1.2–1.8	0.30-0.9	0.50 max	0.25 max	–	A92024
A93003	Al 3003	–	0.05-0.20	–	1.0–1.5	0.6 max	0.10 max	–	A93003
A95052	Al 5052	0.15–0.35	0.10 max	2.2–2.8	0.10 max	–	0.10 max	–	A95052
A95083	Al 5083	0.05–0.25	0.10 max	4.0–4.9	0.40–1.0	0.40 max	0.25 max	–	A95083
A95086	Al 5086	0.05–0.25	0.10 max	3.5–4.5	0.20–0.7	0.40 max	0.25 max	–	A95086
A95154	Al 5154	0.15–0.35	0.10 max	3.1–3.9	0.10 max	0.25 max	0.20 max	–	A95154
A96061	Al 6061	0.04–0.35	0.15–0.40	0.8–1.2	0.15 max	0.40–0.8	0.25 max	–	A96061
A96063	Al 6063	0.10 max	0.10 max	0.45–0.9	0.10 max	0.20–0.6	0.10 max	–	A96063
A97075	Al 7075	0.18–0.28	1.2–2.0	2.1–2.9	0.30 max	0.40 max	5.1–6.1	–	A97075
	Al 2090	0.05 max	3.0 max	0.25 max	0.05 max	0.10 max	0.10 max	Li 1.9–2.6	
	Al 8090	0.10 max	1.8–2.5	1.1–1.9	0.10 max	0.20 max	0.25 max	Li 2.2–2.7	

ALUMINUM ALLOYS—Mechanical Properties

UNS	Common Name	ASTM	Form	Temper	YS-ksi	TS-ksi	YS-MPa	TS-MPa	UNS
A02420	Al 242.0	B26	Casting	O	–	23 min	–	159 min	A02420
A02950	Al 295.0	B26	Casting	T6	20 min	32 min	138 min	221 min	A02950
A03560	Al 356.0	B26	Casting	T6	20 min	30 min	138 min	207 min	A03560
A05140	Al 514.0	B26	Casting	F	9.0 min	22 min	62 min	152 min	A05140
A05200	Al 520.0	B26	Casting	T4	22 min	42 min	152 min	290 min	A05200
A24430	Al B443.0	B26	Casting	F	6.0 min	17 min	41 min	117 min	A24430
A91060	Al 1060	B210	Tube	O	2.5 min	8.5–13.5	17 min	59–93	A91060
A91100	Al 1100	B210	Tube	O	3.5 min	11–15.5	24 min	76–107	A91100
A92014	Al 2014	B210	Tube	T6	55 min	65 min	380 min	450 min	A92014
A92024	Al 2024	B210	Tube	T3	42 min	64 min	290 min	440 min	A92024
A93003	Al 3003	B210	Tube	O	5 min	14–19	35 min	95–130	A93003
A95052	Al 5052	B210	Tube	O	10 min	25–35	70 min	170–240	A95052
A95083	Al 5083	B210	Tube	O	16 min	39–51	110 min	270–350	A95083
A95086	Al 5086	B210	Tube	O	14 min	35–46	95 min	240–315	A95086
A95154	Al 5154	B210	Tube	O	11 min	30–41	75 min	205–280	A95154
A96061	Al 6061	B210	Tube	T6	35 min	42 min	240 min	290 min	A96061
A96063	Al 6063	B210	Tube	T6	28 min	33 min	195 min	225 min	A96063
A97075	Al 7075	B210	Tube	T6	66 min	77 min	455 min	530 min	A97075

COPPER ALLOYS—Composition, %

UNS #	Common Name	Cu*	Ai	Fe	Mn	Ni	Si	Sn	Zn	P	Pb	Bi	Other	UNS #
C10200	OF Copper	99.95 min	–	–	–	–	–	–	–	–	–	–	Oxygen 0.0010 max	C10200
C12200	DHP Copper	99.90 min	–	–	–	–	–	–	–	–	–	–		C12200
C14200	DPA Copper	99.40 min	–	–	–	–	–	–	–	–	–	–		C14200
C23000	Red Brass	84.0–86.0	–	0.05 max	–	–	–	–	bal	–	0.05 max			C23000
C51000	Phos. Bronze A	bal	–	0.10 max	–	–	–	4.2–5.8	0.30 max	0.03–0.35	0.05 max	–		C51000
C52400	Phos. Bronze D	bal	–	0.10 max	–	–	–	9.0–11.0	0.20 max	0.03–0.35	0.05 max	–		C52400
C60800	Al Bronze, 5%	bal	5.0–6.5	0.10 max	–	–	–	–	–	–	0.10 max	–	As 0.2–0.35	C60800
C61300	Al Bronze, 7%	bal	6.0–7.5	2.0–3.0	0.20 max	0.15 max	0.10 max	0.20–0.50	0.10 max	0.015 max	0.01 max	–		C61300
C67500	Mn Bronze A	57.0–60.0	0.25 max	0.8–2.0	0.05–0.50	–	–	0.5–1.5	bal	–	0.20 max	–		C67500
C70600	90–10 Cu-Ni	bal		1.0–1.8	1.0 max	9.0–11.0	–	–	1.0 max	–	0.05 max	–		C70600
C83600	Ounce Metal	84.0–86.0	0.005 max	0.30 max	–	1.0 max	0.005 max	4.0–6.0	4.0–6.0	0.05 max	4.0–6.0	–	S0.08 max, Sb 0.20 max	C83600
C86500	Mn Bronze	55.0–60.0	0.50–1.5	0.40–2.0	0.10–1.5	1.00 max		1.0 max	36.0–42.0	–	0.40 max	–		C86500
C90500	Gun Metal	86.0–89.0	0.005 max	0.20 max	–	1.0 max	0.005 max	9.0–11.0	1.0–3.0	0.05 max	0.30 max	–	S0.05 max, Sb 0.20 max	C90500
C92200	M Bronze	86.0–90.0	0.005 max	0.25 max	–	1.0 max	0.005 max	5.5–6.5	3.0–5.0	0.05 max	1.00–2.00	–	S 0.05 max, Sb 0.25 max	C92200
C95700	Mn-Ni-Al Bronze	71.0 min	7.0–8.5	2.0–4.0	11.0–14.0	1.5–3.0	0.10 max	–	–	–	–	–		C95700
C95800	Ni-Al Bronze	79.0–81.0	8.5–9.5	3.5–4.5	0.8–1.5	4.5–5.0	0.10 max	–	–	–	0.03 max	–		C95800
C96400	Cast 70-30 Cu-Ni	bal	–	0.25–1.5	1.5 max	28.0–32.0	0.50 max	–	–	0.02 max	0.01 max	–	C 0.15 max, Nb 0.5–1.5, S 0.02 max	C96400
C17200	Copper-Beryllium	bal	0.20 max	0.60 max	–	0.20–.060	0.20 max	–	–	–	–	–	Be1.8–2.0, Co 0.20–0.60	C17200
C36000	Free-Cutting Brass	63.0–63.0	–	0.35 max	–	–	–	–	Rem	–	2.5–3.7	–	–	C36000
C89320		87.0–91.0	0.005 max	0.20 max	–	1.0 max	5.0–7.0	1.0 max	0.30 max	0.09 max	4.0–6.0		Sb 0.35 max, S 0.08 max	C89320
C89510	EnviroBrass I	86.0–88.0	0.005 max	0.20 max	–	1.0 max	0.005 max	4.0–6.0	4.0–6.0	0.05 max	0.25 max	0.50–1.5	Sb 0.25 max, Se 0.35–0.75, S 0.08	C89510
C89520	EnviroBrass II	85.0–87.0	0.005 max	0.20 max	–	1.0 max	0.005 max	5.0–6.0	4.0–6.0	0.05 max	0.25 max	1.6–2.2	Sb 0.25 max, Se 0.8–1.1, S 0.08 m	C89520
C89550	EnviroBrass III	58.0–64.0	0.10–6.0	0.50 max	–	1.0 max	0.25 max	0.00–1.2	32.0–38.0	0.01 max	0.10 max	0.6–1.2	Sb 0.05 max, Se 0.1–0.10, S 0.05	C89550
C89831		87.0–91.0	0.005 max	0.30 max	–	1.0 max	0.005 max	2.7–3.7	2.0–4.0	0.050 max	0.10 max	2.7–3.7	Sb 0.25 max, S0.08 max,	C89831
C89833		87.0–91.0	0.005 max	0.30 max	–	1.0 max	0.005 max	4.0–6.0	2.0–4.0	0.050 max	0.10 max	1.7–2.7	Sb 0.25 max, S0.08 max,	C89833
C89835		85.0–89.0	0.005 max	0.20 max	–	1.0 max	0.005 max	6.0–7.5	2.0–4.0	0.10 max	0.10 max	1.7–2.7	Sb 0.35 max, S0.08 max,	C89835
C89837		84.0–88.0	0.005 max	0.30 max	–	1.0 max	0.005 max	3.0–4.0	6.0–10.0	0.050 max	0.10 max	0.7–1.2	Sb 0.25 max, S0.08 max,	C89837
C89844		83.0–86.0	0.005 max	0.30 max	–	1.0 max	0.005 max	3.0–5.0	7.0–10.0	0.050 max	0.20 max	2.0–4.0	Sb 0.25 max, S0.08 max,	C89844

(*) Cu value includes Ag.

COPPER ALLOYS—Mechanical Properties

UNS #	Common Name	ASTM	Form	Temper	Size	YS-ksi(*)	TS-ksi	YS-MPa(*)	TS-MPa	Hardness	UNS #
C11000	ETP Copper	B 152/B 152M	Plate, Sheet	–	–	–	30–38	–	205–260	65 HRF max	C11000
C26000	Cartidge Brass	B 135	Tube	–	–	–	–	–	–	80 HRF max	C26000
C46500	Navel Brass	B 171/B171M	Plate, Sheet	M20-025	=< 3	–	–	–	–	–	C46500
C51000	Phosphors Bronze A	B 139	Bar	–	–	–	–	–	275–400	–	C51000
C52400	Phosphors Bronze D	B 139	Bar	–	–	–	–	–	415–515	–	C52400
C61300	Aluminum Bronze 7 %	B 171/B171M	Plate, Sheet	M20-O25	=< 2	37 min	–	255 min	520 min	–	C61300
C61400	Aluminium Bronze D	B 315	Pipe,Tube	M30-O61	–	–	–	193 min	447 min	–	C61400
C63000	Nickel Aluminum Bronze	B 171/B171 M	Plate, Sheet	M20-O25	=< 2	36 min	–	250 min	–	–	C63000
C65500	High-Silicon Bronze	B315	Pipe, Tube	O30-O61	–	–	–	–	–	–	C65500
C67500	Manganese Bronze A	B138	Bar	O60	–	–	–	–	–	–	C67500
C83600	Ounce Metal	B 62	Casting	M01	–	–	–	95 min	–	–	C83600
C90500	Gun Metal	B 584	Casting	M01	–	–	–	–	–	–	C90500
C10200	Oxygen FreeCu	B 152/B152 M	Plate, Sheet	O25	–	–	30–38	–	205–260	–	C10200
C12200	DHP Copper	B 111	Tube	H55	–	30 min	36 min	205 min	250 min	–	C12200
C14200	DPA Copper	B 111	Tube	H55	–	30 min	36 min	205 min	250 min	–	C14200
C17200	Copper-Beryllium	B 196	Bar	TF00	–	125 min(**)	150 min	860 min(**)	1034 min	32 HRC min	C17200
C60800	Al Bronze 6%	B 111	Tube	O61	–	19 min	50 min	130 min	345 min	–	C60800
C61300	Al Bronze 7%	B 315	Pipe, Tube	M30-O61	–	28 min	65 min	193 min	447 min	–	C61300
C61400	Al Bronze D	B 171/B171 M	Plate, Sheet	M20-O25	=< 2	30 min	70 min	205 min	485 min	–	C61400
C36000	Free-cutting Brass	B16/B16 M	Bar	O16	=< 1	20 min	48 min	140 min	330 min	–	C36000
C89320		B 505	Casting	M01	–	18 min	35 min	124 min	241 min	–	C89320
C89510	EnviroBrass I	B 584	Casting	M01	–	17 min	27 min	119 min	185 min	66 HB500	C89510
C89520	EnviroBrass II	B 584	Casting	M01	–	18 min	21 min	121 min	176 min	68 HB500	C89520
C89550	EnviroBrass III	–	Casting	M01	–	21 min	35 min	140 min	240 min	60 HB500	C89550
C89831		–	Casting	M01	–	15 typ	34 typ	103 typ	234 typ	55 HB500	C89831
C89833		–	Casting	M01	–	17 typ	37 typ	120 typ	255 typ	60 HB500	C89833
C89835		–	Casting	M01	–	18 typ	35 typ	124 typ	241 typ	65 HB500	C89835
C89837		–	Casting	M01	–	17 typ	37 typ	120 typ	255 typ	60 HB500	C89837
C89844		B 584	Casting	M01	–	13 min	28 min	90 min	193 min	–	C89844

(*) 0.5% Extension Under Load.
(**) 0.2% Offset.

CARBON AND LOW ALLOY STEELS—Composition, %

UNS	Common Name	C	Cr	Cu	Mn	Mo	Ni	P	S	Si	UNS
G10200	1020 Carbon Steel	0.17–0.23	–	–	0.30–0.60	–	–	0.040 max	0.050 max	–	G10200
G41300	4130 Steel	0.28–0.33	0.80–1.10	–	0.40–0.60	0.15–0.25	–	0.035 max	0.040 max	0.15–0.35	G41300
G43400	4340 Steel	0.38–0.43	0.70–0.90	–	0.60–0.80	0.20–0.30	1.65–2.00	0.035 max	0.040 max	0.15–0.30	G43400
K02001	A515–55 Steel	0.20 max	–	–	0.90 max	–	–	0.04 max	0.05 max	0.15–0.30	K02001
K02401	A515–60 Steel	0.24 max	–	–	0.90 max	–	–	0.04 max	0.05 max	0.15–0.30	K02401
K02800	A515–65 Steel	0.28 max	–	–	0.90 max	–	–	0.035 max	0.04 max	0.13–0.45	K02800
K03101	A515–70 Steel	0.31 max	–	–	0.90 max	–	–	0.035 max	0.04 max	0.13–0.33	K03101
K01800	A516-55 Steel	0.18 max	–	–	0.55–0.98	–	–	0.035 max	0.04 max	0.13–0.45	K01800
K02100	A516–60 Steel	0.21 max	–	–	0.55–0.98	–	–	0.035 max	0.04 max	0.13–0.45	K02100
K02403	A516–65 Steel	0.24 max	–	–	0.79–1.30	–	–	0.035 max	0.04 max	0.13–0.45	K02403
K02700	A516–70 Steel	0.27 max	–	–	0.79–1.30	–	–	0.035 max	0.04 max	0.13–0.45	K02700
K02801	A285–C Steel	0.28 max	–	–	0.90 max	–	–	0.035 max	0.40 max	–	K02801
K03005	A53–B Steel	0.30 max	–	–	1.20 max	–	–	0.05 max	0.06 max	–	K03005
K03006	A106–B Steel	0.30 max	–	–	0.29–1.06	–	–	0.048 max	0.058 max	0.10 min	K03006
K11510	0.2Cu Steel	0.15 max	–	0.20 min	1.00 max	–	–	0.15 max	0.05 max	–	K11510
K11576	HSLA Steel	0.10–0.20	0.40–0.65	0.15–0.50	0.60–1.00	0.40–0.60	0.70–1.00	0.035 max	0.040 max	0.15–0.35	K11576
K11522	C–0.5Mo Steel	0.10–0.20	–	–	0.30–0.80	0.44-0.65	–	0.045 max	0.045 max	0.10–0.50	K11522
K11597	1.25Cr–0.5Mo Steel	0.15 max	1.00–1.50	–	0.30–0.60	0.44–0.65	–	0.030 max	0.030 max	0.50–1.00	K11597
K21590	2.25Cr-1Mo Steel	0.15 max	2.00–2.50	–	0.30–0.60	0.90–1.10	–	0.030 max	0.030 max	0.50 max	K21590
K41545	5Cr-0.5Mo Steel	0.15 max	4.00–6.00	–	0.30–0.60	0.45–0.65	–	0.030 max	0.030 max	0.50 max	K41545
K81340	9Ni Steel	0.13 max	–	–	0.90 max	–	8.4–9.6	0.045 max	0.045 max	0.13–0.32	K81340
K90941	9Cr-1Mo Steel	0.15 max	8.0–10.0	–	0.30-0.60	0.90–1.10	–	0.030 max	0.030 max	0.50–1.00	K90941
S50300	7Cr-0.5Mo Steel	0.15 max	6.0-8.0	–	1.00 max	0.45–0.65	–	0.040 max	0.040 max	1.00 max	S50300
S50400	9Cr-1Mo Steel	0.15 max	8.0–10.0	–	1.00 max	0.90–1.10	–	0.040 max	0.040 max	1.00 max	S50400
K94610	Kovar	0.04 max	0.20 max	0.20 max	0.50 max	0.20 max	29. nom	–	–	0.20 max	K94610

CARBON AND LOW ALLOY STEELS—Mechanical Properties

UNS	Common Name	ASTM	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	UNS
G10200	1020 Carbon Steel	A519 Gr 1020	Tube	ANN	28 typ	48 typ	193 typ	331 typ	G10200
K02001	A515-55 Steel	A515 Gr 55	Plate	–	30 min	55–75	205 min	380–515	K02001
K02401	A515-60 Steel	A515 Gr 60	Plate	–	32 min	60–80	220 min	414–550	K02401
K02800	A515-65 Steel	A515 Gr 65	Plate	–	35 min	65–85	240 min	450–585	K02800
K03101	A515-70 Steel	A515 Gr 70	Plate	–	38 min	70–90	260 min	485–620	K03101
K01800	A516-55 Steel	A516 Gr 55	Plate	–	30 min	55–75	205 min	380–515	K01800
K02100	A516-60 Steel	A516 Gr 60	Plate	–	32 min	60–80	220 min	415–550	K02100
K02403	A516-65 Steel	A516 Gr 65	Plate	–	35 min	65–85	240 min	450–585	K02403
K02700	A516-70 Steel	A516 Gr 70	Plate	–	38 min	70–90	260 min	485–620	K02700
K02801	A285-C Steel	A285 Gr C	Plate	–	30 min	55–75	205 min	380–515	K02801
K03005	A53-B Steel	A53 Gr B	Pipe	–	35 min	60 min	240 min	414 min	K03005
K03006	A106-B Steel	A106 Gr B	Pipe	–	35 min	60 min	240 min	414 min	K03006
K11510	0.2Cu Steel	A242	Plate	–	50 min	70 min	345 min	480 min	K11510
K11576	HSLA Steel	A517 Gr F	Plate	QT	100 min	115-135	690 min	795-930	K11576
K11522	C-0.5Mo Steel	A335 Gr P1	Pipe	ANN, NT	30 min	55 min	207 min	379 min	K11522
K11597	1.25Cr-0.5Mo Steel	A335 Gr P11	Pipe	ANN, NT	30 min	60 min	207 min	414 min	K11597
K21590	2.25Cr-1Mo Steel	A335 Gr P22	Pipe	ANN, NT	30 min	60 min	207 min	414 min	K21590
K41545	5Cr-0.5Mo Steel	A335 Gr P5	Pipe	ANN, NT	30 min	60 min	207 min	414 min	K41545
K81340	9Ni Steel	A333 Gr 8	Pipe	QT, DNT	75 min	100 min	517 min	689 min	K81340
S50300	7Cr-0.5Mo Steel	A335 Gr P7	Pipe	ANN, NT	30 min	60 min	207 min	414 min	S50300
S50400	9Cr-1Mo Steel	A335 Gr P9	Pipe	ANN, NT	30 min	60 min	207 min	414 min	S50400

CAST IRONS—Composition, %

UNS	Common Name	C	Cr	Cu	Mn	Mo	Ni	Si	UNS
F10006	Gray Cast Iron	3.10–3.40	–	–	0.60–0.90	–	–	2.30–1.90	F10006
F20000	Malleable Cast Iron	2.20–2.90	–	–	0.15–1.25	–	–	0.90–1.90	F20000
F32800	Ductile Iron. 60-40-18	–	–	–	–	–	–	–	F32800
F41000	Ni-Resist Type 1	3.00 max	1.5–2.5	5.50–7.50	0.5–1.5	–	13.5–17.5	1.00–2.80	F41000
F41002	Ni-Resist Type 2	3.00 max	1.5–2.5	0.50 max	0.5–1.5	–	18.0–22.0	1.00–2.80	F41002
F41006	Ni-Resist Type 5	2.40 max	0.10 max	0.50 max	0.5–1.5	–	34.0–36.0	1.00–2.00	F41006
F43000	Ductile Ni-Resist Type D2	3.00 max	1.75–2.75	–	0.70–1.25	–	18.0–22.0	1.50–3.00	F43000
F43006	Ductile Ni-Resist Type D5	2.40 max	0.10 max	–	1.00 max	–	34.0–36.0	1.00–2.80	F43006
F47003	Duriron	0.70–1.10	0.50 max	0.50 max	1.50 max	0.50 max	–	14.20–14.75	F47003

CAST IRONS—Mechanical Properties

UNS	Common Name	ASTM	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	Hardness	UNS
F10006	Gray Cast Iron. G3000	A159	As cast	–	30 min	–	210 min	187–241 HB	F10006
F20000	Malleable Cast Iron. M3210	A602	ANN	32 min	50 min	221 min	345 min	156 HB max	F20000
F32800	Ductile Iron. 60-40-18	A395	–	40 min	60 min	276 min	414 min	143–187 HB	F32800
F41000	Ni-Resist Type 1	A436	As cast	–	25 min	–	172 min	131–183 HB	F41000
F41002	Ni-Resist Type 2	A436	As cast	–	25 min	–	172 min	118–174 HB	F41002
F41006	Ni-Resist Type 5	A436	As cast	–	20 min	–	138 min	99–124 HB	F41006
F43000	Ductile Ni-Resist Type D2	A439	As cast	30 min	58 min	207 min	400 min	139–202 HB	F43000
F43006	Ductile Ni-Resist Type D5	A439	As cast	30 min	55 min	207 min	379 min	131–185 HB	F43006

TOOL STEELS—Composition, %

UNS	Common Name	C	Mn	Si	Cr	Ni	Mo	W	V	Co
T11301	M1	0.78–0.88	0.15–0.40	0.20-0.50	3.5–4.0	0.30 max	8.2–9.2	1.4–2.1	1.0–1.25	–
T11330	M30	0.75–0.85	0.15–0.40	0.20–0.45	3.50–4.25	0.30 max	7.75–9.00	1.3–2.3	1.0–1.4	4.5–5.5
T11394	M44	1.10–1.20	0.20–0.40	0.30–0.55	4.0–4.75	0.30 max	6.0–7.0	5.0–5.75	1.85–2.20	11.0–12.2
T12001	T1	0.65–0.80	0.10–0.40	0.20–0.40	3.75–4.50	0.30 max	–	17.25–18.75	0.90–1.30	–
T12006	T6	0.75–0.85	0.20–0.40	0.20–0.40	4.0–4.75	0.30 max	0.40–1.0	18.50–21.0	1.5–2.1	11.0–13.0
T11350	M50	0.78–0.88	0.15–0.45	0.20-0.60	3.75–4.50	0.30 max	3.90–4.75	–	0.80–1.25	–
T20810	H10	0.35–0.45	0.25–0.70	0.80–1.20	3.0–3.75	0.30 max	2.00–3.00	–	0.25–0.75	–
T20826	H26	0.45–0.55	0.15–0.40	0.15–0.40	3.75–4.50	0.30 max	–	17.25–19.00	0.75–1.25	–
T20842	H42	0.55–0.70	0.15–0.40	0.15–0.40	3.75–4.50	0.30 max	4.5–5.5	5.50–6.75	1.75–2.20	–
T30110	A10	1.25–1.50	1.60–2.10	1.00–1.50	–	1.55–2.05	1.25–1.75	–	–	–
T30407	D7	2.15–2.50	0.60 max	0.60 max	11.5–13.5	0.30 max	0.70–1.20	–	3.80–4.40	–
T31507	O7	1.10–1.30	1.0 max	0.60 max	0.35–0.85	0.30 max	0.30 max	1.00–2.00	0.40 max	–
T41907	S7	0.45–0.55	0.20–0.90	0.20–1.00	3.00–3.50	–	1.30–1.80	–	0.20–0.30	–
T61206	L6	0.65–0.75	0.25–0.80	0.50 max	0.60–1.20	1.25–2.00	0.50 max	–	0.20–0.30	–
T51620	P20	0.28–0.40	0.60–1.00	0.20–0.80	1.4–2.0	–	0.30–0.55	–	–	–
T72305	W5	1.05–1.15	0.10–0.40	0.10–0.40	0.40–0.60	0.20 max	0.40 max	0.15 max	0.10 max	–

GENERAL PROPERTIES OF TOOL STEELS

	Major Factors[a]			Minor Factors				
AISI Designation	Wear Resistance[b]	Toughness[c]	Hot Hardness	Usual Working Hardness HRC	Depth of Hardening[d]	Finest grain Size at Full Hardness, Shepherd Standard	As-quenched Surface Hardness, HRC	Core Hardness (25 mm, or 1 in., diam. Round), HRC
M1	7	3	8	63–65	D	9.5	64–66	64–66
M30	7	2	8	63–65	D	9.5	64–66	64–66
M44	8	1	9	66–70	D	9.5	63–65	63–65
T1	7	3	8	63–65	D	9.5	64–66	64–66
T6	8	1	9	63–65	D	9.5	64–66	64–66
M50	6	3	6	61–63	D	8.5	63–65	63–65
H10	3	9	6	39–56	D	8	52–59	52–59
H26	6	4	8	50–58	D	9	51–59	51–59
H42	6	4	7	45–62	D	8.5	54–62	54–62
A10	3	3	3	55–62	D	8	60–63	60–63
D7	9	1	6	58–66	D	7.5	64–68	64–68
07	5	3	3	58–64	M	9	61–64	59–61
S7	3	8	5	47–57	D	8	59–61	59–61
L6	3	6	2	45–62	M	8	58–63	58–63
P20	1[e]	8	2[e]	30–50	M	7.5	52–54	45–50
W5	3–4	3–7	1	58–65	S	9	65–67	38–43

[a] Rating range from 1 (low) to 9 (high).
[b] Wear resistance increases with increasing carbon content.
[c] Toughness decreases with increasing carbon content and depth of hardening.
[d] S: Shallow, M: medium, and D: deep.
[e] After carburizing.

CAST HEAT RESISTANT STAINLESS STEELS—Composition, %

UNS	ACI	C	Cr	Ni	Mo	Si	Mn	UNS
J92603	HF	0.20–0.40	18.0–23.0	8.0–12.0	0.50 max	2.00 max	2.00 max	J92603
J92605	HC	0.50 max	26.0–30.0	4.00 max	0.50 max	2.00 max	1.00 max	J92605
J93005	HD	0.50 max	26.0–30.0	4.0–7.0	0.50 max	2.00 max	1.50 max	J93005
J93503	HH	0.20–0.50	24.0–28.0	11.0–14.0	0.50 max	2.00 max	2.00 max	J93503
J94003	HI	0.20–0.50	26.0–30.0	14.0–18.0	0.50 max	2.00 max	2.00 max	J94003
J94203	HK-30	0.25–0.35	23.0–27.0	19.0–22.0	–	1.75 max	1.50 max	J94203
J94204	HK-40	0.35–0.45	23.0–27.0	19.0–22.0	–	1.75 max	1.50 max	J94204
J94213	HN	0.20–0.50	19.0–23.0	23.0–27.0	0.50 max	2.00 max	2.00 max	J94213
J94224	HK	0.20–0.60	24.0–28.0	18.0–22.0	0.50 max	2.00 max	2.00 max	J94224
N08604	HL	0.20–0.60	28.0–32.0	18.0–22.0	0.50 max	2.00 max	2.00 max	N08604
N08002	HT	0.35–0.75	15.0–19.0	33.0–37.0	–	2.50 max	2.00 max	N08002
N08004	HU	0.35–0.75	17.0–21.0	37.0–41.0	0.50 max	2.50 max	2.00 max	N08004
N08705	HP	0.35–0.75	24.0–28.0	35.0–37.0	0.50 max	2.50 max	2.00 max	N08705
N08001	HW	0.35–0.75	10.0–14.0	58.0–62.0	–	2.50 max	2.00 max	N08001
N06006	HX	0.35–0.75	15.0–19.0	64.0–68.0	–	2.50 max	2.00 max	N06006

CAST HEAT RESISTANT STAINLESS STEELS—Mechanical Properties

UNS	ACI	ASTM	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	UNS
J92603	HF	A297	As cast	35 min	70 min	240 min	485 min	J92603
J92605	HC	A297	As cast	–	55 min	–	380 min	J92605
J93005	HD	A297	As cast	35 min	75 min	240 min	515 min	J93005
J93503	HH	A297	As cast	35 min	75 min	240 min	515 min	J93503
J94003	HI	A297	As cast	35 min	70 min	240 min	485 min	J94003
J94203	HK-30	A608	As cast	–	26 min*	–	179 min*	J94203
J94204	HK-40	A608	As cast	–	29 min*	–	200 min*	J94204
J94213	HN	A297	As cast	–	63 min	–	435 min	J94213
J94224	HK	A297	As cast	35 min	65 min	240 min	450 min	J94224
N08604	HL	A297	As cast	35 min	65 min	240 min	450 min	N08604
N08002	HT	A297	As cast	–	65 min	–	450 min	N08002
N08004	HU	A297	As cast	–	65 min	–	450 min	N08004
N08705	HP	A297	As cast	34 min	62.5 min	235 min	430 min	N08705
N08001	HW	A297	As cast	36 min	68 min	250 min	470 min	N08001
N06006	HX	A297	As cast	36 min	65 min	250 min	450 min	N06006

*At 1400 F (760°C)

CAST CORROSION RESISTANT STAINLESS STEELS—Composition, %

UNS	ACI	(AISI)	C	Cr	Ni	Mo	Cu	Si	Mn	UNS
J91150	CA-15	410	0.15 max	11.5–14.0	1.00 max	0.50 max	–	1.50 max	1.00 max	J91150
J91151	CA-15M	–	0.15 max	11.5–14.0	1.00 max	0.15–1.0	–	0.65 max	1.00 max	J91151
J91153	CA-40	420	0.20–0.40	11.5–14.0	1.00 max	0.5 max	–	1.50 max	1.00 max	J91153
J91540	CA-6NM	–	0.06 max	11.5–14.0	3.5–4.5	0.40–1.0	–	1.00 max	1.00 max	J91540
J91803	CB-30	431	0.30 max	18.0–21.0	2.00 max	–	–	1.50 max	1.00 max	J91803
J92500	CF-3	304L	0.03 max	17.0–21.0	8.0–12.0	–	–	2.00 max	1.50 max	J92500
J92600	CF-8	304	0.08 max	18.0–21.0	8.0–11.0	–	–	2.00 max	1.50 max	J92600
J92602	CF-20	302	0.20 max	18.0–21.0	8.0–11.0	–	–	2.00 max	1.50 max	J92602
J92615	CC-50	446	0.50 max	26.0–30.0	4.00 max	–	–	1.50 max	1.00 max	J92615
J92701	CF-16F	303	0.16 max	18.0–21.0	9.0–12.0	–	–	2.00 max	1.50 max	J92701
J92710	CF-8C	347	0.08 max	18.0–21.0	9.0–12.0	–	–	2.00 max	1.50 max	J92710
J92800	CF-3M, 3F	316L	0.03 max	17.0–21.0	9.0–13.0	2.0–3.0	–	1.50 max	1.50 max	J92800
J92900	CF-8M	316	0.08 max	18.0–21.0	9.0–12.0	2.0–3.0	–	2.00 max	1.50 max	J92900
J93000	CG-8M	317	0.08 max	18.0–21.0	9.0–13.0	3.0–4.0	–	1.50 max	1.50 max	J93000
J93001	CG-12	–	0.12 max	20.0–23.0	10.0–13.0	–	–	2.00 max	1.50 max	J93001
J93370	CD-4MCu	–	0.04 max	24.5–26.5	4.75–6.00	1.75–2.25	2.75–3.25	1.00 max	1.00 max	J93370
J93402	CH-20	309	0.20 max	22.0–26.0	12.0–15.0	–	–	2.00 max	1.50 max	J93402
J93423	CE-30	312	0.30 max	26.0–30.0	8.0–11.0	–	–	2.00 max	1.50 max	J93423
J94202	CK-20	310	0.20 max	23.0–27.0	19.0–22.0	–	–	2.00 max	2.00 max	J94202
N08007	CN-7M	–	0.07 max	19.0–22.0	27.5–30.5	2.0–3.0	3.0–4.0	1.50 max	1.50 max	N08007
–	CT-15C	–	0.15 max	19.0–21.0	31.0–34.0	(0.5–1.5 V)	–	1.50 max	1.50 max	–

CAST CORROSION RESISTANT STAINLESS STEELS—Mechanical Properties

UNS	ACI	ASTM	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	UNS
J91150	CA-15	A743	ACT	65 min	90 min	450 min	620 min	J91150
J91151	CA-15M	A743	ACT	65 min	90 min	450 min	620 min	J91151
J91153	CA-40	A743	ACT	70 min	100 min	485 min	690 min	J91153
J91540	CA-6NM	A487	QT	80 min	110–135	550 min	760–930	J91540
J91803	CB-30	A743	ANN	30 min	65 min	205 min	450 min	J91803
J92500	CF-3	A743	STQ	30 min	70 min	205 min	485 min	J92500
J92600	CF-8	A743	STQ	30 min	70 min	205 min	485 min	J92600
J92602	CF-20	A743	STQ	30 min	70 min	205 min	485 min	J92602
J92615	CC-50	A743	ANN	–	55 min	–	380 min	J92615
J92701	CF-16F	A743	STQ	30 min	70 min	205 min	485 min	J92701
J92710	CF-8C	A743	STQ	30 min	70 min	205 min	485 min	J92710
J92800	CF-3F	A743	STQ	30 min	70 min	205 min	485 min	J92800
J92900	CF-8M	A743	STQ	30 min	70 min	205 min	485 min	J92900
J93000	CG-8M	A743	STQ	35 min	75 min	240 min	520 min	J93000
J93001	CG-12	A743	STQ	28 min	70 min	195 min	485 min	J93001
J93370	CD-4MCu	A743	STQ	70 min	100 min	485 min	690 min	J93370
J93402	CH-20	A743	STQ	30 min	70 min	205 min	485 min	J93402
J93423	CE-30	A743	STQ	40 min	80 min	275 min	550 min	J93423
J94202	CK-20	A743	STQ	28 min	65 min	195 min	450 min	J94202
N08007	CN-7M	A743	STQ	25 min	62 min	170 min	425 min	N08007

AUSTENITIC STAINLESS STEELS—Composition, %

UNS	Common Name	C	Cr	Mn	Mo	N	Ni	P	S	Si	Other	UNS
S30200	302 SS	0.15 max	17.0–19.0	2.00 max	–	–	8.0–10.0	0.045 max	0.030 max	1.00 max	–	S30200
S30300	303 SS	0.15 max	17.0–19.0	2.00 max	–	–	8.0–10.0	0.20 max	0.15–0.35	1.00 max	–	S30300
S30400	304 SS	0.06 max	18.0–20.0	2.00 max	–	–	8.0–10.5	0.045 max	0.030 max	1.00 max	–	S30400
S30403	304L SS	0.03 max	18.0–20.0	2.00 max	–	–	8.0–12.0	0.045 max	0.030 max	1.00 max	–	S30403
S30409	304H SS	0.04–0.10	18.0–20.0	2.00 max	–	–	8.0–11.0	0.040 max	0.030 max	1.00 max	–	S30409
S30451	304N SS	0.06 max	18.0–20.0	2.00 max	–	0.10–0.16	8.0–10.5	0.045 max	0.030 max	1.00 max	–	S30451
S30453	304LN SS	0.030 max	18.0–20.0	2.00 max	–	0.10–0.16	8.0–12.0	0.045 max	0.030 max	1.00 max	–	S30453
S30500	305 SS	0.12 max	17.0–19.0	2.00 max	–	–	10.0–13.0	0.045 max	0.030 max	1.00 max	–	S30500
S30800	308 SS	0.06 max	19.0–21.0	2.00 max	–	–	10.0–12.0	0.045 max	0.030 max	1.00 max	–	S30800
S30815	253MA	0.10 max	20.0–22.0	0.80 max	–	0.14–0.20	10.0–12.0	0.040 max	0.030 max	1.40–2.00	Ce 0.03–0.08	S30815
S30900	309 SS	0.20 max	22.0–24.0	2.00 max	–	–	12.0–15.0	0.045 max	0.030 max	1.00 max	–	S30900
S30908	309S SS	0.06 max	22.0–24.0	2.00 max	–	–	12.0–15.0	0.045 max	0.030 max	1.00 max	–	S30908
S31000	310 SS	0.25 max	24.0–26.0	2.00 max	–	–	19.0–22.0	0.045 max	0.030 max	1.50 max	–	S31000
S31008	310S SS	0.08 max	24.0–26.0	2.00 max	–	–	19.0–22.0	0.045 max	0.030 max	1.50 max	–	S31008
S31254	254 SMO	0.020 max	19.5–20.5	1.00 max	6.0–6.5	0.18–0.22	17.5–18.5	0.030 max	0.010 max	0.80 max	Cu 0.50–1.00	S31254
S31400	314 SS	0.25 max	23.0–26.0	2.00 max	–	–	19.0–22.0	0.045 max	0.030 max	1.50–3.00	–	S31400
S31600	316 SS	0.08 max	16.0–18.0	2.00 max	2.0–3.0	–	10.0–14.0	0.045 max	0.030 max	1.00 max	–	S31600
S31603	316LSS	0.03 max	16.0–18.0	2.00 max	2.0–3.0	–	10.0–14.0	0.045 max	0.030 max	1.00 max	–	S31603
S31609	316H SS	0.04–0.10	16.0–18.0	2.00 max	2.0–3.0	–	10.0–14.0	0.040 max	0.030 max	1.00 max	–	S31609
S31635	316Ti SS	0.06 max	16.0–18.0	2.00 max	2.0–3.0	0.10 max	10.0–14.0	0.045 max	0.030 max	1.00 max	Ti 5XC + N-0.70	S31635
S31640	316Cb SS	0.08 max	16.0–18.0	2.00 max	2.0–3.0	0.10 max	10.0–14.0	0.045 max	0.030 max	1.50 max	–	S31640
S31651	316N SS	0.08 max	16.0–18.0	2.00 max	2.0–3.0	0.10–0.16	10.0–14.0	0.045 max	0.030 max	1.00 max	–	S31651
S31653	316LN SS	0.03 max	16.0–18.0	2.00 max	2.0–3.0	0.10–0.16	10.0–14.0	0.045 max	0.030 max	1.00 max	–	S31653
S31700	317 SS	0.08 max	18.0–20.0	2.00 max	3.0–4.0	–	11.0–15.0	0.045 max	0.030 max	1.00 max	–	S31700
S31703	317L SS	0.030 max	18.0–20.0	2.00 max	3.0–4.0	–	11.0–15.0	0.045 max	0.030 max	1.00 max	–	S31703
S31725	317LM SS	0.03 max	18.0–20.0	2.00 max	4.0–5.0	0.10 max	13.0–17.0	0.045 max	0.030 max	0.75 max	Cu 0.75 max	S31725
S31726	317L4 SS	0.03 max	17.0–20.0	2.00 max	4.0–5.0	0.10–0.20	13.5–17.5	0.045 max	0.030 max	0.75 max	Cu 0.75 max	S31726
S32100	321 SS	0.08 max	17.0–19.0	2.00 max	–	–	9.0–12.0	0.045 max	0.030 max	1.00 max	Ti 5XC min	S32100
S32109	321H SS	0.04–0.10	17.0–20.0	2.00 max	–	–	9.0–12.0	0.040 max	0.030 max	1.00 max	Ti 4XC-0.60	S32109
S34700	347 SS	0.08 max	17.0–19.0	2.00 max	–	–	9.0–13.0	0.045 max	0.030 max	1.00 max	Cb 10XC min	S34700
S34709	347H SS	0.04–0.10	17.0–20.0	2.00 max	–	–	9.0–13.0	0.040 max	0.030 max	1.00 max	Cb 8XC-1.00	S34709
S34800	348 SS	0.08 max	17.0–19.0	2.00 max	–	–	9.0–13.0	0.045 max	0.030 max	1.00 max	Cb 10XC min Co 0.20 max Ta 0.10 max	S34800
S38400	384 SS	0.08 max	17.0–19.0	2.00 max	–	–	17.5–18.5	0.045 max	0.030 max	1.50–2.50	–	S38400

AUSTENITIC STAINLESS STEELS—Mechanical Properties

UNS	Common Name	ASTM	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	UNS
S30200	302 SS	A240	Plate	STQ	30 min	75 min	205 min	515 min	S30200
S30300	303 SS	A320	Bolting	STQ	30 min	75 min	205 min	515 min	S30300
S30400	304 SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S30400
S30403	304L SS	A312	Pipe	STQ	25 min	70 min	170 min	485 min	S30403
S30409	304H SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S30409
S30451	304N SS	A312	Pipe	STQ	35 min	80 min	240 min	550 min	S30451
S30453	304LN SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S30453
S30500	305 SS	A249	Tube	STQ	30 min	75 min	205 min	515 min	S30500
S30800	308 SS	A473	Forging	STQ	30 min	75 min	205 min	515 min	S30800
S30815	253NA	A312	Pipe	STQ	45 min	87 min	310 min	600 min	S30815
S30900	309 SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S30900
S30908	309S SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S30908
S31000	310 SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S31000
S31008	310S SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S31008
S31254	254 SMO	A312	Pipe	STQ	44 min	94 min	300 min	650 min	S31254
S31400	314 SS	A473	Forging	STQ	30 min	75 min	205 min	515 min	S31400
S31600	316 SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S31600
S31603	316L SS	A312	Pipe	STQ	25 min	70 min	170 min	485 min	S31603
S31609	316H SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S31609
S31635	316Ti SS	A240	Plate	STQ	30 min	75 min	205 min	515 min	S31635
S31651	316N SS	A312	Pipe	STQ	35 min	80 min	240 min	550 min	S31651
S31653	316LN SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S31653
S31700	317 SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S31700
S31703	317LM SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S31703
S31725	317LM SS	A312	Tube	STQ	30 min	75 min	205 min	515 min	S31725
S31726	317L4 SS	A312	Pipe	STQ	35 min	80 min	240 min	550 min	S31726
S32100	321 SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S32100
S32109	321H SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S32109
S34700	347 SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S34700
S34709	347H SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S34709
S34800	348 SS	A312	Pipe	STQ	30 min	75 min	205 min	515 min	S34800
S38400	384 SS	A493	Wire	STQ	35 min	80 min	240 min	550 min	S38400

AUSTENITIC STAINLESS STEELS (High Mn)—Composition, %

UNS	Common Name	C	Cr	Mn	Mo	N	Ni	P	S	Si	Other	UNS
S20100	201 SS	0.15 max	16.0–18.0	5.5–7.5	–	0.25 max	3.5–5.5	0.060 max	0.030 max	1.00 max	–	S20100
S20200	202 SS	0.15 max	17.0–19.0	7.5–10.0	–	0.25 max	4.0–6.0	0.060 max	0.030 max	1.00 max	–	S20200
S20910	22-13-5 SS	0.06 max	20.5–23.5	4.0–6.0	1.50–3.0	0.20–0.40	11.5–13.5	0.040 max	0.030 max	1.00 max	Cb 0.10–0.30 V 0.10–0.30	S20910
S21400	Tenelon	0.12 max	17.0–18.5	14.5–16.0	–	0.35 max	0.75 max	0.045 max	0.030 max	0.30–1.00	–	S21400
S21600	216 SS	0.06 max	17.5–22.0	7.5–9.0	2.0–3.0	0.25–0.50	5.0–7.0	0.045 max	0.030 max	1.00 max	–	S21600
S21800	Nitronic 60	0.10 max	16.0–18.0	7.0–9.0	–	0.08–0.18	8.0–9.0	0.040 max	0.030 max	3.5–4.5	–	S21800
S21900	21-6-9 SS	0.08 max	19.0–21.5	8.0–10.0	–	0.15–0.40	5.5–7.5	0.060 max	0.030 max	1.00 max	–	S21900
S24000	18-3 Mn	0.08 max	17.0–19.0	11.5–14.5	–	0.20–0.40	2.50–3.75	0.060 max	0.030 max	1.00 max	–	S24000
S28200	18-8 Plus	0.15 max	17.0–19.0	17.0–19.0	0.50–1.50	0.40–0.60	–	0.045 max	0.030 max	1.00 max	Cu 0.50–1.50	S28200

AUSTENITIC STAINLESS STEELS (High Mn)—Mechanical Properties

UNS	Common Name	ASTM	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	UNS
S20100	201 SS	A412	Plate	STQ	38 min	95 min	260 min	655 min	S20100
S20200	202 SS	A473	Forging	STQ	45 min	90 min	310 min	620 min	S20200
S20910	22-13-5 SS	A312	Pipe	STQ	55 min	100 min	380 min	690 min	S20910
S21400	Tenelon	A240	Plate	STQ	70 min	125 min	485 min	860 min	S21400
S21600	216 SS	A479	Bar	STQ	50 min	90 min	345 min	620 min	S21600
S21800	Nitronic 60	A479	Bar	STQ	50 min	95 min	345 min	655 min	S21800
S21900	21-6-9 SS	A473	Forging	STQ	50 min	90 min	345 min	620 min	S21900
S24000	18-3 Mn	A312	Pipe	STQ	55 min	100 min	380 min	690 min	S24000
S28200	18-18 Plus	A473	Forging	STQ	60 min	110 min	410 min	760 min	S28200

MARTENSITIC STAINLESS STEELS—Composition, %

UNS	Common Name	C	Cr	Mn	Mo	Ni	P	S	Si	V	W	UNS
S40300	403 SS	0.15 max	11.5–13.0	1.00 max	–	–	0.040 max	0.030 max	0.50 max	–	–	S40300
S41000	410 SS	0.15 max	11.5–13.5	1.00 max	–	–	0.040 max	0.030 max	1.00 max	–	–	S41000
S41400	414 SS	0.15 max	11.5–13.5	1.00 max	–	1.25–2.50	0.040 max	0.030 max	1.00 max	–	–	S41400
S41600	416 SS	0.15 max	12.0–14.0	1.25 max	–	–	0.060 max	0.15 min	1.00 max	–	–	S41600
S41800	Greek Ascoloy	0.15–0.20	12.0–14.0	0.50 max	–	1.80–2.20	0.040 max	0.030 max	0.50 max	–	2.50–3.50	S41800
S42000	420 SS	0.15 min	12.0–14.0	1.00 max	–	–	0.040 max	0.030 max	1.00 max	-	-	S42000
S42200	422 SS	0.20–0.25	11.5–13.5	1.00 max	0.75–1.25	0.50–1.00	0.040 max	0.030 max	0.75 max	0.15–0.03	0.75–1.25	S42200
S42400	F6NM	0.06 max	12.0–14.0	0.50–1.00	0.30–0.70	3.50–4.50	0.03 max	0.03 max	0.30–0.60	–	–	S42400
S43100	431 SS	0.20 max	15.0–17.0	1.00 max	–	1.25–2.50	0.040 max	0.030 max	1.00 max	–	–	S43100
S44002	440A SS	0.60–0.75	16.0–18.0	1.00 max	0.75 max	–	0.040 max	0.030 max	1.00 max	–	–	S44002
S44003	440B SS	0.75–0.95	16.0–18.0	1.00 max	0.75 max	–	0.040 max	0.030 max	1.00 max	–	–	S44003
S44004	440C SS	0.95–1.20	16.0–18.0	1.00 max	0.75 max	–	0.040 max	0.030 max	1.00 max	–	–	S44004
S44020	440F SS	0.95–1.20	16.0–18.0	1.25 max	0.40 max	0.75	–	0.35 max	1.00 max	–	–	S44020

MARTENSITIC STAINLESS STEELS—Mechanical Properties

UNS	Common Name	ASTM	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	Hardness	UNS
S40300	403 SS	A176	Plate	–	30 min	70 min	205 min	485 min	88 HRB max	S40300
S41000	410 SS	A268	Tube	ANN	30 min	60 min	205 min	415 min	95 HRB max	S41000
S41400	414 SS	A473	Forging	OQT	90 min	115 min	620 min	795 min	321 HB max	S41400
S41600	416 SS	A473	Forging	ANN	40 min	70 min	275 min	485 min	223 HB max	S41600
S41800	Greek Ascoloy	A565	Forging	Q2T	110 min	140 min	760 min	965 min	302–352 HB	S41800
S42000	420 SS	A473	Forging	ANN	–	–	–	–	223 HB max	S42000
S42200	422 SS	A565	Forging	QT	110 min	140 min	760 min	965 min	302–352 HB	S42200
S42400	F6NM	A182	Forging	NT	90 min	110 min	620 min	760 min	235–285 HB	S42400
S43100	431 SS	A473	Forging	OQT	90 min	115 min	620 min	795 min	321 HB max	S43100
S44002	440A SS	A473	Forging	ANN	–	–	–	–	269 HB max	S44002
S44003	440B SS	A473	Forging	ANN	–	–	–	–	269 HB max	S44003
S44004	440C SS	A473	Forging	ANN	–	–	–	–	269 HB max	S44004
S44020	440F SS	A473	Forging	ANN	65 min	110 min	448 min	758 min	97 HRB max	S44020

FERRITIC STAINLESS STEELS—Composition, %

UNS	Common Name	C	Cr	Mn	Mo	N	Ni	P	S	Si	Other
S40500	405 SS	0.08 max	11.5–14.5	1.00 max	–	–	–	0.040 max	0.030 max	1.00 max	Al 0.10–0.30
S40900	409 SS	0.08 max	10.50–11.75	1.00 max	–	–	0.50 max	0.045 max	0.030 max	1.00 max	Ti 6XC – 0.75
S42900	429 SS	0.12 max	14.0–16.0	1.00 max	–	–	–	0.040 max	0.030 max	1.00 max	–
S43000	430 SS	0.12 max	16.0–18.0	1.00 max	–	–	–	0.040 max	0.030 max	1.00 max	–
S43400	434 SS	0.12 max	16.0–18.0	1.00 max	0.75–1.25	–	–	0.040 max	0.030 max	1.00 max	–
S43600	436 SS	0.12 max	16.0–18.0	1.00 max	0.75–1.25	–	–	0.040 max	0.030 max	1.00 max	Cb + Ta 5XC – 0.70
S44200	442 SS	0.20 max	18.0–23.0	1.00 max	–	–	–	0.040 max	0.030 max	1.00 max	–
S44400	18-2	0.025 max	17.5–19.5	1.00 max	1.75–2.50	0.025 max	1.00 max	0.040 max	0.030 max	1.00 max	Cb + Ti 0.20 + 4 (C + N) – 0.80
S44600	446 SS	0.20 max	23.0–27.0	1.50 max	–	0.25 max	–	0.040 max	0.030 max	1.00 max	–
S44625	26-1	0.01 max	25.0–27.5	0.40 max	0.75–1.50	0.015 max	0.50 max	0.020 max	0.020 max	0.40 max	Ni + Cu 0.50 max. Cu 0.20 max
S44626	26-1 Ti	0.06 max	25.0–27.0	0.75 max	0.75–1.50	0.04 max	0.50 max	0.040 max	0.020 max	0.75 max	Ti 0.20–1.00, 7X (C + N) min
S44627	26-1 Cb	0.010 max	25.0–27.0	0.40 max	0.75–1.50	0.015 max	0.50 max	0.020 max	0.020 max	0.40 max	Cb 0.05–0.20
S44635	26-4-4	0.025 max	24.5–26.0	1.00 max	3.50–4.50	0.035 max	3.50–4.50	0.040 max	0.030 max	0.75 max	Cb + Ti 0.20 + 4 (C + N) – 0.80
S44660	SC-1	0.025 max	25.0–27.0	1.00 max	2.50–3.50	0.035 max	1.50–3.50	0.040 max	0.030 max	1.00 max	Cb + Ti 0.20 + 4 (C + N) – 0.80
S44700	29-4	0.010 max	28.0–30.0	0.30 max	3.5–4.2	0.020 max	0.15 max	0.025 max	0.020 max	0.20 max	C + N 0.025 max
S44735	29-4C	0.030 max	28.0–30.0	1.00 max	3.60–4.20	0.045 max	1.00 max	0.040 max	0.030 max	1.00 max	Cb + Ti 6(C + N) 0.20-1.00
S44800	29-4-2	0.010 max	28.0–30.0	0.30 max	3.5–4.2	0.020 max	2.0–2.5	0.025 max	0.020 max	0.20 max	C + N 0.025 max, Cu 0.15 max

FERRITIC STAINLESS STEELS—Mechanical Properties

UNS	Common Name	ASTM	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	Hardness	UNS
S40500	405 SS	A268	Tube	ANN	30 min	60 min	205 min	415 min	95 HRB max	S40500
S40900	409 SS	A176	Plate	–	30 min	55 min	205 min	380 min	80 HRB max	S40900
S42900	429 SS	A268	Tube	ANN	35 min	60 min	240 min	415 min	90 HRB max	S42900
S43000	430 SS	A268	Tube	ANN	35 min	60 min	240 min	415 min	90 HRB max	S43000
S43400	434 SS		Plate	ANN	53 min	77 min	365 min	530 min	83 HRB max	S43400
S43600	436 SS		Sheet	ANN	53 min	77 min	365 min	530 min	83 HRB max	S43600
S44200	442 SS	A176	Plate	–	40 min	65 min	275 min	515 min	95 HRB max	S44200
S44400	18-2	A268	Tube	ANN	40 min	60 min	275 min	415 min	95 HRB max	S44400
S44600	446 SS	A268	Tube	ANN	40 min	70 min	275 min	485 min	95 HRB max	S44600
S44626	26-1 Ti	A268	Tube	ANN	45 min	68 min	310 min	470 min	100 HRB max	S44626
S44627	26-1 Cb	A268	Tube	ANN	40 min	65 min	275 min	450 min	90 HRB max	S44627
S44635	26-4.4	A268	Tube	ANN	75 min	90 min	515 min	620 min	27 HRC max	S44635
S44660	SC-1	A268	Tube	ANN	65 min	85 min	450 min	585 min	25 HRC max	S44660
S44700	29-4	A268	Tube	ANN	60 min	80 min	415 min	550 min	100 HRB max	S44700
S44735	29-4C	A268	Tube	ANN	60 min	75 min	415 min	515 min	100 HRB max	S44735
S44800	29-4-2	A268	Tube	ANN	60 min	80 min	415 min	550 min	100 HRB min	S44800

DUPLEX STAINLESS STEELS—Composition, %

UNS	Common Name	C	Cr	Cu	Mn	Mo	N	Ni	P	S	Si	W
S31200	44LN	0.030 max	24.0–26.0	–	2.00 max	1.2–2.0	0.14–0.20	5.5–6.5	0.045 max	0.030 max	1.00 max	
S31260	DP-3	0.030 max	24.0–26.0	0.20–0.80	1.00 max	2.5-3.5	0.10–0.30	5.5–7.5	0.030 max	0.030 max	0.75 max	0.10–0.50
S31500	3RE60	0.030 max	18.0–19.0	–	1.20–2.00	2.5–3.0	–	4.25–5.25	0.030 max	0.030 max	1.40–2.00	
S31803	2205 Alloy	0.030 max	21.0–23.0	–	2.0 max	2.5–3.5	0.08–0.20	4.5–6.5	0.030 max	0.020 max	1.00 max	
S32304	SAF 2304	0.030 max	21.5–24.5	0.05–0.60	2.50 max	0.05–0.60	0.05–0.20	3.0–5.5	0.040 max	0.040 max	1.0 max	
S32404	Uranus 50	0.04 max	20.5–22.5	1.0–2.0	2.0 max	2.0–3.0	0.20 max	5.5–8.5	0.030 max	0.010 max	1.0 max	
S32520	Uranus 52 N+	0.03 max	24.0–26.0	0.5–3.0	1.5 max	3–5	0.20–0.35	5.5–8.0	–	–	0.8 max	–
S32550	Ferralium 255	0.04 max	24.0–27.0	1.5–2.5	1.50 max	2.0–4.0	0.10–0.25	4.5–6.5	0.04 max	0.03 max	1.00 max	
S32750	SAF 2507	0.03 max	24–26	0.5	1.2 max	3–5	0.24–0.32	6–8	0.035 max	0.020 max	0.8 max	–
S32760	Zeron 100	–	25	0.7	1.0 max	3–5	0.25	6–8	0.035 max	0.010 max	0.8 max	0.7
S32900	329 SS	0.20 max	23.0–28.0	–	1.00 max	1.0–2.0	–	2.5–5.0	0.040 max	0.030 max	0.75 max	
S32950	7-Mo Plus	0.030 max	26.0–29.0	–	2.00 max	1.0–2.5	0.15–0.35	3.5–5.2	0.035 max	0.010 max	0.60 max	

DUPLEX STAINLESS STEELS—Mechanical Properties

UNS	Common Name	ASTM	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	Hardness	UNS
S31200	44LN	A790	Pipe	STQ	65 min	100 min	450 min	690 min	280 HB max	S31200
S31260	DP-3	A790	Pipe	STQ	64 min	92 min	440 min	630 min	30.5 HRC max	S31260
S31500	3RE60	A790	Pipe	STQ	64 min	92 min	440 min	630 min	30.5 HRC max	S31500
S31803	2205 Alloy	A790	Pipe	STQ	65 min	90 min	450 min	620 min	30.5 HRC max	S31803
S32304	SAF 2304	A790	Pipe	STQ	58 min	87 min	400 min	600 min	30.5 HRC max	S32304
S32550	Ferralium 255	A790	Pipe	STQ	80 min	110 min	550 min	760 min	31.5 HRC max	S32550
S32750	SAF 2507	A790	Pipe	STQ	80 min	116 min	550 min	800 min	270 HB max	S32750
S32760	Zeron 100	A790	Pipe	STQ	77 min	100 min	530 min	730 min	270 HB max	S32760
S32900	329 SS	A789	Tube	STQ	70 min	90 min	485 min	620 min	28 HRC max	S32900
S32950	7-Mo Plus	A790	Pipe	STQ	70 min	90 min	480 min	620 min	30.5 HRC max	S32950

PRECIPITATION-HARDENABLE STAINLESS STEELS—Composition, %

UNS	Common Name	C	Al	Cr	Cu	Mn	Mo	Ni	Si	P	S	Other
S13800	PH 13-8 Mo	0.05 max	0.90–1.35	12.25–13.25	–	0.20 max	2.00–2.50	7.50–8.50	0.10 max	0.01 max	0.008 max	N 0.01 max
S15500	15-5 PH	0.07 max	–	14.0–15.5	2.50–4.50	1.00 max	–	3.50–5.50	1.0 max	0.040 max	0.030 max	Cb 0.15–0.45
S15700	PH 15-7 Mo	0.09 max	0.75–1.50	14.0–16.0	–	1.00 max	2.00–3.00	6.50–7.75	1.00 max	0.04 max	0.03 max	–
S17400	17-4 PH	0.07 max	–	15.5–17.5	3.00–5.00	1.00 max	–	3.00–5.00	1.00 max	0.040 max	0.030 max	Cb 0.15–0.45
S17600	Stainless W	0.08 max	0.40 max	15.0–17.5	–	1.00 max	–	6.00–7.50	1.00 max	0.040 max	0.030 max	Ti 0.40–1.20
S17700	17-7 PH	0.09 max	0.75–1.50	16.0–18.0	–	1.00 max	–	6.50–7.75	1.00 max	0.040 max	0.040 max	–
S35000	AM 350	0.07–0.11	–	16.0–17.0	–	0.50–1.25	2.50–3.25	4.00–5.00	0.50 max	0.040 max	0.030 max	N 0.07–0.13
S35500	AM 355	0.10–0.15	–	15.0–16.0	–	0.50–1.25	2.50–3.25	4.00–5.00	0.50 max	0.040 max	0.030 max	N 0.07–0.13
S36200	Almar 362	0.05 max	0.10 max	14.0–15.0	–	0.50 max	–	6.00–7.00	0.30 max	0.30 max	0.030 max	Ti 0.55–0.90
S45000	Custom 450	0.05 max	–	14.0–16.0	1.25–1.75	1.00 max	0.50–1.00	5.00–7.00	1.00 max	0.030 max	0.030 max	Cb 8XC min
S45500	Custom 455	0.05 max	–	11.0–12.5	1.50–2.50	0.50 max	0.50 max	7.50–9.50	0.50 max	0.040 max	0.030 max	Cb 0.10–0.50 Ti 0.80–1.40
S66286	A286	0.08 max	0.35 max	13.5–16.0	–	2.00 max	1.00–1.50	24.0–27.0	1.00 max	0.040 max	0.030 max	Ti 1.90–2.35 V 0.10–0.50 B.001–0.01

PRECIPITATION-HARDENABLE STAINLESS STEELS—Mechanical Properties

UNS	Common Name	ASTM	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	Hardness	UNS
S13800	PH 13-8 Mo	A705	Forging	H1150	90 min	135 min	620 min	931 min	30 HRC min	S13800
S15500	15-5 PH	A705	Forging	H1150	105 min	135 min	725 min	930 min	28 HRC min	S15500
S15700	PH 15-7 Mo	A705	Forging	TH1050	160 min	180 min	1100 min	1240 min	375 HB min	S15700
S17400	17-4 PH	A705	Forging	H1150	105 min	135 min	725 min	930 min	28 HRC min	S17400
S17600	Stainless W	A705	Forging	H1050	150 min	170 min	1030 min	1170 min	35 HRC min	S17600
S17700	17-7 PH	A705	Forging	TH1050	140 min	170 min	965 min	1170 min	38 HRC min	S17700
S35500	AM 355	A705	Forging	H1000	155 min	170 min	1070 min	1170 min	37 HRC min	S35500
S36200	Almar 362	A705	Forging	IS	145 min	155 min	1000 min	1070 min	33 HRC min	S36200
S45000	Custom 450	A705	Forging	H1150	75 min	125 min	515 min	860 min	26 HRC min	S45000
S45500	Custom 455	A705	Forging	H1000	185 min	205 min	1275 min	1410 min	40 HRC min	S45500
S66286	A286	A638	Forging	STA	85 min	130 min	585 min	895 min	248 HB min	S66286

NICKEL ALLOYS—Mechanical Properties

UNS	Common Name	ASTM	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	Hardness	UNS
N02200	Nickel 200	B161	Pipe, Tube	ANN	15 min	55 min	105 min	380 min	–	N02200
N02201	Nickel 201	B161	Pipe, Tube	ANN	12 min	50 min	80 min	345 min	–	N02201
N04400	400 Alloy	B165	Pipe, Tube	ANN	28 min	70 min	195 min	480 min	–	N04400
N04405	R-405 Alloy	B164	Bar	ANN	25 min	70 min	170 min	480 min	–	N04405
N06600	600 Alloy	B167	Pipe, Tube	HR	30 min	80 min	205 min	550 min	–	N06600
N06690	690 Alloy	B167	Pipe, Tube	HR	30 min	85 min	205 min	586 min	–	N06690
N07750	X-750 Alloy	B637	Forging	STA	130 min	185 min	896 min	1276 min	27–40 HRC	N07750
N08330	RA-330	B535	Pipe	ANN	30 min	70 min	207 min	483 min	–	N08330
N08800	800 Alloy	B407	Pipe, Tube	ANN	25 min	65 min	170 min	450 min	–	N08800
N08810	800H Alloy	B407	Pipe, Tube	ANN	25 min	65 min	170 min	450 min	–	N08810
N10001	B Alloy	B333	Plate	STQ	45 min	100 min	315 min	690 min	–	N10001
N10665	B-2 Alloy	B333	Plate	STQ	51 min	110 min	352 min	758 min	100 HRB max	N10665

NICKEL ALLOYS—Composition, %

UNS	Common Name	Ni	Co	Cr	Cu	Fe	Mo	Al	C	Mn	UNS
N02200	Nickel 200	99.0 min	–	–	0.25 max	0.40 max	–	–	0.15 max	0.35 max	N02200
N02201	Nickel 201	99.0 min	–	–	0.25 max	0.40 max	–	–	0.02 max	0.35 max	N02201
N02230	Nickel 230	99.0 min	–	–	0.10 max	0.10 max	–	–	0.15 max	0.15 max	N02230
N04400	400 Alloy	63.0–70.0	–	–	bal	2.50 max	–	–	0.30 max	2.00 max	N04400
N04405	R-405 Alloy	63.0–70.0	–	–	bal	2.5 max	–	–	0.30 max	2.0 max	N04405
N05500	K-500 Alloy	63.0–70.0	–	–	bal	2.00 max	–	2.30–3.15	0.25 max	1.50 max	N05500
N05502	502 Alloy	63.0–70.0	–	–	bal	2.00 max	–	2.50–3.50	0.10 max	1.50 max	N05502
N06600	600 Alloy	72.0 min	–	14.0–17.0	0.50 max	6.0–10.0	–	–	0.15 max	1.00 max	N06600
N06601	601 Alloy	58.0–63.0	–	21.0–25.0	1.0 max	bal	–	1.0–1.7	0.1 max	1.0 max	N06601
N06690	690 Alloy	58.0 min	–	27.0–31.0	0.50 max	7.0–11.0	–	–	0.05 max	0.50 max	N06690
N07090	90 Alloy	bal	15.0–21.0	18.0–21.0	–	3.0 max	–	0.8–2.0	0.13 max	1.0 max	N07090
N07750	X-750 Alloy	70.0 min	–	14.0–17.0	0.5 max	5.0–9.0	–	0.40–1.0	0.08 max	1.0 max	N07750
N08330	RA-330	34.0–37.0	–	17.0–20.0	1.00 max	bal	–	–	0.08 max	2.00 max	N08330
N08800	800 Alloy	30.0–35.0	–	19.0–23.0	0.75 max	bal	–	0.15–0.60	0.10 max	1.5 max	N08800
N08801	801 Alloy	30.0–34.0	–	19.0–22.0	0.5 max	bal	–	–	0.10 max	1.5 max	N08801
N08810	800 H Alloy	30.0–35.0	–	19.0–23.0	0.75 max	bal	–	0.15–0.60	0.05–0.10	1.5 max	N08810
N08811	800HT Alloy	30.0–35.0	–	19.0–23.0	0.75 max	39.5 min	–	0.15–0.60	0.06–0.10	1.5 max	N08811
N09706	706 Alloy	39.0–44.0	–	14.5–17.5	0.30 max	bal	–	0.40 max	0.06 max	0.35 max	N09706
N10001	B Alloy	bal	2.50 max	1.00 max	–	6.00 max	26.0–33.0	–	0.12 max	1.00 max	N10001
N10665	B-2 Alloy	bal	1.00 max	1.00 max	–	2.00 max	26.0–30.0	–	0.020 max	1.00 max	N10665

NICKEL ALLOYS—Composition, % (*Continued*)

		Si	P	S	Ti	Other	
N02200	Nickel 200	0.35 max	–	0.010 max	–	–	N02200
N02201	Nickel 201	0.35 max	–	0.010 max	–	–	N02201
N02230	Nickel 230	0.010–0.035	–	0.008 max	0.005 max	Mg 0.04–0.08	N02230
N04400	400 Alloy	0.50 max	–	0.024 max	–	–	N04400
N04405	R-405 Alloy	0.50 max	–	0.025–0.06	–	–	N04405
N05500	K-500 Alloy	0.50 max	–	0.01 max	0.35–0.85	–	N05500
N05502	502 Alloy	0.5 max	–	0.010 max	0.50 max	–	N05502
N06600	600 Alloy	0.50 max	–	0.015 max	–	–	N06600
N06601	601 Alloy	0.50 max	–	0.015 max	–	–	N06601
N06690	690 Alloy	0.50 max	–	0.015 max	–	–	N06690
N07090	90 Alloy	1.5 max	–	–	1.8–3.0	–	N07090
N07750	X-750 Alloy	0.50 max	–	0.01 max	2.25–2.75	–	N07750
N08330	RA-330	0.75–1.50	0.03 max	0.03 max	–	Pb 0.005 max, Sn 0.025 max	N08330
N08800	800 Alloy	1.0 max	–	0.015 max	0.15–0.60	–	N08800
N08801	801 Alloy	1.0 max	–	0.015 max	0.75–1.5	–	N08801
N08810	800H Alloy	1.0 max	–	0.015 max	0.15–0.60	–	N08810
N08811	800HT Alloy	1.0 max	–	0.015 max	0.15–0.60	–	N08811
N09706	706 Alloy	0.35 max	0.020 max	0.015 max	1.5–2.0	B 0.006 max	N09706
N10001	B Alloy	1.00 max	0.040 max	0.030 max	–	V 0.60 max	N10001
N10665	B-2 Alloy	0.10 max	0.04 max	0.03 max	–	–	N10665

See also CrMo NICKEL ALLOYS, page 262.

CrMo NICKEL ALLOYS—Composition, %

UNS	Common Name	Ni	Co	Cr	Cu	Fe	Mo	Al	C	Mn	UNS
N06002	X Alloy	bal	0.5–2.5	20.5–23.0	–	17.0–20.0	8.0–10.0	–	0.05–0.15	1.00 max	N06002
N06007	G Alloy	bal	2.5 max	21.0–23.5	1.5–2.5	18.0–21.0	5.5–7.5	–	0.05 max	1.0–2.0	N06007
N06022	C-22 Alloy	bal	2.50 max	20.0–22.5	–	2.0–6.0	12.5–14.5	–	0.015 max	0.50 max	N06022
N06030	G-30 Alloy	bal	5.0 max	28.0–31.5	1.0–2.4	13.0–17.0	4.0–6.0	–	0.03 max	1.5 max	N06030
N06059	59 Alloy	bal	–	16	–	1.0 max	16	–	–	–	N06059
N06110	Allcor	bal	12.0 max	27.0–33.0	–	–	8.0–12.0	1.50 max	0.15 max	–	N06110
N06333	RA333 Alloy	44.0–47.0	2.50–4.00	24.0–27.0	0.50 max	bal	2.5–4.0	–	0.08 max	2.00 max	N06333
N06455	C-4 Alloy	bal	2.0 max	14.0–18.0	–	3.0 max	14.0–17.0	–	0.015 max	1.00 max	N06455
N06617	617 Alloy	44.5 min	10.0–15.0	20.0–24.0	0.50 max	3.0 max	8.0–10.0	0.80–1.50	0.05–0.15	1.00 max	N06617
N06625	625 Alloy	bal	–	20.0–23.0	–	5.0 max	8.0–10.0	0.40 max	0.10 max	0.50 max	N06625
N06686	686 Alloy	bal	–	19.0–23.0	–	1.0 max	15.0–17.0	–	0.01 max	0.75 max	N06686
N06690	690 Alloy	bal	–	27–31	0.5 max	7–11	–	–	0.05 max	0.5 max	N06690
N06975	2550 Alloy	47.0–52.0	–	23.0–26.0	0.70–1.20	bal	5.0–7.0	–	0.03 max	1.00 max	N06975
N06985	G-3 Alloy	bal	5.0 max	21.0–23.5	1.5–2.5	18.0–21.0	6.0–8.0	–	0.015 max	1.00 max	N06985
N07001	Waspaloy	bal	12.0–15.0	18.0–21.0	0.50 max	2.00 max	3.5–5.0	1.20–1.60	0.03–0.10	1.00 max	N07001
N07031	Alloy 31	55.0–58.0	–	22.0–23.0	0.60–1.20	bal	1.70–2.30	1.00–1.70	0.03–0.06	0.20 max	N07031
N07041	Rene 41	bal	10.0–12.0	18.0–20.0	–	5.00 max	9.0–10.5	1.40–1.80	0.12 max	0.10 max	N07041
N07716	625 Plus	59.0–63.0	–	19.0–22.0	–	bal	7.0–9.5	0.35 max	0.03 max	0.20 max	N07716
N07718	718 Alloy	50.0–55.0	1.00 max	17.0–21.0	0.30 max	bal	2.80–3.30	0.20–0.80	0.08 max	0.35 max	N07718
N07725	725 Alloy	55.0–59.0	–	19.0–22.5	–	bal	7.0–9.5	0.35 max	0.03 max	0.35 max	N07725
N08020	20Cb-3	32.0–38.0	–	19.0–21.0	3.00–4.00	bal	2.00–3.00	–	0.07 max	2.00 max	N08020
N08024	20Mo-4	35.0–40.0	–	22.5–25.0	0.50–1.50	bal	3.50–5.00	–	0.03 max	1.00 max	N08024
N08026	20Mo-6	33.0–37.2	–	22.0–26.0	2.00–4.00	bal	5.00–6.70	–	0.030 max	1.00 max	N08026
N08028	Sanicro 28	29.5–32.5	–	26.0–28.0	0.6–1.4	bal	3.0–4.0	–	0.030 max	2.50 max	N08028
N08320	20 Mod	25.0–27.0	–	21.0–23.0	–	bal	4.0–6.0	–	0.05 max	2.5 max	N08320
N08366	AL-6X	23.5–25.5	–	20.0–22.0	–	bal	6.0–7.0	–	0.035 max	2.00 max	N08366
N08367	AL-6XN	23.5–25.5	–	20.0–22.0	–	bal	6.00–7.00	–	0.030 max	2.00 max	N08367
N08700	JS700	24.0–26.0	–	19.0–23.0	0.50 max	bal	4.3–5.0	–	0.04 max	2.00 max	N08700
N08825	825 Alloy	38.0–46.0	–	19.5–23.5	1.5–3.0	bal	2.5–3.5	0.2 max	0.05 max	1.0 max	N08825
N08904	904L Alloy	23.0–28.0	–	19.0–23.0	1.0–2.0	bal	4.0–5.0	–	0.020 max	2.00 max	N08904
N08925	25–6Mo	24.0–26.0	–	19.0–21.0	0.05–1.50	bal	6.0–7.0	–	0.20 max	1.00 max	N08925
N09925	925 Alloy	38.0–46.0	–	19.5–23.5	1.50–3.00	20.0 min	2.50–3.50	0.10–0.50	0.03 max	1.00 max	N09925
N10002	C Alloy	bal	2.5 max	14.5–16.5	–	4.0–7.0	15.0–17.0	–	0.08 max	1.00 max	N10002
N10003	N Alloy	bal	0.20 max	6.0–8.0	0.35 max	5.00 max	15.0–18.0	0.50 max	0.04–0.08	1.00 max	N10003
N10004	W Alloy	bal	–	4.0–6.0	–	4.0–7.0	23.0–26.0	–	0.12 max	1.00 max	N10004
N10276	C-276 Alloy	bal	2.5 max	14.5–16.5	–	4.0–7.0	15.0–17.0	–	0.02 max	1.0 max	N10276

CrMo NICKEL ALLOYS—Composition, % (*Continued*)

		Si	P	S	B	Ti	Cb	V	W	N	Zr	
N06002	X Alloy	1.00 max	0.040 max	0.030 max	–	–	–	–	0.20–1.0	–	–	N06002
N06007	G Alloy	1.0 max	0.04 max	0.03 max	–	–	–	–	1.0 max	–	–	N06007
N06022	C-22 Alloy	0.08 max	0.02 max	0.02 max	–	–	–	0.35 max	2.5–3.5	–	–	N06022
N06030	G-30 Alloy	0.8 max	0.04 max	0.02 max	–	–	–	–	1.5–4.0	–	–	N06030
N06110	Allcor	–	–	–	–	1.50 max	–	–	4.00 max	–	–	N06110
N06333	RA333 Alloy	0.75–1.50	0.030 max	0.30 max	–	–	–	–	2.50–4.00	–	–	N06333
N06455	C-4 Alloy	0.08 max	0.04 max	0.03 max	–	0.70 max	–	–	–	–	–	N06455
N06617	617 Alloy	1.00 max	–	0.015 max	0.006 max	0.60 max	–	–	–	–	–	N06617
N06625	625 Alloy	0.50 max	0.015 max	0.015 max	–	0.40 max	3.15–4.15	–	–	–	–	N06625
N06975	2550 Alloy	1.00 max	0.03 max	0.03 max	–	0.70–1.50	–	–	–	–	–	N06975
N06985	G-3 Alloy	1.00 max	0.04 max	0.03 max	–	–	0.50 max*	–	1.5 max	–	–	N06985
N07001	Waspaloy	0.75 max	0.030 max	0.030 max	0.003–0.01	2.75–3.25	–	–	–	–	0.02–0.12	N07001
N07031	Alloy 31	0.20 max	0.015 max	0.015 max	0.003–0.007	2.10–2.60	–	–	–	–	–	N07031
N07041	Rene 41	0.50 max	–	0.015 max	0.003–0.010	3.00–3.30	–	–	–	–	–	N07041
N07716	625 Plus	0.20 max	0.015 max	0.010 max	–	1.00–1.60	2.75–4.00	–	–	–	–	N07716
N07718	718 Alloy	0.35 max	0.015 max	0.015 max	0.006 max	0.65–1.15	4.75–5.50	–	–	–	–	N07718
N08020	20Cb-3	1.00 max	0.045 max	0.035 max	–	–	–	–	–	–	–	N08020
N08024	20Mo-4	0.50 max	0.035 max	0.035 max	–	–	–	–	–	–	–	N08024
N08026	20Mo-6	0.50 max	0.03 max	0.03 max	–	–	–	–	–	–	–	N08026
N08028	Sanicro 28	1.00 max	0.030 max	0.030 max	–	–	–	–	–	–	–	N08028
N08320	20 Mod	1.0 max	0.04 max	0.03 max	–	4 × C min	–	–	–	–	–	N08320
N08366	AL-6X	1.00 max	0.030 max	0.030 max	–	–	–	–	–	–	–	N08366
N08367	AL-6XN	1.00 max	0.040 max	0.030 max	–	–	–	–	–	0.18–0.25	–	N08367
N08700	JS700	1.00 max	0.04 max	0.03 max	–	–	–	–	–	–	–	N08700
N08825	825 Alloy	0.5 max	–	0.03 max	–	0.6–1.2	–	–	–	–	–	N08825
N08904	904L Alloy	1.00 max	0.045 max	0.035 max	–	–	–	–	–	–	–	N08904
N08925	25-6Mo	0.50 max	0.045 max	0.030 max	–	–	–	–	–	0.10–0.20	–	N08925
N09925	925 Alloy	0.50 max	–	0.03 max	–	1.90–2.40	–	–	–	–	–	N09925
N10002	C Alloy	1.00 max	0.040 max	0.030 max	–	–	–	0.35 max	3.0–4.5	–	–	N10002
N10003	N Alloy	1.00 max	0.015 max	0.020 max	0.010 max	–	–	0.50 max	0.50 max	–	–	N10003
N10004	W Alloy	1.00 max	0.050 max	0.050 max	–	–	–	0.60 max	–	–	–	N10004
N10276	C-276 Alloy	0.05 max	0.030 max	0.030 max	–	–	–	0.35 max	3.0–4.5	–	–	N10276
N06690	690 Alloy	0.5 max	0.007 max	0.015 max	–	–	–	–	–	–	–	N06690
N07725	725 Alloy	0.20 max	0.315 max	0.010 max	–	–	2.75–4.0	–	–	–	–	N07725
N06686	686 Alloy	0.08 max	0.04 max	0.02 max	–	0.02–0.25	–	–	3.0–4.4	–	–	N06686

*Cb + Ta.

See also NICKEL ALLOYS, page 259.

CrMo NICKEL ALLOYS—Mechanical Properties

UNS	Common Name	ASTM	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	Hardness	UNS
N06002	X Alloy	B435	Plate	STQ	35 min	95 min	240 min	660 min	–	N06002
N06007	G Alloy	B582	Plate	STQ	35 min	90 min	241 min	621 min	100 HRB max	N06007
N06022	C-22 Alloy	B575	Plate	STQ	45 min	100 min	310 min	690 min	100 HRB max	N06022
N06030	G-30 Alloy	B622	Pipe, Tube	STQ	35 min	85 min	241 min	586 min	–	N06030
N06333	RA333 Alloy	B722	Pipe, Tube	ANN	35 min	80 min	241 min	551 min	75–95 HRB	N06333
N06455	C-4 Alloy	B575	Plate	STQ	40 min	100 min	276 min	690 min	100 HRB max	N06455
N06625	625 Alloy	B444	Pipe, Tube	ANN	60 min	120 min	414 min	827 min	–	N06625
N06686	686 Alloy	B575	Plate	ANN	53 min	105 min	364 min	722 min	–	N06686
N06690	690 Alloy	B564	Plate	STQ	41 min	103 min	283 min	714 min	88 HRB max	N06690
N06975	2550 Alloy	B582	Plate	STQ	32 min	85 min	221 min	586 min	100 HRB max	N06975
N06985	G-3 Alloy	B582	Plate	STQ	35 min	90 min	241 min	621 min	100 HRB max	N06985
N07718	718 Alloy	B637	Forging	STA	150 min	185 min	1034 min	1275 min	331 HB min	N07718
N07725	725 Alloy	B575	Plate	ANN	62 min	124 min	427 min	855 min	–	N07725
N08020	20Cb-3	B464	Pipe	ANN	35 min	80 min	241 min	551 min	–	N08020
N08024	20Mo-4	B464	Pipe	ANN	35 min	80 min	241 min	551 min	–	N08024
N08026	20Mo-6	B464	Pipe	STQ	35 min	80 min	241 min	551 min	–	N08026
N08028	Sanicro 28	B668	Tube	STQ	31 min	73 min	214 min	500 min	–	N08028
N08320	20 Mod	B622	Pipe, Tube	STQ	28 min	75 min	193 min	517 min	–	N08320
N08366	AL-6X	B690	Pipe	STQ	30 min	75 min	206 min	517 min	–	N08366
N08367	AL-6XN	B690	Pipe	STQ	46 min	104 min	317 min	717 min	–	N08367
N08700	JS700	B599	Plate	STQ	35 min	80 min	240 min	550 min	75–90 HRB	N08700
N08825	825 Alloy	B423	Pipe, Tube	ANN	25 min	75 min	172 min	517 min	–	N08825
N08904	904L Alloy	B677	Pipe, Tube	STQ	31 min	71 min	220 min	490 min	–	N08904
N08925	25-6Mo	B677	Pipe, Tube	STQ	43 min	87 min	300 min	600 min	–	N08925
N10003	N Alloy	B434	Plate	ANN	40 min	100 min	280 min	690 min	–	N10003
N10276	C-276 Alloy	B575	Plate	STQ	41 min	100 min	283 min	690 min	100 HRB max	N10276

COBALT ALLOYS—Composition, %

UNS	Common Name	Co	Ni	Cr	Fe	Mo	W	C	Mn	Si	UNS
R30003	Elgiloy	39.0–41.0	15.0–16.0	19.0–21.0	bal	6.0–8.0	–	0.15 max	1.5–2.5	–	R30003
R30004	Havar	41.0–44.0	12.0–14.0	19.0–21.0	bal	2.0–2.8	2.3–3.3	0.17–0.23	1.35–1.80	–	R30004
R30006	Stellite 6	bal	3.0 max	27.0–31.0	3.0 max	1.5 max	3.5–5.5	0.9–1.4	1.0 max	1.5 max	R30006
R30031	Stellite 31	bal	9.5–11.5	24.5–26.5	2.0 max	–	7.0–8.0	0.45–0.55	1.0 max	1.00 max	R30031
R30035	MP35N	bal	33.0–37.0	19.0–21.0	1.0 max	9.0–10.5	–	0.025 max	0.15 max	0.15 max	R30035
R30155	N-155	18.5–21.0	19.0–21.0	20.0–22.5	bal	2.5–3.5	2.0–3.0	0.08–0.16	1.0–2.0	1.00 max	R30155
R30188	HS-188	bal	20.0–24.0	20.0–24.0	3.0 max	–	13.0–16.0	0.05–0.15	1.25 max	0.20–0.50	R30188
R30260	Duratherm 2602	–	bal	11.7–12.3	9.8–10.4	3.7–4.3	3.6–4.2	0.05 max	0.4–1.1	–	R30260
R30556	HS-556	16.0–21.0	19.0–22.5	21.0–23.0	bal	2.5–4.0	2.0–3.5	0.05–0.15	0.5–2.0	0.20–0.80	R30556
R30605	L-605	bal	9.0–11.0	19.0–21.0	3.0 max	–	14.0–16.0	0.05–0.15	2.0 max	1.00 max	R30605

		Be	Cb	Cu	La	Sn	Ti	P	S	Other	
R30003	Elgiloy	1.00 max	–	–	–	–	–	–	–	–	R30003
R30004	Havar	0.02–0.06	–	–	–	–	–	–	–	–	R30004
R30006	Stellite 6	–	–	–	–	–	–	–	–	–	R30006
R30031	Stellite 31	–	–	–	–	–	–	–	–	–	R30031
R30035	MP35N	–	–	–	–	–	1.00 max	0.015 max	0.010 max	–	R30035
R30155	N-155	–	0.75–1.25	–	–	–	–	0.040 max	0.030 max	–	R30155
R30188	HS-188	–	–	–	0.03–0.15	–	–	–	–	–	R30188
R30260	Duratherm 2602	0.20–0.30	0.10 max	0.30 max	–	0.20–0.60	0.80–1.20	–	–	–	R30260
R30556	HS-556	–	0.30 max	–	0.005–0.10	–	–	0.04 max	0.015 max	Al 0.10–0.50 B 0.02 max N 0.10–0.30 Ta 0.30–1.25 Zr 0.001–0.10	R30556
R30605	L-605	–	–	–	–	–	–	–	–	–	R30605

COBALT ALLOYS—Mechanical Properties

UNS	Common Name	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	Hardness	UNS
R30155	N-155	Forging	STA	50 min	110 min	345 min	760 min	192 HB min	R30155
R30605	L-605	Bar	ANN	45 min	125 min	310 min	860 min	–	R30605
R30003	Elgiloy	Sheet	ANN	70 min	100 min	480 min	690 min	–	R30003
R30016	Stellite 6B	Sheet	AC	92 min	146 min	635 min	1010 min	40 HRC	R30016
R30035	MP35 N	Bar	AC	235 min	294 min	1620 min	2025 min	90 HRB	R30035
R30159	MP159	Bar	AC	265 min	275 min	1825 min	1895 min	–	R30159
–	HS150	Sheet	ANN	46 min	134 min	317 min	925 min	–	–
R30188	HS188	Sheet	AC	70 min	139 min	485 min	960 min	98 HRC	R30188
–	MAR-M918	Sheet	AC	130 min	135 min	895 min	930 min	–	–
R31233	Ultimet	Sheet	AC	79 min	148 min	545 min	1021 min	30 HRC	R31233

REFRACTORY ALLOYS—Composition, %

UNS	Common Name	Cb	Mo	Ta	W	Zr	C	Fe	Ni	UNS
R03600	Molybdenum	–	bal	–	–	–	0.01–0.04	0.010 max	0.005 max	R03600
R03630	Molybdenum alloy	–	bal	–	–	0.06–0.12	0.01–0.4	0.010 max	0.005 max	R03630
R03650	Molybdenum, low C	–	bal	–	–	–	0.010 max	0.010 max	0.005 max	R03650
R04210	Columbium	bal	0.005 max	0.2 max	0.05 max	0.01 max	0.01 max	0.01 max	0.005 max	R04210
R05200	Tantalum	0.05 max	0.01 max	bal	0.03 max	–	0.01 max	0.01 max	0.01 max	R05200
R07005	Tungsten	–	–	–	99.95 min	–	–	–	–	R07005
R60702	Zr 702	–	–	–	–	–Hf99.2 min	0.05 max	+Cr 0.2 max	–	R60702
R60704	Zr 704	–	–	–	–	–Hf97.5 min	0.05 max	+Cr 0.20–0.40	–	R60704
R60705	Zr 705	2.0–3.0	–	–	–	–Hf95.5 min	0.05 max	–	–	R60705

UNS	Common Name	H	N	D	Si	Other	UNS
R03600	Molybdenum	–	0.0010 max	0.0030 max	0.010 max	–	R03600
R03630	Molybdenum alloy	–	0.001 max	0.003 max	0.010 max	–	R03630
R03650	Molybdenum, low C	–	0.001 max	0.003 max	0.010 max	–	R03650
R04210	Columbium	0.001 max	0.01 max	0.025 max	0.005 max	Hf0.01 max	R04210
R05200	Tantalum	0.001 max	0.01 max	0.015 max	0.005 max	–	R05200
R07005	Tungsten	–	–	–	–	ea 0.01 max. for 0.05 max	R07005
R60702	Zr 702	0.005 max	0.025 max	–	–	Hf 4.5 max	R60702
R60704	Zr 704	0.005 max	0.025 max	–	–	Hf 4.5 max; Sn 1.00–2.00	R60704
R60705	Zr 705	0.005 max	0.025 max	0.018 max	–	Hf 4.5 max	R60705

REFRACTORY ALLOYS—Mechanical Properties

UNS	Common Name	ASTM	Form	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	UNS
R03600	Molybdenum	B386	Plate	RX	25 min	55 min	170 min	380 min	R03600
R03630	Molybdenum alloy	B386	Plate	SRA	100 min	120 min	690 min	830 min	R03630
R03650	Molybdenum, low C	B386	Plate	SRA	80 min	100 min	550 min	690 min	R03650
R04210	Columbium	B394	Tube	ANN	12 min	18 min	85 min	125 min	R04210
R05200	Tantalum	B365	Rod	–	20 min	25 min	138 min	172 min	R05200
R60702	Zr 702	B523	Tube	ANN	30 min	55 min	207 min	380 min	R60702

TITANIUM ALLOYS—Composition, %

UNS #	ASTM Grade	Al	C	Fe	H	Mo	N	O	Other	UNS #
R50250	Titanium, Gr 1	–	0.10 max	0.20 max	0.015 max	–	0.03 max	0.18 max	–	R50250
R50400	Titanium, Gr 2	–	0.10 max	0.30 max	0.015 max	–	0.03 max	0.25 max	–	R50400
R50550	Titanium, Gr 3	–	0.10 max	0.30 max	0.015 max	–	0.05 max	0.35 max	–	R50550
R50700	Titanium, Gr 4	–	0.10 max	0.50 max	0.015 max	–	0.05 max	0.40 max	–	R50700
R56400	Titanium, Gr 5	5.5–6.75	0.10 max	0.40 max	0.015 max	–	0.05 max	0.20 max	V 3.5–4.5	R55400
R54250	Titanium, Gr 6	4.0–6.0	0.10 max	0.50 max	0.020 max	6	0.05 max	0.20 max	Sn 2.0–3.0	R54250
R52400	Titanium, Gr 7	–	0.10 max	0.30 max	0.015 max	–	0.03 max	0.25 max	Pd 0.12–0.25	R52400
R56320	Titanium, Gr 9	2.5–3.5	0.05 max	0.25 max	0.013 max	–	0.02 max	0.12 max	V 2.0–3.0	R56320
R52250	Titanium, Gr 11	–	0.10 max	0.20 max	0.015 max	–	0.03 max	0.18 max	Pd 0.12–0.25	R52250
R53400	Titanium, Gr 12	–	0.08 max	0.30 max	0.015 max	0.2–0.4	0.03 max	0.25 max	Ni 0.6–0.9	R53400
R53413	Titanium, Gr 13	–	0.08 max	0.20 max	0.015 max	–	0.03 max	0.10 max	Ni 0.4–0.6, Ru 0.04–0.06	R53413
R53414	Titanium, Gr 14	–	0.08 max	0.30 max	0.015 max	–	0.03 max	0.15 max	Ni 0.4–0.6, Ru 0.04–0.06	R53414
R53415	Titanium, Gr 15	–	0.08 max	0.30 max	0.015 max	–	0.05 max	0.25 max	Ni 0.4–0.6, Ru 0.04–0.06	R53415
R52402	Titanium, Gr 16	–	0.08 max	0.30 max	0.015 max	–	0.03 max	0.25 max	Pd 0.0.04–0.08	R52402
R52252	Titanium, Gr 17	–	0.08 max	0.20 max	0.015 max	–	0.03 max	0.18 max	Pd 0.0.04–0.08	R52252
R56322	Titanium, Gr 18	2.5–3.5	0.08 max	0.25 max	0.015 max	–	0.03 max	0.15 max	V 2.0–3.0, Ru 0.04–0.08	R56322
R58640	Titanium, Gr 19	3.0–4.0	0.05 max	0.30 max	0.02 max	3.5–4.5	0.03 max	0.12 max	V 7.5–8.5, Cr 5.5–6.5, Zr 3.5–4.5	R58640
R58645	Titanium, Gr 20	3.0–4.0	0.05 max	0.30 max	0.02 max	0.5–4.5	0.03 max	0.12 max	V 7.5–8.5, Cr 5.5–6.5, Zr 3.5–4.5, Pd 0.04–0.08	R58645
R58210	Titanium, Gr 21	2.5–3.5	0.05 max	0.40 max	0.015 max	14.0–16.0	0.03 max	0.17 max	Nb 2.2–3.2, Si 0.15–0.25	R58210
R56407	Titanium, Gr 23	5.5–6.5	0.08 max	0.25 max	0.0125 max	–	0.03 max	0.13 max	V 3.5–4.5	R56407
R56405	Titanium, Gr 24	5.5–6.75	0.08 max	0.40 max	0.015 max	–	0.05 max	0.20 max	V 3.5–4.5, Pd 0.04–0.08	R56405
R56403	Titanium, Gr 25	5.5–6.75	0.08 max	0.40 max	0.0125 max	–	0.05 max	0.20 max	V 3.5–4.5, Pd 0.04–0.08, Ni 0.03–0.8	R56403
R52404	Titanium, Gr 26	–	0.08 max	0.30 max	0.015 max	–	0.03 max	0.25 max	Ru 0.08–0.14	R52404
R52254	Titanium, Gr 27	–	0.08 max	0.20 max	0.015 max	–	0.03 max	0.18 max	Ru 0.08–0.14	R52254
R56323	Titanium, Gr 28	2.5–3.5	0.08 max	0.25 max	0.015 max	–	0.03 max	0.15 max	V 2.0–3.0, Ru 0.08–0.14	R56323
R56404	Titanium, Gr 29	5.5–6.5	0.08 max	0.25 max	0.015 max	–	0.03 max	0.13 max	V 3.5–4.5, Ru 0.08–0.14	R56404
–	Titanium, Gr 30	–	0.08 max	0.30 max	0.015 max	–	0.03 max	0.25 max	Co 0.20–0.80, Pd 0.04–0.08	–
–	Titanium, Gr 31	–	0.08 max	0.30 max	0.015 max	–	0.05 max	0.35 max	Co 0.20– 0.80, Pd 0.04–0.08	–
R55111	Titanium, Gr 32	4.5–5.5	0.08 max	0.25 max	0.015 max	0.6–1.2	0.03 max	0.11 max	V 0.6–1.4, Sn 6.0–1.4, Zr 0.5–1.4, Si 0.06–0.14	R55111
–	Titanium, Gr 33	–	0.08 max	0.30 max	0.015 max	–	0.03 max	0.25 max	Ru 0.02–0.04, Pd 0.01–0 .02, Cr 0.1–0.2 , Ni 0.35–0.55	–
–	Titanium, Gr 34	–	0.08 max	0.30 max	0.015 max	–	0.05 max	0.35 max	Ru 0.02–0.04, Pd 0.01–0.02, Cr 0.1–0.2 , Ni 0.35–0.55	–

TITANIUM ALLOYS—Mechanical Properties

UNS #	ASTM Grade	ASTM	Form	Heat Tr.	YS-ksi	YS-Mpa	UTS-ksi	UTS-Mpa	% E min.	UNS #
R50250	Titanium, Gr. 1	B265	Plate	ANN	25–45	170–310	35 min.	240 min.	24	R50250
R50400	Titanium, Gr. 2	B265	Plate	ANN	40–65	275–450	50 min.	345 min.	20	R50400
R50550	Titanium, Gr. 3	B265	Plate	ANN	55–80	380–550	65 min.	450 min.	18	R50550
R50700	Titanium, Gr. 4	B265	Plate	ANN	70–95	483–655	80 min.	550 min.	15	R50700
R56400	Titanium, Gr. 5	B265	Plate	ANN	120 min.	828 min.	130 min.	895 min.	10	R56400
R54250	Titanium, Gr. 6	B265	Plate	ANN	115 min.	793 min.	120 min.	828 min.	10	R54250
R52400	Titanium, Gr. 7	B265	Plate	ANN	40–65	275–450	50 min.	345 min.	20	R52400
R56320	Titanium, Gr. 9	B265	Plate	ANN	70 min.	483 min.	90 min.	620 min.	15	R56320
R52250	Titanium, Gr. 11	B265	Plate	ANN	25–45	170–310	35 min.	240 min.	24	R52250
R53400	Titanium, Gr. 12	B265	Plate	ANN	50 min.	345 min.	70 min.	483 min.	18	R53400
R53413	Titanium, Gr. 13	B265	Plate	ANN	25 min.	170 min.	40 min.	275 min.	24	R53413
R53414	Titanium, Gr. 14	B265	Plate	ANN	40 min.	275 min.	60 min.	410 min.	20	R53414
R53415	Titanium, Gr. 15	B265	Plate	ANN	55 min.	380 min.	70 min.	483 min.	18	R53415
R52402	Titanium, Gr. 16	B265	Plate	ANN	40–65	275–450	50 min.	345 min.	20	R52402
R52252	Titanium, Gr. 17	B265	Plate	ANN	25–45	170–310	35 min.	240 min.	24	R52252
R56322	Titanium, Gr. 18	B265	Plate	ANN	70 min.	483 min.	90 min.	620 min.	15	R56322
R58640	Titanium, Gr. 19	B265	Plate	ANN	110 min.	759 min.	115 min.	793 min.	15	R58640
R58645	Titanium, Gr. 20	B265	Plate	ANN	110 min.	759 min.	115 min.	793 min.	15	R58645
R58210	Titanium, Gr. 21	B265	Plate	ANN	110 min.	759 min.	115 min.	793 min.	15	R58210
R56407	Titanium, Gr. 23	B265	Plate	ANN	110 min.	759 min.	120 min.	828 min.	10	R56407
R56405	Titanium, Gr. 24	B265	Plate	ANN	120 min.	828 min.	130 min.	895 min.	10	R56405
R56403	Titanium, Gr. 25	B265	Plate	ANN	120 min.	828 min.	130 min.	895 min.	10	R56403
R52404	Titanium, Gr. 26	B265	Plate	ANN	40–65	275–450	50 min.	345 min.	20	R52404
R52254	Titanium, Gr. 27	B265	Plate	ANN	25–45	170–310	35 min.	240 min.	24	R52254
R56323	Titanium, Gr. 28	B265	Plate	ANN	70 min.	483 min.	90 min.	620 min.	15	R56323
R56404	Titanium, Gr. 29	B265	Plate	ANN	110 min.	759 min.	120 min.	828 min.	10	R56404
–	Titanium, Gr. 30	B265	Plate	ANN	40–65	275–450	50 min.	345 min.	20	–
–	Titanium, Gr. 31	B265	Plate	ANN	55–80	380–550	65 min.	450 min.	18	–
R55111	Titanium, Gr. 32	B265	Plate	ANN	85 min.	586 min.	100 min.	689 min.	10	R55111
–	Titanium, Gr. 33	B265	Plate	ANN	40–65	275–450	50 min.	345 min.	20	–
–	Titanium, Gr. 34	B265	Plate	ANN	55–80	380–550	65 min.	450 min.	18	–

LEAD ALLOYS—Composition, %

UNS	Common Name	Pb	Ag	As	Bi	Cu	Fe	Sb	Sn	Zn	UNS
L50045	Common Lead	99.94 min	0.005 max	–	0.050 max	0.0015 max	0.002 max	–	–	0.001 max	L50045
L51120	Chemical Lead	99.94 min	0.002–0.02	–	0.005 max	0.04–0.08	0.002 max	–	–	0.001 max	L51120
L55030	50/50 Solder	50 nom	–	0.03 max	0.25 max	0.08 max	0.02 max	0.12 max	50 nom	0.005 max	L55030

MAGNESIUM ALLOYS—Composition, %

UNS	Common Name	Mg	Al	Cu	Fe	Mn	Ni	Zn	Other	UNS
M11311	Mg AZ31B	bal	2.5–3.5	0.05 max	0.005 max	0.20 min	0.005 max	0.6–1.4	Ca 0.04 max	M11311
M11914	Mg AZ91C	bal	8.1–9.3	0.10 max	–	0.13 min	0.01 max	0.40–1.0	tot 0.30 max	M11914
M12330	Mg EZ33A	bal	–	0.10 max	–	–	0.01 max	2.0–3.1	Rare Earths 2.5–4.0	M12330
M13310	Mg HK31A	bal	–	0.10 max	–	–	0.01 max	0.30 max	Th 2.5–4.0	M13310
	Mg AM60A	bal	6.0	0.10 max	–	0.13	–	–	–	
	Mg AS41A	bal	4.3	0.10 max	–	0.35	–	–	Si 1.0	

MAGNESIUM ALLOYS—Mechanical Properties

UNS	Common Name	ASTM	Form	Temper	YS-ksi	TS-ksi	YS-MPa	TS-MPa	UNS
M11311	Mg AZ31B	B91	Forging	F	19 min	34 min	131 min	234 min	M11311
M11914	Mg AZ91C	B80	Casting	F	11 min	23 min	76 min	158 min	M11914
M12330	Mg EZ33A	B80	Casting	T5	14 min	20 min	96 min	138 min	M12330
M13310	Mg HK31A	B80	Casting	T6	13 min	27 min	89 min	186 min	M13310
	Mg AM60A		Casting	F	17 min	30 min	115 min	205 min	
	Mg AS41A		Casting	F	22 min	32 min	150 min	220 min	

PRECIOUS METALS AND ALLOYS—Composition, %

UNS	Common Name	Ag	Cu	Other	UNS
P00020	Refined gold	0.035 max	0.02 max	Au 99.95 min; Pd 0.02 max	P00020
P03980	Refined palladium	–	–	Ir 0.05 max; Pt 0.15 max; Rh 0.10 max; Ru 0.05 max	P03980
P04995	Refined platinum	0.005 max	0.01 max	0.01 Au, Ru; 0.02 Pd; 0.005 Bi, Ca, Te; 0.015I r; 0.03 Rh max	P04995
P07015	Refined silver	99.95 min	0.04 max	Bi 0.001 max	P07015
P07931	Sterling silver	92.10–93.50	6.50–7.90	0.06 max	P07931

ZINC ALLOYS—Composition, %

UNS	Common Name	ASTM	MILSPEC	Al	Cd	Cu	Fe	Pb	Si	UNS
Z13000	Zinc Anode Type II	B418	–	0.005 max	0.003 max	–	0.0014 max	–	–	Z13000
Z32120	Zinc Anode Type I	B418	–	0.10–0.4	0.03–0.10	–	0.005 max	–	–	Z32120
Z32121	Zinc Anode Type III	B418	MIL-A-18001H	0.10–0.50	0.025–0.15	0.005 max	0.005 max	0.006 max	0.125 max	Z32121
Z35636	Zinc Anode-8	B791	–	0.6–8.8	0.006 max	0.8–1.3	0.075 max	0.006 max	–	Z35636
Z35631	Zinc Anode-12	B791	–	10.5–11.5	0.006 max	0.5–1.2	0.075 max	0.006 max	–	Z35631
Z35841	Zinc Anode-27	B791	–	25.0–28.0	0.006 max	2.0–2.5	0.075 max	0.006 max	–	Z35841
Z33521	AG 40A	B86	–	3.5–4.3	0.004 max	0.25 max	0.10 max	0.005 max	–	Z33521
Z35541	AC 43A	B86	–	3.5–4.3	0.004 max	2.5–3.0	0.10 max	0.005 max	–	Z35541

API GRADES OF CASING AND TUBING—Composition, %

Common Name	C	Cr	Cu	Mn	Mo	Ni	P	S	Si	Common Name
H40	–	–	–	–	–	–	0.040 max	0.060 max	–	H40
J55	–	–	–	–	–	–	0.040 max	0.060 max	–	J55
K55	–	–	–	–	–	–	0.040 max	0.060 max	–	K55
N80	–	–	–	–	–	–	0.040 max	0.060 max	–	N80
C75 Type 1	0.50 max	[a]	[a]	1.90 max	0.15–0.40	[a]	0.040 max	0.060 max	0.45 max	C75 Type 1
C75 Type 2	0.43 max	–	–	1.50 max	–	–	0.040 max	0.060 max	0.45 max	C75 Type 2
C75 Type 3	0.38–0.48	0.80–1.10	–	0.75–1.00	0.15–0.25	–	0.040 max	0.040 max	–	C75 Type 3
C75 9Cr	0.15 max	8.0–10.0	0.25 max	0.30–0.60	0.90–1.10	0.5 max	0.020 max	0.010 max	1.0 max	C75 9Cr
C75 13Cr	0.15–0.22	12.0–14.0	0.25 max	0.25–1.00	–	0.5 max	0.020 max	0.010 max	1.0 max	C75 13Cr
L80 Type 1	0.43 max[d]	–	0.35 max	1.90 max	–	0.25 max	0.040 max	0.060 max	0.45 max	L80 Type 1
L80 9Cr	0.15 max	8.0–10.0	0.25 max	0.30–0.60	0.90–1.10	0.5 max	0.020 max	0.010 max	1.0 max	L80 9Cr
L80 13Cr	0.15–0.22	12.0–14.0	0.25 max	0.25–1.00	–	0.5 max	0.020 max	0.010 max	1.0 max	L80 13Cr
C90 Type 1	0.35 max	1.20 max	–	1.00 max	0.75 max	0.99 max	0.020 max	0.010 max	–	C90 Type 1
C90 Type 2	0.50 max	[b]	–	1.90 max	[b]	0.99 max	0.030 max	0.010 max	–	C90 Type 2
C95	0.45 max[c]	–	–	1.90 max	–	–	0.040 max	0.060 max	0.45 max	C95
P105	–	–	–	–	–	–	0.040 max	0.060 max	–	P105
P110	–	–	–	–	–	–	0.040 max	0.060 max	–	P110
Q125 Type 1	0.35 max	1.20 max	–	1.00 max	0.75 max	0.99 max	0.020 max	0.010 max	–	Q125 Type 1
Q125 Type 2	0.35 max	[b]	–	1.00 max	[b]	0.99 max	0.020 max	0.020 max	–	Q125 Type 2
Q125 Type 3	0.50 max	[b]	–	1.90 max	[b]	0.99 max	0.030 max	0.010 max	–	Q125 Type 3
Q125 Type 4	0.50 max	[b]	–	1.90 max	[b]	0.99 max	0.030 max	0.020 max	–	Q125 Type 4

[a] Cr+Ni + Cu shall not exceed 0.50%.
[b] No limit. Elements shown must be reported in product analysis.
[c] Carbon content may be increased to 0.50% max if product is oil quenched.
[d] Carbon content may be increased to 0.55% max if product is oil quenched.

Reference: Some material gathered from API Specification 5CT (March 15, 1988).

API GRADES OF CASING AND TUBING—Mechanical Properties

Common Name	Form	Mfr. Proc.	Heat Tr.	YS-ksi	TS-ksi	YS-MPa	TS-MPa	Hardness*	Common Name
H40	Casing, Tubing	SMLS, EW	None	40–80	60 min	276–552	414 min	–	H40
J55	Casing, Tubing	SMLS, EW	None, N, NT, QT	55–80	75 min	379–552	517 min	–	J55
K55	Casing	SMLS, EW	None, N, NT, QT	55–80	95 min	379–552	655 min	–	K55
N80	Casing	SMLS, EW	None, N, NT, QT	80–110	100 min	552–758	689 min	–	N80
N80	Tubing	SMLS, EW	N, NT, QT	80–110	100 min	552–758	689 min	–	N80
C75 Type 1	Casing, Tubing	SMLS, EW	NT (1150 F min)	75–90	95 min	517–620	655 min	–	C75 Type 1
C75 Type 2	Casing, Tubing	SMLS, EW	QT (1150 F min)	75–90	95 min	517–620	655 min	–	C75 Type 2
C75 Type 3	Casing, Tubing	SMLS, EW	NT (1150 F min)	75–90	95 min	517–620	655 min	–	C75 Type 3
C75 9Cr	Casing, Tubing	SMLS	QT (1100 F min)	75–90	95 min	517–620	655 min	22 HRC max	C75 9Cr
C75 13Cr	Casing, Tubing	SMLS	QT (1100 F min)	75–90	95 min	517–620	655 min	22 HRC max	C75 13Cr
L80 Type 1	Casing, Tubing	SMLS, EW	QT (1050 F min)	80–95	95 min	552–655	655 min	22 HRC max	L80 Type 1
L80 9Cr	Casing, Tubing	SMLS	QT (1100 F min)	80–95	95 min	522–655	655 min	23 HRC max	L80 9Cr
L80 13 Cr	Casing, Tubing	SMLS	QT (1100 F min)	80–95	95 min	522–655	655 min	23 HRC max	L80 13Cr
C90 Type 1	Casing, Tubing	SMLS	QT (1150 F min)	90–105	100 min	620–724	690 min	25.4 HRC max	C90 Type 1
C90 Type 2	Casing, Tubing	SMLS	QT (1150 F min)	90–105	100 min	620–724	690 min	25.4 HRC max	C90 Type 2
C95	Casing, Tubing	SMLS, EW	QT (1000 F min)	95–110	105 min	655–758	724 min	–	C95
P105	Tubing	SMLS	QT, NT	105–135	120 min	724–931	827 min	–	P105
P110	Casing	SMLS	QT, NT	110–140	125 min	758–965	862 min	–	P110
Q125 Type 1	Casing	SMLS, EW	QT	125–150	135 min	860–1035	930 min	–	Q125 Type 1
Q125 Type 2	Casing	SMLS, EW	QT	125–150	135 min	860–1035	930 min	–	Q125 Type 2
Q125 Type 3	Casing	SMLS, EW	QT	125–150	135 min	860–1035	930 min	–	Q125 Type 3
Q125 Type 4	Casing	SMLS, EW	QT	125–150	135 min	860–1035	930 min	–	Q125 Type 4

See Specification 5CT for allowable hardness variations.

Reference: Some material gathered from API Specification 5CT March 15, 1988.

MAXIMUM ALLOWABLE STRESS IN TENSION FOR ALUMINUM ALLOY TUBES—ksi

Summarized from ASME Pressure Vessel Code, Section VIII, Table UNF-23.1 (1989)
(ksi × 6.895 = MPa)

UNS	Common Name	ASME	Temper	SMYS	100 F	150 F	200 F	250 F	300 F	350 F	400 F	UNS
A91060	Al 1060	SB210	0	2.5	1.7	1.7	1.6	1.5	1.3	1.1	0.8	A91060
A93003	Al 3003	SB210	0	5.0	3.4	3.4	3.4	3.0	2.4	1.8	1.4	A93003
A95052	Al 5052	SB210	0	10.	6.2	6.2	6.2	6.2	5.6	4.1	2.3	A95052
A96061	Al 6061	SB210	T6	35.	10.5	10.5	10.5	9.9	8.4	6.3	4.5	A96061
A96063	Al 6063	SB210	T6	28.	8.3	8.3	7.9	7.4	5.5	3.4	2.0	A96063

MAXIMUM ALLOWABLE STRESS IN TENSION FOR COPPER ALLOY TUBES—ksi

Summarized from ASME Pressure Vessel Code, Section VIII, Table UNF-23.2 (1989)
(ksi × 6.895 = MPa)

UNS	Common Name	ASME	Temper	SMYS	100 F	150 F	200 F	250 F	300 F	350 F	400 F	450 F	500 F	550 F	600 F	650 F	700 F	UNS
C10200	OF Copper	SB111	H55	30.	9.0	9.0	9.0	9.0	8.7	8.5	8.2							C10200
C12200	DHP Copper	SB111	H04	40.	11.3	11.3	11.3	11.3	11.0	10.3	4.3							C12200
C23000	Red Brass	SB111	061	12.	8.0	8.0	8.0	8.0	8.0	7.0	5.0	2.0						C23000
C28000	Muntz Metal	SB111	061	20.	12.5	12.5	12.5	12.5	12.5	10.8	5.3							C28000
C44300	Adm. Brass, As	SB111	061	15.	10.0	10.0	10.0	10.0	10.0	9.8	3.5	2.0						C44300
C60800	Al Bronze, 6%	SB111	061	19.	12.5	12.4	12.2	11.9	11.6	10.0	6.0	4.0	2.0					C60800
C68700	Al Brass, As	SB111	061	18.	12.0	11.9	11.8	11.7	11.7	6.5	3.3	1.8						C68700
C70600	90-10 Cu-Ni	SB111	061	15.	10.0	9.7	9.5	9.3	9.0	8.7	8.5	8.2	8.0	7.0	6.0			C70600
C71500	70-30 Cu-Ni	SB111	061	18.	12.0	11.6	11.3	11.0	10.8	10.6	10.3	10.1	9.9	9.8	9.6	9.5	9.4	C71500

MAXIMUM ALLOWABLE STRESS IN TENSION FOR CARBON AND LOW ALLOY STEELS—ksi

Summarized from ASME Pressure Vessel Code, Section VIII, Table UCS-23 (1989)

(ksi × 6.895 = MPa)

UNS	Common Name	Form	ASME	SMYS	650 F	700 F	750 F	800 F	850 F	900 F	950 F	1000 F	1050 F	1100 F	1150 F	1200 F
K01800	A516-55	Plate	SA516-55	30.	13.8	13.3	12.1	10.2	8.4	6.5	4.5	2.5				
K02100	A516-60	Plate	SA516-60	32	15.0	14.1	13.0	10.8	8.7	6.5	4.5	2.5				
K02403	A516-65	Plate	SA516-65	35	16.3	15.5	13.9	11.4	9.0	6.5	4.5	2.5				
K02700	A516-70	Plate	SA516-70	38	17.5	16.6	14.8	12.0	9.3	6.5	4.5	2.5				
K02801	A285-C	Plate	SA285-C	30.	13.8	13.3	12.1	10.2	8.4	6.5						
K03005	A53-B	Pipe	SA53-B	35.	15.0	14.4	13.0	10.8	8.7	6.5						
K03006	A106-B	Pipe	SA106-B	35.	15.0	14.4	13.0	10.8	8.7	6.5	4.5	2.5				
K11522	C-0.5Mo	Pipe	SA335-P1	30.	13.8	13.8	13.8	13.5	13.2	12.7	8.2	4.8				
K11597	1.25Cr-0.5Mo	Pipe	SA335-P11	30.	15.0	15.0	14.8	14.4	14.0	12.1	9.3	6.3	4.2	2.8	1.9	1.2
K21590	2.25Cr-1Mo	Pipe	SA335-P22	30.	15.0	15.0	15.0	15.0	14.4	13.1	11.0	7.8	5.8	4.2	3.0	2.0
K41545	5Cr-0.5Mo	Pipe	SA335-P5	30.		13.7	13.2	12.8	12.1	10.9	8.0	5.8	4.2	2.9	1.8	1.0
S50400	9Cr-1Mo	Pipe	SA335-P9	30.		13.7	13.2	12.8	12.1	11.4	10.6	7.4	5.0	3.3	2.2	1.5

MAXIMUM ALLOWABLE STRESS IN TENSION FOR STAINLESS STEEL PIPE/TUBE—ksi

Summarized from ASME Pressure Vessel Code, Section VIII, Table UHA-23 (1989)

(ksi × 6.895 = MPa)

UNS	Common Name	ASME	SMYS	−20/100 F	200 F	300 F	400 F	500 F	600 F	650 F	700 F	750 F	800 F	850 F	900 F	Notes	UNS
S30400	304 SS	SA312	30.	18.8	17.8	16.6	16.2	15.9	15.9	15.9	15.9	15.6	15.2	14.9	14.7		S30400
S30403	304L SS	SA312	25.	16.7	16.5	15.3	14.7	14.4	14.0	13.7	13.5	13.3	13.0				S30403
S30451	304N SS	SA312	35.	20.0	20.0	19.0	18.3	17.8	17.4	17.3	17.1	16.9	16.6	16.3	15.9		S30451
S30900	309 SS	SA312	30.	18.8	17.2	16.4	15.9	15.5	15.3	15.2	15.1	15.0	14.9	14.6	13.9		S30900
S31000	310 SS	SA312	30.	18.8	17.2	16.4	15.9	15.5	15.3	15.2	15.1	15.0	14.9	14.6	13.9		S31000
S31254	254 SMO	SA312	44.	23.5	23.5	21.4	19.9	18.5	17.9	17.7	17.5	17.3					S31254
S31600	316 SS	SA312	30.	18.8	18.8	18.4	18.1	18.0	17.0	16.7	16.3	16.1	15.9	15.7	15.6		S31600
S31603	316L SS	SA312	25.	16.7	14.1	12.7	11.7	10.9	10.4	10.2	10.0	9.8	9.6	9.4			S31603
S31651	316N SS	SA312	35.	20.0	20.0	19.2	18.8	18.6	18.6	18.6	18.6	18.5	18.4	18.3	18.1		S31651
S32100	321 SS	SA312	30.	18.7	17.8	16.7	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4		S32100
S34700	347 SS	SA312	30.	18.8	17.9	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4		S34700
S40500	405 SS	SA268	30.	15.0	14.3	13.8	13.3	12.9	12.4	12.3	12.1	11.7	11.1	10.4	9.7	[a]	S40500
S41000	410 SS	SA268	30.	15.0	14.3	13.8	13.3	12.9	12.4	12.3	12.1	11.7	11.1	10.4	9.7		S41000
S43000	430 SS	SA268	35.	15.0	14.3	13.8	13.3	12.9	12.4	12.3	12.1	11.7	11.1	10.4	9.7	[a]	S43000
S44600	446 SS	SA268	40.	17.5	16.6	16.1	15.6	15.0	14.5	14.3							S44600
S31500	3RE60	SA790	64.	23.0	22.2	21.3	21.2	21.2	21.2	21.2	21.2	21.2				[a]	S31500
S31803	2205 alloy	SA790	65.	22.5	22.5	21.7	20.9	20.4	20.2							[b]	S31803
S32550	Ferralium 255	SA790	80.	27.5	27.4	25.7	24.7	24.7								[a]	S32550

Notes:

[a] This material may be expected to develop embrittlement after service at moderately elevated temperatures.

[b] This material may be expected to exhibit embrittlement at room temperature after service above 600°F.

MAXIMUM ALLOWABLE STRESS IN TENSION FOR STAINLESS STEEL PIPE/TUBE—ksi (*Continued*)

UNS	Common Name	ASME	950 F	1000 F	1050 F	1100 F	1150 F	1200 F	1250 F	1300 F	1350 F	1400 F	1450 F	1500 F	UNS
S30400	304 SS	SA312	14.4	14.1	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	S30400
S30451	304N SS	SA312	15.6	15.0	12.4	9.8	7.7	6.1							S30451
S30900	309 SS	SA312	12.4	10.5	8.5	6.5	5.0	3.8	2.9	2.3	1.8	1.3	0.9	0.8	S30900
S31000	310 SS	SA312	12.5	11.0	7.1	5.0	3.6	2.5	1.5	0.8	0.5	0.4	0.3	0.2	S31000
S31600	316 SS	SA312	15.4	11.3	11.2	11.0	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	S31600
S31651	316N SS	SA312	17.8	13.2	12.7	12.2	9.8	7.4							S31651
S32100	321 SS	SA312	16.3	13.8	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	S32100
S34700	347 SS	SA312	16.4	14.4	12.1	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	S34700
S40500	405 SS	SA268	8.4	4.0											S40500
S41000	410 SS	SA268	8.4	6.4	4.4	2.9	1.8	1.0							S41000
S43000	430 SS	SA268	8.5	6.5	4.5	3.2	2.4	1.8							S43000

MAXIMUM ALLOWABLE STRESS IN TENSION FOR ANNEALED NICKEL ALLOY PIPE/TUBE—ksi

Summarized from ASME Pressure Vessel Code, Section VIII, Table UNF 23.3 (1989)
(ksi × 6.895 = MPa)

UNS	Common Name	ASME	SMYS	100 F	500 F	600 F	700 F	800 F	900 F	1000 F	1100 F	1200 F	1300 F	1400 F	1500 F	Notes	UNS
N02200	Nickel 200	SB163	15.	10.0	10.0	10.0											N02200
N04400	400 Alloy	SB163	28.	17.5	14.7	14.7	14.7	14.2	8.0								N04400
N06002	X Alloy	SB619	40.	19.8	14.0	13.3	12.7	12.5	12.3	12.1	12.1	9.6	6.5				N06002
N06022	C-22 Alloy	SB619	45.	21.2	18.0	17.1	16.3	15.8									N06022
N06030	G-30 Alloy	SB619	35.	18.1	13.9	13.4	12.9	12.4									N06030
N06455	C-4 Alloy	SB619	40.	21.2	17.8	17.1	16.7	16.2									N06455
N06600	600 Alloy	SB163	35.	20.0	20.0	20.0	19.6	19.1	16.0	7.0	3.0	2.0					N06600
N06625	625 Alloy	SB444	60.	30.0	27.0	26.4	26.0	26.0	26.0	26.0	26.0	13.2				[a]	N06625
N06985	G-3 Alloy	SB619	35.	19.1	13.8	13.1	12.4	11.9									N06985
N08020	20Cb-3	SB464	35.	17.0	15.5	15.1	14.7	14.3									N08020
N08028	Sanicro 28	SB668	31.	18.2	14.5	13.3											N08028
N08800	800 Alloy	SB163	30.	18.7	16.7	16.3	15.9	15.5	15.1	14.7	13.0	6.6	2.0	1.1			N08800
N08810	800H Alloy	SB163	25.	16.2	12.9	12.2	11.7	11.1	10.7	10.3	10.0	7.4	4.7	3.0	1.9		N08810
N08825	825 Alloy	SB163	35.	21.2	18.3	17.8	17.3	17.1	16.8	16.6							N08825
N10276	C-276 Alloy	SB619	41.	21.2	17.0	16.0	15.1	14.5	14.1	14.0	12.7	8.3					N10276
N10665	B-2 Alloy	SB619	51.	23.4	23.4	23.1	22.6	21.8									N10665

Notes:

[a] Alloy N06625 in the annealed condition is subject to severe loss of impact strength at room temperature after exposure in the range of 1000 F to 1400 F.

MAXIMUM ALLOWABLE STRESS IN TENSION FOR TITANIUM AND ZIRCONIUM ALLOY TUBES—ksi

Summarized from ASME Pressure Vessel Code, Section VIII, Tables UNF-23.4 and –23.5 (1989)
(ksi × 6.895 = MPa)

UNS	Common Name	ASME	SMYS	100 F	150 F	200 F	250 F	300 F	350 F	400 F	450 F	500 F	550 F	600 F	700 F	UNS
R50250	Titanium, Gr 1	SB338	25.	8.8	8.1	7.3	6.5	5.8	5.2	4.8	4.5	4.1	3.6	3.1		R50250
R50400	Titanium, Gr 2	SB338	40.	12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7		R50400
R50550	Titanium, Gr 3	SB338	55.	16.3	15.6	14.3	13.0	11.7	10.4	9.3	8.3	7.5	6.7	6.0		R50550
R52400	Titanium, Gr 7	SB338	40.	12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7		R52400
R53400	Titanium, Gr 12	SB338	50.	17.5	17.5	16.4	15.2	14.2	13.3	12.5	11.9	11.4	11.1	10.8		R53400
R60702	Zirconium 702	SB523	30.	13.0		11.0		9.3		7.0		6.1		6.0	4.8	R60702

APPLICATIONS, SPECIFICATIONS, AND NOMINAL COMPOSITIONS OF SELECTED TIN-BASE SOLDER MATERIALS

Common Name	Specifications				Nominal Composition, %	Liquidus Temperature		Solidus Temperature		Typical Applications
	ASTM	Government	British	German		°C	°F	°C	°F	
Commercially pure tin	B 339, Grade A	QQ-T-371, Grade A	BS 3252, Grade T	DIN 1704, Grade A2	–	–	–	–	–	Soldering side seams of cans for foods or aerosols
Antimonial-tin solder	B 32, Grade S65	–	–	–	95 Sn, 5 Sb	240	464	234	452	Soldering of electrical equipment, joints in copper tubing, and cooling coils for refrigerators. Resistant to SO_2
Tin-silver solder	B 32, Grade Sn95	–	–	–	95 Sn, 5 Ag	245	473	221	430	Soldering of components for electrical and high-temperature service
Tin-silver eutectic alloy	B 32, Grade Sn96	QQ-S-571, Grade Sn96	–	–	96 Sn, 3.5 Ag	221	430	221	430	Popular choice with properties similar to those of ASTM B 32, Grade Sn95
Soft solder (70–30 solder)	B 32, Grade Sn70	QQ-S-571, Grade Sn70	–	–	70 Sn, 30 Pb	192	378	183	361	Joining and coating of metals
Eutectic solder (63–37 soft solder)	B 32, Grade Sn63	QQ-S-571, Grade Sn63	–	DIN 1707, LSn 63Pb	63 Sn, 37 Pb	183	361	183	361	Lowest-melting (eutectic) solder for electronics
Soft solder (60–40 solder)	B 32, Grade Sn60	QQ-S-571, Grade Sn60	BS 219, Grade K	DIN 1707, LSn 60Pb(Sb)	60 Sn, 40 Pb	190	374	183	361	Solder for electronic and electrical work, especially mass soldering of printed circuits

Source: GEM 2001, p. 146, ASM, 2000. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

ELECTRICAL AND MECHANICAL PROPERTIES OF SELECTED TIN-BASE SOLDERS

Solder Type	Tensile Properties	Shear Strength	Impact Strength and/or Hardness	Electrical Conductivity	Electrical Resistivity
Antimonial-tin solder (95Sn-5Sb)	Cast: typical tensile strength, 40.7 MPa (5.9 ksi); elongation in 100 mm (4 in.), 38%. Soldered copper joint: typical tensile strength, 97.9 MPa (14.2 ksi)	Cast: 41.4 MPa (6.0 ksi). Soldered copper joint: 76.5 MPa (11.1 ksi)	Impact strength: Cast (Izod test), 27 J (20 ft·lbf)	Volumetric, 11.9% IACS at 20°C (68°F)	145 nΩ·m at 25°C (77°F)
Tin-silver solder (95Sn-5Ag)	Sheet, 1.02 mm (0.040 in.) thick, aged 14 days at room temperature: typical tensile strength, 31.7 MPa (4.6 ksi); yield strength, 24.8 MPa (3.6 ksi); elongation in 50 mm (2 in.), 49%. Soldered copper joint: typical tensile strength, 96.5 MPa (14 ksi)	Soldered copper joint: 73.1 MPa (10.6 ksi)	N/A	Volumetric, 16.6% IACS at 20°C (68°F)	104 nΩ·m at 0°C (32°F). Temperature coefficient of electrical resistivity: 0–100°C (32–212°F), 42.3 pΩ·m/K
70-30 soft solder (70Sn-30Pb)	Cast: typical tensile strength, 46.9 MPa (6.8 ksi)	N/A	Hardness. 12 HB	Volumetric, 11.8% IACS	146 nΩ·m
Eutectic solder (63Sn–37Pb)	Cast: typical tensile strength, 51.7 MPa (7.5 ksi); elongation in 100 mm (4 in.), 32%. Soldered copper joint: typical tensile strength, 200 MPa (2g ksi)	Cast: 42.7 MPa (6.2 ksi). Soldered copper joint: 55.2 MPa (8 ksi)	Impact strength: Cast (Izod test), 20 J (15 ft·lbf). Hardness: Cast, 14 HB	Volumetric, 11.9% IACS	145 nΩ·m
60–40 soft solder (60Sn–40Pb)	Bulk solder at room temperature (measurements depend greatly on conditions of casting and testing): mean tensile strength, 52.5 MPa (7.61 ksi); elongation, 30–60%.	Mean: 37.1 MPa (5.38 ksi) (depends greatly on conditions of casting and testing)	Hardness: 16 HV (depends on casting conditions)	Volumetric, 11.5% IACS	149.9 nΩ·m

Source: GEM 2001, p. 145, ASM, 2000. Reprinted by permission of ASM International®, Materials Park, OH 44023-0002.

DIFFUSION (COATINGS) TREATMENTS

Process	Type of Case	Process Temperature, °C (°F)	Typical Case Depth, mm (mils)	Case Hardness, HRC	Typical Base Metals
Carburizing					
Pack	Diffused carbon	815–1090 (1500–2000)	125–1.5 (5–60)	50–63[a]	Low-carbon steels, low-carbon alloy steel
Gas	Diffused carbon	815–980 (1500–1800)	75–1.5 (3–60)	50–63[a]	Low-carbon steels, low-carbon alloy steels
Liquid	Diffused carbon and possibly nitrogen	815–980 (1500–1800)	50–1.5 (2–60)	50–65[a]	Low-carbon steels, low-carbon alloy steels
Vacuum	Diffused carbon	815–1090 (1500–2000)	75–1.5 (3–60)	50–63[a]	Low-carbon steels, low-carbon alloy steels
Nitriding					
Gas	Diffused nitrogen, nitrogen compounds	480–590 (900–1100)	125–0.75 (5–30)	50–70	Alloy steels, nitriding steels, stainless steels
Salt	Diffused nitrogen, nitrogen compounds	510–565 (950–1050)	2.5–0.75 (0.1–30)	50–70	Most ferrous metals including cast irons
Ion	Diffused nitrogen, nitrogen compounds	340–565 (650–1050)	75–0.75 (3–30)	50–70	Alloy steels, nitriding, stainless steels
Carbonitriding					
Gas	Diffused carbon and nitrogen	760–870 (1400–1600)	75–0.75 (3–30)	50–65[a]	Low-carbon steels, low-carbon alloy steels, stainless steel
Liquid (cyaniding)	Diffused carbon and nitrogen	760–870 (1400–1600)	2.5–125 (0.1–5)	50–65[a]	Low-carbon steels
Ferritic nitro-carburizing	Diffused carbon and nitrogen	565–675 (1050–1250)	2.5–25 (0.1–1)	40–60[a]	Low-carbon steels
Other					
Aluminizing (pack)	Diffused aluminum	870–980 (1600–1800)	25–1 (1–40)	< 20	Low-carbon steels
Siliconizing by chemical vapor deposition	Diffused silicon	925–1040 (1700–1900)	25–1 (1–40)	30–50	Low-carbon steels
Chromizing by chemical vapor deposition	Diffused chromium	980–1090 (1800–2000)	25–50 (1–2)	< 30 50–60	Low-carbon steel, high-carbon steel High- and low-carbon steels
Titanium carbide	Diffused carbon and titanium, TiC compound	900–1010 (1650–1850)	2.5–12.5 (0.1–0.5)	> 70[a]	Alloy steels, tool steels
Boriding	Diffused boron, boron, compound	400–1150 (750–2100)	12.5–50 (0.5–2)	40–>70	Alloy steels, tool steels, cobalt and nickel alloys

[a]Requires quench from austenitizing temperature.

Source: GEM 2001, p. 171, ASM, 2000. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

CREEP STRENGTH OF METALS

Material	Form, Condition	Stress (ksi) for 0.01% Creep per 1000 h at Indicated Temp.					Stress (ksi) for 0.1% Creep per 1000 h at Indicated Temp.				
		300°F 149°C	400 204	500 260	600 315	800 426	300 149	400 204	500 260	600 315	800°F 426°C
NONFERROUS METALS											
Coppers	Wrought (annealed)	3–8	1.5–5	0.4–2.6	–	–	–	–	–	–	–
Nonleaded Brasses	Wrought (annealed)	0.9–19	2–11	0.3–23	–	–	25	5–9	1–2	–	–
Bronzes	Wrought (annealed)	14–23	5–10	2–5	–	–	–	–	–	–	–
Cupro-Nickel	Wrought (water quenched, aged)	25–40	15–30	8–30	–	–	–	22	13	–	–
Aluminum 2024-T	Sheet	23	9.5	2.5	1.5	–	30	13	3	2	–
Aluminum 7075-T	Sheet	12	4	2.5	1.5	–	16	6	3	2	–
Titanium (commercial)	Sheet (annealed)	–	38	–	32	10	37	40	37	32	13
Ti-6Al-4V	Sheet (annealed)	–	–	–	–	–	–	–	–	80	–
Ti-7Al-4Mo	Bar or Forging (annealed)	–	–	–	–	–	–	–	–	85	18
		1000°F 538°C	**1100 593**	**1200 648**	**1500 816**	**1600 871**	**1000 538**	**1100 593**	**1200 648**	**1500 816**	**1600°F 891°C**
CARBON AND LOW ALLOY STEELS											
Low Carbon Steel	Wrought, Cast	1.8	–	0.1	–	–	3.3–5	–	0.5	–	–
Carbon-Molybdenum Steels	Wrought, Cast	5.7	3	1	–	–	10–12	4	2	–	–
Chromium-Molybdenum Steels (0.5–3%)	Wrought, Cast	6–12	2–4	1–2.5	–	–	10–20	3–8	2–4.5	–	–
Chromium Steels											
4–6%	Wrought, Cast	6–7	2.5–3.5	1–2	–	–	8–11	5–6.5	2–3.5	–	–
6–10%	Wrought, Cast	5–9	2.5–4	1–2	–	–	8–12	4–6	2.5–3	–	–

(*Continued*)

CREEP STRENGTH OF METALS (*Continued*)

Material	Form, Condition	Stress (ksi) for 0.01% Creep per 1000 h at Indicated Temp.					Stress (ksi) for 0.1% Creep per 1000 h at Indicated Temp.				
		1000°F 538°C	1100 593	1200 648	1500 816	1600 871	1000 538	1100 593	1200 648	1500 816	1600°F 891°C
STAINLESS STEELS											
Martensitic Chromium Steels (403, 410, 416, 420, 440)	Wrought	8	3.5	1.3	–	–	9.2	4.2	2	–	–
Ferritic Chromium Steels (405, 430)	Wrought	4.2–7	2.3–4.5	1.0–1.6	–	–	6–8.5	3–5	1.5–2.2	–	–
Nickel-Chromium Steels											
304, 316, 321, 347	Wrought	12–17	7.5–11.5	4.5–7	1–2	–	17–25	12–18.2	7–12.7	1.2–2.8	–
309	Wrought	–	–	4	0.5	–	15.9	11.6	8	1.0	–
310, 314	Wrought	17	13	8	2	–	17	13–14	9	1–2.5	–
HEAT RESISTANT CAST HIGH ALLOYS											
Iron-Chromium Alloys (HA, HC, HD)	Cast	–	–	–	–	–	–	–	–	1.2–3.5[a]	0.7–1.9
Iron-Chromium-Nickel Alloys (HE, HF, HH, HI, HK, HL)	Cast	–	–	–	–	–	–	–	–	3.5–7[a]	2–4.3
Nickel-Chromium Alloys (HN, HT, HU, HW, HX)	Cast	–	–	–	–	–	–	–	–	6–8.5[a]	3–5

[a] At 1400°F (760°C).

Source: *Materials in Design Engineering*, p. 35, 1964.

TEMPER DESIGNATIONS FOR COPPERS AND COPPER ALLOYS

Cold Worked Tempers

H00	1/8 hard
H01	1/4 hard
H02	1/2 hard
H03	3/4 hard
H04	Hard
H06	Extra hard
H08	Spring
H10	Extra spring
H12	Special spring
H13	Ultra spring
H14	Super spring
H50	Extruded and drawn
H52	Pierced and drawn
H55	Light drawn; light cold rolled
H58	Drawn general purpose
H60	Cold heading; forming
H63	Rivet
H64	Screw
H66	Bolt
H70	Bending
H80	Hard drawn
H85	Medium-hard-drawn electrical wire
H86	Hard-drawn electrical wire

Cold Worked and Stress-relieved Tempers

HR01	H01 and stress relieved
HR02	H02 and stress relieved
HR04	H04 and stress relieved
HR06	H06 and stress relieved
HR08	H08 and stress relieved
HR10	H10 and stress relieved
HR50	Drawn and stress relieved

Cold Worked and Order-strengthened Tempers

HT04	H04 and order heat treated
HT06	H06 and order heat treated
HT08	H08 and order heat treated

Solution-Treated Temper

TB00	Solution heat treated

Solution-Treated and Cold Worked Tempers

TD00	TB00 cold worked to 1/4 hard
TD01	TB00 cold worked to 1/4 hard
TD02	TB00 cold worked to 1/2 hard
TD03	TB00 cold worked to 3/4 hard
TD04	TB00 cold worked to full hard

As-manufactured Tempers

M01	As sand cast
M02	As centrifugal cast
M03	As plaster cast
M04	As pressure die cast
M05	As permanent mold cast
M06	As investment cast
M07	As continuous cast
M10	As hot forged and air cooled
M11	As hot forged and quenched
M20	As hot rolled
M30	As hot extruded
M40	As hot pierced
M45	As hot pierced and rerolled

Annealed Tempers(a)

O10	Cast and annealed(b)
O20	Hot forged and annealed
O25	Hot rolled and annealed
O30	Hot extruded and annealed
O40	Hot pierced and annealed
O50	Light annealed
O60	Soft annealed
O61	Annealed
O65	Drawing annealed
O68	Deep drawing annealed
O70	Dead soft annealed
O80	Annealed to temper–1/8 hard
O81	Annealed to temper–1/4 hard
O82	Annealed to temper–1/2 hard

Annealed Tempers(c)

OS005	Average grain size 0.005 mm
OS010	Average grain size 0.010 mm
OS015	Average grain size 0.015 mm
OS025	Average grain size 0.025 mm
OS035	Average grain size 0.035 mm
OS050	Average grain size 0.050 mm
OS070	Average grain size 0.070 mm
OS100	Average grain size 0.100 mm
OS120	Average grain size 0.120 mm
OS150	Average grain size 0.150 mm
OS200	Average grain size 0.200 mm

(*Continued*)

TEMPER DESIGNATIONS FOR COPPERS ALLOYS (*Continued*)

Precipitation-Hardened Temper	
TF00	TB00 and precipitation hardened
Cold Worked and Precipitation-Hardened Tempers	
TH01	TD01 and precipitation hardened
TH02	TD02 and precipitation hardened
TH03	TD03 and precipitation hardened
TH04	TD04 and precipitation hardened
Precipitation-Hardened and Cold Worked Tempers	
TL00	TF00 cold worked to 1/8 hard
TL01	TF00 cold worked to 1/4 hard
TL02	TF00 cold worked to 1/2 hard
TL04	TF00 cold worked to full hard
TL08	TF00 cold worked to spring
TL10	TF00 cold worked to extra spring
TR01	TL01 and stress relieved
TR02	TL02 and stress relieved
TR04	TL04 and stress relieved
Mill-Hardened Tempers	
TM00	AM
TM01	1/4 HM
TM02	1/2 HM
TM04	HM
TM06	XHM
TM08	XHMS
Quench-Hardened Tempers	
TQ00	Quench hardened
TQ50	Quench hardened and temper annealed
TQ75	Interrupted quench hardened
Tempers of Welded Tubing[(d)]	
WH00	Welded and drawn to 1/8 hard
WH01	Welded and drawn to 1/4 hard
WM01	As welded from H01 strip
WM02	As welded from H02 strip
WM03	As welded from H03 strip
WM04	As welded from H04 strip
WM06	As welded from H06 strip
WM08	As welded from H08 strip
WM10	As welded from H10 strip
WM15	WM50 and stress relieved
WM20	WM00 and stress relieved
WM21	WM01 and stress relieved
WM22	WM02 and stress relieved
WM50	As welded from O60 strip
WO50	Welded and light annealed
WR00	WM00; drawn and stress relieved
WR01	WM01; drawn and stress relieved

[(a)]To produce specified mechanical properties. [(b)]Homogenization anneal. [(c)]To produce prescribed average grain size. [(d)]Tempers of fully finished tubing that has been drawn or annealed to produce specified mechanical properties or that has been annealed to produce a prescribed average grain size are commonly identified by the appropriate H, O or OS temper designation.

Source: *Metals Handbook*, 9th ed., Vol. 2, p. 527, ASM, 1979. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

TEMPER DESIGNATIONS FOR MAGNESIUM ALLOYS

F	As fabricated
O	Annealed
H10, H11	Slightly strain hardened
H23, H24, H26	Strain hardened and partially annealed
T4	Solution heat treated
T5	Artificially aged only
T6	Solution heat treated and artificially aged
T8	Solution heat treated, cold worked, and artificially aged

Source: *Metals Handbook*, 9th ed., Vol. 2, p. 527, ASM, 1979. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

TEMPER DESIGNATIONS FOR ALUMINUM ALLOYS

Basic Temper Designations

F **as fabricated.** Applies to the products of shaping processes in which no special control over thermal conditions or strain-hardening is employed. For wrought products, there are no mechanical property limits.

O **annealed.** Applies to wrought products which are annealed to obtain the lowest strength temper, and to cast products which are annealed to improve ductility and dimensional stability. The O may be followed by a digit other than zero.

H **strain-hardened (wrought products only).** Applies to products which have their strength increased by strain-hardening, with or without supplementary thermal treatments to produce some reduction in strength. The H is always followed by two or more digits.

W **solution heat-treated.** An unstable temper applicable only to alloys which spontaneously age at room temperature after solution heat-treatment. This designation is specific only when the period of natural aging is indicated; for example: W 1/2 h.

T **thermally treated to produce stable tempers other than F, O, or H.** Applies to products which are thermally treated, with or without supplementary strain-hardening, to produce stable tempers. The T is always followed by one or more digits.

Subdivision of H Temper: Strain-Hardened

The first digit following the H indicates the specific combination of basic operations, as follows:

H1 **strain-hardened only.** Applies to products which are strain-hardened to obtain the desired strength without supplementary thermal treatment. The number following this designation indicates the degree of strain-hardening.

H2 **strain-hardened and partially annealed.** Applies to products which are strain-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. For alloys that age-soften at room temperature, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H3 tempers. For other alloys, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H1 tempers and slightly higher elongation. The number following this designation indicates the degree of strain-hardening remaining after the product has been partially annealed.

H3 **strain-hardened and stabilized.** Applies to products which are strain-hardened and whose mechanical properties are stabilized either by a low temperature thermal treatment or as a result of heat introduced during fabrication. Stabilization usually improves ductility. This designation is applicable only to those alloys which, unless stabilized, gradually age-soften at room temperature. The number following this designation indicates the degree of strain-hardening remaining after the stabilization treatment.

The digit following the designations H1, H2, and H3 indicates the degree of strain-hardening.

Subdivision of T Temper: Thermally Treated

Numerals 1 through 10 following the T indicate specific sequences of basic treatments, as follows:

T1 **cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition.** Applies to products which are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T2 **cooled from an elevated temperature shaping process, cold worked, and naturally aged to a substantially stable condition.** Applies to products that are cold worked to improve strength after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straighting is recognized in mechanical property limits.

T3 **solution heat-treated, cold worked, and naturally aged to a substantially stable condition.** Applies to products which are cold worked to improve strength after solution heat-treatment, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

T4 **solution heat-treated and naturally aged to a substantially stable condition.** Applies to products which are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T5 **cooled from an elevated temperature shaping process and then artifically aged**. Applies to products which are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T6 **solution heat-treated and then artificially aged**. Applies to products which are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T7 **solution heat-treated and overaged/stabilized.** Applies to wrought products that are artificially aged after solution heat-treatment to carry them beyond a point of maximum strength to provide control of some significant characteristic. Applies to cast products that are artificially aged after solution heat-treatment to provide dimensional and strength stability.

T8 **solution heat-treated, cold worked, and then artificially aged.** Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

T9 **solution heat treated, artificially aged, and then cold worked.** Applies to products which are cold worked to improve strength.

T10 **cooled from an elevated temperature shaping process, cold worked, and then artificially aged.** Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

Source: Aluminum Association, Inc., *Aluminum Standards and Data*, 2000.

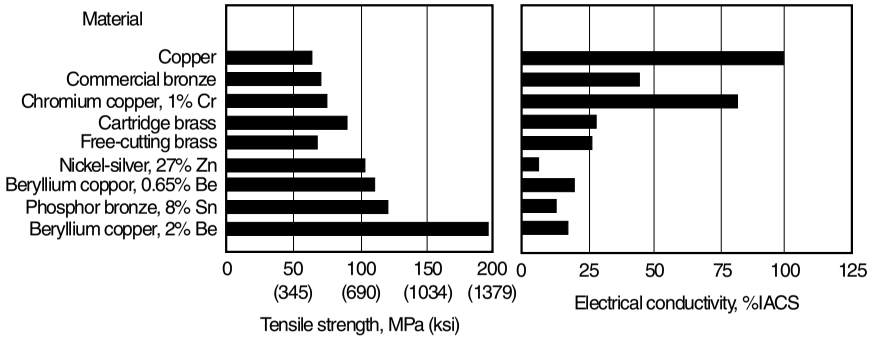
MELTING TEMPERATURES OF COMMON ALLOYS

UNS	Common Name	Melting Temperature °C	Melting Temperature °F
A24430	Cast Al B443.0	570–630	1065–1170
A91100	Al 1100	640–660	1190–1215
A95052	Al 5052	610–650	1125–1200
C11000	ETP Copper	1083	1980
C23000	Red Brass	990–1025	1810–1880
C28000	Muntz Metal	900–905	1650–1660
C44300	Admiralty Brass, As	900–935	1650–1720
C61400	Aluminum Bronze D	1045–1060	1910–1940
C70600	90-10 Copper-Nickel	1100–1150	2010–2100
C71500	70-30 Copper-Nickel	1170–1240	2140–2260
C83600	Ounce Metal	854–1010	1510–1840
F10006	Gray Cast Iron	1150–1200	2100–2200
G10200	Carbon Steel	1520	2760
J94224	HK Cast SS	1400	2550
L13002	Tin	232	450
L51120	Chemical Lead	326	618
L55030	50/50 Solder	183–216	361–421
M11311	Mg AZ31B	605–632	1120–1170
M13310	Mg HK31A	589–651	1092–1204
N02200	Nickel 200	1435–1445	2615–2635
N04400	400 Alloy	1300–1350	2370–2460
N06600	600 Alloy	1350–1410	2470–2575
N10276	C-276 Alloy	1320–1370	2420–2500
N10665	B-2 Alloy	1300–1370	2375–2500
P00020	Gold	1063	1945
P03980	Palladium	1552	2826
P04995	Platinum	1769	3217
P07015	Silver	961	1761
R03600	Molybdenum	2610	4730
R04210	Niobium (Columbium)	2470	4470
R05200	Tantalum	2996	5425
R07005	Tungsten	3410	6170
R50250	Titanium, Gr 1	1705	3100
R56400	Titanium, Gr 5	1600–1660	2920–3020
R60702	Zr 702	1860	3380
S30400	304 SS	1400–1450	2550–2650
S31000	310 SS	1400–1450	2500–2650
S41000	410 SS	1480–1530	2700–2790
S44600	446 SS	1430–1510	2600–2750
S50200	5Cr-0.5Mo Steel	1480–1540	2700–2800
Z13001	Zinc	420	787

COEFFICIENTS OF THERMAL EXPANSION OF COMMON ALLOYS

UNS	Common Name	in/in/°F × 10^{-6}	mm/mm/°C × 10^{-6}	Range-°C
A24430	Cast Al B443.0	12.3	22.	20–100
A91100	Al 1100	13.1	24.	20–100
A95052	Al 5052	13.2	24.	20–100
C11000	ETP Copper	9.4	16.9	20–100
C23000	Red Brass	10.4	18.7	20–300
C28000	Muntz Metal	11.6	21.	20–300
C44300	Admiralty Brass, As	11.2	20.	20–300
C61400	Aluminum Bronze D	9.0	16.2	20–300
C70600	90-10 Copper-Nickel	9.5	17.1	20–300
C71500	70-30 Copper-Nickel	9.0	16.2	20–300
C83600	Ounce Metal	10.2	18.4	0–100
F10006	Gray Cast Iron	6.7	12.1	0–100
G10200	Carbon Steel	6.7	12.1	0–100
J94224	HK Cast SS	9.4	16.9	20–540
L13002	Tin	12.8	23.	0–100
L51120	Chemical Lead	16.4	30.	0–100
L55030	50/50 Solder	13.1	24.	0–100
M11311	Mg AZ31B	14.5	26.	20–100
M13310	Mg HK31A	14.5	26.	20–100
N02200	Nickel 200	7.4	13.3	20–90
N04400	400 Alloy	7.7	13.9	20–90
N06600	600 Alloy	7.4	13.3	20–90
N10276	C-276 Alloy	6.3	11.3	20–90
N10665	B-2 Alloy	5.6	10.1	20–90
R03600	Molybdenum	2.7	4.9	20–100
R05200	Tantalum	3.6	6.5	20–100
R50250	Titanium, Gr 1	4.8	8.6	0–100
R56400	Titanium, Gr 5	4.9	8.8	0–100
R60702	Zr 702	2.9	5.2	0–100
S30400	304 SS	9.6	17.3	0–100
S31000	310 SS	8.0	14.4	0–100
S41000	410 SS	6.1	11.0	0–100
S44600	446 SS	5.8	10.4	0–100
S50200	5Cr-0.5Mo Steel	7.3	13.1	20–540
Z13001	Zinc	18.	32.	0–100

STRENGTH AND ELECTRICAL CONDUCTIVITY RELATIONSHIP FOR COPPER AND COPPER ALLOYS



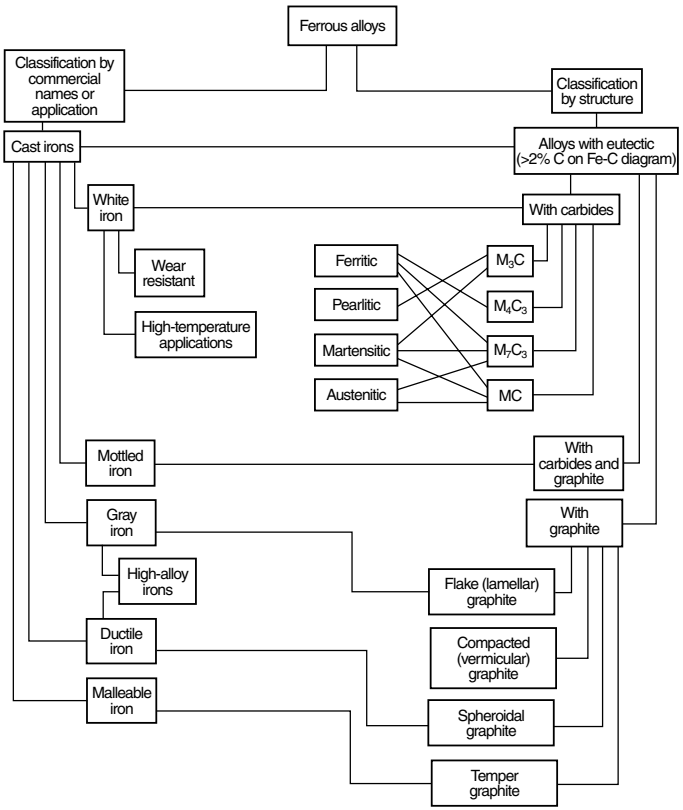
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CLASSIFICATION OF COPPER ALLOYS

Generic Name	UNS No.	Composition
Wrought Alloys		
Coppers	C10100–C15760	> 99% Cu
High-copper alloys	C16200–C19600	> 96% Cu
Brasses	C20500–C28580	Cu-Zn
Leaded brasses	C31200–C38590	Cu-Zn-Pb
Tin brasses	C40400–C49080	Cu-Zn-Sn-Pb
Phosphor bronzes	C50100–C52400	Cu-Sn-P
Leaded phosphor bronzes	C53200–C54800	Cu-Sn-Pb-P
Copper-phosphorus and copper-silver-phosphorus alloys	C55180–C55284	Cu-P-Ag
Aluminum bronzes	C60600–C64400	Cu-Al-Ni-Fe-Si-Sn
Silicon bronzes	C64700–C66100	Cu-Si-Sn
Other copper-zinc alloys	C66400–C69900	–
Copper-nickels	C70000–C79900	Cu-Ni-Fe
Nickel silvers	C73200–C79900	Cu-Ni-Zn
Cast Alloys		
Coppers	C80100–C81100	≫99% Cu
High-copper alloys	C81300–C82800	≫94% Cu
Red and leaded red brasses	C83300–C85800	Cu-Zn-Sn-Pb (75–89% Cu)
Yellow and leaded yellow brasses	C85200–C85800	Cu-Zn-Sn-Pb (57–74% Cu)
Manganese bronzes and leaded manganese bronzes	C86100–C86800	Cu-Zn-Mn-Fe-Pb
Silicon bronzes, silicon brasses	C87300–C87900	Cu-Zn-Si
Tin bronzes and leaded tin bronzes	C90200–C94500	Cu-Sn-Zn-Pb
Nickel-tin bronzes	C94700–C94900	Cu-Ni-Sn-Zn-Pb
Aluminum bronzes	C95200–C95810	Cu-Al-Fe-Ni
Copper-nickels	C96200–C96800	Cu-Ni-Fe
Nickel silvers	C97300–C97800	Cu-Ni-Zn-Pb-Sn
Leaded coppers	C98200–C98800	Cu-Pb
Special alloys	C99300–C99750	–

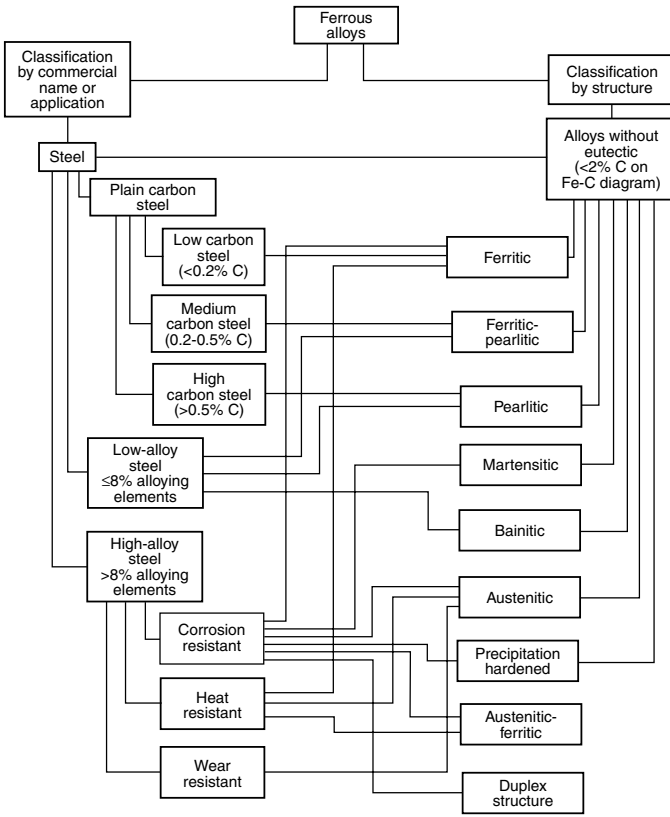
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CLASSIFICATION OF FERROUS CASTING ALLOYS



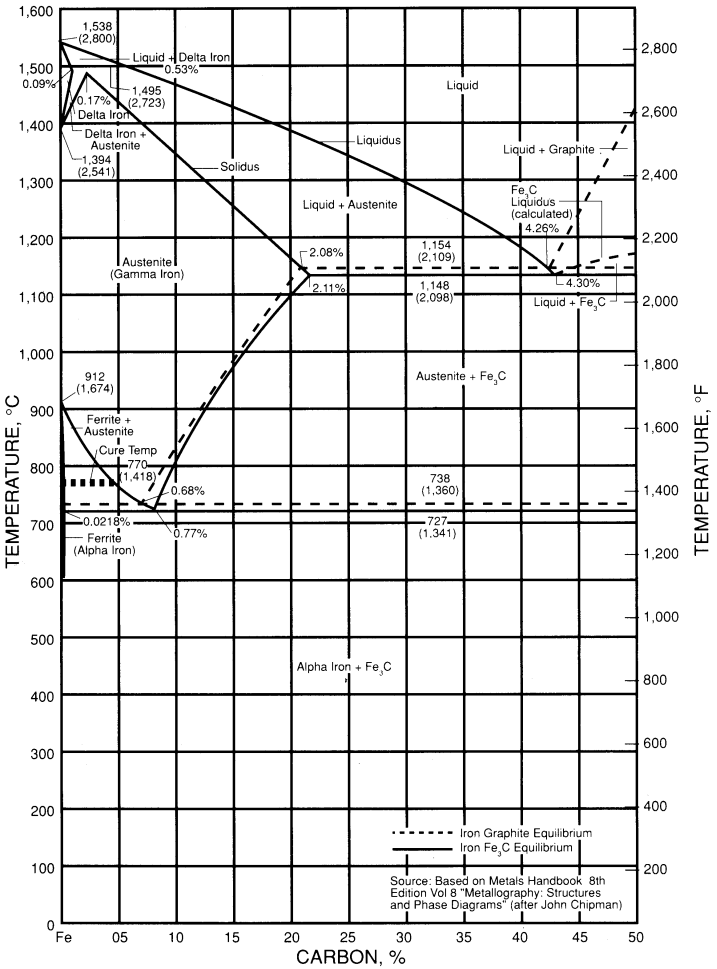
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CLASSIFICATION OF STEELS



Source: GEM 2001, p. 51, ASM, 2000. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

IRON-CARBON EQUILIBRIUM DIAGRAM



Source: *Metals Progress Databook*, p. 109, ASM, 1980. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

CRITICAL TRANSFORMATION TEMPERATURES FOR STEELS

Definitions

Transformation temperature range is that range of temperature within which austenite forms during heating and transforms during cooling. Transformation temperature is the temperature at which a change in phase occurs. The following symbols have been used:

Ac_1 The temperature at which austenite begins to form during heating.

Ac_3 The temperature at which the transformation of ferrite to austenite is completed during heating.

Ar_1 The temperature at which transformation of austenite to ferrite or to ferrite plus cementite is completed during cooling.

Ar_3 The temperature at which austenite begins to transform to ferrite during cooling.

	Thermal Critical Range							
	On heating				On Cooling			
	Ac_1		Ac_3		Ar_3		Ar_1	
Type of Steel	**°F**	**°C**	**°F**	**°C**	**°F**	**°C**	**°F**	**°C**
Low Carbon	1330	723	1605	874	1540	838	1240	671
Medium Carbon	1350	732	1540	838	1470	799	1340	727
Carbon - 1/2 Mo	1340	727	1570	854	1480	804	1225	663
1 Cr 1/2 Mo	1420	771	1635	891	1550	843	1420	771
2 1/4 Cr 1 Mo	1480	804	1600	871	1510	821	1330	721
5 Cr 1/2 Mo	1506	819	1620	882	1445	785	1325	719
7 Cr 1/2 Mo	1520	827	1620	882	1450	788	1340	727
9 Cr 1 Mo	1490	810	1580	860	1420	771	1320	716
12 Cr - Type 410	1435	780	1545	841	1310	710	1130	609

Critical ranges were determined with a heating rate of 250°F per hour and a cooling rate of 50°F per hour.

TEMPER AND RADIATION COLOR OF CARBON STEEL

°F	Approx. °C	Temper Color
380–400	200	Pale yellow
420–440	220	Straw yellow
460–480	240	Yellowish brown
500–540	270	Bluish purple
540–560	285	Violet
560–580	300	Pale blue
600–640	325	Blue
		Radiation Color
1000	540	Black
1100	590	Faint dark red
1200	650	Cherry red (dark)
1300	700	Cherry red (med.)
1400	760	Red
1500	815	Light red
1600	870	Reddish orange
1700	930	Orange
1800	980	Changes
1900	1040	to
2000	1090	Pale orange lemon
2100	1150	Lemon
2200	1205	Light lemon
2300	1260	Yellow
2400	1315	Light yellow
2500	1370	Yellowish gray: “while”

ANNEALING TEMPERATURES FOR AUSTENITIC STAINLESS STEELS AND RELATED ALLOYS

Solution annealing consists of heating to temperature and cooling rapidly. Temperatures are from indicated ASTM standards. Consult alloy producers for details.

UNS	Name	ASTM	Form	°F	°C
J93370	CD-4MCu	A743	Casting	1900 min	1040 min
J95150	CN-7M	A743	Casting	2050 min	1120 min
N08020	20Cb-3	B464	Pipe	1800–1850	980–1010
N08024	20Mo-4	B464	Pipe	1925–1975	1050–1080
N08026	20Mo-6	B464	Pipe	2050–2200	1120–1205
N08028	Sanicro 28	B668	Tube	1975–2085	1080–1140
N08366	AL-6X	B675	Pipe	2200 min	1205 min
N08367	AL-6XN	B675	Pipe	2150 min	1175 min
N08700	JS700	B599	Plate	2000 min	1090 min
N08904	904L Alloy	B677	Pipe, Tube	1950–2100	1065–1150
N08925	25-6Mo	B677	Pipe, Tube	1950–2100	1065–1150
S20910	22-13-5	A312	Pipe	1900 min	1040 min
S24000	18-3 Mn	A312	Pipe	1900 min	1040 min
S30400	304 SS	A312	Pipe	1900 min	1040 min
S30403	304L SS	A312	Pipe	1900 min	1040 min
S30409	304H SS	A312	Pipe	1900 min	1040 min
S30451	304N SS	A312	Pipe	1900 min	1040 min
S30453	304LN SS	A312	Pipe	1900 min	1040 min
S30815	253MA	A312	Pipe	1900 min	1040 min
S30900	309 SS	A312	Pipe	1900 min	1040 min
S31000	310 SS	A312	Pipe	1900 min	1040 min
S31254	254 SMO	A312	Pipe	2100 min	1150 min
S31600	316 SS	A312	Pipe	1900 min	1040 min
S31603	316L SS	A312	Pipe	1900 min	1040 min
S31609	316H SS	A312	Pipe	1900 min	1040 min
S31651	316N SS	A312	Pipe	1900 min	1040 min
S31653	316LN SS	A312	Pipe	1900 min	1040 min
S31700	317 SS	A312	Pipe	1900 min	1040 min
S31703	317L SS	A312	Pipe	1900 min	1040 min
S31725	317LM SS	A312	Pipe	1900 min	1040 min
S31726	317L4 SS	A312	Pipe	1900 min	1040 min
S32100	321 SS*	A312	Pipe	1900 min	1040 min
S32109	321H SS*	A312	Pipe	CW 2000 min HR 1925 min	CW 1095 min HR 1050 min
S34700	347 SS*	A312	Pipe	1900 min	1040 min
S34709	347H SS*	A312	Pipe	CW 2000 min HR 1925 min	CW 1095 min HR 1050 min
S34800	348 SS*	A312	Pipe	1900 min	1040 min
S38100	18-18-2	A312	Pipe	1900 min	1040 min
S31200	44LN	A790	Pipe	1920–2010	1050–1100
S31260	DP-3	A790	Pipe	1870–2010	1020–1100
S31500	3RE60	A790	Pipe	1800–1900	980–1040
S31803	2205 Alloy	A790	Pipe	1870–2010	1020–1100
S32304	SAF 2304	A790	Pipe	1800–1900	930–1040
S32550	Ferralium 255	A790	Pipe	1900 min	1040 min
S32950	7 Mo Plus	A790	Pipe	1820–1880	990–1025

*A stabilization heat treatment after solution anneal improves resistance to intergranular corrosion.

ANNEALING TREATMENTS FOR FERRITIC STAINLESS STEELS

		Treatment Temperature	
UNS	**Common Name**	**°C**	**°F**
Conventional ferritic grades			
S40500	405	650–815	1200–1500
S40900	409	870–900	1600–1650
S43000	430	705–790	1300–1450
S43020	430F	705–790	1300–1450
S43400	434	705–790	1300–1450
S44600	446	760–830	1400–1525
Low-interstitial ferritic grades			
S43035	439	870–925	1600–1700
S44400	444	955–1010	1750–1850
S44626	26–1Ti	760–955	1400–1750
S44660	SC-1	1010–1065	1850–1950
S44735	29–4C	1010–1065	1850–1950
S44800	29–4.2	1010–1065	1850–1950
S44635	26–4.4	1010–1065	1850–1950

Note: Postweld heat treating of low-interstitial ferritic stainless steels is generally unnecessary and frequently undesirable. Any annealing of these grades should be followed by water quenching or very rapid cooling.

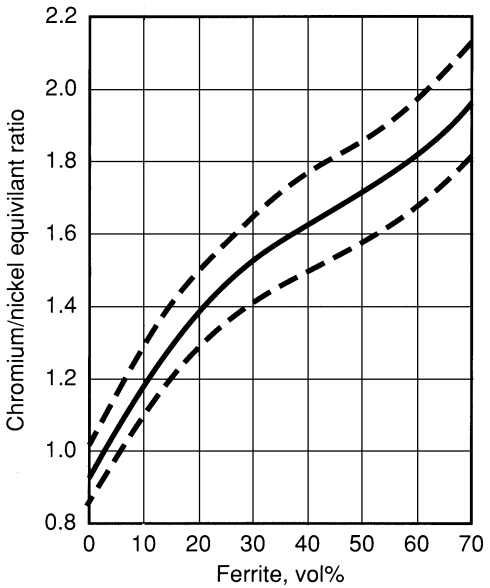
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ANNEALING TEMPERATURES AND PROCEDURES FOR MARTENSITIC STAINLESS STEELS

	Process (subcritical) Annealing[a]		Full Annealing[b][c]		Isothermal Annealing[c]	
UNS	**°C**	**Hardness**	**°C**	**Hardness**	**Procedure[d]**	**Hardness**
S40300, S41000	650–760	82–92 HRB	830–885	75–85 HRB	Heat to 830 to 885°C; hold 6 h at 705°C	85 HRB
S41400	650–730	99 HRB-24 HRC	Not recommended		Not recommended	
S41600, S41623	650–760	86–92 HRB	830–885	75–85 HRB	Heat to 830 to 885°C; hold 2 h at 720°C	85 HRB
S42000	675–760	94–97 HRB	830–885	86–95 HRB	Heat to 830 to 885°C; hold 2 h at 705°C	95 HRB
S43100	620–705	99 HRB-30 HRC	Not recommended		Not recommended	
S44002	675–760	90 HRB-22 HRC	845–900	94–98 HRB	Heat to 845 to 900°C; hold 4 h at 690°C	98 HRB
S44003	675–760	98 HRB-23 HRC	845–900	95 HRB-20 HRC	Same as S44002	20 HRC
S44004	675–760	98 HRB-23 HRC	845–900	98 HRB-25 HRC	Same as S44002	25 HRC

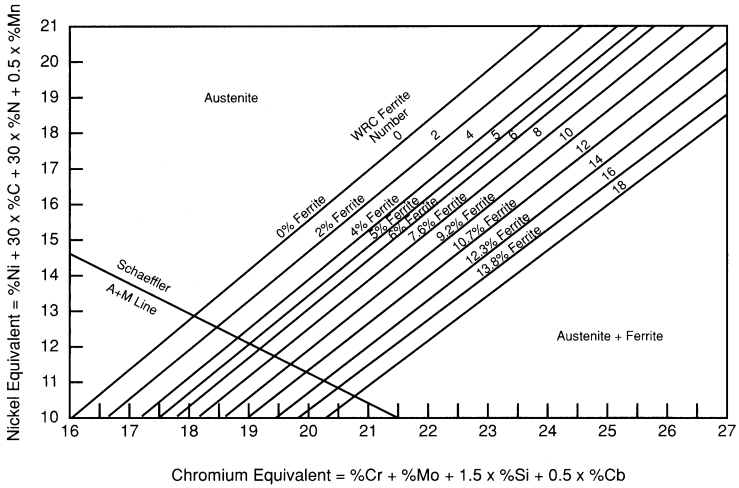
[a] Air cool from temperature; maximum softness is obtained by heating to temperature at high end of range. [b] Soak thoroughly at temperature within range indicated; furnace cool at 790°C; continue cooling at 15 to 25°C/h to 595°C; air cool to room temperature; [c] Recommended for applications in which full advantage may be taken of the rapid cooling to the transformation temperature and from it to room temperature; [d] Preheating to a temperature within the process annealing range is recommended for thin-gage parts, heavy sections, previously hardened parts, parts with extreme variations in section or with sharp re-entrant angles, and parts that have been straightened or heavily ground or machined to avoid cracking and minimize distortion, particularly for S42000, S43100, S44002, S44003, and S44004.

SCHOEFER DIAGRAM FOR ESTIMATING THE AVERAGE FERRITE CONTENT IN AUSTENITIC IRON-CHROMIUM-NICKEL ALLOY CASTINGS



Source: *Metals Handbook*, 9th ed., Vol. 13, p. 577, ASM, 1987. Reprinted by Permission of ASM International®, Materials Park, OH 44073-0002.

DELTA FERRITE CONTENT OF STAINLESS STEEL WELD METALS



Note: The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used; GMAW welds–0.08% (except self-shielding flux cored electrode GMAW welds–0.12%); welds of other process–0.06%.

Source: ASME Pressure Vessel Code, Section III, Fig. NB-2433.1–1, 1977. Reprinted from ASME B31.3–1990, and 1977 BPVC, Section III-NB, by permission of The American Society of Mechanical Engineers. All rights reserved.

OVERVIEW OF JOINING PROCESSES

Material	Thickness	SMAW	SAW	GMAW	FCAW	GTAW	PAW	ESW	EGW	RW	FW	OFW	DFW	FRW	EBW	LBW	Brazing							S
																	TB	FB	IB	RB	DB	IRB	DFB	
Carbon Steel	S	X	X	X		X				X	X	X			X	X	X	X	X	X	X	X	X	X
	I	X	X	X	X	X				X	X	X		X	X	X	X	X	X	X	X		X	X
	M	X	X	X	X					X	X	X		X	X	X	X	X	X				X	
	T	X	X	X	X			X	X		X	X		X	X			X					X	
Low Alloy Steel	S	X	X	X		X				X	X	X	X		X	X	X	X	X	X	X	X	X	X
	I	X	X	X	X	X				X	X		X	X	X	X	X	X	X				X	X
	M	X	X	X	X						X		X	X	X	X	X	X	X				X	
	T	X	X	X	X			X		X	X		X	X	X		X						X	
Stainless Steel	S	X	X	X		X	X			X	X	X	X		X	X	X	X	X	X	X	X	X	X
	I	X	X	X	X	X	X			X	X		X	X	X	X	X	X	X				X	X
	M	X	X	X	X		X				X		X	X	X	X	X	X	X				X	
	T	X	X	X	X			X			X		X	X	X			X					X	
Cast Iron	I	X										X					X	X	X				X	X
	M	X	X	X	X							X					X	X	X				X	X
	T	X	X	X	X							X						X					X	
Nickel and Alloys	S	X		X		X	X			X	X	X			X	X	X	X	X	X	X	X	X	X
	I	X	X	X		X	X			X	X			X	X	X	X	X	X				X	X
	M	X	X	X			X				X			X	X	X	X	X					X	
	T	X		X				X			X			X	X			X					X	

Material	Thickness	SMAW	SAW	GMAW	FCAW	GTAW	PAW	ESW	EGW	RW	FW	OFW	DFW	FRW	EBW	LBW	Brazing TB	Brazing FB	Brazing IB	Brazing RB	Brazing DB	Brazing IRB	Brazing DFB	S
Aluminum and Alloys	S	X		X		X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	I	X		X		X				X	X		X	X	X	X	X	X			X		X	X
	M	X		X		X					X			X	X		X	X			X		X	
	T	X		X				X	X		X				X			X					X	
Titanium and Alloys	S			X		X	X			X	X		X		X	X		X	X			X	X	
	I			X		X	X				X		X	X	X	X		X					X	
	M			X		X	X				X		X	X	X	X		X					X	
	T			X							X		X		X		X	X					X	
Copper and Alloys	S			X		X	X				X				X		X	X	X	X			X	X
	I			X			X				X			X	X		X	X		X			X	X
	M			X							X			X	X		X	X					X	
	T			X							X				X			X					X	
Magnesium and Alloys	S			X		X				X					X	X	X	X			X		X	
	I			X		X				X	X			X	X	X	X	X			X		X	
	M			X							X			X	X	X		X					X	
	T			X							X				X									
Refractory Alloys	S			X		X	X			X	X				X		X	X	X	X		X	X	
	I			X			X				X				X		X	X					X	
	M									X	X													
	T																							

This table presented as a general survey only. In selecting processes to be used with specific alloys, the reader should refer to other appropriate sources of information.

(*Continued*)

OVERVIEW OF JOINING PROCESSES (*Continued*)

Legend

Process Code		Thickness
SMAW - Shielded Metal Arc Welding-	FRW-Friction Welding	S-Sheet up to 3 mm (1/8 in.)
SAW-Submerged Arc Welding	EBW-Electron Beam Welding	I-Intermediate 3 to 6 mm (1/8 to 3/4 in.)
GMAW-Gas Metal Arc Welding	LBW-Laser Beam Welding	M-Medium 6 to 19 mm (1/4 to 3/4 in.)
FCAW-Flux Cored Arc Welding	Brazing	T-Thick 19 mm (3/4 in.) and up
GTAW-Gas Tungsten Arc Welding	TB-Torch Brazing	
PAW-Plasma Arc Welding	FB-Fumace Brazing	
ESW-Electroslag Welding	IB-Induction Brazing	
EGW-Electrogas Welding	RB-Resistance Brazing	X-Commercial Process
RW-Resistance Welding	DB-Dip Brazing	
FW-Flash Welding	IRB-Infrared Brazing	
OFW-Oxyfuel Gas Welding	DFB-Diffusion Brazing	
DFW-Diffusion Welding	S-Soldering	

Source: *Welding Handbook*, 8th ed., Vol. 1, p. 3, AWS, 1987. Reprinted by permission of American Welding Society.

PREHEAT TEMPERATURES FOR WELDING CARBON AND ALLOY STEELS

Base Metal P-No.[1]	Weld Metal Analysis A-No.[2]	Base Metal Group	Nominal Wall Thickness		Min. Specified Tensile Strength, Base Metal		Min. Temperature			
							Required		Recommended	
			in.	mm	ksi	MPa	°F	°C	°F	°C
1	1	Carbon steel	<1	<25.4	≤71	≤490	···	···	50	10
			≥1	≥25.4	All	All	···	···	175	79
			All	All	>71	>490	···	···	175	79
3	2, 11	Alloy steels,	<1/2	<12.7	≤71	≤490	···	···	50	10
		Cr ≤ 1/2%	≥1/2	≥12.7	All	All	···	···	175	79
			All	All	>71	>490	···	···	175	79
4	3	Alloy steels 1/2% < Cr ≤ 2%	All	All	All	All	300	149	···	···
5	4, 5	Alloy steels, 2 1/4% ≤ Cr ≤ 10%	All	All	All	All	350	177	···	···
6	6	High alloy steels martensitic	All	All	All	All	···	···	300[3]	149[3]
7	7	High alloy steels ferritic	All	All	All	All	···	···	50	10
8	8, 9	High alloy steels austenitic	All	All	All	All	···	···	50	10
9A, 9B	10	Nickel Alloy steels	All	All	All	All	···	···	200	93

Base Metal P-No.[1]	Weld Metal Analysis A-No.[2]	Base Metal Group	Nominal Wall Thickness		Min. Specified Tensile Strength, Base Metal		Min. Temperature			
							Required		Recommended	
			in.	mm	ksi	MPa	°F	°C	°F	°C
10	...	Cr-Cu steel	All	All	All	All	300–400	149–204	...	...
10A	...	Mn-V steel	All	All	All	All	...	...	175	79
10E	...	27Cr steel	All	All	All	All	300[4]	149[4]	...	...
11A SG 1	...	8Ni. 9Ni steel	All	All	All	All	...	...	50	10
11A SG 2	...	5Ni steel	All	All	All	All	50	10	...	...
21–52	...	...	All	All	All	All	...	...	50	10

Notes:
(1) P-Number from BPV Code, Section IX, Table QW-422, Special P-Numbers (SP-1, SP-2, SP-3, SP-4, and SP-5) require special consideration. The required thermal treatment for Special P-Numbers shall be established by the engineering design and demonstrated by the welding procedure qualification.
(2) A-Number from BPV Code, Section IX, Table QW-442.
(3) Maximum interpass temperature 600°F (315°C).
(4) Maintain interpass temperature between 350°F–450°F (177°C–232°C).

Source: ASME B31.3-1990 EDITION, TABLE 330.1. Reprinted from ASME B31.3-1990, and 1977 BPVC, Section III-NB, by permission of The American Society of Mechanical Engineers. All rights reserved.

POSTWELD HEAT TREATMENT REQUIREMENTS FOR CARBON AND ALLOY STEELS

Base Metal P-Number[1]	Weld Metal Analysis A-Number[2]	Base Metal Group	Nominal Wall Thickness		Min. Specified Tensile Strength, Base Metal		Metal Temperature Range		Holding Time		Brinell Hardness,[4] Max.
			in.	mm	ksi	MPa	°F	°C	hr/in. Nominal Walt[3]	Min. Time, hr	
1	1	Carbon steel	≤3/4	≤19	All	All	None	None	...	...	...
			>3.4	>19	All	All	1100–1200	593–649	1	1	...
3	2, 11	Alloy steels	≤3/4	≤19	≤71	≤490	None	None	...	...	...
		Cr ≤ 1/2%	>3/4	>19	All	All	1100–1325	593–718	1	1	225
			All	All	>71	>490	1100–1325	593–718	1	1	225
4	3	Alloy steels°	≤1/2	≤12.7	≤71	≤490	None	None	...	...	...
		1/2% ≤ Cr ≤ 2%	>1/2	>12.7	All	All	1300–1375	704–746	1	2	225
			All	All	>71	>490	1300–1375	704–746	1	2	225
5	4, 5	Alloy steels									
		2 1/4% ≤ Cr ≤ 10%									
		≤3% Cr & ≤0.15% C &	≤1/2	≤12.7	All	All	None	None	...	...	...
		≥3% Cr or >0.15% C or	>1/2	>12.7	All	All	1300–1400	704–760	1	2	241
6	6	High alloy steels martensitic	All	All	All	All	1350–1450	732–788	1	2	241
		A 240 Gr. 429	All	All	All	All	1150–1225	621–663	1	2	241
7	7	High alloy steels ferritic	All	All	All	All	None	None	...	...	...

Base Metal P-Number[1]	Weld Metal Analysis A-Number[2]	Base Metal Group	Nominal Wall Thickness		Min. Specified Tensile Strength, Base Metal		Metal Temperature Range		Holding Time		Brinell Hardness,[4] Max.
			In.	mm	kal	MPa	°F	°C	hr/in. Nominal Walt[3]	Min. Time, hr	
8	8, 9	High alloy steels austenitic	All	All	All	All	None	None	...	...	...
9A, 9B	10	Nickel alloy steels	≤3/4	≤19	All	All	None	None	...	...	...
	...		> 3/4	> 19	All	All	1100–1175	593–635	1/2	1	...
10	...	Cr-Cu steel	All	All	All	All	1400–1500[5]	760–816[5]	1/2	1/2	...
10A	...	Mn-V steel	≤3/4	≤19	≤71	≤490	None	None	...	...	...
			> 3/4	> 19	All	All	1100–1300	593–704	1	1	225
			All	All	> 71	> 490	1100–1300	593–704	1	1	225
10E	...	27Cr steel	All	All	All	All	1225–1300[6]	663–704[6]	1	1	...
10H	...	Cr-Ni-Mo steel	All	All	All	All	See Note[7]		1/2	1/2	...
11A SG 1	...	8Ni, 9Ni steel	≤2	≤51	All	All	None	None	...	...	...
			> 2	> 51	All	All	1025–1085[8]	552–585[8]	1	1	...
11A SG 2	...	5Ni steel	> 2	> 51	All	All	1025–1085[8]	552–585[8]	1	1	...

Notes:

(1) P-Number from BPV Code, Section IX, Table QW-422. Special P-Numbers (SP-1, SP-2, SP-3, SP-4, and SP-5) require special consideration. The required thermal treatment for Special P-Numbers shall be established by the engineering design and demonstrated by the welding procedure qualification.

(2) A-Number from BPV Code, Section IX, Table QW-442.

(3) For SI equivalent, h/mm, divide hr/in. by 25.

(4) See 331.1.7.

(5) Cool as rapidly as possible after the hold period.

(6) Cooling rate to 1200°F (650°C) shall be less than 100°F (55°C)/h; thereafter, the cooling rate shall be fast enough to prevent embrittlement.

(7) Postweld heat treatment is neither required nor prohibited, but any heat treatment applied shall be performed at 1800°F–1900°F. (982°C–1038°C) followed by rapid cooling.

(8) Cooling rate shall be > 300°F (167°C)/hr to 600°F (316°C).

Source: ASME B31.3-1990 EDITION, TABLE 331.1.1. Reprinted from ASME B31.3-1990, and 1977 BPVC, Section III-NB, by permission of The American Society of Mechanical Engineers. All rights reserved.

FILLER METALS SUITABLE FOR WELDING JOINTS BETWEEN DISSIMILAR AUSTENITIC STAINLESS STEELS

Suitable filler metals (listed in no preferred order, prefix ER omitted) Base metal B (type of steel being welded to base metal listed in the first column)

Base Metal A	Base Metal B											
	304L	306	309	309S	310	310S	316, 316H	316	317	321, 321 H	347, 347 H	348, 348 H
304, 304H, 305	308L	308L	308, 309	308, 309	306, 309, 310	306, 309, 310	308, 316	308, 316	308, 316, 317	308	308	
304L		308L	308, 309	308, 309	308, 309, 310	308, 309, 310	308, 316	308L, 316L	308, 316, 317	308L, 347	308L, 347	
308			308, 309	308, 309	308, 309, 310	308, 309, 310	308, 316	308, 316	308, 316, 317	308	308, 347	
309				309	309, 310	309, 310	309, 316	309, 316	309, 316	309, 347	309, 347	
309S					309, 310	309S, 310S	309, 316	309S, 316L	309, 316	309, 347	309, 347	
310							310, 316	310, 316	310, 317	308, 310	308, 310	
310S							316	316	317	308, 310	308, 310	
316, 316H								316	316, 317	308, 316	308, 316, 347	
316L									317	316L	316L, 347	
317										308, 317	308, 317, 347	
321, 321H											308L, 347	

Source: *Metals Handbook*, 9th ed., Vol. 6, p. 335. ASM, 1983. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

ELECTRODES AND FILLER METALS FOR DISSIMILAR JOINTS BETWEEN NICKEL ALLOYS AND OTHER METALS

		Carbon and Low Alloy Steels		300 Series Stainless Steels		Copper	
UNS	Common Name	Electrode	Filler Metal	Electrode	Filler Metal	Electrode	Filler Metal
N02200	Nickel 200	Weld A	82	Weld A	82	190	60
N04400	400 Alloy	190	61	Weld A	82	190	60
N05500	K-500 Alloy	190	61	Weld A	82	190	60
N06002	X Alloy	X	X	X	X		
N06022	C-22 Alloy	C-22	C-22	C-22	C-22		
N06030	G-30 Alloy	C-22	C-22	C-22	C-22		
N06455	C-4 Alloy	C-22	C-22	C-22	C-22		
N06600	600 Alloy	Weld A	82	Weld A	82	141	61
N06625	625 Alloy	Weld A	82	Weld A	82	141	61
N06985	G-3 Alloy	C-22	C-22	C-22	C-22		
N07718	718 Alloy	Weld A	82	Weld A	82	141	61
N07750	X-750 Alloy	Weld A	82	Weld A	82	141	61
N08020	20Cb-3	C-22	C-22	C-22	C-22		
N08366	AL-6X	C-22	C-22	C-22	C-22		
N08800	800 Alloy	Weld A	82	Weld A	82	141	61
N08825	825 Alloy	112	625	112	625	141	61
N08904	904L Alloy	C-22	C-22	C-22	C-22		
N10276	C-276 Alloy	C-276	C-276	C-276	C-276		
N10665	B-2 Alloy	B-2	B-2	B-2	B-2		

Designations for Nickel-Base Electrodes and Filler Metals:

Common	UNS	AWS
60	N04060	A5.14 (ERNiCu-7)
61	N02061	A5.14 (ERNi-1)
82	N06082	A5.14 (ERNiCr-3)
141	W82141	A5.11 (ENi-1)
190	W84190	A5.11 (ENiCu-7)
Weld A	W86133	A5.11 (ENiCrFe-2)

Source: This partial listing is adapted from Inco Alloys International “Joining” and Haynes International “Welding Filler Material Information.”

TYPICAL PROPERTY RANGES FOR PLASTICS

Thermosets[a]	Specific Gravity	Tensile Strength ksi	Tensile Strength (MPa)	Modulus of Elast., Tension 10^2 ksi	Modulus of Elast., Tension (10^2 MPa)	Impact Strength, Izod[c] ft-lb	Impact Strength, Izod[c] (J)	Max use Temp. (no Load) °F	Max use Temp. (no Load) (°C)	HDT at 254 psi[d] °F	HDT at 254 psi[d] (°C)	Chemical Resistance[e] Weather res	Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents
Alkyds																	
Glass filled	2.12–2.15	4–9.5	(28–66)	20–28	(138–193)	0.6–10	(0.8–14)	450	(230)	400–500	(200–260)	R	A	A	A	A	A
Mineral filled	1.60–2.30	3–9	(21–62)	5–30	(34–207)	0.3–0.5	(0.4–0.7)	300–450	(150–230)	350–500	(180–260)	R	R	A	A	D	A
Asbestos filled	1.65	4.5–7	(31–48)	–	–	0.4–0.5	(0.6–0.7)	450	(230)	315	(160)	R	R	S	R	S	R
Syn. fiber filled	1.24–2.10	4.5–7	(31–48)	20	(138)	0.5–4.5	(0.7–6.1)	300–430	(150–220)	245–430	(120–220)	R	R	S	R	S	A
Alkyl diglycol carbonate	1.30–1.40	5–6	(34–41)	3.0	(21)	0.2–0.4	(0.3–0.5)	212	(100)	140–190	(60–90)	R	R	A[k]	R	R-S	R
Diallyl pythalates																	
Glass filled	1.61–1.78	6–11	(41–76)	14–22	(97–152)	0.4–15	(0.5–20)	300–400	(150–200)	330–540	(165–280)	R	R	S	R-S	S	R
Mineral filled	1.65–1.68	5–9	(34–62)	12–22	(83–152)	0.3–0.5	(0.4–1)	300–400	(150–200)	320–540	(160–280)	R	R	S	R-S	S	R
Asbestos filled	1.55–1.65	7–8	(48–55)	12–22	(83–152)	0.4–0.5	(0.5–0.7)	300–400	(150–200)	320–540	(160–280)	R	R	S	R-S	S	R
Epoxies (bis A)																	
No filler	1.06–1.40	4–13	(28–90)	2.15–5.2	(15–36)	0.2–1.0	(0.3–1.4)	250–500	(120–260)	115–500	(45–260)	R	R	A	R	S	R-S
Graphite fiber reinf.	1.37–1.38	185–200	(1280–1380)	118–120	(814–827)	–	–	–	–	–	–	S	R	R	R	R	R-S
Mineral filled	1.6–2.0	5–15	(34–103)	–	–	0.3–0.4	(0.4–0.5)	300–500	(150–260)	250–500	(120–260)	S	R	R	R	R	R-S
Glass filled	1.7–2.0	10–30	(69–207)	30	(207)	10–30	(14–41)	300–500	(150–260)	250–500	(120–260)	S	R	R-S	R	R	R-S
Epoxies (novolac)																	
No filler	1.12–1.24	5–11	(34–76)	2.15–5.2	(15–36)	0.3–0.7	(0.4–0.9)	400–500	(200–260)	450–500	(230–260)	R	R	R	R	R	R
Epoxies (cycloaliphatic)																	
No filler	1.12–1.18	10–17.5	(69–121)	5–7	(34–48)	–	–	480–550	(250–290)	500–550	(260–290)	R	R	R-A	R	R-A	R

Thermosets[a]	Specific Gravity	Tensile Strength ksi	Tensile Strength (MPa)	Modulus of Elast., Tension 10^2 ksi	Modulus of Elast., Tension (10^2 MPa)	Impact Strength, Izod[c] ft-lb	Impact Strength, Izod[c] (J)	Max use Temp. (no Load) °F	Max use Temp. (no Load) (°C)	HDT at 254 psi[d] °F	HDT at 254 psi[d] (°C)	Chemical Resistance[e] Weather res	Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents
Melamines																	
Cellulose filled	1.45–1.52	5–9	(34–62)	11	(76)	0.2–0.4	(0.3–0.5)	250	(120)	270	(130)	S	R-S	D	R	D	R
Flock filled	1.50–1.55	7–9	(48–62)	–	–	0.4–0.5	(0.5–0.7)	250	(120)	270	(130)	S	R-S	D	R	D	R-S
Asbestos filled	1.70–2.0	5–7	(34–48)	20	(138)	0.3–0.4	(0.4–0.5)	250–400	(120–200)	265	(130)	S	R-S	D	S	S	R
Fabric filled	1.5	8–11	(55–76)	14–16	(97–110)	0.6–1.0	(0.8–1.4)	250	(120)	310	(150)	S	R	D	R	A	R-S
Glass filled	1.8–2.0	5–10	(34–69)	24	(165)	0.6–18	(0.8–24)	300–400	(150–200)	400	(200)	S	R	D	R	R-S	R
Phenolics																	
Woodflour filled	1.34–1.45	5–9	(34–62)	8–17	(55–117)	0.2–0.6	(0.3–0.8)	300–350	(150–180)	300–370	(150–190)	S	R-S	S-D	S-D	A	R-S
Asbestos filled	1.45–2.00	4.5–7.5	(31–52)	10–30	(69–207)	0.2–0.4	(0.3–0.5)	350–500	(180–260)	300–500	(150–260)	S	R-S	S-D	S-D	A	R-S
Mica filled	1.65–1.92	5.5–7	(38–48)	25–50	(172–345)	0.3–0.4	(0.4–0.5)	250–300	(120–150)	300–350	(150–180)	S	R-S	S-D	S-D	A	R-S
Glass filled	1.69–1.95	5–18	(34–124)	19–33	(131–228)	0.3–18	(0.4–24)	350–550	(180–290)	300–600	(150–320)	S	R-S	S-D	S-D	A	R-S
Fabric filled	1.36–1.43	3–9	(21–62)	9–14	(62–97)	0.8–8	(1.1–11)	220–250	(100–120)	250–330	(120–170)	S	R-S	S-D	S-D	A	R-S
Polybutadienes																	
Very high vinyl (no filler)	1.00	8	(55)	2	(14)	1.1	(1.5)	500	(260)	–	–	S	R	R	R	R	R
Polyesters																	
Glass filled BMC	1.7–2.3	4–10	(28–69)	16–25	(110–172)	1.5–16	(2.0–22)	300–350	(150–180)	400–450	(200–230)	R-E	R-A	S-A	S-A	S-D	A-D
Glass filled SMC	1.7–2.1	8–20	(55–138)	16–25	(110–172)	8–22	(11–30)	300–350	(150–180)	400–450	(200–230)	R-E	R-A	S-A	S-A	S-D	A-D
Glass cloth reinf.	1.3–2.1	25–50	(172–345)	19–45	(131–310)	5–30	(7–41)	300–350	(150–180)	400–450	(200–230)	R-E	R-A	S-A	S-A	S-D	A-D
Silicones																	
Glass filled	1.7–2.0	4–6.5	(28–45)	10–15	(69–103)	3–15	(4–20)	600	(320)	600	(320)	R-S	R-S	R-S	S	S-A	R-A
Mineral filled	1.8–2.8	4–6	(28–41)	13–18	(90–124)	0.3–0.4	(0.4–0.5)	600	(320)	600	(320)	R-S	R-S	R-S	S	S-A	R-A
Ureas																	
Cellulose filled	1.47–1.52	5.5–13	(38–90)	10–15	(69–103)	0.2–0.4	(0.3–0.5)	170	(80)	260–290	(130–140)	S	R-S	A-D	S-A	D	R-S
Urethanes																	
No filler	1.1–1.5	0.2–10	(1–69)	1–10	(7–69)	5-NB	(7)	190–250	(90–120)	–	–	R-S	S	A	S	S-A	R-S

(*Continued*)

TYPICAL PROPERTY RANGES FOR PLASTICS (*Continued*)

Thermoplastics		Specific Gravity	Tensile Strength ksi	Tensile Strength (MPa)	Modulus of Elast., Tension 10^2 ksi	Modulus of Elast., Tension (10^2 MPa)	Impact Strength, Izod[c] ft-lb	Impact Strength, Izod[c] (J)	Max use Temp. (no Load) °F	Max use Temp. (no Load) (°C)	HDT at 66 psi °F	HDT at 66 psi (°C)	HDT at 264 psi °F	HDT at 264 psi (°C)	Chemical Resistance[e] Weather res	Week acid	Strong acid	Week alkali	Strong alkali	Solvents
ABS	GP	1.05–1.07	5.9	(41)	3.1	(21)	6	(8)	160–200	(70–90)	210–225	(100–110)	190–206	(90–95)	R-E	R	A[k]	R	R	A[m]R
	Hi. imp.	1.01–1.06	4.8	(33)	2.4	(17)	7.5	(10)	140–210	(60–100)	210–225	(100–110)	188–211	(85–100)	R-E	R	A[k]	R	R	A[m]R
	Ht. res.	1.06–1.08	7.4	(51)	3.9	(27)	2.2	(30)	190–230	(90–110)	225–252	(110–120)	226–240	(110–115)	R-E	R	A[k]	R	R	A[m]R
	Trans.	1.07	5.6	(39)	2.9	(20)	5.3	(7.1)	130	(55)	180	(80)	165	(75)	R-E	R	A[k]	R	R	A[m]R
		1.20	6.0	(41)	3.2	(22)	2.5	(3.4)	130–180	(55–80)	210–220	(100–105)	195	(90)	R-E	R	A[k]	R	R	A[m]R
Acetals	Homo	1.42	10	(69)	5.2	(36)	1.4	(1.9)	195	(90)	338	(170)	255	(125)	R[j]	R	A	R	A-D	R
	Copol	1.41	8.8	(61)	4.1	(28)	1.2–1.6	(1.6–2.2)	212	(100)	316	(160)	230	(110)	R[j]	R	A	R	R	R
Acrylics	GP	1.11–1.19	5.6–11.0	(39–76)	2.25–4.65	(16–32)	0.3–2.3	(0.4–3.1)	130–230	(55–110)	175–225	(80–110)	165–210	(75–100)	R	R	A[k]	R	A	A[m]R
	Hi. imp.	1.12–1.16	5.8–8.0	(40–55)	2.3–3.3	(16–23)	0.8–2.3	(1.1–3.1)	140–195	(60–90)	180–205	(80–95)	165–190	(75–90)	R	R	A[k]	R	R	A[m]R
		1.21–1.28	8.0–12.5	(55–86)	3.5–4.8	(24–33)	0.3–0.4	(0.4–0.5)	125–200	(50–90)	170–200	(75–95)	155–205	(70–95)	R	R	A[k]	R	A	A[m]R
	Cast	1.18–1.28	9.0–12.5	(62–86)	3.7–5.0	(26–34)	0.4–1.5	(0.5–2.0)	140–200	(60–90)	165–235	(75–115)	160–215	(70–100)	R	R	A[k]	R	A	A[m]R
	Multi polymer	1.09–1.14	6–8	(41–55)	3.1–4.3	(21–30)	1–3	(1–4)	165–175	(75–80)	–	–	185–195	(85–90)	E	R	A[k]	R	S	A[m]
Cellulosics	Acetate	1.23–1.34	3.0–8.0	(21–55)	1.05–2.55	(7–18)	1.1–6.8	(1.5–9)	140–220	(60–105)	120–209	(50–100)	111–195	(45–90)	S	S	D	S	D	D-S
	Butyrate	1.15–1.22	3.0–6.9	(21–48)	0.7–1.8	(5–12)	3.0–10.0	(4–14)	140–220	(60–105)	130–227	(55–110)	113–202	(45–95)	S	S	D	S	D	D-S

Thermoplastics		Specific Gravity	Tensile Strength ksi	(MPa)	Modulus of Elast., Tension 10^2 ksi	(10^2 MPa)	Impact Strength, Izod[c] ft-lb	(J)	Max use Temp. (no Load) °F	(°C)	HDT at 66 psi °F	(°C)	HDT at 264 psi °F	(°C)	Chemical Resistance[e] Weather res	Week acid	Strong acid	Week alkali	Strong alkali	Solvents
Cellulosics	E. cellulose	1.10–1.17	3–8	(21–55)	0.5–3.5	(3–24)	1.7–7.0	(2.3–9.5)	115–185	(45–85)	–	–	115–190	(45–90)	S	S	D	R	S	D
	Nitrate	1.35–1.40	7–8	(48–55)	1.9–2.2	(13–15)	5–7	(7–9)	140	(60)	–	–	140–160	(60–70)	E	S	D	S	D	D
	Propionate	1.19–1.22	4.0–6.5	(28–45)	1.1–1.8	(8–12)	1.7–9.4	(2.3–13)	155–220	(70–105)	147–250	(65–120)	111–228	(45–110)	S	S	D	S	D	D-S
Ch. polyether		1.4	5.4	(37)	1.5	(10)	0.4	(0.5)	290	(140)	285	(140)	–	–	R-S	R	A[k]	R	R	R
Eth. copolymers	EEA	0.93	2.0	(14)	0.05	(0.3)	NB	–	190	(90)	–	–	–	–	S	R	A[k]	R	R	A-D
	EVA	0.94	3.6	(25)	0.02–0.12	(0.14–0.8)	NB	–	–	–	140–147	(60–65)	93	(35)	S	R	A	R	R	A-D
Fluoro-polymers	FEP	2.14–2.17	2.5–3.9	(17–27)	0.5–0.7	(3–5)	NB	–	400	(208)	158	(70)	–	–	R	R	R	R	R	R
	PTFE	2.1–2.3	1.4	(7–28)	0.38–0.65	(2.6–4.5)	2.5–4.0	(3.4–5.4)	550	(290)	250	(120)	–	–	R	R	R	R	R	R
	CTFE	2.10–2.15	4.6–5.7	(32–39)	1.8–2.0	(12–14)	3.5–3.6	(4.7–4.9)	350–390	(180–200)	256	(125)	–	–	R	R	R	R	R	S[m]
	PVF_2	1.77	7.2	(50)	1.7	(12)	3.8	(5.2)	300	(150)	300	(150)	195	(90)	S	R	A[l]	R	R	R
	ETFE & ECTFE	1.68–1.70	6.5–70.	(45–48)	2–2.5	(14–17)	NB	–	300	(150)	220	(105)	160	(70)	R	R	R	R	R	R
Methyl-pentene		0.83	3.3–3.6	(23–25)	1.3–1.9	(10–13)	0.95–3.8	(1.3–5.2)	275	(135)	–	–	–	–	E	R	A[l]	R	R	A

(*Continued*)

TYPICAL PROPERTY RANGES FOR PLASTICS (*Continued*)

Thermoplastics		Specific Gravity	Tensile Strength		Modulus of Elast., Tension		Impact Strength, Izod[c]		Max use Temp. (no Load)		HDT at 66 psi		HDT at 264 psi		Chemical Resistance[e]					
			ksi	(MPa)	10^2 ksi	(10^2 MPa)	ft-lb	(J)	°F	(°C)	°F	(°C)	°F	(°C)	Weather res	Week acid	Strong acid	Week alkali	Strong alkali	Solvents
Nylons	6/6	1.13–1.15	9–12	(62–83)	3.85	(27)	2.0	(2.7)	180–300	(80–150)	360–470	(180–240)	150–220	(65–105)	R	R	A	R	R	R-D[o]
	6	1.14	12.5	(86)	–	–	1.2	(1.6)	180–250	(80–120)	300–365	(150–185)	140–155	(60–70)	R	R	A	R	R	R-A[o]
	6/10	1.07	7.1	(49)	2.8	(19)	1.6	(2.2)	180	(80)	300	(150)	–	–	R	R	A	R	R	R-A[o]
	8	1.09	3.9	(27)	–	–	> 16	(> 22)							R	R	A	R	R	R-A[o]
	12	1.01	6.5–8.5	(45–59)	1.7–2.1	(12–14)	1.2–4.2	(1.6–5.7)	175–260	(80–125)	–	–	120–130	(50–55)	R	R	A	R	R	R-A[o]
	Copolymers	1.08–1.14	7.5–11.0	(52–76)	–	–	1.5–19	(2–26)	180–250	(80–120)	–	–	130–350	(55–180)	R	R	A	R	R	R-A[o]
Polyesters	PET	1.37	10.4	(72)	–	–	0.8	(1.1)	175	(80)	240	(115)	185	(85)	R	R	A[k]	R	A	R-A[o]
	PBT	1.31	8.0–8.2	(55–57)	3.6	(25)	1.2–1.3	(1.6–1.8)	280	(140)	310	(155)	130	(55)	R	R	R	R	A	R
	PTMT	1.31	8.2	(57)	–	–	1.0	(1.4)	270	(130)	302	(150)	122	(50)	R	R	R	R	A	R
	Copol.	1.2	7.3	(50)	–	–	1.0	(1.4)	–	–	–	–	154	(70)	–	–	–	–	–	–
Polyaryl ether		1.14	7.5	(52)	3.2	(22)	10	(14)	250	(120)	320	(160)	300	(150)	E	R	R	R	R	A
Polyaryl sulfone		1.36	13	(90)	3.7	(26)	2	(2.7)	500	(260)	–	–	525	(275)	Darkens	R	R	R	R	R
Polybutylene		0.910	3.8	(26)	0.26	(1.8)	NB	–	225	(105)	215	(100)	130	(55)	E	R	A[k]	R	R	–
Polycarbonate		1.2	9	(62)	3.45	(24)	12–16	(16–22)	250	(120)	270–290	(130–145)	265–285	(130–140)	R	R	A[k]	A	A	A
PC/ABS		1.14	8.2	(57)	3.7	(26)	10	(14)	220	(105)	235	(115)	220	(105)	R-E	R	A[k]	R	S	A
Polyetheylenes*	LD	0.91–9.93	0.9–2.5	(6–17)	0.20–0.27	(1.4–1.9)	NB	–	180–212	(80–100)	100–120	(40–50)	90–105	(30–40)	E	R	A[k]	R	R	R
	HD	0.95–0.96	2.9–5.4	(20–37)	– –	– –	0.4–14	(0.5–19)	175–250	(80–120)	140–190	(60–90)	110–130	(45–55)	E	R	R-A[k]	R	R	R
	HMW	0.945	2.5	(17)	1	(7)	NB	–	–	–	155–180	(70–80)	105–180	(40–80)	E	R	A[k]	R	R	R
Ionomer		0.94–0.95	3.4–4.5	(23–31)	0.3–0.7	(2–5)	6–NB	(8–	160–180	(70–80)	110	(45)	100–120	(40–50)	E	A	A[k]	R	R	R
Phenylene oxide based mtls.		1.06–1.10	7.8–9.6	(54–66)	3.5–3.8	(24–26)	5.0	(68)	175–220	(80–105)	230–280	(110–140)	212–265	(100–130)	R	R	R	R	R	R-A

Thermoplastics		Specific Gravity	Tensile Strength ksi	Tensile Strength (MPa)	Modulus of Elast., Tension 10^2 ksi	Modulus of Elast., Tension (10^2 MPa)	Impact Strength, Izod[c] ft-lb	Impact Strength, Izod[c] (J)	Max use Temp. (no Load) °F	Max use Temp. (no Load) (°C)	HDT at 66 psi °F	HDT at 66 psi (°C)	HDT at 264 psi °F	HDT at 264 psi (°C)	Chemical Resistance[e] Weather res	Week acid	Strong acid	Week alkali	Strong alkali	Solvents
Polyphenylene sulfide		1.34	10	(69)	4.8	(33)	0.3	(0.4)	500	(260)	–	–	278	(135)	R	R	A[k]	R	R	R
Polyimide		1.43	5–7.5	(34–52)	5.4	(37)	5–7	(7–9)	500	(260)	–	–	680	(360)	–	R	R	A	A	R
Polypropylenes	GP	0.90–0.91	4.8–5.5	(33–38)	1.6–2.2	(11–15)	0.4–2.2	(0.5–3.0)	225–300	(105–150)	200–230	(95–110)	125–140	(50–60)	E	R	A[k]	R	R	R
	Hi. imp.	0.90–0.91	3–5	(21–34)	1.3	(9)	1.5–12	(2–16)	200–250	(95–120)	160–200	(70–95)	120–135	(50–60)	E	R	A[k]	R	R	A
Propylene copolymer		0.91	4	(28)	1.0–1.7	(7–12)	1.1	(1.5)	190–240	(90–115)	185–230	(85–110)	115–140	(45–60)	E	R	A[k]	R	R	R
Polystyrenes	GP	1.04–1.07	6.0–7.3	(41–50)	4.5	(31)	0.3	(0.4)	150–170	(65–80)	–	–	180–220	(80–105)	S	R	A[k]	R	R	D
	Hi. imp.	1.04–1.07	2.8–4.6	(20–32)	2.9–4.0	(20–28)	0.7–1.0	(0.9–1.4)	140–175	(60–80)	–	–	175–210	(80–100)	S	R	A[k]	R	R	D
Polysulfone		1.24	10.2	(70)	3.6	(25)	1.2	(1.6)	300	(150)	360	(180)	345	(175)	S	R	R	R	R	R-A
Polyurethanes		1.11–1.25	4.5–8.4	(31–58)	0.1–3.5	(0.7–24)	NB	–	190	(90)	–	–	–	–	R-S	S-D	S-D	S-D	S-D	R
Vinyl Rigid		1.3–1.5	5–8	(34–55)	3.5	(21–34)	0.5–20	(0.7–27)	150–175	(65–80)	135–180	(60–80)	130–175	(55–80)	R	R	R-S	R	R	R-A
Vinyl Flexible		1.2–1.7	1.4	(7–28)	–	–	0.5–20	(0.7–27)	140–175	(60–80)	–	–	–	–	S	R	R-S	R	R	R-A
Rigid CPVC		1.49–1.58	7.5–9.0	(52–62)	3.6–4.7	(25–32)	1.0–5.6	(1.4–7.6)	230	(110)	215–245	(100–120)	200–235	(95–115)	R	R	R	R	R	R
PVC/acrylic		1.30–1.35	5.5–6.5	(38–45)	2.75–3.35	(19–23)	15	(20)	–	–	180	(80)	170	(80)	R	R	S	R	R	A
PVC/ABS		1.10–1.21	2.6–6.0	(18–41)	0.8–3.4	(6–23)	10–15	(14–20)	–	–	–	–	–	–	S	R	R-S	R	R	R-D
SAN		1.08	10–12	(69–83)	5.0–5.6	(34–39)	0.4–0.5	(0.5–0.7)	140–200	(60–95)	–	–	190–220	(90–105)	S-E	R	A	R	R	A

*Polyethylene may stress crack in HF service.

[a]All values at room temperature unless otherwise listed. [b]Per ASTM. [c]Notched samples. [d]Heat deflection temperature. [e]Ac is acid and Al is alkali; R is resistant; A is attacked; S is slight effects; E is embrittles and D is decomposes. [j]Chalks slightly. [k]By oxidizing acids. [l]By fuming sulfuric. [m]By ketones, esters, and chlorinated and aromatic hydrocarbons. [n]Halogenated solvents cause swelling. [o]Dissolved by phenols and formic acid.

Source: Berins, *Plastics Engineering Handbook of the Society of the Plastics Industry Inc.*, 5th ed., 1991, Kluwer Academic Publishers.

PROPERTIES OF ELASTOMERS

Property	NR Natural Rubber (Cis-polyisoprene)	SBR Butadiene-styrene (GR-S)	IR Synthetic (Polyisoprene)	COX Butadiene-Acrylonitrile (Nitrile)	CR Chloroprene (Neoprene)	ITR Butyl (Isobutylene-isoprene)	BR Polybuta-diene	T Poly-sulfide	Silicone (Poly-siloxane)
Physical Properties:									
Specific gravity (ASTM D792)	0.93	0.91	0.93	0.98	1.25	0.90	0.91	1.35	1.1–1.6
Thermal conductivity Btu/(h)(ft^2)(°F/ft) (ASTM C 177)	0.082	0.143	0.082	0.143	0.112	0.053	–	–	0.13
Coefficient of thermal expansion (cubical), 10^{-5} per °F (ASTM D 696)	37	37	–	39	34	32	37.5	–	45
Electrical insulation	Good	Good	Good	Fair	Fair	Good	Good	Fair	Excellent
Flame resistance	Poor	Poor	Poor	Poor	Good	Poor	Poor	Poor	Good
Min. recommended service temp. °F	−60	−60	−60	−60	−40	−50	−150	−60	−178
Max. recommended service temp. °F	180	180	180	300	240	300	200	250	600
Mechanical Properties									
Tensile strength, lb./in.^{2}:									
Pure gum (ASTM D 412)	2,500–3,500	200–300	2,500–3,500	500–900	3,000–4,000	2,500–3,000	200–1,000	250–400	600–1,300
Black (ASTM D 412)	3,500–4,500	2,500–3,500	3,500–4,500	3,000–4,500	3,000–4,000	2,500–3,000	2,000–3,000	1,000	–
Elongation, %									
Pure gum (ASTM D 412)	750–850	400–600	–	300–700	800–900	750–950	400–1,000	450–650	100–500
Black (ASTM D 412)	550–650	500–600	300–700	300–650	500–600	650–850	450–600	150–450	–
Hardness (durometer)	A30–90	A40–90	A40–80	A40–95	A20–95	A40–90	A40–90	A40–85	A30–90

Property	NR Natural Rubber (Cis-polyisoprene)	SBR Butadiene-styrene (GR-S)	IR Synthetic (Polyisoprene)	COX Butadiene-Acrylonitrile (Nitrile)	CR Chloroprene (Neoprene)	ITR Butyl (Isobutylene-isoprene)	BR Polybutadiene	T Polysulfide	Silicone (Polysiloxane)
Mechanical Properties									
Rebound:									
Cold	Excellent	Good	Excellent	Good	Very good	Bad	Excellent	Good	Very good
Hot	Excellent	Good	Excellent	Good	Very good	Very good	Excellent	Good	Very good
Tear resistance	Excellent	Fair	Excellent	Good	Fair to good	Good	Fair	Poor	Fair
Abrasion resistance	Excellent	Good to excellent	Excellent	Good to excellent	Good	Good to excellent	Excellent	Poor	Poor
Chemical Resistance:									
Sunlight aging	Poor	Poor	Fair	Poor	Very good	Very good	Poor	Very good	Excellent
Oxidation	Good	Good	Excellent	Good	Excellent	Excellent	Good	Very good	Excellent
Heat aging	Good	Very good	Good	Excellent	Excellent	Excellent	Good	Fair	Excellent
Solvents:									
Aliphatic hydrocarbons	Poor	Poor	Poor	Excellent	Good	Poor	Poor	Excellent	Fair
Aromatic hydrocarbons	Poor	Poor	Poor	Good	Fair	Poor	Poor	Excellent	Poor
Oxygenated, alcohols	Good	Good	Good	Good	Very good	Very good	–	Very good	Excellent
Oil, Gasoline	Poor	Poor	Poor	Excellent	Good	Poor	Poor	Excellent	Poor
Animal, vegetable oils	Poor to good	Poor to good	–	Excellent	Excellent	Excellent	Poor to good	Excellent	Excellent
Acids:									
Dilute	Fair to good	Fair to good	Fair to good	Good	Excellent	Excellent	–	Good	Very good
Concentrated	Fair to good	Fair to good	Fair to good	Good	Good	Excellent	–	Good	Good
Permeability to gases	Low	Low	Low	Very low	Low	Very low	Low	Very low	High
Water-swell resistance	Fair	Excellent	Excellent	Excellent	Fair to Excellent	Excellent	Excellent	Excellent	Excellent

(*Continued*)

PROPERTIES OF ELASTOMERS (*Continued*)

Property	ECO, CO Epichlorohydrin Homopolymer and Copolymer	Fluorosilicone	EPDM Ethyiene Propylene	CSM Chloro-Sulfonated Polyethylene	FPM Fluorocarbon Elastomers
Physical Properties:					
Specific gravity	1.32–1.49	1.4	0.86	1.11–1.26	1.4–1.95
Thermal conductivity, Btu/(h)(ft^2)(°F/ft)	–	0.13	–	0.065	0.13
Coefficient of thermal expansion, 10^{-5}/ °F	–	45	–	27	8.8
Flame resistance	Fair	Poor	Poor	Good	Excellent
Colorability	Good	Good	Excellent	Excellent	Good
Mechanical Properties:					
Hardness (Shore A)	30–95	40–70	30–90	45–95	65–90
Tensile strength, 1,000 lb./in.^{2}					
Pure gum	–	1	< 1	4	< 2
Reinforced	2–3	< 2	0.8–3.2	1.5–2.5	1.5–3
Elongation, %					
Reinforced	320–350	200–400	200–600	250–500	100–450
Resilience	Poor to excellent	Good to fair	Good	Good	Fair
Compression-set resistance	Very good	–	Good	Fair to good	Good to excellent
Hysteresis resistance	Good	Good	Good	Good	Good
Flex-cracking resistance	Very good	Good	Good	Good	Good
Slow rate	Very good	Good	Good	Good	Good
Fast rate	Good	Good	Good	Good	Good
Tear strength	Good	Fair	Poor to fair	Fair to good	Poor to fair
Abrasion resistance	Fair to good	Poor	Good	Excellent	Good
Electrical Properties					
Dielectric strength	Fair	Good	Excellent	Excellent	Good
Electrical insulation:	Fair	Good	Very good	Good	Fair to good
Thermal Properties:					
Service temp. °F:					
Min for continuous use	−15 to −80	−90	−60	−40	−10
Max for continuous use	300	400	< 350	< 325	< 500

(*Continued*)

PROPERTIES OF ELASTOMERS (*Continued*)

Property	ECO, CO Epichlorohydrin Homopolymer and Copolymer	Fluorosilicone	EPDM Ethylene Propylene	CSM Chloro-Sulfonated Polyethylene	FPM Fluorocarbon Elastomers
Corrosion Resistance:					
Weather	Excellent	Excellent	Excellent	Excellent	Excellent
Oxidation	Very good	Excellent	Excellent	Excellent	Outstanding
Ozone	Good to excellent	Excellent	Excellent	Excellent	Excellent
Radiation	–	Good	Excellent	Fair to Good	Fair to Good
Water	Good	Excellent	Good to excellent	Good	Good
Acids	Good	Very good to excellent	Good to excellent	Excellent	Good to excellent
Alkalies	Good	Very good	Good to excellent	Excellent	Poor to good
Aliphatic hydrocarbons	Excellent	Excellent	Poor	Fair	Excellent
Aromatic hydrocarbons	Very good	Excellent	Fair	Poor to fair	Excellent
Halogenated hydrocarbons	Good	–	Poor	Poor to fair	Good
Alcohol	Good	–	Good	Very good	Excellent
Synthetic lubricants (diester)	Fair to good	Excellent	Poor to fair	Poor	Fair to good
Hydraulic fluids:					
Silicates	Very good	Excellent	Fair to good	Good	Good
Phosphates	Poor to fair	Excellent	Good to excellent	Poor to fair	Poor

Source: C. H. Harper, *Handbook of Plastics & Elastomers*, Table 35. Reproduced by permission of The McGraw-Hill Companies.

PROPERTIES OF SELECTED CHEMICALLY REACTIVE ADHESIVES

Property	Epoxy	Polyurethane	Modified Acrylic	Cyanoacrylate	Anaerobic
Substrates bonded	Most	Most smooth, nonporous	Most smooth, nonporous	Most nonporous metals or plastics	Metals, glass, thermosets
Service temperature range, °C (°F)	−55 to 121 (−67 to 250)	−157 to 79 (−250 to 175)	−73 to 121 (−100 to 250)	−55 to 79 (−67 to 175)	−55 to 149 (−67 to 300)
Impact resistance	Poor	Excellent	Good	Poor	Fair
Tensile shear strength, MPa (ksi)	15.4 (2.20)	15.4 (2.20)	25.9 (3.70)	18.9 (2.70)	17.5 (2.50)
T-peel strength, N/m (lbf/in.)	<525 (3)	14,000 (80)	5250 (30)	<525 (3)	1750 (10)
Heat cure or mixing required	Yes	Yes	No	No	No
Solvent resistance	Excellent	Good	Good	Good	Excellent
Moisture resistance	Excellent	Fair	Good	Poor	Good
Gap limitation, mm (in.)	None	None	0.762 (0.030)	0.254 (0.010)	0.635 (0.025)
Odor	Mild	Mild	Strong	Moderate	Mild
Toxicity	Moderate	Moderate	Moderate	Low	Low
Flammability	Low	Low	High	Low	Low

Source: GEM 2001, p. 162, ASM, 2000. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

PROPERTIES OF HOT-MELT ADHESIVES

Property	Ethylene/Vinyl Acetate and Polyolefin Homopolymers and Copolymers	Polyvinyl Acetate	Polyurethane	Polyamides	Polyamide Copolymer	Aromatic Polyamide
Brookfield viscosity, Pa-s	1–30	1.6–10	2	0.5–7.5	11	2.2
Viscosity test temperature, °C (°F)	204 (400)	121 (250)	104 (220)	204 (400)	230 (446)	204 (400)
Softening temperature, °C (°F)	99–139	–	–	93–154 (200–310)	–	129–140 (265–285)
Application temperature, °C (°F)	–	121–177 (250–350)	–	–	–	–
Service temperature range, °C (°F)	−34–80 (−30–176)	−1–120 (30–248)	–	−40–185 (−40–365)	–	–
Relative cost[a]	Lowest	Low to medium	Medium to high	High	High	High
Bonding substrates	Paper, wood, selected thermoplastics, selected metals, selected glasses	Paper, wood, leather, glass, selected plastics, selected metals	Plastics	Wood, leather, selected, plastics, selected metals	Selected metals, selected plastics	Selected metals, selected plastics
Applications	Bookbinding, packaging, toys, automotive, furniture, electronics	Tray forming, packaging, binding, sealing cases and cartons, ottle labels, cans, jars	Laminates	Packaging, electronics, furniture, footwear	Packaging, electronics binding	Electronics, packaging, binding

[a]Relative to other hot-melt adhesives.

Source: GEM 2001, p. 162, ASM, 2000. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

OXYGEN AND WATER PERMEABILITY IN PLASTIC FILMS

Plastic	Permeability to O_2 cm^3-mil/100 in^2/ 24 hr. 25°C ASTM D1434	Rate of H_2O Vapor Trans. g-mil/100 In^2/ 24 hr. 38°C ASTM E96
Acrylonitrite-Butadiene-Styrene (ABS)	50–70	–
Ethylene-Chlorotrifluoroethylene Copolymer	25	0.6
Ethylene-Tetrofluoroethylene Copolymer	100	1.7
Fluorinated Ethylene-Propylene Copolymer	750	0.4
Polyvinyl Fluoride	3	3.2
Polycarbonate	300	11
Polyester (PE Terephthalate)	3–6	1.0–1.3
Nylon 6/6	5	3–8
Nylon 11	34	0.32–0.85
Nylon 12	52–92	0.07
Polyethylene, low dens.	500	1.0–1.5
Polyethylene, med. dens.	250–535	0.7
Polyethylene, high dens.	185	0.3
Polyimide	25	5.4
Polypropylene	150–240	0.7
Polystyrene	350	7–10
Polysulfone	230	18
Vinyl Chloride-Acetate Copolymer (Non-plasticized)	15–20	4
Vinyl Chloride-Acetate Copolymer (Plasticized)	20–150	5–8
Vinylidene Chloride-Vinyl Chloride Copolymer	0.8–6.9	0.2–0.6
Polyvinyl Chloride-(Non-Plasticized)	5–20[(a)]	0.9–5.1
Polyvinyl Chloride-(Plasticized)	2–4000	5–30
Polyurethane Elastomer	75–327	40–75

[(a)] 50% R. H.

Source: Adapted from *Modern Plastics Encyclopedia*, 1985–1986, pp. 481–485, McGraw Hill.

DIMENSIONS OF POLYETHYLENE LINE PIPE (API)
(All Dimensions are in Inches)
(inches × 25.40 = mm)

Nominal Pipe Size	Outside Diameter	Minimum Wall Thickness								
		SDR 32.5	SDR 26	SDR 21	SDR 17	SDR 13.5	SDR 11	SDR 9	SDR 7.3	SDR 7
1/2	0.840	–	–	0.062	0.062	0.062	0.076	0.083	0.115	–
3/4	1.050	–	–	0.062	0.062	0.078	0.095	0.117	0.144	–
1	1.315	–	–	0.062	0.077	0.097	0.119	0.146	0.180	–
1 1/4	1.660	–	–	0.079	0.098	0.123	0.151	0.184	0.227	–
1 1/2	1.900	–	–	0.090	0.112	0.141	0.173	0.211	0.260	–
2	2.375	–	–	0.113	0.140	0.176	0.216	0.264	0.325	–
3	3.500	–	–	0.167	0.206	0.259	0.318	0.389	0.479	0.500
4	4.500	–	–	0.214	0.264	0.333	0.409	0.500	0.616	0.643
5	5.563	–	–	0.265	0.328	0.413	0.506	0.618	0.762	0.795
6	6.625	0.204	0.255	0.316	0.390	0.491	0.603	0.736	0.908	0.946
8	8.625	0.265	0.332	0.410	0.508	0.639	0.785	0.985	1.182	1.232
10	10.750	0.331	0.413	0.511	0.633	0.797	0.978	1.194	1.473	1.536
12	12.750	0.392	0.490	0.608	0.745	0.945	1.160	1.417	1.747	1.821

See API Spec 15LE for dimensions of pipe sizes 14–36 in.

Reference: Some material gathered from API Spec 15LE, 3rd ed. (1995).

POLYETHYLENE LINE PIPE (API)

Mechanical Properties

Property	Method of Test ASTM	Minimum Strength psi	Minimum Strength MPa
Short-Term Hydrostatic Hoop Strength	D1599*	2520	17.4
Long-Term Hydrostatic Hoop Strength (PE2406, 3406)	D1598	1320	9.1
	(PE3408)	1600	11.0
Elevated Temperature, Hydrostatic Hoop Strength	D1598	(see table below)	

*Ring Tensile ASTM D2290 may be used as alternate on sizes above 4″ OD.

Reference: Some material gathered from API Spec 15LE, 3rd ed. (1995).

176°F (80°C) Sustained Pressure Requirements for Water Pipe

Pipe Test Category	Base Resin Melt Index, D1238 (g/10 min)	Base Resin Density, D1505 (g/cc)	S = 725 psi (5 MPa)	Minimum Average Hours to Failure S = 580 psi (4 MPa)	S = 435 psi (3 MPa)
C1	< 0.05	0.941–0.948	100	200	–
C2	< 0.05	0.935–0.940	100	200	–
C3	0.05–0.25	0.941–0.948	60	150	–
C4	0.05–0.25	0.935–0.940	60	150	–
C5	> 0.25	0.941–0.948	45	100	–
C6	> 0.25	0.935–0.940	45	100	–
C7	> 0.50	0.926–0.940	–	80	150

DIMENSIONS OF POLY (VINYL CHLORIDE) AND CHLORINATED POLY (VINYL CHLORIDE) LINE PIPE (API)
(All Dimensions are in Inches)
(inches × 25.40 = mm)

		Minimum Wall Thickness							
Nominal Pipe Size	Outside Diameter	Schedule 40	Schedule 80	SDR 32.5	SDR 26	SDR 21	SDR 17	SDR 13.5	SDR 11
1/2	0.840	0.109	0.147	–	–	0.062	0.062	0.062	0.076
3/4	1.050	0.113	0.154	–	–	0.090	0.090	0.090	0.095
1	1.315	0.133	0.179	–	–	0.090	0.090	0.097	0.119
1 1/4	1.660	0.140	0.191	–	–	0.090	0.098	0.123	0.151
1 1/2	1.900	0.145	0.200	–	–	0.090	0.112	0.141	0.173
2	2.375	0.154	0.218	–	–	0.113	0.140	0.176	0.216
2 1/2	2.875	0.203	0.276	–	–	0.137	0.169	0.213	0.261
3	3.500	0.216	0.300	–	–	0.167	0.206	0.259	0.318
3 1/2	4.000	0.226	0.318	–	–	0.190	0.236	0.296	0.363
4	4.500	0.237	0.337	–	–	0.214	0.264	0.333	0.409
5	5.563	0.258	0.375	–	–	0.265	0.328	0.413	0.506
6	6.625	0.280	0.432	0.204	0.255	0.316	0.390	0.491	0.603
8	8.625	0.322	0.500	0.265	0.332	0.410	0.508	0.639	0.785
10	10.750	0.365	0.593	0.331	0.413	0.511	0.633	0.797	0.978
12	12.750	0.406	0.687	0.392	0.490	0.608	0.745	0.945	1.160

Reference: Some material gathered from API Spec 15LP, Sixth Edition (1987).

PVC AND CPVC LINE PIPE (API)

Mechanical Properties

Property	Method of Test	PVC and CPVC psi	PVC and CPVC MPa
Short-Term Hydrostatic Hoop Strength, min.	ASTM D 1599	6,400	44
Long-Term* Hydrostatic Hoop Strength, min.	ASTM D 1598	4,200	29
Ring Tensile Strength, min.	ASTM D 2513	6,400	44

*Test specimens for long-term hydrostatic hoop strength shall include representative fittings in the center of each specimen. Minimum strength listed is for the 1000-hour test.

Reference: Some material gathered from API Spec 15LP, Sixth Edition (1987).

Minimum Impact Strength, ft-lbs (Joules) at 32–35°F (0–2°C)*

Nominal Pipe Size	Schedules 40 and 80	SDR 17	SDR 21	SDR 26
1/2	16 (21.7)			
3/4	20 (27.1)			
1	20 (27.1)			
1 1/4	20 (27.1)	20 (27.1)		
1 1/2	30 (40.7)	30 (40.7)	30 (40.7)	
2	40 (54.2)	40 (54.2)	40 (54.7)	40 (54.7)
2 1/2	40 (54.2)	40 (54.2)	40 (54.7)	40 (54.7)
3	40 (54.2)	40 (54.2)	40 (54.7)	40 (54.7)
4	40 (54.2)	40 (54.2)	40 (54.7)	40 (54.7)
6	55 (74.5)	55 (74.5)	55 (74.5)	55 (74.5)
8	60 (81.3)	60 (81.3)	60 (81.3)	60 (81.3)
Fittings all Sizes and Types	5 (6.8)			

*Test Method ASTM D 2444.

FIBER REINFORCED PLASTIC THERMOSETTING RESIN LINE PIPE-DIMENSIONS

API Specification

Nominal Size (Inches)	Outside[1] Dia. (Inches)	Inside[2] Dia. (Inches) Minimum
2	2.375	2.00
2 1/2	2.875	2.40
3	3.500	3.00
4	4.500	4.00
6	6.625	5.80
8	8.625	8.20
10	10.750	10.30
12	12.750	11.90
14	[3]	13.50
16	[3]	15.40

Notes:

[1] The outer diameters are applicable to
- A. Sizes 2″ through 5″ with 300 psi cyclic pressure ratings.
- B. Sizes 8″ through 12″ with 150 psi cyclic pressure ratings.
- C. All centrifugal cast pipe.
- D. Other outside diameters shall be permitted by agreement between purchaser and manufacturer.

[2] The minimum inside diameters are applicable to all filament wound pipe with cyclic pressure ratings greater than pipe covered by Note (1).

[3] The minimum inside diameters are applicable to all pressure ratings of 14″ and 16″ diameter pipe.

Reference: Some material gathered from API Specification 15LR, 5th ed. (1986).

Typical Values

Nominal Pipe Size		Pipe OD	Pipe ID	Nominal Wall Thickness*	Pipe Weight
(in)	(mm)	(in)	(in)	(in)	(lb/ft)
2	50	2.37	2.09	0.157	0.8
3	80	3.50	3.22	0.157	1.2
4	100	4.50	4.14	0.203	2.0
6	150	6.62	6.26	0.203	3.0
8	200	8.62	8.22	0.226	4.3
10	250	10.75	10.35	0.226	5.4
12	300	12.75	12.35	0.226	6.4

*Determined in accordance with ASTM D2996.

Source: Ameron (1985).

FIBER REINFORCED PLASTIC THERMOSETTING RESIN LINE PIPE

Typical Physical Properties

Pipe Property	Units	Value	Method ASTM
Thermal conductivity	Btu-in/(h·ft^2·°F)	1.7	C177
Thermal expansion (linear)	10^{-6} in/in/°F	8.5	D696
Flow coefficient	Hazen-Williams	150	–
Absolute roughness	10^{-6}ft	50	–
Specific gravity	–	1.81	D792
Bore of hardness	Impressor 934-1	65	D2583

Typical Mechanical Properties

Property	Units	Value*	Method ASTM
Tensile strength			
Longitudinal	10^3 psi	25.0	D2105
Circumferential	10^3 psi	50.0	D1599
Tensile modulus			
Longitudinal	10^6 psi	2.0	D2105
Circumferential	10^6 psi	3.0	–
Compressive strength			
Longitudinal	10^3 psi	25.0	–
Compressive modulus			
Longitudinal	10^6 psi	2.0	–
Long-term hydrostatic design basis			
Static	10^3 psi	31.5	D2992(B)
Poisson's ratio**			
ν_{yx}	–	0.11	–
ν_{xy}	–	0.19	–

*Based on structural wall thickness.
**The first subscript denotes the direction of contraction and the second that of the applied stress.
x denotes longitudinal direction.
y denotes circumferential direction.

Source: Ameron (1985).

TYPES OF PORTLAND CEMENT

Type	Non-Air-Entraining
I	For general concrete construction when special properties specified for the other types are not required. When no type is indicated, it is assumed to be Type I.
II	For general concrete construction exposed to moderate sulfate action or where moderate heat of hydration is required.
III	For construction when high early strength is required.
IV	For construction when a low heat of hydration is required. This type is not generally carried in stock.
V	For construction when high sulfate resistance is required. This type is not generally carried in stock.
	Air-Entraining
IA IIA IIIA	Same as corresponding Types I, II, and III of non-air-entraining cement, but imparting to the concrete properties of greatly improved resistance to (1) severe weathering, and (2) the deleterious effect of applications of sodium or calcium salts to pavement surfaces for snow and ice removal.

CHEMICAL REQUIREMENTS FOR PORTLAND CEMENTS*

Cement Type	I and IA	II and IIA	III and IIIA	IV	V
Silicon dioxide (SiO_2), min, %	...	20.0	...	...	...
Aluminum oxide (Al_2O_3), max, %	...	6.0	...	...	...
Ferric oxide (Fe_2O_3), max, %	...	6.0	...	6.5	...
Magnesium oxide (MgO), max, %	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO_3), max, %					
When (C_3A) is 8% or less	3.0	3.0	3.5	2.3	2.3
When (C_3A) is more than 8%	3.5		4.5		
Loss on ignition, max, %	3.0	3.0	3.0	2.5	3.0
Insoluble residue, max, %	0.75	0.75	0.75	0.75	0.75
Tricalcium silicate (C_3S) max, %	...	...	...	35	...
Dicalcium silicate (C_2S) min, %	...	...	...	40	...
Tricalcium aluminate (C_3A) max, %	...	8	15	7	5
Tetracalcium aluminoferrite plus twice the tricalcium aluminate ($C_4AF + 2(C_3A)$), or solid solution ($C_4AF + C_2F$), as applicable, max, %	...	...	...	...	25

OPTIONAL CHEMICAL REQUIREMENTS

Cement Type	I and IA	II and IIA	III and IIIA	IV	V	Remarks
Tricalcium aluminate (C_3A), max, %	...	...	8	...	...	for moderate sulfate resistance
Tricalcium aluminate (C_3A), max, %	...	...	5	...	...	for high sulfate resistance
Sum of tricalcium silicate and tricalcium aluminate, max, %	...	58	...	...	...	for moderate heat of hydration
Alkalies ($Na_2O + 0.658K_2O$), max, %	0.60	0.60	0.60	0.60	0.60	low-alkali cement

The expressing of chemical limitations by means of calculated assumed compounds does not necessarily mean that the oxides are actually or entirely present as such compounds. When expressing compounds, $C = CaO$, $S = SiO_2$, $A = Al_2O_3$, $F = Fe_2O_3$. For example, $C_3A = 3CaO{\cdot}Al_2O_3$.

*Summarized from ASTM C150. For additional details see the current edition of that standard.

HYDRAULIC CEMENTS

Some typical properties of mortars (1 Cements 3 Sand-Water/Cement: 0.32)	Portland Cement	High-Alumina Cement
Specific gravity	2.2	2.2
Tensile strength, MPa*	3.5–4.1	4.0–4.4
Compressive strength, MPa*	38–50	68–70
Modulus of elasticity, MPa	14,100–15.200	
Linear coeff. of thermal expansion/°C	about 11×10^{-6}	
Maximum working temperature,°C	Above about 100°C, decrease in tensile and compressive strength. However, useful in concrete up to 300–400°C depending on composition and preparation of the concrete.	used in refractory concrete

*After hardening for about one month in water.

Chemical Resistance	Portland Cement	High-Alumina Cement
Water	+	+
Acids	minimum pH 6.5	minimum pH 5.5
Phenol	–	+
Alkalis	+	5% NaOH:–
Salt solutions:		
sodium chloride	+	+
sodium sulfate 0.07%	+	
sodium sulfate 0.7%	+	
sodium sulfate 2% or more	–	
calcium chloride 5%	–	–
magnesium chloride 1%	+	5–15%: +
Hydrocarbons		
aliphatic	+	+
aromatic	+	+
chlorinated	+	+
Alcohols	–	+
Esters	+	+
Ketones	+	+

High-alumina cement has a normal setting time, but shows extremely rapid hardening and development of high strength (24 hrs) as compared with Portland cement. Concrete to be used in seawater is made with blast furnace cement.

+ Resistant
– Not resistant

CHEMICAL RESISTANT MORTARS AND GROUTS

	Furan	Epoxy	Polyester	Vinyl Ester	Phenolic	Silicate	Sulfur
Density, lb./ft^3	95–120	110–125	100–125	110–125	95–120	130	135
Tensile strength, psi	1,000	1,800	2,300	2,300	1,200	500	600
Flexural strength, psi	2,800	3,800	4,800	4,200	2,800	900	1,300
Compressive strength, psi	8,800	12,000	10,000	10,000	9,000	5,800	8,000
Bond strength, psi	280	*	280	175	280	175	120
Thermal resistance, max F	380	200	225	180	380	2,000	200
Chemical resistance (ASTM C267)							
Acetic Acid, Glacial	R	NR	NR	NR	–	–	NR
Acetone	R	NR	NR	NR	–	–	NR
Chlorine Dioxide Solution	NR	NR	R	R	–	–	R
Chromic Acid, 10%	NR	NR	R	R	–	–	NR
Dichloracetic Acid, 10%	R	NR	R	R	–	–	NR
Ethyl Alcohol	R	R	R	R	–	–	R
Formic Acid, 20%	R	C	C	C	–	–	NR
Gasoline	R	R	R	R	–	–	NR
Hydrochloric Acid, 20%	R	R	R	R	–	–	R
Lactic Acid, 15%	R	C	R	R	–	–	R
Nitric Acid, 20%	NR	NR	R	R	–	–	R
Phosphoric Acid, 30%	R	R	R	R	–	–	R
Sodium Choride	R	R	R	R	–	–	R
Sodium Hydroxide, 25%	R	R	R	R	–	–	NR
Sodium Hypochlorite, 10%	NR	NR	R	R	–	–	NR
Sulfuric Acid, 20%	R	R	R	R	–	–	R
Trichloroethylene	R	NR	C	C	–	–	NR
Xylene	R	NR	C	C	–	–	NR
	R Recommended		NR Not Recommended		C Conditional		
Oxidizing Acids	P	P	E	E	P	E	E
Nonoxidizing Acids	E	E	E	E	E	E	E
Alkali	E	E	G	G	P	P	P
Alkaline Hypochlorite	P	P	E	E	P	P	P
Solvents	E	G	G	G	E	E	P
			E Excellent	G Good	P Poor		

*Brick failed

Source: Adapted from A. A. Boova, *Process Industries Corrosion, The Theory and the Practice*, p. 657, NACE, 1986.

PROPERTIES OF SELECTED ENGINEERING CERAMICS

Material	Crystal Structure	Theoretical Density, g/cm^3	Hardness, HK or HV, GPa (10^6 psi)	Transverse Rupture Strength, MPa (ksi)	Fracture Toughness, MPa$\cdot\sqrt{m}$ (ksi$\cdot\sqrt{in.}$)	Young's Modulus, GPa (10^6 psi)	Poisson's ratio	Thermal Expansion Coefficient, 10^{-6}/K	Thermal Conductivity, W/m$\cdot$K
Glass-ceramics	Variable	2.4–5.9	6–7 (0.9–1.0)	70–350 (10–51)	2.4 (2.2)	83–138 (12–20)	0.24	5–17	2.0–5.4[2]
Pyrex glass	Amorphous	2.52	5 (0.7)	69 (10)	0.75 (0.7)	70 (10)	0.2	4.6	1.3[2], 1.7[5]
TiO_2	Rutile tetragonal	4.25	7–11 (1.0–1.6)	69–103 (10–15)	2.5 (2.3)	283 (41)	0.28	9.4	8.8[2]
	Anatase tetragonal	3.84	–	–	–	–	–	–	3.3[6]
	Brookite orthorhombic	4.17	–	–	–	–	–	–	–
Al_2O_3	Hexagonal	3.97	18–23 (2.6–3.3)	76–1034 (40–150)	2.7–4.2 (2.5–3.8)	380 (55)	0.26	7.2–8.6	27.2,[2] 5.8[6]
Cr_2O_3	Hexagonal	5.21	29 (4.2)	>262 (>38)	3.9 (3.5)	>103 (>15)	–	7.5	10–33[7]
Mullite	Orthorhombic	2.8	–	185 (27)	2.2 (2.0)	145 (21)	0.25	5.7	5.2[2], 3.3[6]
Partially stabilized ZrO_2	Cubic, monoclinic, tetragonal	5.70–5.75	10–11 (1.5–1.6)	600–700 (87–102)	8–9 (7.3–8.2[8]) 6–6.5 (5.5–5.9[9]) 5 (4.6[10])	205 (30)	0.23	8.9–10.6	1.8–2.2
Fully stabilized ZrO_2	Cubic	5.56–6.1	10–15 (1.5–2.2)	245 (36)	2.8 (2.5)	97–207 (14–30)	0.23–0.32	13.5	1.7[2], 1.9[11]

(*Continued*)

PROPERTIES OF SELECTED ENGINEERING CERAMICS (*Continued*)

Material	Crystal Structure	Theoretical Density, g/cm^3	Hardness, HK or HV, GPa (10^6 psi)	Transverse Rupture Strength, MPa (ksi)	Fracture Toughness, MPa $\cdot \sqrt{m}$ (ksi $\cdot \sqrt{in.}$)	Young's Modulus, GPa (10^6 psi)	Poisson's ratio	Thermal Expansion Coefficient, 10^{-6}/K	Thermal Conductivity, W/m $\cdot$ K
Plasma sprayed ZrO_2	Cubic, monoclinic, tetragonal	5.6–5.7	–	6–80 (0.9–12)	1.3–3.2 (1.2–2.9)	48[12] (7[12])	0.25	7.6–10.5	0.69–2.4
CeO_2	Cubic	7.28	–	–	–	172 (25)	0.27–0.31	13	9.6[2], 1.2[6]
TiB_2	Hexagonal	4.5–4.54	15–45 (1.5–6.5)	700–1000 (102–145)	6–8 (5.5–7.3)	514–574 (75–83)	0.09–0.13	8.1	65–120[13] 33–80[14] 54–122[15]
TiC	Cubic	4.92	28–35 (4.0–5.1)	241–276 (35–40)	–	430 (62)	0.19	7.4–8.6	33[2], 43[6]
TaC	Cubic	14.4–14.5	16–24 (2.3–3.5)	97–290 (14–42)	–	285 (41)	0.24	6.7	32[2], 40[6]
Cr_3C_2	Orthorhombic	6.70	10–18 (1.5–2.6)	49 (7.1)	–	373 (54)	–	9.8	19
Cemented carbides	Variable	5.8–15.2	8–20 (1.2–2.9)	758–3275 (110–475)	5–18 (4.6–16.4)	396–654 (57–95)	0.2–0.29	4.0–8.3	16.3–119
SiC	Alpha, hexagonal	3.21	20–30 (2.9–4.4)	96–520 (14–75)[16] 250 (36)[17] 230–825 (33–120)[18] 398–743 (58–108)[19]	4.8 (4.4)[16] 2.6–5.0 (2.4–4.6)[17] 4.8–6.1 (4.4–5.6)[18] 4.1–5.0 (3.7–4.6)[19]	207–483 (30–70)	0.19	4.3–5.6	63–155[2] 21–33[6]
	Beta, cubic	3.21	–	–	–	–	–	–	–

Material	Crystal Structure	Theoretical Density, g/cm^3	Hardness, HK or HV, GPa (10^6 psi)	Transverse Rupture Strength, MPa (ksi)	Fracture Toughness, MPa$\cdot\sqrt{m}$ (ksi$\cdot\sqrt{in.}$)	Young's Modulus, GPa (10^6 psi)	Poisson's ratio	Thermal Expansion Coefficient, 10^{-6}/K	Thermal Conductivity, W/m$\cdot$K
SiC (CVD)	Beta, cubic	3.21	28–44 (4.1–6.4)	1034–1380 (150–200)[13] 2060–2400 (300–350)[20] 2060–2400 (300–350)[20]	5–7 (4.6–6.4) 5–7 (4.6–6.4)	415–441 (60–64)	0.16	5.5	121[2] 34.6[11]
Si_3N_4	Alpha, hexagonal	3.18	8–19 (1.2–2.8)	414–650 (60–94)[21] 700–1000 (100–145)[22] 250–345 (36–50)[23]	5.3 (4.8)[21] 4.1–6.0 (3.7–5.5)[22] 3.6 (3.3)[23]	304 (44)	0.24	3.0	9–30[2]
	Beta, hexagonal	3.19	–	–	–	–	–	–	–
TiN	Cubic	5.43–5.44	16–20 (2.3–2.9)	–	–	251 (36)	–	8.0	24[2] 67.8[24] 56.9[25]

1. Source: "Overview of Ceramic Design and Process Engineering," by Richard L. Lehman, *Engineered Materials Handbook*, Vol. 4, Ceramics and Glasses, ASM International, Materials Park, OH, 1991, p. 30
2. At 400K, 127°C, 260°F
3. At 1200K, 927°C, 1700°F
4. Pyrex is a trademark of Corning Inc., Corning, N Y
5. At 800K, 527°C, 9280°F
6. At 1400K, 1127°C, 2060°F
7. At 350K, 77°C, 170°F
8. At 293K, 20°C, 70°F
9. At 723K, 450°C, 840°F
10. At 1073K, 800°C, 1470°F
11. At 1600K, 1327°C, 2420°F
12. 21 GPa, 3×10^6 psi at 1373K, 1100°C, 2010°F
13. At 300K, 27°C, 80°F
14. At 1100K, 827°C, 1520°F
15. At 2300K, 2027°C, 3680°F
16. Sintered, at 300K, 27°C, 80°F
17. Sintered, at 1273K, 1000°C, 1830°F
18. Hot pressed, at 300K, 27°C, 80°F
19. Hot pressed, at 1273K, 1000°C, 1830°F
20. At 1473K, 1200°C, 2190°F
21. Sintered
22. Hot pressed
23. Reaction bonded
24. At 1773K, 1500°C, 2730°F
25. At 2473K, 2200°C, 3990°F

Source: GEM 2001, pp. 159–160, ASM, 2000. Reprinted by permission of ASM International®, Materials Park, OH 44073-0002.

PROPERTIES OF GRAPHITE AND SILICON CARBIDE

	Graphite	Impervious Graphite	Impervious Silicon Carbide
Specific gravity	1.4–1.8	1.75	3.10
Tensile strength, psi (MPa)	400–1400 (3–10)	2600 (18)	20.650 (143)
Compressive strength psi (MPa)	2000–6000 (14–42)	10,500 (72)	150,000 (1000)
Flexural strength, psi (MPa)	750–3000 (5–21)	4700 (32)	–
Modulus of elasticity ($\times 10^6$), psi (MPa)	0.5–1.8 (0.3–12 $\times 10^4$)	2.3 (1.6 $\times 10^4$)	56 (39 $\times 10^4$)
Thermal expansion, in/in/°F $\times 10^{-6}$ (mm/mm/°C)	0.7–2.1 (1.3–3.8)	2.5 (4.5)	1.80 (3.4)
Thermal conductivity, Btu/hr/ft^2/°F/ft (Watts/m, K)	15–97 (85–350)	85 (480)	60 (340)
Max. working temp (inert atm) °F (°C)	5000 (2800)	350 (180)	4200 (2300)
Max. working temp (oxidizing atm) °F (°C)	660 (350)	350 (180)	3000 (1650)

Source: Carborundum Co.

PROPERTIES OF GLASS AND SILICA

	Pyroceram	96% Silica	Borosilicate	Glass lining
Specific gravity, 77°F	2.60	2.18	2.23	2.56
Water absorption, %	0.00	0.00	0.00	
Gas permeability	Gastight	Gastight	Gastight	
Softening temp., °F (°C)	2282 (1250)	2732 (1500)	1508 (820)	
Specific heat, 77°F, B.t.u./lb.) (°F) (Joules/kg/K)	0.185 (775)	0.178 (746)	0.186 (779)	
Mean specific heat (77°–752°F)	0.230	0.224	0.233	
Thermal conductivity, mean temp. 77°F, B.t.u./(sq. ft.) (hr.)(°F)/(in.) (Watts/m, K)	25.2 (3.6)	–	7.5 (1.1)	
Linear thermal expansion, per °F, (77°–572°F)(per °C) $\times 10^{-6}$	3.2 (5.8)	0.44 (0.79)	1.8 (3.2)	
Modulus of elasticity, ksi (MPa) $\times 10^3$	17.3 (119)	9.6 (66)	9.5 (66)	6–9 (40–60)
Poisson's ratio	0.245	0.17	0.20	
Modulus or rupture, ksi (MPa)	20 (140)	5–9 (35–63)	6–10 (42–70)	
Knoop hardness, 100 g	698	532	481	480
Knoop hardness, 500 g	619	477	442	
Adhesion strength ksi (MPa)	–	–	–	5–10 (35–70)
Max. operating temp., °F (°C)	–	–	–	500 (260)
Thermal shock resistance, temp. diff., °F (°C)	–	–	–	305 (152)

PROPERTIES OF HIGH TEMPERATURE REFRACTORIES

Item	Magnesia[1] F	Magnesia[1] C	Mullite F	Mullite C	Silicon Stabilized Carbide F	Silicon Stabilized Carbide C	Bonded Zirconia F	Bonded Zirconia C	99% Al_2O_3 F	99% Al_2O_3 C
Fusion Point	4800	2650	3300	1815	–	–	4700	2600	3650	2010
Use Limit, oxid.	4170	2300	3000	1650	3000	1650	4400	2430	3300	1815
Modulus of rupture, psi	2500		1500		2000[3]		1900		2000	
MPa	17		10		14		13		14	
Moh's hardness[2]	6		6.5		9.6		7		9	
Thermal shock resist.	Poor		Good		Good		Fair		Fair	
Relative Cost	2.8		1		2.1		10		3.1	

[1] Basic refractories have poor resistance to hot acids.
[2] Scale 1 to 10. Talc = 1, low carbon steel = 4, diamond = 10.
[3] At 2500°F (1371°C).

Source: NACE, *Basic Corrosion Course*.

TYPICAL PROPERTIES OF CERAMIC BRICKS AND CHEMICAL STONEWARE

Composition	Regular Acid Brick	High Temp. Acid Brick	Chemical Stoneware	Silica Brick
SiO_2	68	66	71	98.–99.6
Al_2O_3	26	28	23	0.2–0.5
Fe_2O_3	1.3	1.3	0.6	0.02–0.3
TiO_2	7.5	1.5	0.9	–
CaO	0.2	0.2	0.4	0.02–0.03
MgO	0.5	0.5	1.1	0.02–0.1
$Na_2O + K_2O + Li_2O$	2.8	2.5	2.3	0.01–0.2
Density, g/cm^3	2.2	2.2	2.3	1.8–2.0
Apparent porosity, %	7–10	6–9	–	7–16
Water absorption, %	4.5–5.0	2.5–3.5	0.5–2.5	3–14
Acid solubility, %w	8.5–10.5	8.-10.5		1–4
Mod. of rupture, ksi	2.5–2.8	3.0–3.2	6–12	0.5–2
Compressive strength, ksi	6–10	7–12	70–80	2–12
MPa	40–70	50–80	500–550	14–80
Mod. of elasticity, ksi ($\times 10^3$)	–	–	4–10	1–5
MPa ($\times 10^3$)	–	–	30–70	7–35
Coefficient of thermal expansion				
in/in/°F ($\times^-6$)	–	–	2	0.2–3
mm/mm/°C ($\times 10^{-6}$)	–	–	4	0.4–5

Source: Adapted from: “Corrosion and Chemical Resistant Masonry Materials Handbook,” 1985. Noyes Publication and “Process Industries Corrosion,” p. 644, NACE, 1986.

SURFACE PREPARATION STANDARDS

These standards used in industry to describe surface preparation are the National Association of Corrosion Engineers Standards (NACE), Steel Structures Painting Council (SSPC) "Surface Preparation Specifications" and Swedish Pictorial Standards (SA)

		Comparable Standards
NACE No. 1 "For Tank Linings"	White Metal Blast—This is defined as removing all rust, scale, paint, etc. to clean white metal which has a uniform gray-white appearance. Streaks and stains of rust or other contaminants are not allowed.	SSPC 5 SA-3*
NACE No. 2 "For Some Tank Linings and Heavy Maintenance"	Near-White Metal Blast—This provides a surface about 95% as clean as white metal. Light shadows and streaks are allowed.	SSPC 10 SA-2 1/2*
NACE No. 3 "For Maintenance"	Commercial Blast—This type of blast is more difficult to describe. It essentially amounts to about 2/3 of a SA-2* white metal blast which allows for very slight residues of rust and paint in the form of staining.	SSPC 6 SA-2
NACE No. 4 "For Very Light Maintenance"	Brush Off Blast—This preparation calls for removal of loose paint, scale, rust, etc. Tightly adherent paint rust, scale is permitted to remain.	SSPC 7 SA-1*
NACE No. 5 For Recoating	Water Jetting—Defines four levels of visible surface cleanliness and these levels of nonvisible cleanliness.	SSPC 12
NACE No. 6 For Concrete	Requirements—For preparation of concrete surfaces prior to coating of lining.	SSPC 13
NACE No. 8 Cleaning	Industrial blast—For cleaning of steel surfaces by use of abrasives.	SSPC 14
SSPC 1	Solvent Cleaning—Removal of all visible oil, grease, soil and other contaminants from steel.	–
SSPC 2	Hand tools—Use of hand tools to remove loose mill scale, rust, paint and other matter.	–
SSPC 3	Power tools—Use of power tools for removal of loose mill scale, rust, paint and other matter.	–
SSPC 8	Pickling—Preparing steel by chemical reaction and/or electrolysis.	–

*Swedish standards are not exactly the same as the NACE and SSPC standards. It is advisable to check the wording of the Swedish standards prior to use.

ABRASIVE/PROFILE COMPARATIVE CHART

The following chart should be used only for approximating abrasive size required to obtain a specified anchor pattern. This information can be used for centrifugal wheel as well as pressure blasting. Pressure blasting should be done using 90–100 psi nozzle pressure. The depth of anchor pattern used in this chart is an average and not a minimum or maximum depth obtainable.

1 Mil Profile
30/60 Mesh Silica Sand
G-80 Steel Grit
S-110 Steel Shot*
80 Mesh Gamet
100 Aluminum Oxide
Clemtex #4

1.5 Mil Profile
16/35 Mesh Silica Sand
G-50 Steel Grit
S-170 SteelShot*
36 Mesh Gamet
50 Grit Aluminum Oxide
Clemtex #3

2 Mil Profile
16/35 Mesh Silica Sand
G-40 Steel Grit
S-230 Steel Shot*
36 Mesh Gamet
36 Grit Aluminum Oxide
Clemtex #3
Black Beauty BB-50 or BB-2040

2.5 Mils Profile
8/35 Mesh Silica Sand
G-40 Steel Grit
S-280 Steel Shot*
16 Mesh Gamet
24 Grit Aluminum Oxide
Clemtex #2
Black Beauty BB-400

3–4 Mils Profile
8/20 Mesh Silica Sand
G-25 Steel Grit
S-330 or 390 Steel Shot*
16 Mesh Gamet
16 Grit Aluminum Oxide
Clemtex #2
Black Beauty BB-40 or BB-25

*The steel shot alone will not give a good angular anchor pattern and should be used in combination with steel grit for best results.

COMPARATIVE MAXIMUM HEIGHTS OF PROFILE OBTAINED WITH VARIOUS ABRASIVES IN DIRECT PRESSURE BLAST CLEANING OF MILD STEEL PLATES USING 80 PSIG AIR AND $\frac{5}{16}$ IN. DIAMETER NOZZLE

Abrasive	Size[1]	Maximum Height of Profile	
		In Mils	In Microns
Large River Sand	Through U.S. 12, on U.S. 50	2.8	70
Medium Ottawa Silica Sand	Through U.S. 18, on U.S. 40	2.5	62
Fine Ottawa Silica Sand	Through U.S. 30, on U.S. 80	2.0	50
Very Fine Ottawa Silica Sand	Through U.S. 50, 80% through U.S. 100	1.5	37
Black Beauty (Crushed Slag)	Estimated at minus 80 mesh	1.3	32
Crushed Iron Grit	G-50	3.3	82
Crushed Iron Grit	G-40	3.6	90
Crushed Iron Grit	G-25	4.0	100
Crushed Iron Grit	G-16	8.0	200
Chilled Iron Shot	S-230	3.0	75
Chilled Iron Shot	S-330	3.3	82
Chilled Iron Shot	S-390	3.6	90

[1] Sizes listed are U.S. Sieve Series Screen sizes or Society of Automotive Engineers grit or shot sizes.

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings,* 2nd ed., p. 433, NACE, 1999.

PROPERTIES OF ABRASIVES

Abrasive	Type	Major Component	Shape	Hardness	Specific Gravity	Reusable	Recommended Use
Steel Shot	Metallic	Iron	Round	Hard*	7.2	Yes	Peening
Steel Grit	Metallic	Iron	Angular	Hard*	7.6	Yes	Metal Etching
Iron Grit	Metallic	Iron	Angular	Hard	7.4	Yes	Metal Etching
Alum. Oxide	Oxide	Alumina	Angular	Hard	3.8	Yes	Metal Etching
Silicon Carbide	Oxide	Silicon Carbide	Angular	Hard	3.8	Yes	Metal Etching
Garnet	Oxide	Iron Silica	Irregular	Hard	4.0	Yes	Metal Etching
Mineral Slag	Conglomerate	Iron Alum-Silica	Irregular	Hard	2.8	Yes	Metal Etching
Flint	Silica	Silica	Sharp	Medium	2.7	Yes	Metal Etching
Sand	Silica	Silica	Irregular	Medium	2.7	No	Metal Etching
Limestone	Oxide	$CaCO_3$	Irregular	Soft	2.4	No	Light Cleaning—No Etch
Walnut Shell	Vegetable	Cellulosic	Irregular	Soft	1.3	Yes	Light Cleaning—No Etch
Corn Cob Grit	Vegetable	Cellulosic	Irregular	Soft	1.2	Yes	Light Cleaning—No Etch
Glass Beads	Oxide	Silica	Round	Medium	2.7	Yes	Light Cleaning—No Etch

*Various hardnesses available.

Source: *Good Painting Practice, SSPC Painting Manual*, Third Edition, Vol. 1, p. 58, SSPC, 1994. Reprinted by permission of SSPC: The Society for Protective Coatings.

PICKLING METHODS FOR DIFFERENT METALS

Metal	Soak Cleaning	Immersion Pickling	Electrolytic Pickling	Salt-Bath Descaling
Iron or steel	Dilute acids used for removing light corrosion only. Pitting can occur with cast iron	Simple acid solutions used for removing rust or scale from plain carbon steels or cast irons. Stronger acid mixtures used for alloy steel. High-strength steels may suffer hydrogen embrittlement. Cast irons may become pitted	Anodic or cathodic treatment in acids used for steels especially prior to electroplating. Alkaline processes suitable for treating cast iron.	Mainly used for removing heavy scales from alloy steels and for removing siliceous scales from cast iron
Copper-base alloys	Dilute sulphuric acid used for removing light tarnish	Dilute mineral acids, often in mixtures or with addition of dichromate salts, used for removing heavier oxide scales	Mild cathodic alkali processes used for removal of light tarnish	Mainly used to remove very tough scales or adherent siliceous scales
Zinc and its alloys	Very dilute acids only used with short duration treatments		Not used	Not used
Tin and lead	Dilute acids used for removing light tarnish	Fluoboric acid solutions used for general pickling	Not used	Not used
Aluminium and its alloys	Dilute acid or alkali solutions used for light etching only. Smut deposits removed by subsequent nitric acid dipping	Nitric/ hydrofluoric acid mixtures and hot chromic/sulphuric acid mixtures used for general pickling. Hydrofluoric acid or caustic alkali mixtures used for etching	Not used	Sodium hydride used for removing adherent siliceous scales

(*Continued*)

PICKLING METHODS FOR DIFFERENT METALS (*Continued*)

Metal	Soak Cleaning	Immersion Pickling	Electrolytic Pickling	Salt-Bath Descaling
Magnesium and its alloys	Not often used	Chromic/hydro-fluoric, nitric, phosphoric, acetic and sulphuric acids all used in combinations for general pickling and etching	Not used	Not used
Nickel and its alloys	Not used	Sulphuric and hydrofluoric acids used for general pickling	Cathodic treatment in acids	Little used except for heat-resisting high-nickel alloys
Titanium	Not used	Sulphuric acid used for removing light scale. Fluoboric, hydrofluoric and nitric acids and mixtures used to remove heavier scales	Not used	Frequently used for removal of very heavy scale. With caustic salts treatment temperature must not exceed 480°C

Source: *Metal Finishing Handbook and Guide*, Sawell Pub., London, 1970.

PROTECTIVE COATING CLASSIFICATIONS

Basic Coating Formation	Generic Coating Material
Natural Air-Oxidizing Coatings	Drying Oils Tung Oil Phenolic Varnish
Synthetic Air-Oxidizing Coatings	Alkyds Vinyl Alkyds Epoxy Esters Silicone Alkyds Uralkyds
Solvent Dry Lacquers	Nitrocellulose Polyvinylchloride-acetate Copolymers Acrylic Polymers Chlorinated Rubber Coal Tar Curback Asphalt Cutback
Coreactive Coatings	Epoxy Coal Tar Epoxy Polyurethane Polyesters Silicone
Emulsion-Type (Coalescent) Coatings	Vinyl Acetate Vinyl Acrylic Acrylic Epoxy
Heat-Condensing Coatings	Pure Phenolic Epoxy Phenolic
100% Solid Coatings	Coal Tar Enamel Asphalt Polyesters Epoxy Powder Coatings Vinyl Powder Coatings Plastisols Furan Materials Polyurethane

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 88, NACE, 1999.

CHARACTERISTICS OF COMMONLY APPLIED COATINGS

	Material		Flammability				Toxicity
			Flash Point Open Cup		% Solvent Vapor in	M.A.C. Parts/Million	
Type of Coating	Resin	Solvent	Deg. F	Deg. C	Air, (L.E.L.)	Solvents	Resin
Oil-Based Paint	Linseed Oil–Flammable	Aliphatic hydrocarbon may contain turpentine.	100+	38	0.80 if contains turpentine, 1.1 if contains mineral spirits.	If turpentine, 100; If only mineral spirits, 500.	Nontoxic
Alkyds	Flammable	Aliphatic or aromatic petroleum	100	38	1.1	200–500	Nonirritating
Chlorinated Rubber	Chlorinated rubber and plasticizing resins, generally nonflammable.	Aromatics	40–60	4–16	1–1.3	100	Chlorinated rubber is nontoxic. Possible skin irritation due to aromatic solvent.
Vinyls	High molecular weight chlorinated hydrocarbons, self-extinguishing	Ketones and aromatics	30–100	−1– −38	1.3–1.8	100	Nontoxic
Vinyl (water dispersed)	Vinyl acetate, Will support combustion	Water	None	None	None	None	Nontoxic
Epoxies (solvent base)	Epoxy-amine Epoxy-polyamide, will support combustion	Ketones and aromatics	30–95	−1– −36	1.3–1.8	100	Some cause dermatitis in sensitive individuals.

Type of Coating	Material		Flammability				Toxicity
			Flash Point Open Cup		% Solvent Vapor in	M.A.C. Parts/Million	
	Resin	Solvent	Deg. F	Deg. C	Air, (L.E.L.)	Solvents	Resin
Epoxy-Coal Tar	Will support combustion	Ketone and aromatics	30–95	−1—36	1.3–1.8	100	Fumes very irritating. Skin irritation. Dermatitis.
Epoxy (water dispersed)	Epoxy, will support combustion	Water	None	None	None	None	Possible skin irritation.
Polyurethane	Flammable	Ketones aromatics	40–75	4–2.5	1–1.3	100	Contains isocyanates. Toxic fumes can cause irritation during application. Dermatitis possible.
Asphalt Gilsonite Cutback	Will support combustion	Aliphatic or aromatic petroleum	100+	38	1.1	200–500	Nontoxic
Coal Tar Cutback	Flammable	Aromatics	40–100	4–38	1.1–1.27	200	Severe skin irritation.
Inorganic Zinc Silicate (water base)	Inorganic silicate, nonflammable	Water	None	None	None	None	Silicate mildly alkaline. Limited skin irritation.
Inorganic Zinc Silicate (solvent base)	Inorganic silicate, nonflammable	Ethyl Alcohol	55–60	15	3.2	1000	Silicate–possible mild skin irritation.

Source: C. G. Munger, “Safe Application of Protective Coatings—Identifying the Hazards,” *Plant Engineering*, Feb. 7 (1974).

COMPARISON OF PRIMERS

Requirement	Alkyd or Oil Primer	Inhibitive Primer (May be Mixed Resin System)	Primer Type Impervious Primer (Resin May be Identical to Topcoats)	Cathodic (Zinc) Primer
Bonding to Surface	Usually wets and bonds to most surfaces. Somewhat tolerant of substandard surface preparation. May be used on metal or wood surfaces, but not concrete. Not recommended for immersion.	Adhesive properties are major consideration. Not as tolerant of substandard surface preparation as oil primers. Used primarily on metal. Inhibition not necessary on wood or concrete. Usually not for immersion.	Surface must be properly prepared. Primers require maximum adhesion. Used on metal or concrete. Used for immersion.	Inorganic zinc: outstanding adhesion to properly cleaned steel or iron surfaces. Chemical as well as physical adhesion. Organic zinc: adhesion depends on base resin.
Adhesion of Topcoats	Satisfactory for oil types. Usually unsatisfactory for vinyls, epoxies, and other synthetic polymers. Soften and lose integrity by attack from solvent systems of synthetic topcoats.	Formulated for adhesion of topcoats. Specific coating systems may require specific primer.	Usually part of specific generic system. Primer designed for specific intermediate or topcoats.	Fits into wide range of systems. "Tie Coat" may be required. Specific recommendation should be obtained for immersion systems.
Corrosion Suppression	Limited, Alkali produced at cathode attacks film (saponification). Spread of underfilm corrosion results.	Usually formulated with good resistance to alkali undercut. Contain inhibitive pigment for a degree of corrosion resistance.	Relies on inert characteristics. Very strong adhesion.	Inorganic zinc: outstanding ability to resist disbonding and underfilm corrosion. Anodic property of metallic zinc protects minor film discontinuities.
Protection as Single Coat	Limited by severity of exposure.	Limited by severity of exposure.	Limited by serverity of exposure. Usually suppresses corrosion alone for some period of time.	Will protect without topcoat with very few exceptions.
Chemical Resistance	Typical of alkyds. Not recommended for alkali exposure.	May be of lower order of resistance than that of topcoat due to inhibitor.	Typical of coating system.	Not resistant to strong acids and alkalies. Inorganic: outstanding solvent resistance.

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 65, NACE 1999.

ALKYD COATINGS—PROPERTIES

Property	Medium Oil Alkyd	Vinyl Alkyd	Silicone Alkyd	Uralkyd	Epoxy Ester
Physical Properties	Flexible	Tough	Tough	Hard Abrasion Resistant	Hard
Water Resistance	Fair	Good	Good	Fair	Good
Acid Resistance	Fair	Best of group	Fair	Fair	Fair-Good
Alkali Resistance	Poor	Poor	Poor	Poor	Fair
Salt Resistance	Fair	Good	Good	Fair	Good
Solvent Resistance	Poor-Fair	Fair	Fair	Fair-Good	Fair-Good
Weather Resistance	Good	Very Good	Very Good Excellent gloss retention	Fair	Poor
Temperature Resistance	Good	Fair-Good	Excellent	Fair-Good	Good
Age Resistance	Good	Very Good	Very Good	Good	Good
Best Characteristic	Application	Weather Resistance	Weather & Heat Resistance	Abrasion Resistance	Alkali Resistance
Poorest Characteristic	Chemical Resistance	Alkali Resistance	Alkali Resistance	Chemical Resistance	Weathering
Recoatability	Excellent	Difficult	Fair	Difficult	Fair
Primary Coating Use	Weather-Resistant Coating	Corrosion-Resistant Coating	Corrosion-Resistant Coating	Abrasion-Resistant Coating	Machinery Enamel

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 94, NACE, 1999.

SOLVENT DRY LACQUERS—PROPERTIES

Properties	Vinyl Chloride Acetate Copolymer	Vinyl Acrylic Copolymer	Chlorinated Resin Modified	Rubber Alkyd Modified	Acrylic Lacquers	Coal Tar	Asphalt
Physical Property	Tough Strong	Tough	Hard	Tough	Hard-Flexible	Soft Adherent	Soft Adherent
Water Resistance	Excellent	Good	Very Good	Good	Good	Very Good	Good
Acid Resistance	Excellent	Very Good	Very Good	Fair	Good	Very Good	Very Good
Alkali Resistance	Excellent	Fair-Good	Very Good	Poor-Fair	Fair	Good	Good
Salt Resistance	Excellent	Very good	Very Good	Good	Good	Very Good	Very Good
Solvent (Hydrocarbon)							
Aromatic	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Aliphatic	Good	Good	Okay	Okay	Okay	Fair	Poor
Oxygenated	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Temperature Resistance	Fair 65°C (150°F)	Fair 65°C (150°F)	Fair	Fair 60°C (140°F)	Fair	Depends on softening point	Depends on softening point
Weather Resistance	Very Good	Excellent	Good	Very Good	Excellent	Poor	Good
Age Resistance	Excellent	Excellent	Very Good	Good	Very Good	Good	Good
Best Characteristic	Broad Chemical Resistance	Weather Resistance	Water Resistance	Drying Speed	Clear Color Retention Gloss Retention	Easy Application	Easy Application
Poorest Characteristic	Critical Application	Critical Application	Spray Application	Chemical Resistance	Solvent Resistance	Black Color	Black Color
Recoatability	Easy	Easy	Easy	Easy	Easy	Easy	Easy
Primary Coating Use	Chemical-Resistant Coatings	Exterior Chemical-Resistant	Maintenance Coatings	Weather-Resistant Coatings	Weather-Resistant Coatings	Water-Resistant Coatings	Chemical-Resistant Coatings

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings,* 2nd ed., p. 102, NACE, 1999.

EPOXY COATINGS—PROPERTIES

Properties	Alphatic Amine Cure	Polyamide Cure	Aromatic Amine Cure	Phenolic Epoxy	Silicone Epoxy	Coal Tar Epoxy		Water Based Epoxy
						Amine Cure	Polyamide Cure	
Physical Property	Hard	Tough	Hard	Hard	Medium-Hard	Hard (brittle)	Tough	Tough
Water Resistance	Good	Very Good	Very Good	Excellent	Good-Excellent	Excellent	Excellent	Fair-Good
Acid Resistance	Good	Fair	Very Good	Excellent	Good	Good	Good	Fair
Alkali Resistance	Good	Very Good	Very Good	Excellent	Good	Good	Very Good	Fair
Salt Resistance	Very Good	Very Good	Very Good	Excellent	Very Good	Very Good	Very Good	Fair-Good
Solvent Resistance (Hydrocarbons)								
Aromatic	Very Good	Fair	Very Good	Very Good	Good	Poor	Poor	Poor-Fair
Aliphatic	Very Good	Good	Very Good	Very Good	Very Good	Good	Good	Good
Oxygenated	Fair	Poor	Good	Very Good	Fair	Poor	Poor	Poor
Temperature Resistance	95°C	95°C	120°C	120°C	120°C	95°C	95°C	95°C
Weather Resistance	Fair, Chalks	Good, Chalks	Good	Fair	Very Good, Chalk Resistant	Fair	Fair	Good
Age Resistance	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Good
Best Characteristics	Strong Corrosion Resistance	Water and Alkali Resistance	Chemical Resistance	Chemical Resistance	Water and Weather Resistance	Water Resistance	Water Resistance	Ease of Application
Poorest Characteristics	Recoatability	Recoatability	Slow Cure	Very Slow Air Cure	Recoatability	Black Color Recoatability	Poor Recoatability Black Color	Proper Coalescence
Recoatability	Difficult	Difficult	Difficult	Difficult	Difficult	Difficult	Difficult	Difficult
Primary Coating Use	Chemical Resistance	Water Immersion	Chemical Coating	Chemical Lining	Weather Resistance	Water Immersion	Water Immersion	Atmospheric Corrosion

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 108, NACE, 1999.

100% SOLIDS COATINGS—PROPERTIES

Properties	Coal Tar Enamel	Asphalt Enamel	Polyester	Epoxy Powder	100% Solids Liquid Epoxy	Vinyl Powder	Vinyl Plastisol	Furfural Alcohol Resins
Physical Properties	Hard	Somewhat Resistant	Hard	Hard	Hard-Tough	Hard-Tough	Soft-Rubbery	Hard-Brittle
Water Resistance	Excellent	Very Good	Good	Good	Good	Good	Good	Excellent
Acid Resistance	Very Good	Very Good	Excellent	Good	Good	Good	Very Good	Excellent
Alkali Resistance	Good	Fair-Good	Poor	Very Good	Very Good	Good	Good	Excellent
Salt Resistance	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Excellent
Solvent Resistance (Hydrocarbons)								
Aliphatic	Good	Poor	Very Good	Very Good	Very Good	Very Good	Good	Excellent
Aromatic	Poor	Poor	Fair	Very Good	Very Good	Fair	Poor	Excellent
Oxygenated	Poor	Poor	Poor	Good	Good	Poor	Poor	Good
Temperature Resistance	60 C (140 F)	50 C (122 F)	65 C (150 F)	93 C (200 F)	93 C (200 F)	60 C (140 F)	60 C (140 F)	120 C (210 F)
Weather Resistance	Poor	Good	Good	Good (Chalks)	Good (Chalks)	Very Good	Very Good	Good
Age Resistance	Excellent	Very Good	Good	Good	Good	Very Good	Very Good	Good
Best Characteristic	Water Resistance	Water and Weather Resistance	Acid and Oxidizing Chemical Resistance	General Water and Alkali Resistance	General Chemical and Alkali Resistance	General Chemical Resistance	Water and Chemical Resistance	Temperature and Acid Resistance
Poorest Characteristic	Weather Resistance Black	Solvent Resistance. Black	Alkali Resistance	Critical Application	Critical Application	Critical Application	Adhesion	Adhesion Brittleness
Recoatability	Poor	Good	Fair	Poor	Difficult	Good	Good	Good
Principal Use	Lining and Coating Pipe	Waterproofing Structures	Tank Lining	Exterior Pipe Coating	Chemical Lining	Chemical Resistant Product Finish	Pipe Lining	Cement for Acid-Proof Brick

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 126, NACE, 1999.

URETHANE COATINGS–PROPERTIES[1]

Properties	Type 1 Oil Modified	Type 2 Moisture Cure	Type 3 Blocked	Type 4 Prepolymer Catalyst	Type 5 Two Component	Allphatic Isocyanate Cure (Non-Yellowing)
Physical Property	Very Tough	Very Tough Abrasion Resistant	Tough Abrasion Resistant	Tough Abrasion Resistant	Tough-Hard Rubbery	Tough-Rubbers
Water Resistance[2]	Fair	Good	Good	Fair	Good	Good
Acid Resistance[2]	Poor	Fair	Fair	Poor-Fair	Fair	Fair
Alkali Resistance[2]	Poor	Fair	Fair	Poor	Fair	Fair
Salt Resistance[2]	Fair	Fair	Fair	Fair	Fair	Fair
Solvent Resistance (Hydrocarbon)						
Aromatic	Fair	Good	Good	Poor	Good	Good
Aliphatic	Fair	Good	Good	Fair	Good	Good
Oxygenated	Poor	Fair	Fair	Fair	Good	Fair
Temperature Resistance	Good 100°C	Good 120°C	Good 120°C	Good 100°C	Good 120°C	Good 120°C
Weather Resistance	Good, Yellows	Good, Yellows	Good, Yellows	Good, Yellows	Good, some yellowing, chalk	Excellent, good color and gloss retention
Age Resistance	Good	Good	Good	Good	Good	Good
Best Characteristic	Exterior, Wood Coating	Abrasion, Impact	Abrasion, Impact	Speed of cure	Abrasion, Impact	Weather resistance, color and gloss retention
Poorest Characteristic	Oil Base Chemical Resistance	Dependent on humidity for cure	Heat required for cure	Chemical Resistance	Two package	–
Recoatability	Fair	Difficult	Difficult	Difficult	Difficult	Difficult
Primary Coating Use	Clear Wood Coating	Abrasion Resistance, Floors	Product Finish	Abrasion Resistance	Abrasion Resistance, Impact	Exterior Coatings

[1] The properties of urethanes vary over a wide range due to the many and varied basic polyols and isocyanates. The above listings are only indicative. Manufacturers must be contacted for specific properties of specific materials. Harder coatings are more resistant than softer, more rubbery types.

[2] Resistances are for nonimmersion conditions.

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 111, NACE, 1999.

HEAT-CONDENSING COATINGS—PROPERTIES

Properties	Phenolic	Epoxy Phenolics
Physical Property	Very Hard	Hard-Tough
Water Resistance	Excellent 100 C	Excellent 100 C
Acid Resistance	Excellent	Good
Alkali Resistance	Poor	Excellent
Salt Resistance	Excellent	Excellent
Solvent Resistance		
Hydrocarbon		
Aliphatic	Excellent	Excellent
Aromatic	Excellent	Excellent
Oxygenated	Very Good	Good
Temperature Resistance	120 C (250 F)	120 C (250 F)
Weather Resistance	Good (darkens)	Good
Age Resistance	Excellent	Excellent
Best Characteristics	Acid and Temperature Resistance	Alkali and Temperature Resistance
Worst Characteristics	Brittle, poor recoatability	Poor Recoatability
Recoatability	Poor	Poor
Principal Use	Chemical and Food Lining	Chemical Lining

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 119, NACE, 1999.

COALESCENT-EMULSION COATINGS—PROPERTIES

Properties	Vinyl Acetate	Vinyl Acrylic	Acrylic	Epoxy	Alkyd
Physical Property	Scour Resistant	Scour Resistant	Scour Resistant	Tough	Pliable
Water Resistance	Fair	Good	Good	Good	Good
Acid Resistance	NR[1]	NR	NR	Fair	NR
Alkali Resistance	NR	NR	NR	Good	NR
Salt Resistance	Fair	Fair	Fair	Good	Fair
Solvent Resistance					
Aliphatic hydrocarbon	Fair	Good	Fair	Good	Good
Aromatic hydrocarbon	NR	NR	NR	Good	NR
Oxygenated hydrocarbon	NR	NR	NR	NR	NR
Temperature Resistance	60 C (140 F)	60 C (140 F)	60 C (140 F)	70 C (158 F)	60 C (140 F)
Weather Resistance	Good	Very Good	Very Good	Fair	Good
Age Resistance	Good	Good	Good	Good	Good
Best Characteristic	Weather Resistant	Weather Resistant	Weather Resistant	Reasonable Corrosion Resistance	Weather Resistant, Easy Application
Poorest Characteristic	Porosity	Porosity	Porosity	More porous than solvent base	Poor Alkali Resistance
Recoatability	Good	Good	Good	Fair-Good	Good
Principal Use	Decorative Topcoat	Decorative Topcoat	Decorative Topcoat	Topcoat	Exterior Wood

[1]NR = Not Recommended.
These coatings are primarily for decorative purposes over primed steel or stucco. Alkyd formulations good for exterior wood.

Source: Charles G. Munger, *Corrosion Prevention by Protective Coatings*, p. 118, NACE, 1984.

ZINC COATINGS—SUMMARY OF PROPERTIES

	Organic Zinc Rich		Inorganic Zinc	
	Chlorinated Rubber Base	**Epoxy Base**	**Water Base**	**Solvent Base**
Physical Property	Tough	Medium hard	Hard-metallic	Medium hard
Water Resistance	Very good	Very good	Excellent	Very good
Acid Resistance	Poor	Poor	Poor	Poor
Alkali Resistance	Fair	Fair	Fair	Fair
Salt Resistance	Good	Good	Very good	Very good
Solvent Resistance				
Aliphatic Hydrocarbon	Very good	Very good	Excellent	Very good
Aromatic Hydrocarbon	Poor	Good	Excellent	Good
Oxygenated Hydrocarbon	Poor	Fair	Excellent	Good
Temperature Resistance	80 C (180° F) Dry	90 C (200° F) Dry	370 C (700° F) Dry	370 C (700° F) Dry
Weather Resistance	Very Good	Good	Excellent	Excellent
Age Resistance	Good	Good	Excellent	Excellent
Best Characteristic	Fast dry	Good adhesion	Hard abrasion resistant	Easier Application
Poorest Characteristic	Solvent resistance	Application Weather resistance	More difficult application	Poor cure, dry condition
Reactability	Good	Fair	Good	Good
Principal Use	Touch up-galvanize inorganic zinc	Touch up topcoated zinc systems. Corrosion resistant base coat	Corrosion resistance-abrasion resistance	Corrosion resistant base coat

Source: C. G. Munger.

ZINC COATINGS—PROPERTIES

	Inorganic Zinc, Postcured	Inorganic Zinc, Self-Cured, Water-Based	Inorganic Zinc, Self-Cured, Water-Based, Ammonium	Inorganic Zinc, Self-Cured, Solvent-Based	Organic Zinc, One-Package	Organic Zinc, Two-Package	Modified Inorganic Zinc Primer
Cure type	Inorganic	Inorganic	Inorganic	Hydrolyzable organic silicate	Lacquer	Coreacting	Coreacting
Effect of Sunlight	Unaffected	Unaffected	Unaffected	Unaffected	Surface chalking	Surface chalking	Very slow; chalk
Wet or humid environments	Outstanding	Outstanding	Outstanding	Outstanding	Very good	Very good	Very good
Industrial-atmosphere contaminants:							
Acids	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat
Alkalies	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat
Oxidizing	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat	Requires topcoat
Solvents	Outstanding	Outstanding	Outstanding	Outstanding	Limited	Very good	Very good
Spillage and splash of industrial compounds:							
Acids	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended
Alkalies	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended
Oxidizing	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended
Solvents	Outstanding	Outstanding	Outstanding	Outstanding	Limited	Very good	Good

	Inorganic Zinc, Postcured	Inorganic Zinc, Self-Cured, Water-Based	Inorganic Zinc, Self-Cured, Water-Based, Ammonium	Inorganic Zinc, Self-Cured, Solvent-Based	Organic Zinc, One-Package	Organic Zinc, Two-Package	Modified Inorganic Zinc Primer
Water immersion	With suitable topcoat system on ship hutts and other marine structures				Not recommended	With epoxy topcoat on marine structures	See manual-user's literature
Tank linings	Marine cargo and ballast tanks, fuel storage, including floating root tanks				Not used	With suitable topcoat in marine cargo and ballast	New manual-user's literature
Physical properties:							
Abrasion resistance	Outstanding	Outstanding	Outstanding	Outstanding	Good	Good	Excellent
Heat stability	Outstanding	Outstanding	Outstanding	Outstanding	Good	Good	Good
Hardness	Outstanding	Outstanding	Outstanding	Outstanding	Good	Good	Excellent
Gloss	None	None	None	None	Flat	Flat	None
Colors	Gray or tints of gray	Gray or tints of gray	Gray or tints of gray	Gray or tints of gray	Gray or tints of gray	Gray or tints of gray	Gray or tints of gray
Additional notes	As primers for organic systems, provide greatly extended service life. Special application technique or use of tie coat may be required to avoid solvent bubbling in organic topcoat. Alkyds always require tie coat				Can be used to touch up inorganic primers compatible with topcoats	Choice of topcoat is critical	In some applications, satisfactory over mechanically cleaned surfaces. Excellent for touch-up of inorganic zincs

Source: G. E. Weismantel, *Paint Handbook*, pp. 7–30, 1981. Reproduced by permission of The McGraw-Hill Companies.

INORGANIC ZINC COATINGS AND COMPOSITIONS

Coating Type	Powder #/Gal. (Two Component)	Zinc Dust #/Gal.	Volume Solids %	Mil Sq. Ft. Coverage	DFT Mils	Ounces Zinc Dust Per Sq. Ft. at DFT	Pigment Other Than Zinc
Reconstruction Primer–Single Package	N.A.	6.91	35.0	561	3/4	0.15	–
Preconstruction Primer–Water Base	14.15	14.00	35.0	561	3/4	0.30	–
Water Base–Post-Cure	23.0	19.89	66.2	1052	3	0.90	Red Lead
Water Base–Self-Cure	25.0	21.62	75.4	1209	3	0.86	Red Lead
Water Base–Self-Cure	19.4	16.78	67.8	1088	3	0.74	Red Lead
Organic Base–Self-Cure	14.94	14.79	66.1	1060	2.5	0.56	Iron Oxide
Organic Base–Single Package	N.A.	10.0	50.0	800	2.5	0.50	–
Organic Base–Self-Cure	14.6	14.6	62.3	1000	3.0	0.70	–
Organic Base–Self-Cure	18.0	16.82	65.0	1042	2.5	0.65	Celite
Organic Base–Self-Cure	15.0	12.0	63	1010	2.5	0.475	Celite
Organic Base–Self-Cure	8.0	7.42	31.0	497	1.0	0.24	Celite

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 151, NACE, 1999.

REINFORCING PIGMENTS USED IN CORROSION-RESISTANT COATINGS

Rating: F = Fair; G = Good; P = Poor; E = Excellent; B = Borderline

		Resistant Characteristics				
Generic Type	**Common Name**	**Alkali**	**Acid**	**Water**	**Weather**	**Physical Characteristics**
Magnesium Silicate	Talc; Asbestine Asbestos	F	G	E	E	Fiborus-platelike fiborus
Barium Sulphate	Barytes	G	G	G	G	Cubical, heavy
Silica	Diatomite; Silica Flour	P	E	E	E	Porpos, hard, sharp crystals
Aluminum Silicate	Clay	F	G	F	G	Platelike
Potassium-Aluminum Silicate	Mica	G	G	G	G	Platelike, used to reduce moisture vapor transfer

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 78, NACE, 1999.

METALLIC PIGMENTS USED FOR CORROSION RESISTANCE

Rating: E = Excellent; G = Good; F = Fair; NR = Not Recommended

		Resistance				
Generic Type	**Common Name**	**Alkali**	**Acid**	**Water**	**Weather**	**Physical Characteristics**
Aluminum	Aluminum flake	NR	NR	E	E	Creats single effect, protects binder, increases moisture upon transfer resistance.
Stainless	Stainless flake	E	E	E	G	Does not leaf as well as aluminum flakes. Reinforces binder without reducing chemical resistance.
Lead	Lead flake	E	E	E	E	Does not leaf as well as aluminum. Excellent chemical and water resistance.
Copper	Copper flake	NR	NR	G	F-G	Leafs well, good copper color, chemical resistance only fair. Has good antiflaking properties.
Zinc	Zinc powder	NR	NR	E	E	Provides cathodic protection to steel. Reacts with inorganic vehicles to form hard adherent coating.
	Zinc flake	NR	NR	E	E	Provides some cathodic protection to steel. Reinforces some organic binders. May be used with zinc powder for reinforcing purposes.

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 80, NACE, 1999.

COMPATABILITY OF COATING MATERIALS WITH VARIOUS PRIMERS

Topcoats

Primers	Alkyd	Alkyd-phenolic	Vinyl-alkyd	Vinyl	Vinyl-acrylic	Epoxy catalyzed	Epoxy ester	Coal-tar epoxy	Chlorinated-rubber	Phenolic oleoresinous	Polyurethane	Polyester flake or glass
Alkyd	R	R	NR	NR	NR	NR	NR	NR	NR	R	NR	NR
Bituminous (aluminum)[a]	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Vinyl-alkyd[b]	R	R	R	R*	R*	NR	R	NR	NR	NR	NR	NR
Vinyl[b]	R	R	R	R	R	NR	NR	NR	R	NR	NR	NR
Epoxy ester	R	R	NR	NR	NR	NR	R	NR	X	R	NR	NR
Epoxy catalyzed[c]	NR	NR	R*	R*[d]	R*	R*	R*	R*	X	NR	R*	R*
Epoxy noncatalyzed[c]	R	R	R	X	X	R	R	X	X	R	NR	R*
Epoxy-organic zinc[c]	NR	NR	NR	R*	NR	R	R	R	R	NR	NR	NR
Phenolic oleoresinous	R	R	NR	NR	NR	NR	R	NR	NR	R	NR	NR
Vinyl-phenolic	R	R	R	R	R	NR	R	NR	R	R	X	NR
Coal-tar epoxy	NR	NR	NR	NR[d]	NR	R*	R*	R*	NR	NR	NR	NR
Inorganic zinc, postcure[e]	NR	NR	NR	R*	NR	R*	R*	R*	R*	NR	NR	NR
Inorganic zinc, self-cure[c]; water-base[e]	NR	NR	NR	R*	NR	R*	R*	R*	R*	NR	NR	NR
Inorganic zinc, self-cure[c]; solvent-base[e]	NR	NR	NR	R*	NR	R*	R*	R*	R*	NR	NR	NR
Chlorinated-rubber	R	R	R	NR	R	NR	R	NR	R	R	NR	NR

Note: R = known compatibility; normal practice, R* = known compatibility with special surface preparation and/or application. NR = not recommended. This is defined as meaning that it is not common practice to apply this topcoat over the specified primer, although certain products, if properly formulated, may be compatible. Attention is called also to the fact that certain combinations marked NR may be used, provided a suitable tie coat is applied between the two. X = not recommended because of insufficient data.

[a] Topcoated with itself or with an antifouling coating.
[b] Vinyl wash primer required.
[c] May be used as an after-blast primer.
[d] Vinyl antifouling coating such as MIL-P-15931 may be applied.
[e] May be used without topcoat.

Source: G. E. Weismantel, *Paint Handbook*, pp. 14–29, 1981. Reproduced by permission of The McGraw-Hill Companies.

RESISTANT PROPERTIES OF BINDERS FOR COATINGS

Rating: E = Excellent, G = Good, F = Fair, P = Poor

Binder Type	Generic Type	Resistant Properties				Temperature	Primary Use
		Alkali	Acid	Water	Weather		
Lacquer	Copolymer-Vinyl Chloride-Vinyl Acetate	E	E	E	E	to 65 C (150 F)	Resistant intermediate and topcoats
	Polyacrylates	F	F	F	E	to 65 C (150 F)	Resistant topcoats
	Chlorinated Rubber	E	E	E	G	to 60 C (140 F)	Resistant intermediate
Co-reacting	Epoxy-Amine Cure	E	G	G	F	to 93 C (200 F)	Resistant coatings and linings
	Epoxy-Polyamide	E	F	G	G	to 93 C (200 F)	Resistant coatings and linings
	Urethane (2 package)	G	F	G	F	to 120 C (250 F)	Abrasion-resistant coatings
	Urethane (moisture cure)	G	F	G	G	to 120 C (250 F)	Abrasion-resistant coatings
	Urethane-Aliphatic Isocyanate	G	F	G	E	to 120 C (250 F)	Weather- and abrasion-resistant topcoats
Condensation (requires added heat to cure)	Phenolic	P	E	E	F	up to C (250 F)	Chemical- and food-resistant lining
	Epoxy Phenolic	F	E	E	F	to 120 C (250 F)	Chemical- and food-resistant lining
	Epoxy-Powder Coating (requires high heat to fuse and cure)	G	G	G	F	to 93 C (200 F)	Pipe coating and lining
Inorganic	Zinc Silicate	P	P	G	E	to 315 C (600 F)	Permanent primer or single coat weather-resistant coating
	Glass (fused to metallic substrate)	F	E	E	E	to 260 C (500 F)	Chemical- and Food-resistant lining

Source: *Kirk-Othmer Encyclopedia of Chemical Technology*, C. G. Munger, *Coatings Resistant*, Vol. 6, 3rd ed., John Wiley & Sons, pp. 456–578, 1979.

PROPERTIES OF GENERIC COATINGS FOR ATMOSPHERIC SERVICE

APPLICATION PROPERTIES

	Alkyd	2-Can Epoxy	Acrylic Latex	Linseed Oil	Phenolic	Chlorinated Rubber	Aliphatic Urethane	Vinyl
Solvents	Aliphatic or Aromatic	Lacquer	Water	Aliphatic	Aromatic	Aromatic	Lacquer	Lacquer
Min. Surface Preparation*	SP 3	SP 6	SP 6	SP 2	SP 6	SP 6	* * *	SP 6
Stability During Use	EX	F	EX	EX	EX	EX	F	EX
Brushability	G	F	EX	VG	G	F	G	P
Method of Cure	Oxid.	Chem.	Coal.	Oxid.	Oxid.	Evap.	Chem.	Evap.
Speed of Cure								
50°F–90°F**	G	G	EX	F	G	EX	EX	EX
35°F–50°F**	F	NR	NR	P	F	G	G	G
Film Build per Coat	G	VG	F	G	G	G	VG	G
Use in Primers	G	EX	F	EX	G	G	G	G
Use on Damp Surfaces	P	G	VG	P	P	P	G	G

APPEARANCE PROPERTIES

	Alkyd	2-Can Epoxy	Acrylic Latex	Linseed Oil	Phenolic	Chlorinated Rubber	Aliphatic Urethane	Vinyl
Use as Clear Finish (Varnish)	VG	F	P	NR	VG	NR	EX	NR
Use in Ready Mixed Aluminum Paint	G	F	NR	F	EX	F	F	G
Pipe Color	VG	G	EX	G	P	VG	EX	EX
Ability to Produce High Gloss	EX	EX	F	G	EX	VG	EX	F

PERFORMANCE PROPERTIES

	Alkyd	2-Can Epoxy	Acrylic Latex	Linseed Oil	Phenolic	Chlorinated Rubber	Aliphatic Urethane	Vinyl
Hardness	G	VG	F	P	VG	VG	EX	G
Adhesion	G	EX	F	VG	G	VG	VG	F
Flexibility	G	G	EX	VG	F	VG	VG	EX
Resistance To–								
Abrasion	F	VG	F	P	G	VG	EX	VG
Water	G	EX	F	P	EX	EX	VG	EX
Strong Solvents	P	EX	F	P	G	P	EX	P
Acid	F	VG	F	P	EX	EX	EX	EX
Alkali	P	EX	G	P	G	EX	VG	EX
Heat–200°F	G	G	F	F	G	NR	G	NR

(*Continued*)

PROPERTIES OF GENERIC COATINGS FOR ATMOSPHERIC SERVICE (*Continued*)

DURABILITY

	Alkyd	2-Can Epoxy	Acrylic Latex	Linseed Oil	Phenolic	Chlorinated Rubber	Aliphatic Urethane	Vinyl
Moisture Permeability	Mod	Low	High	Mod	Low	Low	Low	Low
Normal Exposure	VG	VG	VG	G	VG	EX	EX	EX
Marine Exposure	F	EX	F	F	G	EX	EX	EX
Corrosive Exposure	F	EX	F	NR	G	VG	EX	EX
Color Retention	G	P	VG	F	P	G	EX	VG
Gloss Retention	G	P	EX	P	G	G	EX	VG
Chalk Resistance	G	P	VG	P	G	G	EX	VG

CODES
EX–Excellent
VG–Very Good
G–Good
F–Fair
P–Poor
NR–Not Recommended

SOLVENTS
Aliphatic–Mineral spirits
Aromatic–Xylene, toluene, etc.
Lacquer–Aromatic plus ketone, ester, or ether solvents (See Solvents)

ABBREVIATIONS
Oxid.–Oxidative polymerization or oxidation
Chem.–Chemical reaction (two component)
Coal.–Coalescence (latex)
Evap.–Solvent evaporation (lacquer)
Min.–Minimum

*SSPC Surface Preparation Specifications
**Painting should not be done above 90°F or below 34°F
***Usually used in topcoats

Source: *Good Painting Practice, SSPC Painting Manual*, Third Edition, Vol. 1, pp. 121–122, SSPC, 1994. Reprinted by permission of SSPC: The Society for Protective Coatings.

TEMPERATURE LIMITS OF COATINGS

Coating	Immersion	Nonimmersion
Vinyl Copolymer	38 C (100 F)	65 C (150 F)
Chlorinated Rubber	38 C (100 F)	60 C (140 F)
Coal Tar	50 C (120 F)	65 C (150 F)
Coal Tar Epoxy	50 C (120 F)	95 C (200 F)
Epoxy	50 C (120 F)	95 C (200 F)
Urethane	38 C (100 F)	120 C (250 F)
Epoxy Phenolic	82 C (180 F)	120 C (250 F)
Baked Phenolic	82 C (180 F)	120 C (250 F)
Inorganic Zinc	–	370 C (700 F)
Silicone	–	370 C (700 F)

Source: *Kirk-Othmer Encyclopedia of Chemical Technology*, C. G. Munger, *Coatings Resistant*, Vol. 6, 3rd ed., John Wiley & Sons, New York, NY, ©1979. This material is used by permission of John Wiley & Sons, Inc.

RADIATION TOLERANCE OF COATINGS

Severe Exposure = Greater than 4.5×10^9 Rads
Moderate Exposure = 5×10^8 to 4.5×10^9 Rads
Light Exposure = Less than 5×10^8 Rads

Coating	Maximum Allowable Radiation Dose in Air	
	On Steel	On Concrete
Chlorinated Rubber	1×10^8 Rads[1]	1×10^8 Rads
Epoxy-Amine	1×10^9	1×10^9
Epoxy Coal Tar	5×10^8	5×10^8
Epoxy-Polyamide	1×10^{10}	NA
Inorganic Silicate Finish	1×10^{10}	1×10^{10}
Inorganic Zinc	2.2×10^{10}	NA
Epoxy Phenolic	1×10^{10}	1×10^{10}
Silicone (Baked)	1×10^{10}	NA
Urethane	5×10^8	6×10^9
Vinyl	1×10^8	–

[1] Rad: The unit of absorbed radiation. For most organic material, one rentgen = 1 Rad (ANSI N 5.12, 1973).

Source: *Kirk-Othmer Encyclopedia of Chemical Technology*, C. G. Munger, *Coatings Resistant*, Vol. 6, 3rd ed., John Wiley & Sons, New York, NY, ©1979. This material is used by permission of John Wiley & Sons, Inc.

COEFFICIENT OF FRICTION–SLIP FACTOR FOR VARIOUS SURFACE FINISHES AND COATINGS

Surface Treatment	No. of Tests	Slip Factor		
		Mean	Max.	Min.
Plain Steel				
Mill Scale	352	0.32	0.60	0.17
Rusted	15	0.43	0.55	0.41
Flame cleaned	88	0.48	0.75	0.31
Blast cleaned	183	0.57	0.81	0.32
Coated Steel				
Red lead paint	6	0.07	–	0.05
Rust preventive paint	3	0.11	–	0.07
Hot-dip galvanized	95	0.19	0.36	0.08
Lacquer-varnish	17	0.24	0.30	0.10
Blast cleaned vinyl wash primer	24	0.28	0.34	0.22
Galvanized and grit blasted	12	0.49	0.55	0.42
Grit blasted and inorganic zinc rich paint	48	0.51	0.65	0.38
Grit blasted and zinc sprayed	42	0.65	0.99	0.42

Source: Transportation Research Board #112. National Research Council, Dec. 1984.

WATER PERMEABILITY OF PLASTICIZED PVC FILMS

P × 10^8 [(g/hr) $(cm)^2$ (mmHg)/(cm))]

	Mole % of Plasticizer					
Plasticizer	**0**	**4**	**6**	**8**	**10**	**12**
Tricresyl Phosphate	0.50	0.55	0.65	0.92	1.74	2.06
Dibutyl Phosphate	0.50	0.60	0.94	1.33	2.46	44.02
Dioctyl Phthalate	0.50	0.64	1.16	1.98	3.05	4.97
Dibutyl Adipate	0.50	0.96	1.72	2.67	4.08	5.89
Dioctyl Adipate	0.50	1.45	3.00	4.02	6.81	10.95
Dibutyl Sebacate	0.50	1.09	2.13	3.30	5.00	8.64
Dioctyl Sebacate	0.50	1.64	3.20	5.32	8.03	12.05

Note: For comparison of mole %. DOP concentration in PHR (Parts/Hundred of Resin) are: 0 26 40 54 69 86.

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings,* 2nd ed., p. 84, NACE, 1999.

PERMEANCE OF ORGANIC TOPCOATS

Topcoat Type	**Permeance-Metric Perms (ASTM E-96) (Gm/24 Hour. Sqm. mm Mercury)**
High-Build Polyamide Epoxy	0.35
High-Build Fast-Drying Epoxy	0.30
Epoxy/Urethane	0.105
Coal Tar Epoxy	0.042
High-Build Vinyl	0.092
Vinyl-Acrylic	0.115
Chlorinated Rubber	0.089

Note: Comparing these permeance values with onset of primer hardness reveals a correlation between rapid development of primer hardness and the higher permeance values of the topcoat.

Source: C. G. Munger and L. D. Vincent, *Corrosion Prevention by Protective Coatings*, 2nd ed., p. 165, NACE, 1999.

CHEMICAL RESISTANCE OF COATINGS FOR IMMERSION SERVICE
(Room Temperature)

Chemical resistance data are for coatings only. Thin coatings generally are not suitable for substrates such as carbon steel which are corroded significantly (*e.g.*, >20 mpy) in the test environment.

		Coal Tar									
	Asphalt, Unmodified	Hot Applied	Cold Applied	Coal Tar -Epoxy	Coal Tar -Urethanes	Epoxy-Phenolic Baked	Epoxy-Amine Cured	Epoxy Ester	Furturyl Alcohol	Phenolics, Baked	Polyesters (Unsaturated)
Acids											
Sulfuric, 10%	R	LR	NR	R	R	R	R	LR	R	R	R
Sulfuric, 80%	–	NR	NR	–	NR	NR	NR	NR	LR	NR	R
Hydrochloric, 10%	R	LR	NR	LR	LR	R	R	LR	R	R	R
Hydrochloric, 35%	R	NR	NR	–	–	NR	NR	NR	R	R	R
Nitric, 10%	NR	LR	NR	–	–	LR	NR	NR	NR	NR	R
Nitric, 50%	NR	NR	NR	–	–	NR	NR	NR	NR	NR	NR
Acetic, 100%	–	NR	NR	NR	NR	NR	NR	NR	LR	LR	NR
Water											
Distilled	R	R	R	R	LR	R	R	R	R	R	R
Salt Water	R	R	R	R	LR	R	R	R	R	R	R
Alkalies											
Sodium Hydroxide, 10%	R	R	LR	R	R	R	R	NR	R	NR	R
Sodium Hydroxide, 70%	–	NR	NR	–	LR	R	R	NR	LR	NR	NR
Ammonium Hydroxide, 10%	R	R	LR	R	R	R	LR	LR	R	NR	R
Sodium Carbonate, 5%	R	R	R	–	–	R	–	–	–	–	–

	Asphalt, Unmodified	Coal Tar		Coal Tar -Epoxy	Coal Tar -Urethanes	Epoxy-Phenolic Baked	Epoxy-Amine Cured	Epoxy Ester	Furturyl Alcohol	Phenolics, Baked	Polyesters (Unsaturated)
		Hot Applied	Cold Applied								
Gases											
Chlorine	R	NR	NR	LR	NR	LR	LR	LR	NR	NR	R
Ammonia	–	LR	LR	NR	NR	LR	LR	R	R	NR	NR
Hydrogen Sulfide	–	R	R	R	–	R	R	–	R	R	–
Organics											
Alcohols	R	LR	LR	NR	NR	R	R	LR	R	R	R
Aliphatic Hydrocarbons	NR	LR	LR	LR	LR	R	R	R	R	R	R
Aromatic Hydrocarbons	NR	NR	NR	NR	LR	R	R	R	R	R	R
Ketones	NR	NR	NR	NR	NR	LR	LR	NR	LR	R	NR
Ethers	NR	NR	NR	–	–	LR	LR	NR	LR	R	–
Esters	NR	NR	NR	NR	NR	LR	LR	NR	R	R	LR
Chlorinated Hydrocarbons	NR	NR	NR	NR	LR	LR	LR	NR	LR	R	NR
Max. Temp. (dry conditions) °F	150	–	–	200	200	250	250	250	300	250–300	–
Max. Temp. (wet conditions) °F	–	120	120	150	150	150	150	150	190	160–250	250

R = Recommended
LR = Limited recommendation
NR = No recommendation

CHEMICAL RESISTANCE OF COATINGS FOR IMMERSION SERVICE (*Continued*)
(Room Temperature)

Chemical resistance data are for coatings only. Thin coatings generally are not suitable for substrates such as carbon steel which are corroded significantly (*e.g.*, > 20 mpy) in the test environment.

	Polyvinyl Chlor – acetates	Vinyl Ester	Urethanes		Vinylidene Chloride	Chlorinated Rubber
			Air-Dry	Bake		
Acids						
Sulfuric, 10%	R	R	LR	LR	R	R
Sulfuric, 80%	NR	R	NR	LR	LR	R
Hydrochloric, 10%	R	R	LR	LR	R	R
Hydrochloric, 35%	LR	R	LR	LR	R	R
Nitric, 10%	R	R	LR	LR	R	R
Nitric, 50%	NR	–	NR	NR	LR	NR
Acetic, 100%	NR	LR	NR	NR	NR	NR
Water						
Distilled	R	R	LR	LR	–	R
Salt Water	R	R	LR	LR	R	R
Alkalies						
Sodium Hydroxide, 10%	R	R	LR	LR	LR	R
Sodium Hydroxide, 70%	LR	R	LR	LR	NR	R
Ammonium Hydroxide, 10%	R	R	LR	R	NR	R
Sodium Carbonate, 5%	R	R	R	R	R	R

	Polyvinyl Chlor – acetates	Vinyl Ester	Urethanes		Vinylidene Chloride	Chlorinated Rubber
			Air-Dry	Bake		
Gases						
Chlorine	LR	R	LR	R	LR	R
Ammonia	LR	R	LR	R	NR	NR
Hydrogen Sulfide	LR	R	R	R	R	R
Organics						
Alcohols	R	R	NR	R	R	LR
Aliphatic Hydrocarbons	R	R	R	R	R	LR
Aromatic Hydrocarbons	NR	LR	R	R	LR	NR
Ketones	NR	NR	NR	R	NR	NR
Ethers	NR	NR	R	R	NR	NR
Esters	NR	LR	NR	R	NR	NR
Chlorinated Hydrocarbons	LR	LR	LR	R	LR	NR
Max. Temp. (dry conditions) °F	160	350	–	–	–	160
Max. Temp. (wet conditions) °F	150	210	–	–	150	140

R = Recommended
LR = Limited recommendation
NR = No recommendation

Source: NACE, TPC 2 *Coatings & Linings for Immersion Service.*

TYPICAL PHYSICAL PROPERTIES OF SURFACE COATINGS FOR CONCRETE[1]

		Polyestar		Epoxy		
	Concrete	Isophthalic	Bisphenol	Polyamide	Amine	Urethane[4]
Tensile Strength						
(ASTM C307) psi	200–400	1200–2500	1200–2500	600–4000	1200–2500	200–1200
MPa	1.4–2.8	8.3–17	8.3–17	4.0–28	8.3–17	1.4–8.3
Thermal coefficient of expansion (ASTM C531)						
max. in/in/F	6.5×10^6	20×10^6	20×10^6	40×10^6	40×10^6	[2]
mm/mm/C	11.7×10^6	36×10^6	36×10^6	72×10^6	72×10^6	
Compressive strength,						
(ASTM C579) psi	3.500	10.000	10.000	4.000	6.000	[2]
MPa	24	70	70	28	42	
Abrasion resistance						
Taber Abraser–Wt loss in milligrams 1000 gram load/1000 cycles		15 to 27	15 to 27	15 to 27	15 to 27	[2]
Shrinkage, ASTM C531 %		2 to 4	2 to 4	0.25 to 0.75	0.25 to 0.75	0 to 2
Work life, minutes		15 to 45	15 to 45	30 to 90	30 to 90	15 to 60

		Polyestar		Epoxy		
	Concrete	**Isophthalic**	**Bisphenol**	**Polyamide**	**Amine**	**Urethane[4]**
Traffic limitations, hours after application	Light	16	16	24	24	24
	Heavy	36	36	48	48	48
	Ready for service	48	48	72	72	72
Adhesion characteristics[3]		Poor	Fair	Excellent	Good	Fair
Flexural Strength (ASTM C580) psi		1500	1500	1000	1500	[2]
MPa		10	10	7	10	

[1] All physical values depend greatly on reinforcing. Values are for ambient temperatures.
[2] Urethanes not shown because of great differences in physical properties, depending on formulations. Adhesion characteristics should be related by actual test data. Any system which shows concrete failure when tested for surfacing adhesion should be rated excellent with decreasing rating for systems showing failure in cohesion or adhesion below concrete failure.
[3] Adhesion to concrete: primers usually are used under polyesters and urethanes to improve adhesion.
[4] Type of urethane used is one of three: (1) Type II Moisture Cured. (2) Type IV Two Package Catalyst or (3) Type V Two Package Polyol. Ref. ASTM C16.

TYPES OF PIPELINE COATINGS

Pipe Coating	Desirable Characteristics	Limitations
Coal tar enamels	80+ years of use Minimum holiday susceptibility Low current requirements Good resistance to cathodic disbondment Good adhesion to steel	Limited manufacturers Limited applicators Health and air quality concerns Change in allowable reinforcements
Mill-applied tape systems	30+ years of use Minimum holiday susceptibility Ease of application Good adhesion to steel Low energy required for application	Handling restrictions—shipping and installation UV and thermal blistering—storage potential Shielding CP from soil Stress disbondment
Crosshead-extruded polyolefin with asphalt/butyl adhesive	40+ years of use Minimum holiday susceptibility Low current requirements Ease of application Nonpolluting Low energy required for application	Minimum adhesion to steel Limited storage (except with carbon black) Tendency for tear to propagate along pipe length
Dual-side-extruded polyolefin with butyl adhesive	25 years of use Minimum holiday susceptibility Low current requirements Excellent resistance to cathodic disbondment Good adhesion to steel Ease of application Nonpolluting Low energy required for application	Difficult to remove coating Limited applicators
Fusion-bonded	35+ years of use Low current requirements Excellent resistance to cathodic disbondment Excellent adhesion to steel Excellent resistance to hydrocarbons	Exacting application parameters High application temperature Subject to steel pipe surface imperfections Lower impact and abrasion resistance High moisture absorption
Multi-layer epoxy/extruded polyolefin systems	Lowest current requirements Highest resistance to cathodic disbondment Excellent adhesion to steel Excellent resistance to hydrocarbons High impact and abrasion resistance	Limited applicators Exacting application parameters Higher initial cost Possible shielding of CP current

Source: A. W. Peabody and R. L. Bianchetti, eds., *Peabody's Control of Pipeline Corrosion*, 2nd ed., p. 14, NACE, 2001.

FILM THICKNESS FORMULAS[1]

Wet Film Thickness to Dry Film Thickness

No Solvent Added:

$$\text{DFT} = \text{WFT} \times \%\ \text{solids by volume}$$

Solvent Added:

$$\text{DFT} = \text{WFT} \times \frac{\%\ \text{solids by volume}}{1 + \%\ \text{thinner by volume}}$$

Dry Film Thickness to Wet Film Thickness

$$\text{WFT} = \frac{\text{DFT}}{\%\ \text{solids by volume}}$$

$$\text{WFT} = \frac{\text{DFT}(1 + \%\ \text{thinner by volume})}{\%\ \text{solids by volume}}$$

Spreading Rate

$$\#\ \text{of Gallons of coating} \times \%\ \text{solids per gallon} \times \frac{1{,}604}{\#\ \text{mils DFT}} = \text{Coverage in sq.ft}$$

$$\#\ \text{of Liters of coating} \times \%\ \text{solids liter} \times \frac{1{,}000}{\#\ \text{microns DFT}} = \text{Coverage in sq. meters}$$

[1]From NACE International Coating Inspector Training and Certification Program.

DRY FILM THICKNESS (IN MILS) OF COATINGS AS A FUNCTION OF SOLIDS CONTENT AND COVERAGE RATE

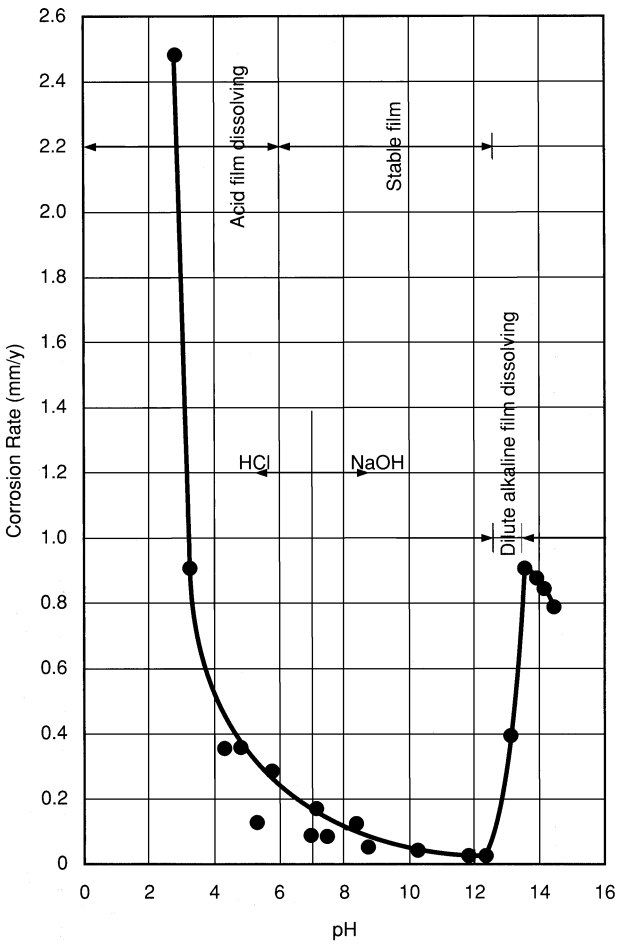
	Gallons to Coat 1000 Sq. Ft.																				
	10.	8.0	6.7	5.7	5.0	4.4	4.0	3.6	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.9	1.8	1.7	1.7
	Coverage Rates, Sq. Ft. Per Gallon																				
Film Forming Solids by Volume, Percent	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600
10	1.6	1.3	1.1	.9	.8	.7	.6	.6	.4												
15	2.4	1.9	1.6	1.4	1.2	1.1	1.	.9	.8	.7	.7	.6	.6	.6	.5						
20	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.2	1.1	1.	.9	.8	.8	.8	.7	.7	.6	.6	.6	.6	.5
25	4.	3.2	2.7	2.3	2.	1.8	1.6	1.5	1.4	1.2	1.1	1.1	1.	1.	.9	.8	.8	.8	.7	.7	.7
30	4.8	3.8	3.2	2.7	2.4	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.	1.	.9	.8	.8	.8
35	5.6	4.5	3.7	3.2	2.8	2.5	2.2	2.1	1.9	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.1	1.	1.	.9
40	6.2	5.1	4.3	3.6	3.2	2.8	2.6	2.4	2.2	2.	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1
45	7.2	5.8	4.8	4.1	3.6	3.2	2.9	2.7	2.4	2.2	2.	2.	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2
50	8.	6.4	5.4	4.6	4.	3.6	3.2	2.9	2.7	2.4	2.3	2.1	2.	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.4
55	8.8	7.	5.9	5.	4.4	3.9	3.5	3.2	3.	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.8	1.7	1.6	1.5	1.5
60	9.6	7.7	6.4	5.5	4.8	4.3	3.8	3.5	3.2	2.9	2.7	2.5	2.4	2.3	2.1	2.	1.9	1.8	1.7	1.7	1.6
65	10.4	8.3	7.	5.9	5.2	4.6	4.2	3.8	3.5	3.2	2.9	2.7	2.6	2.5	2.3	2.1	2.1	2.	1.9	1.8	1.8
70	11.2	9.	7.5	6.4	5.6	5.	4.5	4.1	3.8	3.4	3.2	2.9	2.8	2.7	2.5	2.3	2.2	2.1	2.	2.	1.8
75	12.	9.5	8.	6.8	6.	5.1	4.8	4.4	4.	3.7	3.4	3.2	3.	2.9	2.6	2.5	2.4	2.3	2.2	2.1	2.
80	12.8	10.	8.6	7.3	6.4	5.7	5.1	4.7	4.3	3.9	3.6	3.4	3.2	3.	2.8	2.6	2.6	2.4	2.3	2.2	2.2
85	13.6	10.7	9.2	7.7	6.8	6.	5.4	5.	4.6	4.2	3.8	3.6	3.4	3.4	3.	2.8	2.7	2.6	2.5	2.3	2.3
90	14.4	11.3	9.6	8.2	7.2	6.4	5.8	5.3	4.9	4.4	4.1	3.8	3.6	3.4	3.2	3.	2.9	2.7	2.6	2.5	2.4
95	15.2	12.2	10.2	8.7	7.6	6.8	6.1	5.5	5.1	4.7	4.4	4.1	3.8	3.6	3.4	3.2	3.	2.9	2.8	2.7	2.5
100	16.	12.8	10.7	9.2	8.	7.1	6.4	5.8	5.4	4.9	4.6	4.3	4.	3.8	3.6	3.4	3.2	3.1	2.9	2.8	2.7

Coverages are theoretical, assuming 100 percent utility, no loss, on a perfectly flat, smooth surface.

Source: P. E. Weaver, *Industrial Maintenance Painting*, p. 137, NACE, 1978.

EFFECT OF pH ON CORROSION OF ZINC IN AERATED AQUEOUS SOLUTIONS

Dilute HCl or NaOH at 30°C. CO_2 free



Source: *Zinc, Its Corrosion Resistance, 2nd ed.*, p. 4, International Lead Zinc Research Organization, 1983. Reprinted by permission of International Lead Zinc Research Organization.

RUST PREVENTIVES[a]

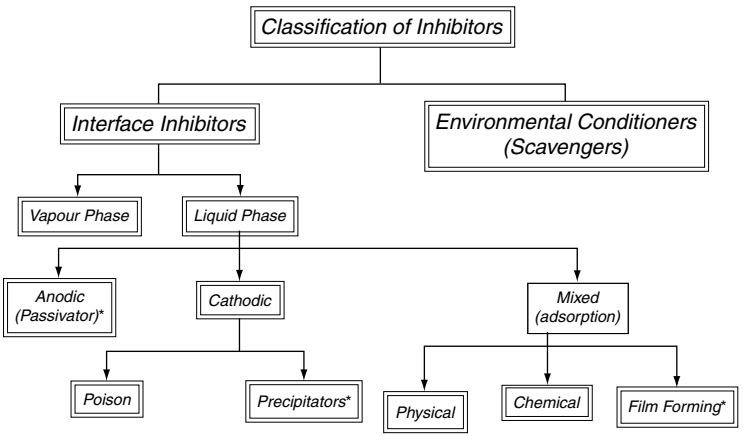
	Oil Type	Solvent Type	Emulsifiable Type	Wax Type (applied hot)
Metals Coated	Generally applied to ferrous metals; nonferrous metals sometimes with extreme care			
Coating Composition, Structure	Non-setting minerals oils of various weights and viscosities; thin oily layer, thickness depending on viscosity	Petroleum-base film-forming materials and rust inhibitors dissolved in petroleum solvents; soft to hard, depending on composition	Petroleum-base, rust preventives modified to form stable emulsions when mixed with water	Waxy layer; soft to firm, depending on composition
Application Methods	Brushing, spraying, dipping, flushing	Brushing, spraying, dipping, flushing	Brushing, spraying, dipping, flushing	Heating and then dipping, brushing or swabbing; special techniques required (for spraying)
Appearance	Transparent only film	Transparent to black	Transparent oily to tacky film	Transparent, brown, amber, or black
Thickness, mil	0.2–0.3	0.2–0.4; occasionally up to 2.0	0.2	1.5–3.0
Pretreatment	Alkaline, solvent or emulsion cleaning; scaly surfaces should be freed of all deposits by mechanical cleaning Emulsifiable coatings can often be applied directly.			
How Coatings Removed	Removal seldom required, solvent rinsing, vapor degreasing, emulsion spraying, or alkaline washing	Removal often unnecessary; solvent rinsing or alkali cleaning	Removal seldom required; solvent rinsing	Solvent rinsing or alkali cleaning

	Oil Type	Solvent Type	Emulsifiable Type	Wax Type (applied hot)
Properties				
Durability	Excellent protection for indoor storage	Excellent indoor protection from 4 months to 2 years; in some cases. can also be used outdoors	Excellent indoor protection for 1–2 years	Good protection indoors (up to 3 years) and outdoors (1–2 years)
Adhesion	Good[b]	Good[b]	Good[b]	Good[b]
Abrasion Resistance	Fair	Fair	Fair	Good
Impact Resistance	Very good	Very good	Very good	Very good
Heat Resistance		Up to 120–140°F (50–60°C) (all types)		
Typical Uses	Internal combustion engines, gear cases, hydraulic systems, highly finished auto parts, galvanized products, steel sheet, bar, wire	External surfaces of machinery and tools; highly finished surfaces; steel sheet, bar and wire		Any highly finished part stored for prolonged periods of time, e.g., ball bearings
Relative Cost per ft^2	1.0	4.	2.	5.-30.

[a] Rust preventives are essentially petroleum-type coatings designed to provide low cost corrosion protection during manufacture, shipment, and storage.
[b] Soft types can be wiped off, but hard types have relatively good adhesion. Degree of adhesion is also influenced by porosity of base metal.

Source: *Materials in Design Engineering*, p. 403, 1964.

CLASSIFICATION OF INHIBITORS



*Form three-dimensional layers at the interface, so they are classified collectively as interphase inhibitors.

Source: R. W. Revie, ed., *Uhlig's Corrosion Handbook*, 2nd ed., p. 1090, John Wiley & Sons, Inc., © 2000. This material is used by permission of John Wiley & Sons, Inc.

ANCHORING (FUNCTIONAL) GROUPS IN ORGANIC INHIBITORS

Structure	Name	Structure	Name
–OH	hydroxy	$–CONH_2$	Amide
–C≡C–	-yne	–SH	Thiol
–C–O–C–	epoxy	–S–	Sulfide
–COOH	carboxy	–S=O	Sulfoxide
–C–N–C–	amine	–C=S–	Thio
$–NH_2$	amino	–P=O	Phosphonium
–NH	imino	–P–	Phospho
$–NO_2$	nitro	–As–	Arsano
–N=N–N–	triazole	–Se–	Seleno

Source: R. W. Revie, ed., *Uhlig's Corrosion Handbook*, 2nd ed., p. 1097, John Wiley & Sons Inc., © 2000. This material is used by permission of John Wiley & Sons, Inc.

PRESSURE LOSS IN HOSE (psi)

Inside Diameter (In.)	Length (ft)	Free Air (cfm)	Line Pressure (psig) 60	80	100	120	150	200	300
3/4	50	60	3.1	2.4	2.0				
		80	5.3	4.2	3.5	2.9	2.4	1.8	1.2
		100	8.1	6.4	5.2	4.5	3.6	2.8	1.9
		120		9.0	7.4	6.3	5.1	3.9	2.7
		140		12.0	9.9	8.4	6.9	5.3	3.6
		160			12.7	10.8	8.9	6.8	4.6
		180				13.6	11.1	8.5	5.8
		200				16.6	13.5	10.4	7.1
		220					16.2	12.4	8.4
1	50	120	2.7	2.1					
		150	4.1	3.2	2.7	2.3			
		180	5.8	4.6	3.8	3.2	2.6	2.0	1.3
		210	7.7	6.1	4.0	4.3	3.5	2.7	1.8
		240		7.9	6.5	5.5	4.5	3.4	2.3
		270		9.8	8.1	6.9	5.6	4.3	2.9
		300		12.0	9.9	8.4	6.9	5.3	3.6
		330			11.8	10.0	8.2	6.3	4.3
		360			13.9	11.9	9.7	7.4	5.0
		390				13.8	11.3	8.7	5.9
		420				15.9	13.0	10.0	6.8
		450					14.8	11.4	7.7
1–1/4	50	200	2.4						
		250	3.7	2.9	2.4	2.0			
		300	5.2	4.1	3.4	2.9	2.3	1.8	1.2
		350	7.0	5.5	4.5	3.8	3.1	2.4	1.6
		400	8.9	7.0	5.8	4.9	4.0	3.1	2.1
		450		8.8	7.3	6.2	5.0	3.9	2.6
		500		10.8	8.9	7.6	6.2	4.7	3.2
		550			10.7	9.1	7.4	5.7	3.9
		600			12.6	10.7	8.7	5.7	4.6
		650			14.6	12.4	10.2	7.8	5.3
		700				14.3	11.7	9.0	6.1
		750					13.3	10.2	6.9
		800					15.0	11.5	7.8
1–1/2	50	300	2.1						
		400	3.7	2.9	2.4	2.0			
		500	5.6	4.4	3.7	3.1	2.5	1.9	1.3
		600	8.0	6.3	5.2	4.4	3.6	2.8	1.9
		700		8.5	7.0	5.9	4.9	3.7	2.5
		800		10.9	9.0	7.7	6.3	4.8	3.2
		900			11.2	9.5	7.8	6.0	4.1
		1000			13.6	11.6	9.5	7.3	4.9
		1100				14.0	11.4	8.8	6.0
		1200					13.6	10.4	7.1
		1300					15.8	12.1	8.3

(*Continued*)

PRESSURE LOSS IN HOSE (psi) (*Continued*)

Inside Diameter (In.)	Length (ft)	Free Air (cfm)	Line Pressure (psig)						
			60	80	100	120	150	200	300
2	50	600	1.9						
		800	3.2	2.5	2.1				
		1000	5.0	3.9	3.2	2.7	2.2	1.7	1.1
		1200	7.0	5.5	4.5	3.8	3.1	2.4	1.6
		1400	9.3	7.4	6.1	5.2	4.2	3.2	2.2
		1600		9.6	7.9	6.7	5.5	4.2	2.8
		1800		12.1	9.9	8.4	6.9	5.3	3.6
		2000			12.2	10.4	8.5	6.5	4.4
		2200			14.6	12.5	10.2	7.8	5.3
		2400				14.7	12.0	9.2	6.3
		2600					14.1	10.8	7.3
		2800					16.2	12.4	8.5
2–1/2	50	1000	1.7						
		1500	3.7	2.9	2.4	2.0			
		2000	6.5	5.1	4.2	3.6	2.9	2.2	1.5
		2500	10.0	7.9	6.5	5.5	4.5	3.4	2.3
		3000		11.2	9.3	7.9	6.4	4.9	3.3
		3500			12.4	10.6	8.7	6.6	4.5
		4000				13.7	11.2	8.6	5.8
		4500					14.0	10.7	7.3
3	50	2000	2.5	2.0					
		2500	3.9	3.0	2.5	2.1			
		3000	5.5	4.4	3.6	3.1	2.5	1.9	1.3
		3500	7.5	5.9	4.9	4.1	3.4	2.6	1.7
		4000	9.8	7.6	6.3	5.3	4.4	3.3	2.3
		4500		9.6	7.9	6.7	5.5	4.2	2.8
		5000		11.7	9.6	8.2	6.7	5.1	3.5
		5500			11.5	9.8	8.0	6.1	4.2
		6000			13.6	11.5	9.4	7.2	4.9
		6500				13.5	11.0	8.4	5.7
		7000				15.6	12.7	9.8	6.6
		7500					14.5	11.1	7.6
4	25	5000	1.9						
		6000	2.7	2.1	1.7				
		7000	3.6	2.8	2.3	2.0		1.2	
		8000	4.7	3.7	3.0	2.6	2.1	1.6	
		9000	5.9	4.6	3.8	3.2	2.6	2.0	
		10000	7.2	5.7	4.7	4.0	3.2	2.5	
		11000	8.7	6.8	5.6	4.8	3.9	3.0	
		12000		8.1	6.7	5.7	4.6	3.5	
		13000		9.4	7.8	6.6	5.4	4.1	
		14000			9.0	7.6	6.2	4.8	
		15000				8.7	7.1	5.4	
		16000				9.8	8.0	6.2	
		17000					9.1	6.9	

Note: Lubrication only at tool, no line lubricator.

Source: *Journal of Protective Coatings & Linings*, Vol. 2, No. 7, p. 28, 1985. Reprinted by permission of Technology Publishing.

APPROXIMATE SQUARE FEET PER LINEAR FOOT AND PER TON FOR DIFFERENT STEEL MEMBERS

Size	Wt.	Sq. Ft./ Lin. Ft.	Sq. Ft. Per Ton	Size	Wt.	Sq. Ft./ Lin. Ft.	Sq. Ft. Per Ton
24 WF	160	8.9	110	14 WF	426	8.5	4.0
(24 × 14)	145	8.8	121	(14 × 16)	398	8.5	43
	130	8.7	135		370	8.5	46
					342	8.5	50
24 WF	120	8.1	133		314	8.5	54
(24 × 12)	110	8.0	144				
	100	8.0	160		287	8.0	56
					264	8.0	61
24 WF	94	7.1	149		246	8.0	65
(24 × 9)	84	7.0	167		237	8.0	68
	76	7.0	184		228	8.0	70
21 WF	142	7.9	111		219	7.9	72
(21 × 13)	127	7.9	124		211	7.9	75
	112	7.8	139		202	7.9	78
					193	7.9	82
21 WF	95	6.5	135		184	7.9	86
(21 × 9)	82	6.5	159				
					176	7.7	87
21 WF	73	6.3	173		167	7.7	92
(21 × 8 1/4)	68	6.3	185		158	7.7	97
	62	6.2	200		150	7.7	103
					142	7.7	108
18 WF	114	7.0	123				
(18 × 11 3/4)	105	7.0	133	14 WF	136	7.3	107
	96	7.0	146	(14 × 14 1/2)	127	7.3	115
					119	7.3	123
18 WF	85	6.0	141		111	7.3	132
(18 × 8 3/4)	77	6.0	156		103	7.3	142
	70	5.9	169		95	7.3	154
	64	5.9	184		87	7.3	168
18 WF	60	5.5	183	14 WF	84	6.4	152
(18 × 7 1/2)	55	5.5	200	(14 × 12)	78	6.3	162
	50	5.5	220				
				14 WF	74	5.7	154
16 WF	96	6.6	137	(14 × 10)	68	5.7	168
(16 × 11 1/2)	88	6.5	148		61	5.7	187
16 WF	78	5.6	144	14 WF	53	5.0	189
(16 × 8 1/2)	71	5.5	155	(14 × 8)	48	5.0	208
	64	5.5	172		43	4.9	228
	58	5.5	190				
16 WF	50	5.1	204	14 WF	38	4.6	242
(16 × 7)	45	5.0	222	(14 × 6 3/4)	34	4.6	271
	40	5.0	250		30	4.6	307
	36	5.0	278				

(*Continued*)

APPROXIMATE SQUARE FEET PER LINEAR FOOT AND PER TON FOR DIFFERENT STEEL MEMBERS (*Continued*)

Size	Wt.	Sq. Ft./ Lin. Ft.	Sq. Ft. Per Ton
12 WF	190	6.6	69
(12 × 12)	161	6.5	81
	133	6.4	96
	120	6.3	105
	106	6.2	117
	99	6.2	125
	92	6.2	135
	85	6.1	144
	79	6.1	154
	72	6.1	169
	65	6.0	185
12 WF	58	5.4	186
(12 × 10)	53	5.3	200
12 WF	50	4.7	188
(12 × 8)	45	4.7	209
	40	4.7	235
12 WF	36	4.2	233
(12 × 6 1/2)	31	4.2	271
	27	4.2	311
10 WF	112	5.4	96
(10 × 10)	100	5.3	106
	89	5.2	117
	77	5.2	135
	72	5.1	142
	66	5.1	155
	60	5.1	170
	54	5.0	185
	49	5.0	204
10 WF	45	4.4	196
(10 × 8)	39	4.3	221
	33	4.3	261
10 WF	29	3.6	248
(10 × 5 3/4)	25	3.6	288
	21	3.6	343
8 WF	67	4.3	128
(8 × 8)	58	4.2	145
	48	4.1	171
	40	4.1	205
	35	4.0	229
	31	4.0	258
8 WF	28	3.5	250
(8 × 6 1/2)	24	3.5	292
8 WF	20	3.1	310
(8 × 5 1/4)	17	3.1	365
6 WF	25	3.1	248
(6 × 6)	20	3.0	300
	15.5	3.0	387
5 WF	18.5	2.5	270
(5 × 5)	16	2.5	313
4 WF	13	2	308
	I-BEAMS		
24 I	120	6.7	112
	106	6.6	125
	100	6.4	128
	90	6.4	142
	79.9	6.3	158
20 I	95	5.7	120
	85	5.7	134
	75	5.5	147
	65.4	5.4	165
18 I	70	5.1	148
	54.7	5.0	183
15 I	50	4.4	176
	42.9	4.3	200
12 I	50	3.8	152
	40.8	3.8	186
	35	3.7	211
	31.8	3.7	233
10 I	35	3.3	189
	25.4	3.2	252
8 I	23	2.7	322
	18.4	2.7	402

(*Continued*)

APPROXIMATE SQUARE FEET PER LINEAR FOOT AND PER TON FOR DIFFERENT STEEL MEMBERS (*Continued*)

Size	Wt.	Sq. Ft./ Lin. Ft.	Sq. Ft. Per Ton
	I-BEAMS (Cont.)		
71	20	2.5	250
	15.3	2.4	314
61	17.25	2.2	255
	12.5	2.1	336
51	14.75	1.9	258
	10	1.8	360
41	9.5	1.6	337
	7.7	1.6	416
31	7.5	1.3	347
	5.7	1.3	456
	CHANNELS		
18	58	4.4	152
	51.9	4.4	172
	45.8	4.3	188
	42.7	4.3	201
15	50	3.7	148
	40	3.7	185
	33.9	3.6	212
13	50	3.6	144
	31.8	3.5	220
12	30	3.1	207
	25	3.0	240
	20.7	3.0	290
10	30	2.7	180
	25	2.6	208
	20	2.6	260
	15.3	2.5	327
9	20	2.4	240
	15	2.3	307
	13.4	2.3	343
8	18.75	2.2	235
	13.75	2.1	305
	11.5	2.1	365
7	14.75	1.9	258
	12.25	1.9	310
	9.8	1.9	388
6	13.0	1.7	262
	10.5	1.7	324
	8.2	1.6	390
5	9.0	1.5	333
	6.7	1.4	418
4	7.25	1.2	331
	5.4	1.2	444
3	6.0	1.0	333
	5.0	1.0	400
	4.1	1.0	488

(*Continued*)

APPROXIMATE SQUARE FEET PER LINEAR FOOT AND PER TON FOR DIFFERENT STEEL MEMBERS (*Continued*)

Size	Wt.	Sq. Ft./ Lin. Ft.	Sq. Ft. Per Ton
ANGLES EQUAL LEG			
8 × 8 × 1/2	26.4	2.7	205
6 × 6 × 5/16	12.5	2.0	320
5 × 5 × 5/16	10.3	1.7	330
4 × 4 × 1/4	6.6	1.3	394
3 1/2 × 3 1/2 × 1/4	5.8	1.2	414
3 × 3 × 3/16	3.71	1.0	539
2 1/2 × 2 1/4 × 3/16	3.07	0.8	521
2 × 2 × 1/8	1.65	0.7	848
1 1/4 × 1 1/4 × 1/8	1.23	0.5	813
1 × 1 × 1/8	0.80	0.3	750
FLAT 1-Surface Only 1 Foot Wide*			
Wt. Lbs./Sq. Ft.			
1/16″	2.55	1.0	784
1/8″	5.10	1.0	392
3/16″	7.65	1.0	261
1/4″	10.20	1.0	196
3/8″	15.30	1.0	131
1/2″	20.40	1.0	98
5/8″	25.50	1.0	78
3/4″	30.60	1.0	65
7/8″	35.70	1.0	56
1″	40.80	1.0	49

Size	Wt.	Sq. Ft./ Lin. Ft.	Sq. Ft. Per Ton
ANGLES UNEQUAL LEG			
8 × 6 × 1/2	23.0	2.3	200
8 × 4 × 1/2	19.6	2.0	204
7 × 4 × 3/8	13.6	1.8	265
6 × 4 × 5/16	10.3	1.7	330
6 × 3 1/2 × 5/16	9.8	1.6	327
5 × 3 1/2 × 5/16	8.7	1.4	322
5 × 3 × 1/4	6.6	1.3	394
4 × 3 1/2 × 1/4	6.2	1.25	403
4 × 3 × 1/4	5.8	1.17	403
3 1/2 × 3 1/4	5.4	1.08	400
3 × 2 1/2 × 1/4	4.5	0.92	409
3 × 2 × 3/16	3.07	0.83	541
2 1/2 × 2 × 3/16	2.75	0.75	545
2 1/2 × 1 1/2 × 3/16	2.44	0.67	549
2 × 1 1/2 × 1/8	1.44	0.58	806
1 1/2 × 1 11/4 × 3/16	1.67	0.31	371
1 × 3/4 × 1/8	0.70	0.15	429
1 × 5/8 × 1/8	0.64	0.14	438

*If 2 surfaces (top and bottom) are desired, multiply figures in the 2 columns at right above by 2. This is for flat material only, such as plates.

Source: P. E. Weaver, *Industrial Maintenance Painting*, pp. 129–132, NACE, 1978.

SURFACE AREA PER TON OF STEEL FOR VARIOUS TYPES OF CONSTRUCTION

	Sq Ft Per Ton
Light construction	300 to 500
Medium construction	150 to 300
Heavy construction	100 to 150
Extra heavy construction	50 to 100

Note: The average in industrial plants is around 200 to 250 sq ft per ton.

SCHEDULE 40 STEEL PIPE EXTERIOR SURFACE AREA SQ FT/TON

Nominal Size Inch	Sq Ft/Ton	Nominal Size Inch	Sq Ft/Ton
1	410	8	158
1 1/2	365	10	139
2	341	12	125
2 1/2	260	14	116
3	242	16	101
3 1/2	230	18	90
4	218	20	85
5	199	24	73
6	183		

For weight of pipe not shown use following equation:

$$W = K(D^2 - d^2)$$

where W = weight in lb/1 ft; D = outside diameter; d = inside diameter; K = 2.67 for steel pipe; K = 2.45 for cast iron pipe; K = 2.82 for brass pipe.

Source: P. E. Weaver, *Industrial Maintenance Painting*, p. 133, NACE, 1978.

SQUARE FEET OF AREA AND GALLON CAPACITY PER FOOT OF DEPTH IN CYLINDRICAL TANKS

Diameter ft.	Circumference ft.	Cross Section Area ft.^{2}	Gallons per ft. of Depth
5.0	15.708	19.635	146.88
5.5	17.279	23.758	177.72
6.0	18.850	28.274	211.51
6.5	20.420	33.183	248.23
7.0	21.991	38.485	287.88
7.5	23.562	44.179	330.48
8.0	25.133	50.265	376.01
8.5	26.704	56.745	424.48
9.0	28.274	63.617	475.89
9.5	29.845	70.882	530.24
10.0	31.416	78.540	587.52
10.5	32.987	86.590	647.74
11.0	34.558	95.033	710.90
11.5	36.128	103.87	776.99
12.0	37.699	113.10	846.03
12.5	39.270	122.72	918.00
13.0	40.841	132.73	992.91
13.5	42.412	143.14	1070.8
14.0	43.982	153.94	1151.5
14.5	45.553	165.13	1235.3
15.0	47.124	176.71	1321.9
15.5	48.695	188.69	1411.5
16.0	50.265	201.06	1504.1
16.5	51.836	213.82	1599.5
17.0	53.407	226.98	1697.9
17.5	54.978	240.53	1799.3
18.0	56.549	254.47	1903.6
18.5	58.119	268.80	2010.8
19.0	59.690	283.53	2120.9
19.5	61.261	298.65	2234.0
20.0	62.832	314.16	2350.1
20.5	64.403	330.06	2469.1
21.0	65.973	346.46	2591.0
21.5	67.544	363.05	2715.8
22.0	69.115	380.13	2843.6
22.5	70.686	397.61	2974.3
23.0	72.257	415.48	3108.0
23.5	73.827	433.74	3244.6
24.0	75.398	452.39	3384.1
24.5	76.969	471.44	3526.6
25.0	78.540	490.87	3672.0
25.5	80.111	510.71	3820.3
26.0	81.681	530.93	3971.6
26.5	83.252	551.55	4125.9
27.0	84.823	572.56	4283.0
27.5	86.394	593.96	4443.1
28.0	87.965	615.75	4606.2
28.5	89.535	637.94	4772.1
29.0	91.106	660.52	4941.0
29.5	92.677	683.49	5112.9
30.0	94.248	706.86	5287.7
30.5	95.819	730.62	5465.4

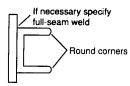
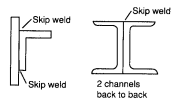
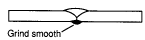
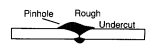
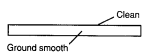
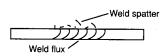
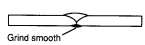
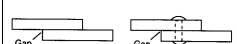
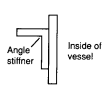
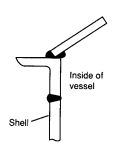
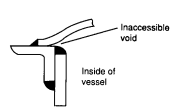
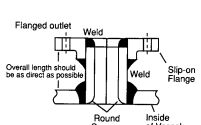
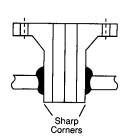
Total area = circumference $\times$ length + area of two ends. (Use area of one end for open top tanks).

PROPERTIES OF FLAMMABLE LIQUIDS USED IN PAINTS AND LACQUERS

Name	Flash Point °F		Flash Point °C		Explosive Limits % by Volume in Air		Vapor Density (Air = 1.00)	Point Boiling	
	Closed Cup	Open Cup	Closed Cup	Open Cup	Lower	Upper		°F	°C
Acetone	0	15	−18	−9	2.15	13.0	2.00	134	56
n-Amyl Acetate	76	80	24	27	1.10	–	4.49	300	149
n-Amyl Alcohol	91	120	32	49	1.20	–	3.04	280	138
Benzene	12	–	−11	–	1.40	8.0	2.77	176	80
n-Butyl Acetate	72	90	22	32	1.70	15.0	4.00	260	127
n-Butyl Alcohol	84	110	29	43	1.70	–	2.55	243	117
Cellosolve	104	120	40	49	2.60	15.7	3.10	275	135
Cellosolve Acetate	124	125	51	52	1.71	–	4.72	313	156
Cyclohexanone	147	–	64	–	–	–	3.38	313	156
Ethyl Acetate	24	30	−5	−1	2.18	11.5	3.04	171	77
Ethyl Alcohol	55	–	13	–	3.23	19.0	1.59	173	78
Fuel Oil No. 1	100−165	–	38−74	–	–	–	–	–	–
Gasoline	−50	–	−45	–	1.30	6.0	3−4	100−400	38−204
n-Hexane	−7	–	−21	–	1.25	6.9	2.97	156	69
Kerosene	100−165	–	38−74	–	–	–	–	–	–
Methyl Alcohol	54	60	12	16	6.00	36.5	1.11	147	64
Methyl n-Butyl Ketone	–	95	–	35	1.22	8.0	3.45	262	128
Methyl Isobutyl Ketone	73	–	23	–	1.34	8.0	3.45	244	117
Methyl Ethyl Ketone	30	–	−1	–	1.81	11.5	2.41	176	80
Methyl n-Propyl Ketone	–	60	–	16	1.55	8.1	2.96	216	102
Mineral Spirits	100−110	–	38−43	–	1.10	6.0	–	300−400	150−200
Naphtha Coal Tar	100−110	–	38−43	–	–	–	–	300−400	150−200
Naphtha, Safety Solvent	100−110	–	38−43	–	1.10	6.0	–	300−400	150−200
Naphtha, V.M. & P.	20−45	–	−7.7	–	1.20	6.0	–	212−320	100−160
n-Propyl Alcohol	59	85	15	29	2.50	–	2.07	207	97
Isopropyl Alcohol	53	60	11	16	2.50	–	2.07	181	83
Stoddard Solvent	100−110	–	38−43	–	1.10	6.0	–	300−400	150−200
Toluene	40	45	4	7	1.27	7.0	3.14	232	111
Turpentine	95	–	35	–	0.80	–	–	300	150
o-Xylene	63	75	17	24	1.00	–	3.66	291	143

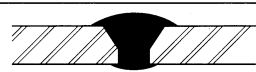
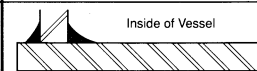
Source: P. E. Weaver, *Industrial Maintenance Painting*, p. 118, NACE, 1978.

DO'S AND DON'TS FOR STEEL CONSTRUCTION TO BE COATED

	DO	DON'T
Construction involving pockets or crevices that will not drain or cannot be cleaned and coated properly, should be avoided.		
All joints should be continuously and solidly welded.		
All weld spatter should be removed.		
Butt welding should be used rather than lap welding or riveted construction.		
Stiffening members should be on outside surface of vessel or tank.		
Eliminate crevice and lap weld at roof to shell interface in non-pressure vessel.		
The outlets should be flanged or pad type rather than threaded. Within pressure limitations, slip-on flanges are preferred as the inside surface of the attaching weld is readily available for radiusing and grinding.		

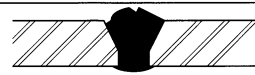
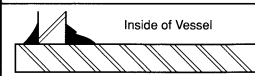
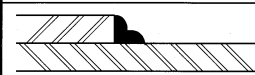
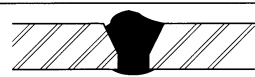
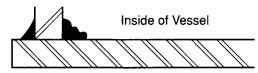
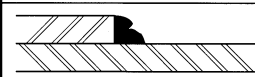
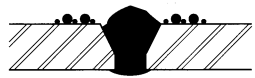
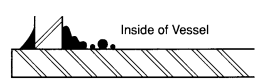
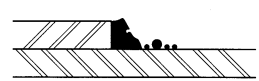
Source: NACE Standard RP0178. P. E. Weaver, *Industrial Maintenance Painting*, p. 2, NACE, 1973.

SURFACE FINISHING OF WELDS IN PREPARATION FOR LINING

NACE Weld Preparation Designation	Type of Grinding	Butt Weld	Fillet Welded Tee Joint	Lap Weld
A	Ground flush and smooth: free of all defects.	Weld spatter removed and all surface imperfections repaired as necessary. The weld is ground flush with the plate surface.	Not Applicable	Not Applicable
			Not Applicable	Not Applicable
B	Ground flush	Minor imperfections such as porosity and undercutting exist. The weld is ground flush with the plate surface.	Not Applicable	Not Applicable
			Not Applicable	Not Applicable
C	Ground smooth; free of all defects.	Weld spatter removed and all surface imperfections repaired as necessary. The weld is ground smooth and blended into the plate surface.	Weld spatter removed and all surface imperfections repaired as necessary. The weld is ground smooth and blended into the plate surfaces.	Full fillet weld between the two plates. Weld spatter removed and all surface imperfections repaired as necessary. The weld is ground smooth and blended into the plate surfaces.
				

(*Continued*)

SURFACE FINISHING OF WELDS IN PREPARATION FOR LINING (*Continued*)

NACE Weld Preparation Designation	Type of Grinding	Butt Weld	Fillet Welded Tee Joint	Lap Weld
D	Ground smooth and blended.	Minor imperfections such as porosity and undercutting exist. Weld spatter is removed, welds are ground smooth and blended into the plate surfaces.	Minor imperfections such as porosity and undercutting exist. Weld spatter is removed, welds are ground smooth and blended into the plate surfaces.	Minor imperfections such as porosity and undercutting exist. Weld spatter is removed, welds are ground smooth and blended into the plate surfaces.
				
E	Minimal.	Sharp projections on the weld bead, slag and weld spatter are removed.	Sharp projections on the weld bead, slag and weld spatter are removed.	Sharp projections on the weld bead, slag, and weld spatter are removed.
				
Weld Condition Prior to Finishing				

Source: NACE Standard RP0178.

ACRONYMS FOR STANDARDS ORGANIZATIONS

ABNT	Associaçao Brasileira de Normas Técnicas
ACCSQ	ASEAN Consultative Committee for Standards and Quality
AENOR	Asociación Española de Normalización y Certificación
AFNOR	Association Française de normalisation
AIDMO	Arab Industrial Development and Mining Organization
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
AWWA	American Water Works Association
BASMP	Institute for Standardization, Metrology, and Patents of Bosnia and Herzegovina
BIPM	Bureau international des poids et mesures
BIS	Bureau of Indian Standards
BISFA	International Bureau for the Standardization of Man-made Fibres
BPS	Bureau of Product Standards
BSI	British Standards Institution
BSN	Badan Standardisasi Nasional
CAC	Codex Alimentarius Commission
CCSDS	Consultative Committee for Space Data Systems
CEB	Comité Electrotechnique Belge
CEI	Comitato Elettrotecnico Italiano
CEN	Comité Européen de Normalisation
CENELEC	Comité Européen de Normalisation Electrotechnique
CES	Swiss Electrotechnical Committee
CIB	International Council for Research and Innovation in Building and Construction
CIE	International Commission on Illumination
CIMAC	International Council on Combustion Engines
COPANT	Pan American Standards Commission

CSBTS	China State Bureau of Quality and Technical Supervision
CSNI	Czech Standards Institute
CSSN	China Standards Information Center
DGN	Dirección General de Normas
DGSM	Directorate General for Specifications and Measurements
DIN	Deutsches Institut für Normung
DKE	Deutsches Komitee der IEC
DS	Dansk Standard
DSM	Department of Standards Malaysia
DZNM	State Office for Standardization and Metrology
ELOT	Hellenic Organization for Standardization
EOS	Egyptian Organization for Standardization and Quality Control
ETSI	European Telecommunications Standards Institute
FDI	World Dental Federation
FID	International Federation for Information and Documentation
FONDONORMA	Fondo para la Normalización y Certificación de la Calidad
GOST-R	State Committee of the Russian Federation for Standardization, Metrology, and Certification
IAEA	International Atomic Energy Agency
IAF	International Accreditation Forum, Inc
IATA	International Air Transport Association
IBN	The Belgian Institution for Standardization
ICAO	International Civil Aviation Organization
ICC	International Association for Cereal Science and Technology
ICID	International Commission on Irrigation and Drainage
ICONTEC	Instituto Colombiano de Normas Técnicas y Certificación
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
IDF	International Dairy Federation
IDHKSAR	Industry Department
IEC	International Electrotechnical Commission
IETF	Internet Engineering Task Force
IFAN	International Federation of Standards Users
IFLA	International Federation of Library Associations and Institutions

IFOAM	International Federation of Organic Agriculture Movements
IGU	International Gas Union
IIR	International Institute of Refrigeration
ILAC	International Laboratory Accreditation Cooperation
ILO	International Labour Office
IMO	International Maritime Organization
INDECOPI	Instituto Nacional de Defensa de la Competenciay de la Protección de la Propiedad Intelectual
INEN	Instituto Ecuatoriano de Normalización
INN	Instituto Nacional de Normalización
INTECO	Instituto de Normas Técnicas de Costa Rica
IPQ	Instituto Português da Qualidade
IRAM	Instituto Argentino de Normalización
ISO	International Organization for Standardization
ISTA	International Seed Testing Association
ITU	International Telecommunication Union
IUPAC	International Union of Pure and Applied Chemistry
IWTO	International Wool Textile Organization
JISC	Japan Industrial Standards Committee
KATS	Korean Agency for Technology and Standards
KEBS	Kenya Bureau of Standards
LST	Lithuanian Standards Board
MOLDST	Department of Standards, Metrology, and Technical Supervision
MSZT	Magyar Szabványügyi Testület
NEK	Norsk Electroteknisk Komite
NIST	National Institute of Standards and Technology
NNI	Nederlands Normalisatie-Instituut
NSAI	National Standards Authority of Ireland
NSF	Norges Standardiseringsforbund
OIE	International Office of Epizootics
OIML	International Organization of Legal Metrology
OIV	International Vine and Wine Office
ON	Austrian Standards Institute
OVE	Austrian Electrotechnical Committee
PASC	Pacific Area Standards Congress
PSB	Singapore Productivity and Standards Board
RILEM	International Union of Testing and Research Laboratories for Materials and Structures
SABS	South African Bureau of Standards
SAE	Society of Automotive Engineers
SAI	Standards Australia International Ltd.

SASO	Saudi Arabian Standards Organization
SCC	Standards Council of Canada
SEE	Service de l'Energie de l'Etat, Département Normalisation
SEK	Svenska Elektriska Kommissionen
SESKO	Finnish Electrotechnical Standards Association
SFS	Finnish Standards Association
SII	Standards Institution of Israel
SIS	Standardiseringen i Sverige
SLSI	Sri Lanka Standards Institution
SMIS	Standards and Metrology Institute
SNIMA	Service de normalisation industrielle marocaine
SNV	Swiss Association for Standardization
SNZ	Standards New Zealand
SSPC	Steel Structures Painting Council
SSUAE	Directorate of Standardization and Metrology
STRI	Icelandic Council for Standardization
TCVN	Directorate for Standards and Quality
TISI	Thai Industrial Standards Institute
TraFIX	Trade Facilitation Information Exchange
TSE	Türk Standardlari Enstitüsü
TTBS	Trinidad and Tobago Bureau of Standards
UIC	International Union of Railways
UN/CEFACT	Centre for the Facilitation of Procedures and Practices for Administration, Commerce and Transport
UN/ECE	UN Economic Commission for Europe
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNI	Ente Nazionale Italiano di Unificazione
UNIT	Instituto Uruguayo de Normas Técnicas
UNMS	Slovak Office of Standards, Metrology and Testing
UTE	Union Technique de l'Electricité
WCO	World Customs Organization
WHO	World Health Organisation
WIPO	World Intellectual Property Organisation
WMO	World Meteorological Organization
WTO	World Trade Organization

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ISO STANDARDS

ISO 3160-2:1992. Watch cases and accessories—Gold alloy coverings—Part 2: Determination of fineness, thickness, corrosion resistance, and adhesion

ISO 3506-1:1997. Mechanical properties of corrosion-resistant stainless-steel fasteners—Part 1: Bolts, screws, and studs

ISO 3506-2:1997. Mechanical properties of corrosion-resistant stainless-steel fasteners—Part 2: Nuts

ISO 3506-3:1997. Mechanical properties of corrosion-resistant stainless-steel fasteners—Part 3: Set screws and similar fasteners not under tensile stress

ISO 3651-1:1998. Determination of resistance to intergranular corrosion of stainless steels—Part 1: Austenitic and ferritic-austenitic (duplex) stainless steels—Corrosion test in nitric acid medium by measurement of loss in mass (Huey test)

ISO 3651-2:1998. Determination of resistance to intergranular corrosion of stainless steels—Part 2: Ferritic, austenitic and ferritic-austenitic (duplex) stainless steels—Corrosion test in media containing sulfuric acid

ISO 4404:1998. Petroleum and related products—Determination of the corrosion resistance of water-containing fire-resistant fluids for hydraulic systems

ISO 4536:1985. Metallic and non-organic coatings on metallic substrates—Saline droplets corrosion test (SD test)

ISO 4538:1978. Metallic coatings—Thioacetamide corrosion test (TAA test)

ISO 4539:1980. Electrodeposited chromium coatings—Electrolytic corrosion testing (EC test)

ISO 4541:1978. Metallic and other non-organic coatings—Corrodkote corrosion test (CORR test)

ISO 4543:1981. Metallic and other non-organic coatings—General rules for corrosion tests applicable for storage conditions

ISO 4623:1984. Paints and varnishes—Filiform corrosion test on steel

ISO 4623-1:2000. Paints and varnishes—Determination of resistance to filiform corrosion—Part 1: Steel substrates

ISO 4952:1981. Structural steels with improved atmospheric corrosion resistance

ISO 5952:1998. Continuously hot-rolled steel sheet of structural quality with improved atmospheric corrosion resistance (available in English only)

ISO 6315:1980. Road vehicles—Brake linings—Seizure to ferrous mating surface due to corrosion—Test procedure

ISO 6509:1981. Corrosion of metals and alloys—Determination of dezincification resistance of brass

ISO 6743-8:1987. Lubricants, industrial oils, and related products (class L)—Classification—Part 8: Family R (Temporary protection against corrosion)

ISO 6957:1988. Copper alloys—Ammonia test for stress corrosion resistance

ISO 7384:1986. Corrosion tests in artificial atmosphere—General requirements

ISO 7441:1984. Corrosion of metals and alloys—Determination of bimetallic corrosion in outdoor exposure corrosion tests

ISO 7539-1:1987. Corrosion of metals and alloys—Stress corrosion testing—Part 1: General guidance on testing procedures

ISO 7539-2:1989. Corrosion of metals and alloys—Stress corrosion testing—Part 2: Preparation and use of bent-beam specimens

ISO 7539-3:1989. Corrosion of metals and alloys—Stress corrosion testing—Part 3: Preparation and use of U-bend specimens

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NACE STANDARDS

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RPO197. Standard Format for Computerized Electrochemical Polarization Curve Data Files
RPO198. The Control of Corrosion Under Thermal Insulation and Fireproofing Materials—A Systems Approach
RPO199. Installation of Stainless Chromium—Nickel Alloy Roll-Bonded and Explosion-Bonded Clad Plate in Air Pollution Control Equipment
RPO294. Design, Fabrication, and Inspection of Tanks for the Storage of Concentrated Sulfuric Acid and Oleum at Ambient Temperatures
RPO300. Pilot Scale Evaluation of Corrosion and Scale Control Additives for Open Recirculating Cooling Water Systems
RPO390. Maintenance and Rehabilitation Considerations for Corrosion Control of Existing Steel-Reinforced Concrete Structures
RPO487. Considerations in the Selection and Evaluation of Rust Preventives and Vapor Corrosion Inhibitors for Interim (Temporary) Corrosion Protection
RPO497. Field Corrosion Evaluation Using Metallic Test Specimens
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TMO399. Test Method for Phosphonate in Brine
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CATHODIC PROTECTION

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RPO675. Control of Corrosion on Offshore Steel Pipelines
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RPO177. Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems
RPO180. Cathodic Protection of Pulp and Paper Mill Effluent Clarifiers
RPO285. Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems
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RPO286. The Electrical Isolation of Cathodically Protected Pipelines
RPO387. Metallurgical and Inspection Requirements for Cast Sacrificial Anodes for Offshore Applications
RPO388. Impressed Current Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks
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RPO193. External Cathodic Protection of On-Grade Metallic Storage Tank Bottoms
RPO194. Criteria and Test Methods for Cathodic Protection of Lead Sheath Cable
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TMO497. Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems

OIL PRODUCTION

MRO174. Recommendations for Selecting Inhibitors for Use as Sucker Rod Thread Lubricants
MRO175. Sulfide Stress Cracking Resistant Metallic Materials for Oil Field Equipment
MRO176. Metallic Materials for Sucker Rod Pumps for Hydrogen Sulfide Environments
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RPO181. Liquid Applied Internal Protective Linings and Coatings for Oil Field Production Equipment

RPO273. Handling and Proper Usage of Inhibited Oilfield Acids (API Bulletin D-15) (Joint API-NACE Project)

RPO278. Design and Operation of Stripping Columns for Removal of Oxygen from Water

RPO475. Selection of Metallic Materials to be Used in All Phases of Water Handling for Injection into Oil Bearing Formations

RPO775. Preparation and Installation of Corrosion Coupons and Interpretation of Test Data in Oil Production Practice

RPO191. The application of Internal Plastic Coatings for Oilfield Tubular Goods and Accessories

RPO192. Monitoring Corrosion in Oil and Gas Production with Iron Counts

RPO291. Care, Handling and Installation of Internal Plastic Coatings for Oilfield Tubular Goods and Accessories

RPO296. Guidelines for Detection, Repair and Mitigation of Cracking of Existing Petroleum Refinery Pressure Vessels in Wet H_2S Environments

RPO472. Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments

RPO475. Selection of Metallic Materials to be used in all Phases of Water Handling for Injection into Oil-Bearing Formations

RPO491. Worksheet for the Selection of Oilfield Non-Metallic Seal Systems

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TMO275. Performance Testing of Sucker Rods by the Mixed String, Alternate Rod Method

TMO284. Evaluation of Pipeline Steels for Resistance to Stepwise Cracking

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TMO197. Laboratory Screening Test to Determine the Ability of Scale Inhibitors to Prevent the Precipitation of Barium Sulfate and/or Strontium Sulfate From Solution (For Oil and Gas Production Systems)

TMO198. Slow Strain Rate Test Method for Screening Corrosion-Resistant Alloys (CRAs) for Stress Corrosion Cracking in Sour Oilfield Service

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RPO274. High Voltage Electrical Inspection of Pipeline Coatings Prior to Installation
RPO275. Application of Organic Coating to the External Surface of Steel Pipe for Underground Service
RPO276. Extruded Asphalt Mastic Type Protective Coatings for Underground Pipelines
RPO375. Application and Handling of Wax-Type Protective Coatings and Wrapper Systems for Underground Pipelines
RPO190. External Protective Coatings for Joints, Fittings and Valves on Metallic Underground or Submerged Pipelines and Piping Systems
RPO200. Steel-Cased Pipeline Practices
RPO375. Wax Coating Systems for Underground Piping Systems
RPO490. Holiday Detection of Fusion-Bonded Epoxy External Pipeline Coatings of 250–760 microns (10–30 mils)
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RPO189. On-Line Monitoring of Cooling Waters
RPO472. Methods and Controls to Prevent In-Service Cracking of Carbon Steel (P-1) Welds in Corrosive Petroleum Refining Environments
RPO292. Installation of Thin Metallic Wallpaper Lining in Air Pollution Control and Other Process Equipment
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TMO274. Dynamic Corrosion Testing of Metals in High Temperature Water

TMO286. Cooling Water Test Units Incorporating Heat Transfer Surfaces

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PROTECTIVE COATINGS

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TMO183. Evaluation of Internal Plastic Coatings for Corrosion Control

TMO184. Accelerated Test Procedures for Screening Atmospheric Surface Coating Systems for Offshore Platforms and Equipment

TMO185. Evaluation of Internal Plastic Coatings for Corrosion Control of Tubular Goods by Autoclave Testing

TMO186. Holiday Detection of Internal Tubular Coatings of 10–30 mils (0.25–0.76 mm) Dry Film Thickness

TMO384. Holiday Detection of Internal Tubular Coatings of Less Than 10 mils (0.25 mm) Dry Film Thickness

TMO192. Evaluating Elastomeric Materials in Carbon Dioxide Decompression Environments

TMO196. Chemical Resistance of Polymeric Materials by Periodic Evaluation

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RPO178. Design, Fabrication and Surface Finish of Metal Tanks and Vessels to be Lined for Chemical Immersion Service

RPO184. Repair of Lining Systems

RPO188. Discontinuity (Holiday) Testing of Protective Coatings

RPO281. Method for Conducting Coating (Paint) Panel Evaluation Testing in Atmospheric Exposure

RPO287. Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape

RPO288. Inspection of Linings on Steel and Concrete

RPO372. Method for Lining Lease Production Tanks with Coal Tar Epoxy

RPO376. Monolithic Organic Corrosion Resistant Floor Surfacings

RPO386. Applications of a Coating System to Interior Surfaces of Covered Railroad Hopper Cars in Plastic, Food and Chemical Service

RPO487. Considerations in the Selection and Evaluation of Interim Petroleum-Based Coatings

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RPO297. Maintenance Painting of Electrical Substation Apparatus Including Flow Coating of Transformer Radiators

RPO295. Application of a Coating System to Interior Surfaces of New and Used Rail Tank Cars

RPO298. Sheet Rubber Linings for Abrasion and Corrosion Service

RPO394. Application, Performance and Quality Control of Paint-Applied, Fusion-Bonded Epoxy External Pipe Coating

RPO395. Fusion-Bonded Epoxy Coating of Steel Reinforcing Bars

RPO398. Recommendations for Training and Qualifying Personnel as Railcar Coating and Lining Inspectors

RPO399. Plant Applied, External Coal Tar Enamel Pipe Coating System: Application, Performance and Quality Control

RPO495. Guidelines for Qualifying Personnel as Abrasive Blasters and Coatings and Linings Applicators in the Rail Industries

RPO591. Coatings and Concrete Surfaces in Non-Immersion and Atmospheric Service

RPO592. Application of a Coating System to Interior Surfaces of New and Used Rail Tank Cars in Concentrated (90–98%) Sulfuric Acid Service

RPO692. Application of a Coating System to Exterior Surfaces of Steel Rail Cars

ASTM–G COMMITTEE STANDARDS

GENERAL

G1-90(1999). Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
G4-95. Standard Guide for Conducting Corrosion Coupon Tests in Field Applications
G15-99b. Standard Terminology Relating to Corrosion and Corrosion Testing
G16-95(1999). Standard Guide for Applying Statistics to Analysis of Corrosion Data
G30-97. Standard Practice for Making and Using U-Bend Stress-Corrosion Test Specimens
G31-72(1999). Standard Practice for Laboratory Immersion Corrosion Testing of Metals
G32-98. Standard Test Method for Cavitation Erosion Using Vibratory Apparatus
G34-99. Standard Test Method for Exfoliation Corrosion Susceptibility in 2XXX and 7XXX Series Aluminum Alloys (EXCO Test)
G40-99. Standard Terminology Relating to Wear and Erosion
G44-99. Standard Practice for Exposure of Metals and Alloys by Alternate Immersion in Neutral 3.5% Sodium Chloride Solution
G46-94(1999). Standard Guide for Examination and Evaluation of Pitting Corrosion
G51-95(2000). Standard Test Method for Measuring pH of Soil for Use in Corrosion Testing
G52-00. Standard Practice for Exposing and Evaluating Metals and Alloys in Surface Seawater
G54-84(1996). Standard Practice for Simple Static Oxidation Testing
G57-95a. Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method
G60-95. Standard Test Method for Conducting Cyclic Humidity Tests
G71-81(1998). Standard Guide for Conducting and Evaluating Galvanic Corrosion Tests in Electrolytes
G79-83(1996). Standard Practice for Evaluation of Metals Exposed to Carburization Environments
G82-98. Standard Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance
G85-98. Standard Practice for Modified Salt Spray (Fog) Testing
G87-98. Standard Practice for Conducting Moist SO_2 Tests
G107-95. Standard Guide for Formats for Collection and Compilation of Corrosion Data for Metals for Computerized Database Input

G109-99a. Standard Test Method for Determining the Effects of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete
G111-97. Standard Guide for Corrosion Tests in High Temperature or High Pressure Environment, or Both
G117-98. Standard Guide for Calculating and Reporting Measures of Precision Using Data from Interlaboratory Wear or Erosion Tests
G131-96. Standard Practice for Cleaning of Materials and Components by Ultrasonic Techniques
G135-95. Standard Guide for Computerized Exchange of Corrosion Data for Metals
G141-96. Standard Guide for Addressing Variability in Exposure Testing on Nonmetallic Materials
G142-98. Standard Test Method for Determination of Susceptibility of Metals to Embrittlement in Hydrogen Containing Environments at High Pressure, High Temperature, or Both
G161-00. Standard Guide for Corrosion-Related Failure Analysis
G166-00. Standard Guide for Statistical Analysis of Service Life Data

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G7-97. Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials
G33-99. Standard Practice for Recording Data from Atmospheric Corrosion Tests of Metallic-Coated Steel Specimens
G50-76(1997). Standard Practice for Conducting Atmospheric Corrosion Tests on Metals
G84-89(1999). Standard Practice for Measurement of Time-of-Wetness on Surfaces Exposed to Wetting Conditions as in Atmospheric Corrosion Testing
G90-98. Standard Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight
G91-97. Standard Practice for Monitoring Atmospheric SO_2 Using the Sulfation Plate Technique
G92-86(1997). Standard Practice for Characterization of Atmospheric Test Sites
G101-97. Standard Guide for Estimating the Atmospheric Corrosion Resistance of Low-Alloy Steels
G113-94. Standard Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials
G116-99. Standard Practice for Conducting Wire-on-Bolt Test for Atmospheric Galvanic Corrosion
G118-96. Standard Guide for Recommended Data Format of Wear Test Data Suitable for Databases

G140-96. Standard Test Method for Determining Atmospheric Chloride Deposition Rate by Wet Candle Method
G147-96. Standard Practice for Conditioning and Handling of Non-Metallic Materials for Natural and Artificial Weathering Tests
G149-97. Standard Practice for Conducting the Washer Test for Atmospheric Galvanic Corrosion
G156-97. Standard Practice for Selecting and Characterizing Weathering Reference Materials Used to Monitor Consistency of Conditions in an Exposure Test

ELECTROCHEMICAL

G3-89(1999). Standard Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing
G5-94(1999). Test Method for Making Potentiostatic and Potentiodynamic Anodic Polarization Measurements
G59-97 Standard Practice for Conducting Potentiodynamic Polarization Resistance Measurements
G61-86(1998). Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements for Localized Corrosion Susceptibility of Iron-, Nickel-, or Cobalt-Based Alloys
G69-97. Standard Test Method for Measurement of Corrosion Potentials of Aluminum Alloys
G96-90(1996). Standard Guide for On-line Monitoring of Corrosion in Plant Equipment (Electrical and Electrochemical Methods)
G100-89(1999). Standard Test Method for Conducting Cyclic Galvanostaircase Polarization
G102-89(1999). Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements
G106-89(1999). Standard Practice for Verification of Algorithm and Equipment for Electrochemical Impedance Measurements
G108-94(1999). Standard Test Method for Electrochemical Reactivation (EPR) for Detecting Sensitization of AISI Type 304 and 304L Stainless Steels Exposed to Chloride Environments
G148-97. Standard Practice for Evaluation of Hydrogen Uptake, Permeation, and Transport in Metals by an Electrochemical Technique
G150-99. Standard Test Method for Electrochemical Critical Pitting Temperature Testing of Stainless Steels

METALS AND ALLOYS

G2M-88(1996). Standard Test Method for Corrosion Testing of Products of Zirconium, Hafnium, and Their Alloys in Water at 633°K or in Steam at 673°K [Metric]

G28-97. Standard Test Methods of Detecting Susceptibility to Intergranular Corrosion in Wrought, Nickel-Rich, Chromium-Bearing Alloys

G48-00. Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution

G66-99. Standard Test Method for Visual Assessment of Exfoliation Corrosion Susceptibility of 5XXX Series Aluminum Alloys (ASSET Test)

G67-99. Standard Test Method for Determining the Susceptibility to Intergranular Corrosion of 5XXX Series Aluminum Alloys by Mass Loss After Exposure to Nitric Acid (NAMLT Test)

G78-95. Standard Guide for Crevice Corrosion Testing of Iron-Base and Nickel-Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments

G110-92(1997). Standard Practice for Evaluating Intergranular Corrosion Ressistance of Heat Treatable Aluminum Alloys by Immersion in Sodium Chloride + Hydrogen Peroxide Solution

G112-92(1997). Standard Guide for Conducting Exfoliation Corrosion Tests in Aluminum Alloys

G146-96. Standard Practice for Evaluation of Disbonding of Bimetallic Stainless Alloy/Steel Plate for Use in High-Pressure, High-Temperature Refinery Hydrogen Service

G157-98. Standard Guide for Evaluating the Corrosion Properties of Wrought Iron- and Nickel-Based Corrosion Resistant Alloys for the Chemical Process Industries

PIPELINE COATINGS

G6-88(1998). Standard Test Method for Abrasion Resistance of Pipeline Coatings

G8-96. Standard Test Methods for Cathodic Disbonding of Pipeline Coatings

G9-87(1998). Standard Test Method for Water Penetration into Pipeline Coatings

G11-88(1996). Standard Test Method for Effects of Outdoor Weathering on Pipeline Coatings

G12-83(1998). Standard Test Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel

G17-88(1998). Standard Test Method for Penetration Resistance of Pipeline Coatings (Blunt Rod)

G19-88(1996). Standard Test Method for Disbonding Characteristics of Pipeline Coatings by Direct Soil Burial

G20-88(1996). Standard Test Method for Chemical Resistance of Pipeline Coatings

G42-96. Standard Test Method for Cathodic Disbonding of Pipeline Coatings Subjected to Elevated Temperatures
G62-87(1998). Standard Test Methods for Holiday Detection in Pipeline Coatings
G80-88(1998). Standard Test Method for Specific Cathodic Disbonding of Pipeline Coatings
G95-87(1998). Standard Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method)

STRESS-CORROSION CRACKING

G35-98. Standard Practice for Determining the Susceptibility of Stainless Steels and Related Nickel-Chromium-Iron Alloys to Stress-Corrosion Cracking in Polythionic Acids
G36-94(2000). Standard Practice for Evaluating Stress-Corrosion-Cracking Resistance of Metals and Alloys in a Boiling Magnesium Chloride Solution
G37-98. Standard Practice for Use of Mattsson's Solution of pH 7.2 to Evaluate the Stress-Corrosion Cracking Susceptibility of Copper-Zinc Alloys
G38-73(1995). Standard Practice for Making and Using C-Ring Stress-Corrosion Test Specimens
G39-99. Standard Practice for Preparation and Use of Bent-Beam Stress-Corrosion Test Specimens
G41-90(2000). Standard Practice for Determining Cracking Susceptibility of Metals Exposed Under Stress to a Hot Salt Environment
G47-98. Standard Test Method for Determining Susceptibility to Stress-Corrosion Cracking of 2XXX and 7XXX Aluminum Alloy Products
G49-85(2000). Standard Practice for Preparation and Use of Direct Tension Stress-Corrosion Test Specimens
G58-85(1999). Standard Practice for Preparation of Stress-Corrosion Test Specimens for Weldments
G64-99. Standard Classification of Resistance to Stress-Corrosion Cracking of Heat-Treatable Aluminum Alloys
G103-97. Standard Test Method for Performing Stress-Corrosion Cracking Resistance of Low Copper 7XXX Series Al-Zn-Mg-Cu Alloys in Boiling 6% Sodium Chloride Solution
G123-00. Standard Test Method for Evaluating Stress-Corrosion Cracking of Stainless Alloys with Different Nickel Content in Boiling Acidified Sodium Chloride Solution
G129-00. Standard Practice for Slow Strain Rate Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking

G139-96. Standard Test Method for Determining Stress-Corrosion Cracking Resistance of Heat-Treatable Aluminum Alloy Products Using Breaking Load Method
G168-00. Standard Practice for Making and Using Precracked Double Beam Stress Corrosion Specimens

SOILS

G97-97. Standard Test Method for Laboratory Evaluation of Magnesium Sacrificial Anode Test Specimens for Underground Applications
G158-98. Standard Guide for Three Methods of Assessing Buried Steel Tanks
G160-98. Standard Practice for Evaluating Microbial Susceptibility of Nonmetallic Materials by Laboratory Soil Burial
G162-99. Standard Practice for Conducting and Evaluating Laboratory Corrosions Tests in Soils
G165-99. Standard Practice for Determining Rail-to-Earth Resistance

WEAR AND ABRASION

G65-00a. Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus
G73-98. Standard Practice for Liquid Impingement Erosion Testing
G75-95. Standard Test Method for Determination of Slurry Abrasivity (Miller Number) and Slurry Abrasion Response of Materials (SAR Number)
G76-95(2000). Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets
G77-98. Standard Test Method for Ranking Resistance of Materials to Sliding Wear Using Block-on-Ring Wear Test
G83-96. Standard Test Method for Wear Testing with a Crossed-Cylinder Apparatus
G98-91(1996). Standard Test Method for Galling Resistance of Materials
G99-95a(2000). Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus
G105-89(1997). Standard Test Method for Conducting Wet Sand/Rubber Wheel Abrasion Tests
G119-93(1998). Standard Guide for Determining Synergism Between Wear and Corrosion
G134-95. Standard Test Method for Erosion of Solid Materials by a Cavitating Liquid Jet
G163-99. Standard Guide for Digital Data Acquisition in Wear and Friction Measurements

ASTM–OTHER STANDARDS

GENERAL

B117-97. Practice for Operating Salt Spray (FOG) Apparatus
B154-95. Test Method for Mercurous Nitrate Test for Copper and Copper Alloys
B368-85(1990). Method for Copper-Accelerated Acetic Acid-Salt Spray(Fog) Testing(CASS) Test
B577-93. Test Methods for Detection of Cuprous Oxide (Hydrogen Embrittlement Susceptibility) in Copper
B627-84(1992). Test Method for Electrolytic Corrosion Testing (EC Test)
B808-97. Standard Test Method for Monitoring of Atmospheric Corrosion Chambers by Quartz Crystal Microbalances
B810-00. Standard Test Method for Calibration of Atmospheric Corrosion Test Chambers by Change in Mass of Copper Coupons
B826-97. Standard Test Method for Monitoring Atmospheric Corrosion Tests by Electrical Resistance Probes
C692-00. Standard Test Method for Evaluating the Influence of Thermal Insulations on External Stress Corrosion Cracking Tendency of Austenitic Stainless Steel
C876-91. Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete
C1431-99. Standard Guide for Corrosion Testing of Aluminum-Based Spent Nuclear Fuel in Support of Repository Disposal
D1141-90(1992). Specification for Substitute Ocean Water
D1193-91. Specification for Reagent Water
D1611-00. Standard Test Method for Corrosion Produced by Leather in Contact with Metal
D3299-00. Standard Specification for Filament-Wound Glass-Fiber-Reinforced Thermoset Resin Corrosion-Resistant Tanks
D3310-90(1995). Test Method for Determining Corrosivity of Adhesive Material
D3482-90(2000). Standard Test Method for Determining Electrolytic Corrosion of Copper by Adhesives
D4097-95ae3. Standard Specification for Contact-Molded Glass-Fiber-Reinforced Thermoset Resin Corrosion-Resistant Tanks
D4585-92. Practice for Testing Water Resistance of Coating Using Controlled Condensation
D5485-99. Standard Test Method for Determining the Corrosive Effect of Combustion Products Using the Cone Corrosimeter
E866-96. Standard Specification for Corrosion-Inhibiting Adhesive Primer for Aluminum Alloys to Be Adhesively Bonded in Honeycomb Shelter Panels

E1524-98. Standard Test Method for Saltwater Immersion and Corrosion Testing of Photovoltaic Modules for Marine Environments
E1826-96. Standard Specification for Low Volatile Organic Compound (VOC)
F336-97. Standard Practice for Design and Construction of Nonmetallic Enveloped Gaskets for Corrosive Service
F363-99. Standard Test Method for Corrosion Testing of Gaskets
F1110-90(1998). Standard Test Method for Sandwich Corrosion Test

AIRCRAFT

F482-84(1999). Standard Test Method for Corrosion of Aircraft Metals by Total Immersion in Maintenance Chemicals
F483-98. Standard Test Method for Total Immersion Corrosion Test for Aircraft Maintenance Chemicals
F519-93. Test Method for Mechanical Hydrogen Embrittlement Testing of Plating Processes and Aircraft Maintenance Chemicals
F945-98. Standard Test Method for Stress-Corrosion of Titanium Alloys by Aircraft Engine Cleaning Materials
F1111-88(1998). Standard Test Method for Corrosion of Low-Embrittling Cadmium Plate by Aircraft Maintenance Chemicals

COATINGS

B457-67(1993). Test Method for Measurement of Impedance of Anodic Coatings on Aluminum
B680-80(1995). Test Method for Seal Quality of Anodic Coatings on Aluminum by Acid Dissolution
D610-95. Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces
D1654-92(2000). Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments
D2803-93. Standard Guide for Testing Filiform Corrosion Resistance of Organic Coatings on Metal
D2933-74(1986). Test Method for Corrosion Resistance of Coated Steel Specimens (Cyclic Method)

ELECTRODEPOSITS

B380-97. Standard Test Method of Corrosion Testing of Decorative Electrodeposited Coatings by the Corrodkote Procedure
B537-70(1992). Practice for Rating of Electroplated Panels Subjected to Atmospheric Exposure

B545-92. Specification for Electrodeposited Coatings of Tin
B605-95. Specification for Electrodeposited Coatings of Tin-Nickel Alloy
B650-93. Specification for Electrodeposited Engineering Chromium Coatings on Ferrous Substrates
B651-83(1995). Standard Test Method for Measurement of Corrosion Sites in Nickel Plus Chromium or Copper Plus Nickel Plus Chromimum Electroplated Surfaces with the Double-Beam Interference Microscope
B689-90. Specification for Electroplated Engineering Nickel Coatings
B733-90(1994). Specification for Autocatylitic and Nickel-Phosphorus Coatings on Metals
B735-95. Test Method for Porosity in Gold Coatings on Metal Substrates by Nitric Acid Vapor
B741-95. Test Method for Porosity in Gold Coatings on Metal Substrates by Paper Electrograph
B765-93. Guide for Selection of Porosity Tests for Electrodeposites and Related Metallic Coatings
B809-95. Test Method for Porosity in Metal Coatings by Humid Sulfur Vapor ("Flowers of Sulfur")

ENVIRONMENTS

C621-84(1995). Standard Test Method for Isothermal Corrosion Resistance of Refractories to Molten Glass
D849-97. Standard Test Method for Copper Strip Corrosion by Industrial Aromatic Hydrocarbons
D930-89(1996). Standard Test Method of Total Immersion Corrosion Test of Water-Soluble Aluminum Cleaners
D1275-96a. Standard Test Method for Corrosive Sulfur in Electrical Insulating Oils
D1280-00. Standard Test Method for Total Immersion Corrosion Test for Soak Tank Metal Cleaners
D1384-97a. Standard Test Method for Corrosion Test for Engine Coolants in Glassware
D1838-91(1996). Standard Test Method for Copper Strip Corrosion by Liquefied Petroleum (LP) Gases
D2251-96. Standard Test Method for Metal Corrosion by Halogenated Organic Solvents and Their Admixtures
D2570-96. Standard Test Method Simulated Service Corrosion Testing of Engine Coolants
D2809-94. Test Method for Cavitation Corrosion and Erosion Corrosion Characteristics of Aluminum Pumps with Engine Coolants
D4310-98. Standard Test Method for Determination of the Sludging and Corrosion Tendencies of Inhibited Mineral Oils

D4340-96. Standard Test Method for Corrosion of Cast Aluminum Alloys in Engine Coolants Under Heat-Rejecting Conditions

D4627-92(1997). Standard Test Method for Iron Chip Corrosion for Water-Dilutable Metalworking Fluids

D4778-94(1999). Standard Test Method for Determination of Corrosion and Fouling Tendency of Cooling Water Under Heat Transfer Conditions

E745-80(1996). Standard Practices for Simulated Service Testing for Corrosion of Metallic Containment Materials for Use With Heat-Transfer Fluids in Solar Heating and Cooling Systems

FASTENERS

D6294-98. Standard Test Method for Corrosion Resistance of Ferrous Metal Fastener Assemblies Used in Roofing and Waterproofing

F1135-99. Standard Specification for Cadmium or Zinc Chromate Organic Corrosion Protective Coating for Fasteners

F1136-88(1998). Standard Specification for Chromium/Zinc Corrosion Protective Coatings for Fasteners

F1137-00. Standard Specification for Phosphate/Oil and Phosphate/Organic Corrosion Protective Coatings for Fasteners

F1428-92(1999). Standard Specification for Aluminum Particle-Filled Basecoat/Organic or Inorganic Topcoat, Corrosion Protective Coatings for Fasteners

LUBRICANTS

D1743-94. Standard Test Method for Determining Corrosion Preventive Properties of Lubricating Greases

D2649-99. Standard Test Method for Corrosion Characteristics of Solid Film Lubricants

D4048-97. Standard Test Method for Detection of Copper Corrosion from Lubricating Grease

D5969-96. Standard Test Method for Corrosion-Preventive Properties of Lubricating Greases in Presence of Dilute Synthetic Sea Water Environments

D6138-97. Standard Test Method for Determination of Corrosion-Preventive Properties of Lubricating Greases Under Dynamic Wet Conditions (Emcor Test)

MEDICAL

F746-87(1999). Standard Test Method for Pitting or Crevice Corrosion of Metallic Surgical Implant Materials

F897-84(1997). Standard Test Method for Measuring Fretting Corrosion of Osteosynthesis Plates and Screws
F1089-87(1994). Standard Test Method for Corrosion of Surgical Instruments
F1801-97. Standard Practice for Corrosion Fatigue Testing of Metallic Implant Materials
F1875-98. Standard Practice for Fretting Corrosion Testing of Modular Implant Interfaces: Hip Femoral Head-Bore and Cone Taper Interface

METALS AND ALLOYS

A262-93a. Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
A263-94a(1999). Standard Specification for Corrosion-Resisting Chromium Steel-Clad Plate, Sheet, and Strip
A380-94a. Practice for Cleaning, Descaling and Passivation of Stainless Steel Parts, Equipment, and Systems
A409/A409M-95a. Standard Specification for Welded Large Diameter Austenitic Steel Pipe for Corrosion or High-Temperature Service
A518/A518M-99. Standard Specification for Corrosion-Resistant High-Silicon Iron Castings
A606-98. Standard Specification for Steel, Sheet and Strip, High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, with Improved Atmospheric Corrosion Resistance
A743/A743M-98a. Standard Specification for Castings, Iron-Chromium, Iron-Chromium-Nickel, Corrosion Resistant, for General Application
A744/A744M-00. Standard Specification for Castings, Iron-Chromium-Nickel, Corrosion Resistant, for Severe Service
A763-93. Practices for detecting Susceptibility to Intergranular Attack in Ferritic Stainless Steels
A774/A774M-00. Standard Specification for As-Welded Wrought Austenitic Stainless Steel Fittings for General Corrosive Service at Low and Moderate Temperatures
A847-99a. Standard Specification for Cold-Formed Welded and Seamless High Strength, Low Alloy Structural Tubing with Improved Atmospheric Corrosion Resistance
A858/A858M-00. Standard Specification for Heat-Treated Carbon Steel Fittings for Low Temperature and Corrosive Service
A871/A871M-00a. Standard Specification for High-Strength Low-Alloy Structural Steel Plate With Atmospheric Corrosion Resistance
A872-91(1997). Standard Specification for Centrifugally Cast Ferritic/Austenitic Stainless Steel Pipe For Corrosive Environments

A890/A890M-99. Standard Specification for Castings, Iron-Chromium-Nickel-Molybdenum Corrosion-Resistant, Duplex (Austenitic/Ferritic) for General Application

A946-95(2000). Standard Specification for Chromium, Chromium-Nickel and Silicon Alloy Steel Plate, Sheet, and Strip for Corrosion and Heat Resisting Service

A968-96. Standard Specification for Chromium, Chromium-Nickel, and Silicon Alloy Steel Bars and Shapes for Corrosion and Heat-Resisting Service

A990-00. Standard Specification for Chastings, Iron-Nickel-Chromium and Nickel Alloys, Specially Controlled for Pressure Retaining Parts for Corrosion Service

A1004/A1004M-99. Standard Practice for Establishing Conformance to the Minimum Expected Corrosion Characteristics of Metallic, Painted-Metallic, and Nonmetallic-Coated Steel Sheet Intended for Use as Cold Formed Framing Members

B76-90(1995). Test Method for Accelerated Life of Nickel-Chromium and Nickel-Chromium-Iron Alloys for Electrical Heating

B78-90(1995). Test Method for Accelerated Life of Iron-Chromium-Aluminum Alloys for Electrical Heating

B462-00a. Specification for Forged or Rolled UNS NO6030, UNS N06022, UNS N06200, UNS N08020, UNS N08024, UNS N08024, UNS N08026, UNS N08367, UNS N10276, UNS N10665, UNS N10675, and UNS R20033 Alloy Pipe Flanges, Forged Fittings & Valves & Parts for Corrosive High-Temperature Svc.

B732-84(1993). Test Method for Evaluating the Corrosivity of Solder Fluxes for Copper Tubing Systems

B752-97. Standard Specification for Castings, Zirconium-Base, Corrosion Resistant, for General Applications.

B858-95. Standard Test Method for Determination of Susceptibility to Stress Corrosion Cracking in Copper Alloys Using an Ammonia Vapor Test

B895-99. Standard Test Methods for Evaluating the Corrosion Resistance of Powder Metallurgy (P/M) Stainless Steel Parts/Specimens by Immersion in a Sodium Chloride Solution

D130-94(2000). Standard Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test

E937-93. Standard Test Method for Corrosion of Steel by Sprayed Fire-Resistive Material (SFRM) Applied to Structural Members

SSPC STANDARDS

SURFACE PREPARATION (SP)

SSPC-SP COM. Surface Preparation Commentary for Steel and Concrete Substrates
SSPC-SP 1. Solvent Cleaning
SSPC-SP 2. Hand Tool Cleaning
SSPC-SP 3. Power Tool Cleaning
SSPC-SP 5/NACE No. 1. White Metal Blast Cleaning
SSPC-SP 6/NACE No. 3. Commercial Blast Cleaning
SSPC-SP 7/NACE No. 4. Brush-Off Blast Cleaning
SSPC-SP 8. Pickling
SSPC-SP 10/NACE No. 2. Near-White Blast Cleaning
SSPC-SP 11. Power Tool Cleaning to Bare Metal
SSPC-SP 12/NACE No. 5. Surface Preparation and Cleaning of Steel and Other Hard Materials by High- and Ultrahigh-Pressure Water Jetting Prior to Recoating
SSPC-SP 13/NACE No. 6. Surface Preparation of Concrete
SSPC-SP 14/NACE No. 8. Industrial Blast Cleaning

TECHNOLOGY REPORTS (TR)

SSPC-TR 1/NACE 6G194. Thermal Pre-Cleaning
SSPC-TR 2/NACE 6G198. Wet Abrasive Blast Cleaning

ABRASIVES (AB)

SSPC-AB 1. Mineral and Slag Abrasives
SSPC-AB 2. Cleanliness of Recycled Ferrous Metallic Abrasives
SSPC-AB 3. Newly Manufactured or Re-Manufactured Steel Abrasives

PAINTING SYSTEMS (PS) AND COATING SYSTEMS (CS)

SSPC-PS COM. Commentary on Painting Systems
SSPC-PS Guide 1.00. Guide for Selecting Oil Base Painting Systems
SSPC-PS 1.09. Three-Coat Oil Base Zinc Oxide Painting System (Without Lead or Chromate Pigment)
SSPC-PS 1.10. Four-Coat Oil Base Zinc Oxide Painting System (Without Lead or Chromate Pigment)
SSPC-PS 1.12. Three-Coat Oil Base Zinc Chromate Painting System
SSPC-PS 1.13. One-Coat Oil Base Slow Drying Maintenance Painting System (Without Lead or Chromate Pigments)

SSPC-PS Guide 2.00. Guide for Selecting Alkyd Painting Systems
SSPC-PS Guide 3.00. Guide for Selecting Phenolic Painting Systems
SSPC-PS Guide 4.00. Guide for Selecting Vinyl Painting Systems
SSPC-PS 4.02. Four-Coat Vinyl Painting System (For Fresh Water, Chemical, and Corrosive Atmospheres)
SSPC-PS 4.04. Four-Coat White or Colored Vinyl Painting System (For Fresh Water, Chemical, and Corrosive Atmospheres)
SSPC-PS Guide 7.00. Guide for Selecting One-Coat Shop Painting Systems
SSPC-PS Guide 20.00. Guide for Selecting Painting Systems for Boot-toppings
SSPC-PS Guide 21.00. Guide for Selecting Painting Systems for Topsides
SSPC-PS Guide 22.00. Guide for Selecting One-Coat Preconstruction or Prefabrication Painting Systems
SSPC-CS 23.00(I). Interim Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel
SSPC-PS 24.00. Latex Painting System for Industrial and Marine Atmospheres, Performance-Based
SSPC-PS 26.00. Aluminum Pigmented Epoxy Coating System Materials Specification, Performance-Based Type I, for Use over Blast Cleaned Steel Type II, for Use over Hand Cleaned Steel
SSPC-PS 27.00. Alkyd Coating System Materials Specification, Performance-Based

PAINTS AND COATINGS (PAINT)

SSPC-Paint COM. Commentary on Paint Specifications
SSPC-Paint 5. Zinc Dust, Zinc Oxide, and Phenolic Varnish Paint
SSPC-Paint 8. Aluminum Vinyl Paint
SSPC-Paint 9. White (or Colored) Vinyl Paint
SSPC-Paint 11. Red Iron Oxide, Zinc Chromate, Raw Linseed Oil, and Alkyd Primer
SSPC-Paint 12. Cold-Applied Asphalt Mastic (Extra Thick Film)
SSPC-Paint 15. Steel Joist Shop Primer
SSPC-Paint 16. Coal Tar Epoxy-Polyamide Black (or Dark Red) Paint
SSPC-Paint 17. Chlorinated Rubber Inhibitive Primer
SSPC-Paint 18. Chlorinated Rubber Intermediate Coat Paint
SSPC-Paint 19. Chlorinated Rubber Topcoat Paint
SSPC-Paint 20. Zinc-Rich Primers (Type I, Inorganic, and Type II, Organic)
SSPC-Paint 21. White or Colored Silicone Alkyd Paint
SSPC-Paint 22. Epoxy-Polyamide Paints (Primer, Intermediate, and Topcoat)
SSPC-Paint 23. Latex Primer for Steel Surfaces

SSPC-Paint 24. Latex Semigloss Exterior Topcoat
SSPC-Paint 25. Zinc Oxide, Alkyd, Linseed Oil Primer for Use Over Hand Cleaned Steel, Type I and Type II
SSPC-Paint 25. 1BCS, Zinc Oxide, Alkyd, Linseed Oil Primer for Use Over Blast Cleaned Steel
SSPC-Paint 26. Slow Drying Linseed Oil Black Maintenance Primer, (Without Lead and Chromate Pigment)
SSPC-Paint 27. Basic Zinc Chromate-Vinyl Butyral Wash Primer
SSPC-Paint 28. Water-Borne Epoxy Primer for Steel Surfaces
SSPC-Paint 29. Zinc Dust Sacrificial Primer, Performance-Based
SSPC-Paint 30. Weld-Through Inorganic Zinc Primer
SSPC-Paint 31. Single-Package Waterborne Alkyd Primer for Steel Surfaces, Performance-Based
SSPC-Paint 32. Coal Tar Emulsion Coating
SSPC-Paint 33. Coal Tar Mastic, Cold Applied
SSPC-Paint 34. Water-Borne Epoxy Topcoat for Steel Surfaces
SSPC-Paint 35. Medium Oil Alkyd Primer (Air Dry/Low Bake), Type I and Type II
SSPC-Paint 36. Two-Component Weatherable Aliphatic Polyurethane Topcoat, Performance-Based
SSPC-Paint 101. Aluminum Alkyd Paint (Type I, Leafing and Type II, Non-Leafing)
SSPC-Paint 102. Black Alkyd Paint
SSPC-Paint 103. Black Phenolic Paint
SSPC-Paint 104. White or Tinted Alkyd Paint
SSPC-Paint 106. Black Vinyl Paint
SSPC-Paint 108. High-Build Thixotropic Leafing Aluminum Paint

PAINT APPLICATION (PA)

SSPC-PA COM. Commentary on Paint Application
SSPC-PA 1. Shop, Field, and Maintenance Painting of Steel
SSPC-PA 2. Measurement of Dry Coating Thickness With Magnetic Gages
SSPC-PA Guide 3. A Guide to Safety in Paint Application
SSPC-PA Guide 4. Guide to Maintenance Repainting with Oil Base or Alkyd Painting Systems
SSPC-PA Guide 5. Guide to Maintenance Painting Programs

QUALIFICATION PROCEDURES (QP)

SSPC-QP COM. Commentary on Qualification Procedures
SSPC-QP 1. Standard Procedure for Evaluating Painting Contractors (Field Application to Complex Industrial Structures)

SSPC-QP 2. Standard Procedure for the Qualification of Painting Contractors (Field Removal of Hazardous Coatings from Complex Structures)
SSPC-QP 3. Standard Procedure for Evaluating Qualifications of Shop Painting Applicators
SSPC-QP 4. Standard Procedure for Evaluating the Qualifications of Contractors Disturbing Hazardous Coatings During Demolition and Repair Work
SSPC-QP 5. Standard Procedure for Evaluating Qualifications of Coating and Lining Inspection Companies

TECHNOLOGY GUIDES (GUIDE)

SSPC-Guide 6. Guide for Containing Debris Generated During Paint Removal Operations
SSPC-Guide 7. Guide for the Disposal of Lead-Contaminated Surface Preparation Debris
SSPC-Guide 9. Guide for Atmospheric Testing of Coatings in the Field
SSPC-Guide 10. Guide to Specifying Coatings Conforming to Volatile Organic Compound (VOC) Content Requirements
SSPC-Guide 11. Guide for Coating Concrete
SSPC-Guide 12. Guide for Illumination of Industrial Painting Projects
SSPC-Guide 13. Guide for the Identification and Use of Industrial Coating Material in Computerized Product Databases
SSPC-Guide 14. Guide for the Repair of Imperfections in Galvanized or Inorganic Zinc Coated Steel Using Organic Zinc-Rich Coating

TEST PANEL PREPARATION METHODS (ME)

SSPC-ME 1. Uncontaminated Rusted Steel

AWWA STANDARDS

C115/A211.15-99. ANSI Standard for Flanged Ductile-Iron Pipe with Ductile-Iron or Gray-Iron Threaded Flanges

C116/A21.16-98. ANSI Standard for Protective Fusion-Bonded Epoxy Coating for the Interior and Exterior Surfaces of Ductile-Iron and Gray-Iron Fittings for Water Supply Service

C200-97. Steel Water Pipe–6 in. (150 mm) and larger

C203-97. Coal-Tar Protective Coatings and Linings for Steel Water Pipelines–Enamel and Tape–Hot Applied (Includes addendum **C203a–99**)

C205-95. Cement-Mortar Protective Lining and Coating for Steel Water Pipe–(100 mm) and Larger–Shop Applied

C209-95. Cold-Applied Tape Coatings for the Exterior of Special Sections, Connections, and Fittings for Steel Water Pipelines

C210-97. Liquid-Epoxy Coating Systems for the Interior and Exterior of Steel Water Pipelines

C213-96. Fusion-Bonded Epoxy Coating for the Interior and Exterior of Steel Water Pipelines

C214-95. Tape Coating Systems for the Exterior of Steel Water Pipelines

C218-99. Coating the Exterior of Above Ground Steel Water Pipelines and Fittings

C220-98. Stainless-Steel Pipe, 4 in. (100 mm) and Larger (Includes addendum **C220a–99)**

C222-99. Polyurethane Coatings for the Interior and Exterior of Steel Water Pipelines and Fittings

C300-97. Reinforced Concrete Pressure Pipe, Steel-Cylinder Type

C301-99. Pre-Stressed Concrete Pressure Pipe, Steel-Cylinder Type

C302-95. Reinforced Concrete Pressure Pipe, Non-Cylinder Type

C303-95. Concrete Pressure Pipe, Bar-Wrapped, Steel-Cylinder Type

C900. Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 in. through 12 in. (100 mm through 300 mm) for Water Distribution

C901-96. Polyethylene (PE) Pressure Pipe and Tubing, 1/2 in. (13 mm) through 3 in. (76 mm), for Water Service

C909-98. Molecularly Oriented Polyvinyl Chloride (PVCO) Pressure Pipe, 4 in. Through 12 in. (100 mm through 300mm) for Water Distribution

C950-95. Fiberglass Pressure Pipe

D100-96. Welded Steel Tanks for Water Storage

D102-97. Coating Steel Water-Storage Tanks

D104-97. Automatically Controlled, Impressed-Current Cathodic Protection for Interior of Steel Water Tanks

D130-96. Flexible-Membrane-Lining and Floating-Cover Materials for Potable Water Storage

ASME STANDARDS/CODES

B16.20 (98). Metallic Gaskets For Pipe Flanges: Ring Joint Spiral Wound and Jacketed

B18.18.1M (99). Inspection and Quality Assurance For General Purpose Fasteners

B31 (91). Code-Pressure Piping

B31G (91). Manual: Determining Remaining Strength of Corroded Pipelines: Supplement to B31 Code-Pressure Piping

B133.16 (00). Procurement Standard For Gas Turbine Marine Applications

OM/S/G (00). Standards and Guides for Operation and Maintenance of Nuclear Power Plants

BPVC (95). BPVC Section III-Rules Construction Nuclear Power Plant

BPVC (95). BPVC Section VIII-Division 1-Pressure Vessels

PTC 2 (85). Code On Definition and Values

RTP-1 (95). Reinforced Thermoset Plastic Corrosion-Resistant Equipment

SAE STANDARDS

CORROSION

J2334 (98). Cosmetic Corrosion Lab Test

FERROUS METALS AND ALLOYS

J126 (86). Selecting and Specifying Hot and Cold Rolled Steel Sheet and Strip
J158 (86). Automotive Malleable Iron Castings
J401 (92). Selection and Use of Steels
J403 (00). Chemical Compositions of SAE Carbon Steels
J404 (00). Chemical Compositions of SAE Alloy Steels
J405 (98). Chemical Compositions of SAE Wrought Stainless Steels
J422 (83). Microscopic Determination of Inclusions in Steels
J471 (73). Sintered Powder Metal Parts: Ferrous
J810 (96). Classification of Common Surface Imperfections in Sheet Steel
J940 (94). Glossary of Carbon Steel Sheet and Strip Terms
J1562 (99). Selection of Zinc and Zinc-Alloy (Hot-Dipped and Electrodeposited) Coated Steel Sheet
J1677 (96). Tests and Procedures for SAE Low-Carbon Steel and Copper Nickel Tubing
J1755 (95). Guidelines for Usage of Stainless Steel and Bimetal for Exterior Automotive Bright Trim
J2329 (97). Categorization and Properties of Low Carbon Automotive Sheet Steels
J2340 (99). Categorization and Properties of Dent Resistant, High Strength and Ultra High Strength Automobile Sheet Steel

NON-FERROUS METALS AND ALLOYS

J452 (89). General Information, Chemical Compositions, Mechanical and Physical Properties of SAE Aluminum Casting Alloys
J454 (91). General Data on Wrought Aluminum Alloys
J461 (81). Wrought and Cast Copper Alloys
J464 (89). Magnesium Alloys
J468 (88). Zinc Alloy Ingot and Die Casting Compositions
J469 (89). Zinc Die Casting Alloys
J993 (89). Alloy and Temper Designation Systems for Aluminum
J1086 (95). Numbering Metals and Alloys
J1434 (89). Wrought Aluminum Applications Guidelines

API STANDARDS

OFFSHORE STRUCTURES

Spec 2B. Fabrication of Structural Steel Pipe
Spec 2H. Carbon Manganese Steel Plate for Offshore Platform Tubular Joints
Spec 2MT1. As-Rolled Carbon Manganese Steel Plate With Improved Toughness for Offshore Structures
Spec 2Y. Steel Plates, Quenched-and-Tempered, for Offshore Structures

TUBULAR GOODS

RP 5A5. Field Inspection of New Casing, Tubing and Plain End Drill Pipe
RP 5C5. Evaluation Procedures for Casing and Tubing Connections
RP 5C6. Welding Connections to Pipe
Spec 5CT. Casing and Tubing (U.S. Customary Units)
Spec 5CTM. Casing and Tubing (Metric Units)
RP 5L2. Internal Coating of Line Pipe for Non-Corrosive Gas Transmission Service
RP 5L7. Unprimed Internal Fusion Bonded Epoxy Coating of Line Pipe
RP 5L8. Field Inspection of New Line Pipe
Std 5T1. Imperfection Terminology

FIBERGLASS AND PLASTIC PIPE

Spec 15HR. High Pressure Fiberglass Line Pipe
Spec 15LE. Polyethylene (PE) Line Pipe
Spec 15LR. Low Pressure Fiberglass Line Pipe
Spec 15LT. PVC Lined Steel Tubular Goods

PIPELINE AND REFINERY

RP 1102. Steel Pipelines Crossing Railroads and Highways
Std 1104. Welding of Pipelines and Related Facilities
RP 1110. Pressure Testing of Liquid Petroleum Pipelines
RP 572. Inspection of Pressure Vessels
RP 574. Inspection Practices for Piping System Components
RP 578. Material Verification Program for New and Existing Alloy Piping Systems

STORAGE TANKS

RP 12R1. Setting, Maintenance, Inspection, Operation And Repair of Tanks in Production Service
RP 575. Inspection of Atmospheric and Low-Pressure Storage Tanks
Std 620. Design and Construction of Large, Welded, Low-Pressure Storage Tanks
Std 650. Welded Steel Tanks for Oil Storage
RP 651. Cathodic Protection of Above Ground Storage Tanks
RP 652. Lining of Aboveground Petroleum Storage Tank Bottoms
Std 653. Tank Inspection, Repair, Alteration, and Reconstruction
RP 1604. Closure of Underground Petroleum Storage Tanks
RP 1615. Installation of Underground Petroleum Storage Systems
RP 1631. Interior Lining of Underground Storage Tanks
RP 1632. Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems
Std 2015. Safe Entry and Cleaning of Petroleum Storage Tanks
Std 2610. Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities

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