

Basic Metallurgy and Material Specification

PART OF THE CWB CERTIFICATE PROGRAMS



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MODULE 8

**BASIC STEEL METALLURGY
AND
MATERIAL SPECIFICATION**

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Basic Steel Metallurgy and Material Specification

MODULE 8

BASIC STEEL METALLURGY AND MATERIAL SPECIFICATION

Introduction

Almost all welding operations involve the heating and cooling of the metal being welded. This may change the properties of the metal. It is important, therefore, that anyone associated with welding has an understanding of the effects of heating and cooling on the properties of metals. It is the objective of this module to provide an elementary introduction to the basic principles of metallurgy. It is designed to give a foundation for understanding the effects of welding on metals and the various metallurgical phenomena that occur in welds.

Objectives

The following main topics will be discussed:

- The major metals and their uses
- Iron and steel making
- Types of steel products
- The structure of iron
- The effect of temperature on structure
- Microstructures of steel
- Phase diagrams
- Heat treatment operations
- Classification and properties of steels
- Specifications

The main emphasis is on steels because of their practical importance and other metals are not discussed in detail.

The major metals and their uses

Metals have special properties that distinguish them from *non-metals* and make them particularly useful as engineering materials. The differences arise from the structure of the atoms and electrons within the material, giving metals the property of good electrical and thermal conductivity. Most metals are also *ductile* and can be formed into useful shapes. *Alloys* are mixtures of a metal with other metals or non-metals. Alloying can change the properties of a metal and most metals in use today are alloys. It is usual to divide metals and alloys into two classes: those containing iron, called *ferrous* alloys and those without iron, called *non-ferrous* (Fig. 1).

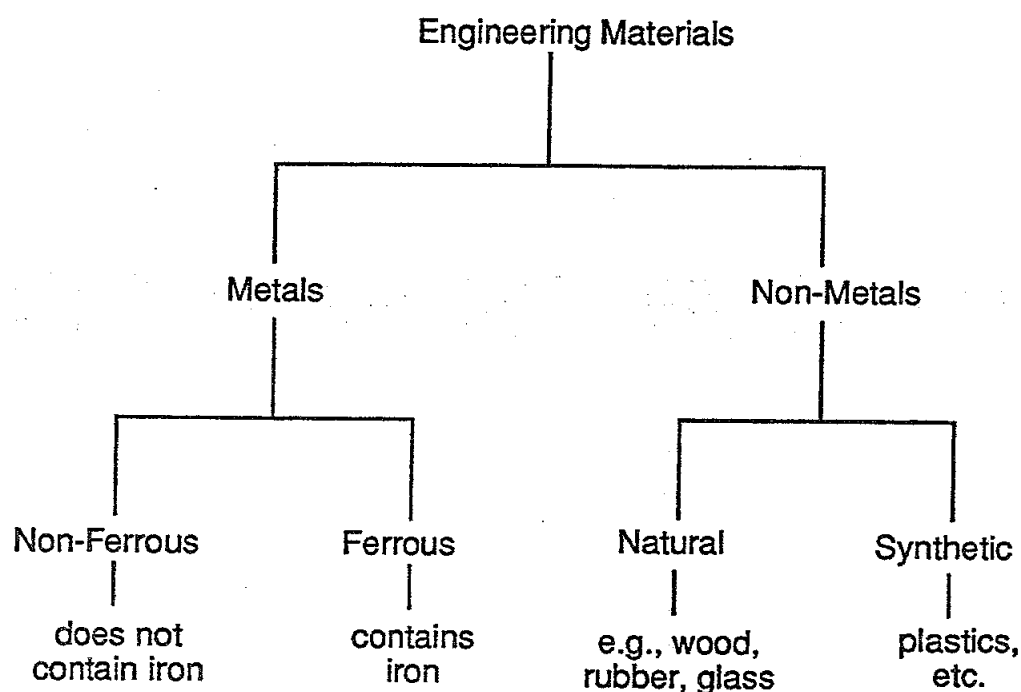


Figure 1. Grouping of engineering materials.

Ferrous alloys

The main groups of ferrous alloys are shown in Table 1 with some typical applications. The most important group, discussed more fully in this module, is the carbon and low alloy steel group since these materials are used for major engineering constructions. Wrought iron, once a very common structural material, is now seldom used.

Table 1. The main groups of ferrous alloys.

Alloy	Properties	Some Uses
Wrought Iron	Ductile, can be hammered into complex shapes	Lifting tackle, decorative work
Cast Iron	Lower melting point, easily cast	Machine castings
Carbon and Low Alloy Steels	Good strength and ductility	Bridge girders, pressure vessels
Alloy Steels	Many special properties depending on alloy	Tools, gears, high temperature uses, special applications
Stainless Steels	Corrosion resistance	Chemical plant, vessels, tubing

Non-ferrous metals

All metals, except iron and all alloys in which iron is not the major alloy element, are termed *non-ferrous*. Very few of them are widely used as structural materials, but other properties such as corrosion resistance or electrical conductivity make them valuable to the engineer. A short list of the more important non-ferrous metals is given in Table 2.

Basic Steel Metallurgy and Material Specification

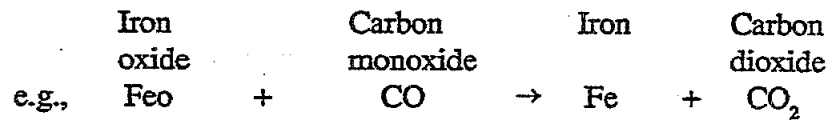
Table 2. Common non-ferrous metals.

Metal	Melting Point °C (°F)	Properties	Typical Uses
Aluminum	660 (1220)	Very light, ductile, high electrical conductivity.	Lightweight structural material, aircraft, electrical conductors.
Copper	1083 (1981)	High electrical conductivity, good corrosion resistance. Easily joined by brazing.	Electrical conductors, heat exchanger tubing, basis of brass and bronze alloys.
Lead	328 (622)	Good corrosion resistance, soft.	Linings in chemical plants, electrical cable sheaths, solder.
Magnesium	595 (1103)	Lighter than aluminum. Excellent machinability.	Lightweight extrusions, household goods, die-cast parts.
Nickel	1450 (2642)	Corrosion resistant.	Chemical plant, alloying in steel.
Silver	960 (1760)	Highest electrical conductivity.	Electronics, photography.
Tin	232 (450)	Corrosion resistance.	Coating steel to make tin plate, solder, bearing metal.
Zinc	420 (788)	Corrosion resistance.	Coating steel to make galvanized sheet.

Iron and steel making

Except for a very few metals, such as gold, most do not occur naturally in their elemental form. Rather the metal is found combined with other elements, usually oxygen or sulphur, in the form of an *ore*. The metal must be extracted from the ore, a process known as *smelting*. For many metals this is achieved by heating in a furnace but in some cases, such as aluminum, electrical energy is used for smelting.

The separation of the metal from an oxide ore requires a *reducing agent* to combine with the oxygen in the ore. In the case of iron ore smelting, the reducing agent is *carbon monoxide* which forms from coke in the heat of the furnace.



The coke is made from coal, as shown in Fig. 2, in special coking ovens.

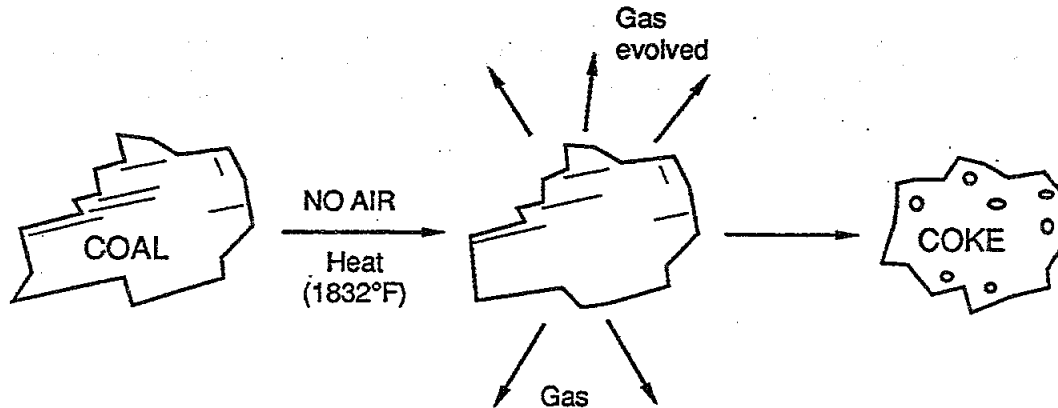


Figure 2. Distillation of coal.

The main types of ore are hematite, limonite, magnetite, and taconite.

The first step in converting iron ore into steel is the production of pig iron in a blast furnace. A blast furnace is shown in Fig. 3. The charge loaded into the top of the furnace comprises:

- Iron ore
- Limestone
- Coke

The limestone is a fluxing agent that removes impurities to form a slag. The molten iron collects at the bottom of the furnace and is run out into a hot metal ladle. The pig iron formed contains many impurities such as phosphorus and about 3 or 4% of carbon.

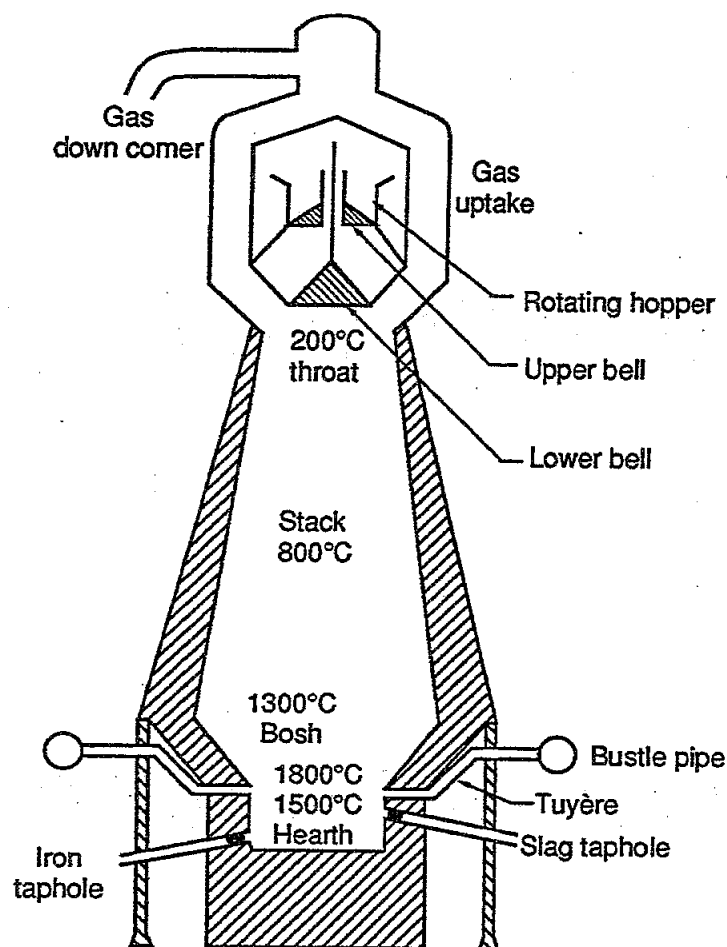


Figure 3. Modern iron-making blast furnace.

Steel

To convert pig iron into steel, most of the impurities must be removed by oxidation. To do this the steel making industry has used a variety of methods such as the open hearth furnace and Bessemer converter. However, now the *basic oxygen (or L-D) process* produces most of the world's steel and is shown in Fig. 4. It comprises a furnace in which oxygen is blown onto the liquid. Heat is generated by the oxidation of elements such as carbon and silicon in the metal and the vessel can be tilted to pour out the steel when ready. It is more rapid than the open hearth furnace requiring less than an hour to produce a 250 ton heat. The term "*basic*" refers to the chemical nature of the refractory lining of the furnace. Basic materials help in removing impurities such as phosphorus. Because oxygen is used instead of air, the steel contains very little nitrogen.

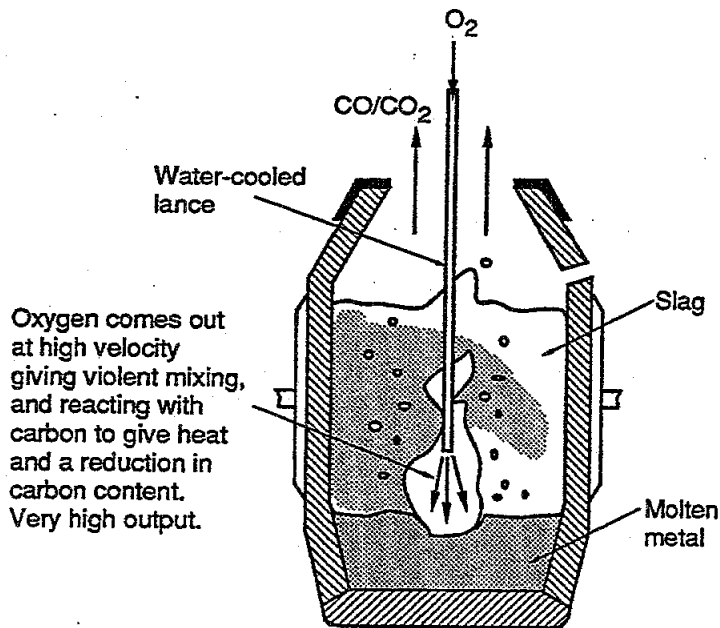


Figure 4. The basic oxygen furnace.

The electric furnace (Fig. 5) is heated by an arc between carbon electrodes and the metal. The charge is usually completely scrap (carefully selected) and the method is commonly used for high quality, alloy and tool steels. Alloying can be achieved by addition of certain materials in the furnace. A heat of steel takes four to twelve hours to produce.

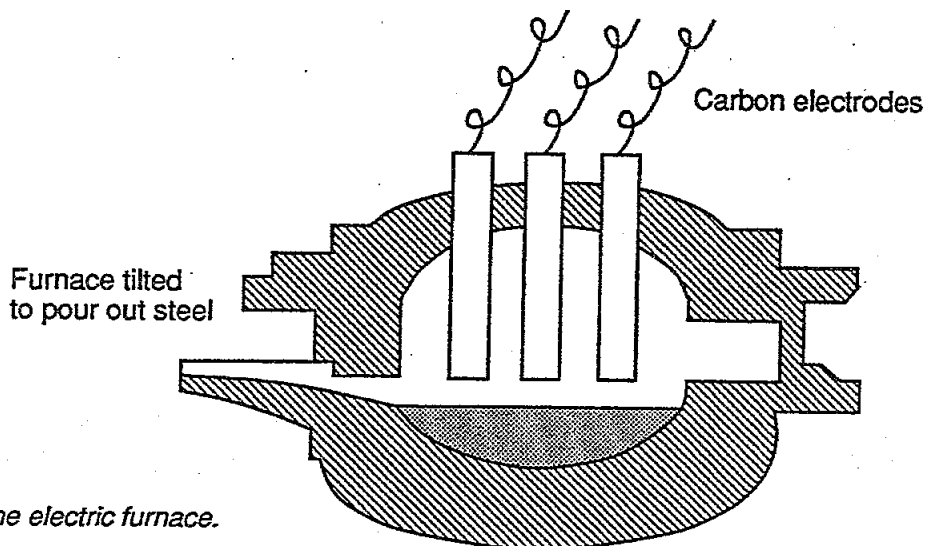


Figure 5. The electric furnace.

Casting and rolling

The molten steel from the furnace is transferred to a ladle and then either cast in individual ingots, or the tundish of a continuous casting machine (strand casting is the same as continuous casting, but in batches). The cast ingots or slab are then rolled into a variety of steel products. Figs. 6 and 7 illustrate schematically the two casting methods and Fig. 8 shows a modern steel making facility. Continuous casting is now used for most plate and shape steel products. Some products, such as plates, are rolled hot, whereas others, such as sheet or strip, may be finished by rolling cold.

Figure 6. Pouring or teeming steel from a ladle into ingot molds.

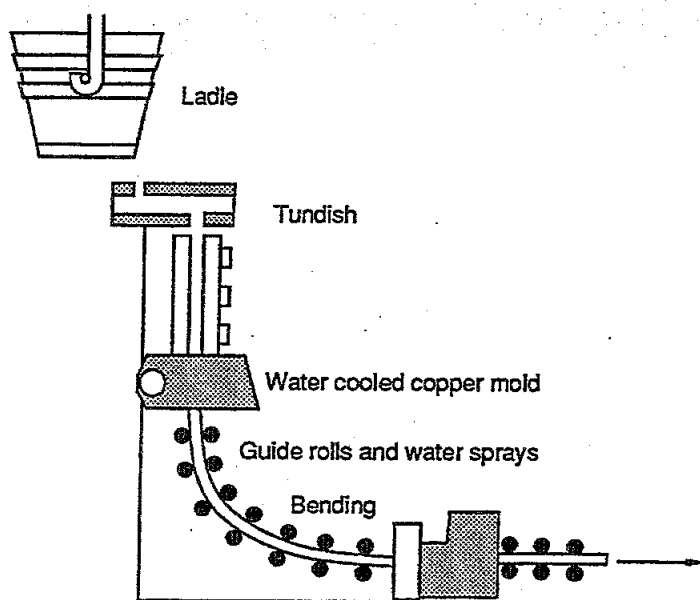
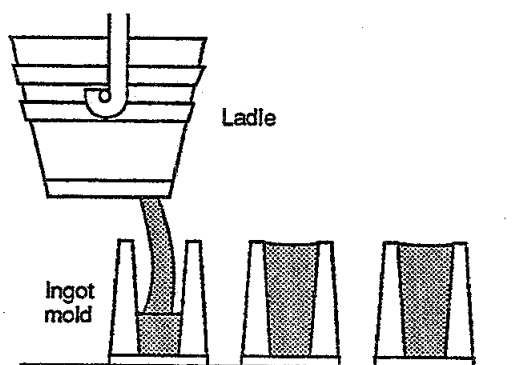


Figure 7. Continuous casting.

Continuous casting eliminates the following cost factors:

- teeming
- mold stripper
- soaking pit to reheat the ingot
- ingot breakdown mill

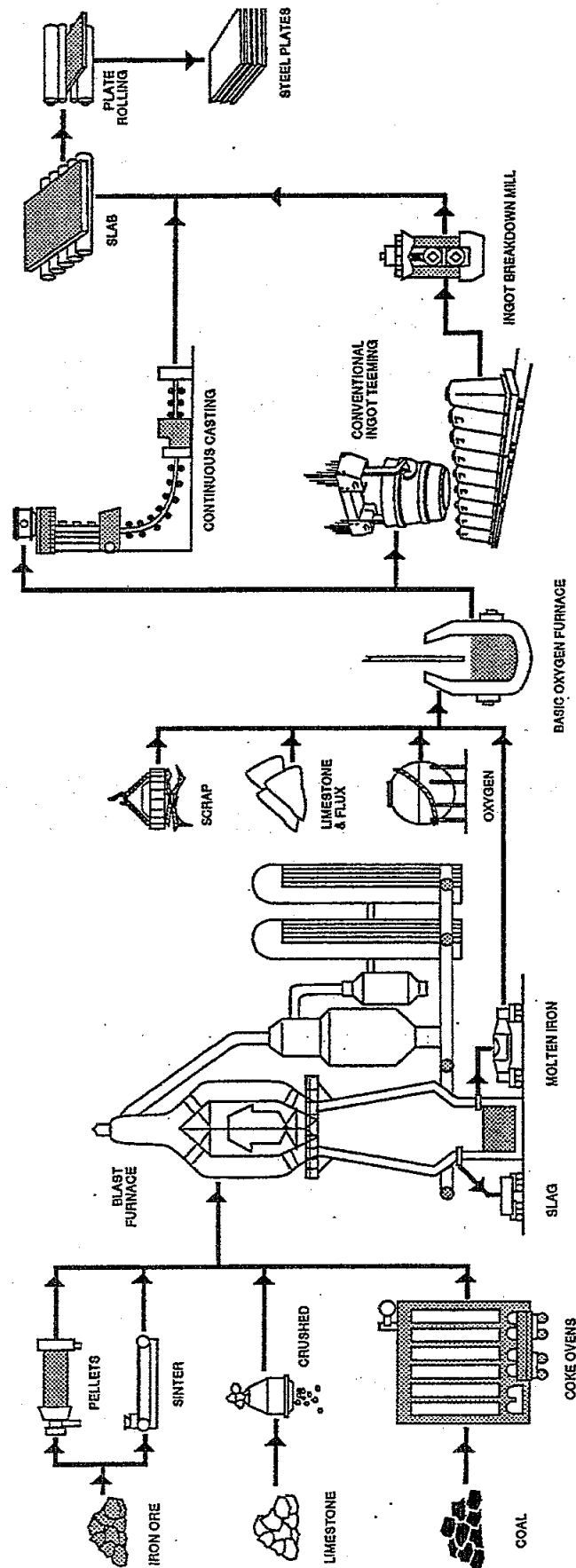
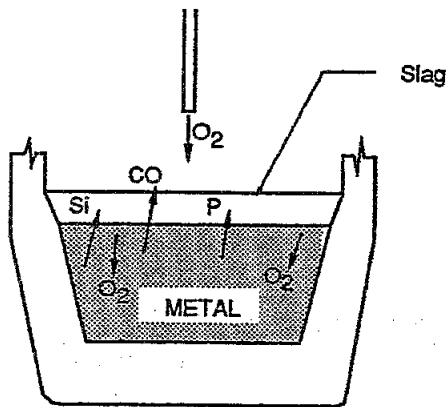


Figure 8. Modern steel making facility.

Chemical processes in steel making

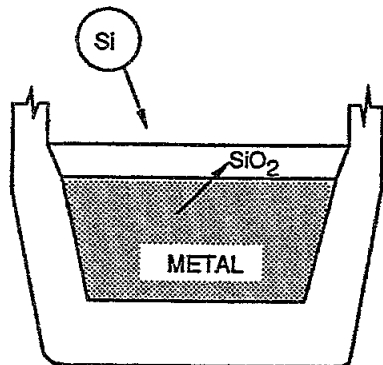
Also because of the rapid solidification of the steel, there is little opportunity for selective freezing and chemical segregation is minimized.

It was mentioned that the smelting of iron from ore involves a process of reduction, i.e., removing the oxygen from the ore. The pig iron so produced contains carbon, silicon, phosphorus, etc., which must be removed during steel making by oxidation. When the steel has been made, the extra oxygen in the metal must be removed by deoxidation using elements such as silicon and aluminum that readily combine with oxygen as shown in Fig. 9.



Oxidation

Steel making lowers C, Si, P by combining these with O_2 and removal through the slag.



Deoxidation

Molten steel contains almost 0.20% dissolved oxygen which tends to make the steel brittle. This extra oxygen must be removed by adding deoxidizers such as Mn/Si/Al just before casting.

Figure 9. Chemical processes in steel making.

The degree of deoxidation can vary and will influence the way the steel solidifies. There are three classes of steel:

- Rimmed
- Semi-killed
- Killed

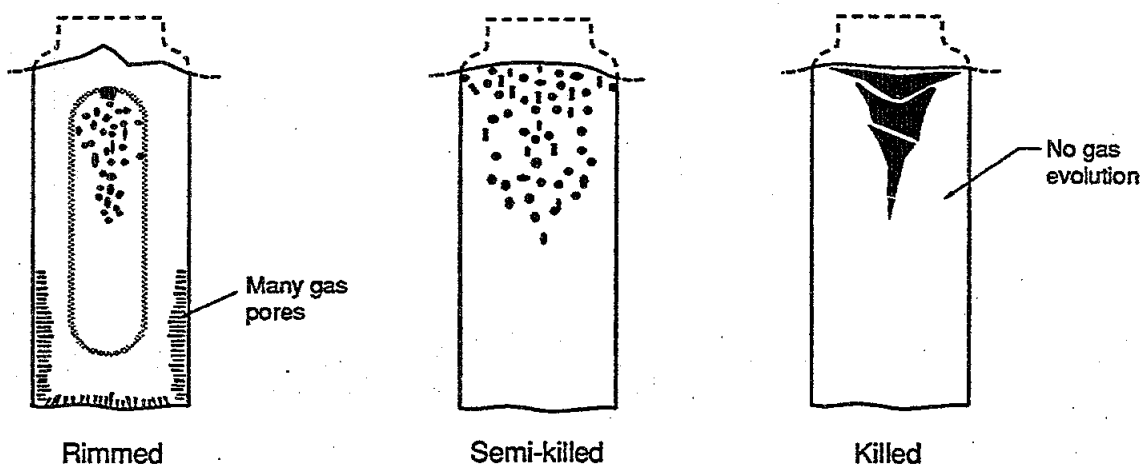


Figure 10. Typical ingot structures.

Rimmed steel is produced when no deoxidants are added. The excess oxygen reacts with the carbon causing the steel to “boil” in the mold due to gas evolution. Because of this, rimmed steel has to be ingot cast. The ingot is characterized by an outer rim of almost pure iron and the impurities are segregated to the core. There are many gas pockets but the absence of a deep shrinkage cavity allows most of the ingot to be used. The rim on the outside produces an excellent surface when rolled down and rimmed steels are good for sheet steels. They are also used in the core wire of electrodes. TEST QUESTION

The disadvantages of rimmed steel are the greater segregation in the centre of an ingot, possibility of blowholes causing surface defects and the limited compositions that can be achieved.

Semi-killed steel is made when a small amount of deoxidizing material is added to the melt. This lowers the oxygen content and reduces gas evolution in the solidifying ingot. There is, however, sufficient gas formation to compensate for shrinkage during solidification but blowholes are generally confined to the upper half of the ingot. Semi-killed steels are characterized by variable degrees of uniformity in composition, intermediate between killed and rimmed steels.

Killed steels are fully deoxidized, (silicon and aluminum are commonly used), and no gas evolution occurs. The steel is uniform in composition without the strong segregation of a rimmed steel. Because there is no gas formation to compensate for shrinkage, a cavity or “pipe” will form at the top of an ingot. This must be removed prior to rolling.

In the case of continuous casting, there is always liquid steel in the mold, and there are not normally any shrinkage cavities until pouring is completed. Primary pipe is therefore seldom encountered on this product, although secondary pipe can occur if the cooling sequence is not carefully controlled.

A *Capped steel* is similar to a rimmed steel but a cap or seal is added to the top of the mold after the ingot is poured. This suppresses some of the gas evolution. A capped steel ingot retains the thin rim zone but has less segregation than a rimmed steel.

It is important to note that a steel may be made in different ways depending on the thickness to which it is to be rolled. Thick plates are generally fully killed, but thinner plates in the same steel may not be required to be killed. Structural steel, particularly in thinner sections, is often semi-killed. Alloy steels and steels with greater than 0.3% carbon are fully killed.

Special treatments

A number of special processes are used in steel making when certain properties are desired. Some of these are designed to remove impurities and gases and improve the quality of the steel. *Vacuum degassing* is a method by which gases, principally hydrogen and oxygen, are removed by exposing the molten steel to a low pressure. One method is to cast the steel in a vacuum. Another method provides a degassing treatment in the ladle before the steel is cast. An evacuated vessel is dipped into the steel which rises into the vessel and is degassed.

Impurities, such as sulphur, may be reduced by special additives. Calcium, for example, is sometimes used when very low sulphur levels are desired, improving through thickness ductility.

Characteristics of rolled plate

When an ingot is rolled into a plate many of the features of the ingot will be retained. The rim of almost pure iron on the outside of a rimmed steel ingot will result in a very good surface quality of the rolled plate. The segregation of impurities to the centre of the ingot will result, however, in a concentration of impurities and other elements in the mid-thickness of the plate. A killed steel ingot cropped too high may retain part of a shrinkage cavity that would form a lamination when rolled to a plate. Laminations may open up at the edge of a plate when flame cut and may cause problems when welding, particularly butt joints. The segregation of carbon and sulphur to the centre of the plate may lead to cracking or porosity in the weld. Sometimes it is necessary to repair laminations and segregated regions by welding. Correct welding

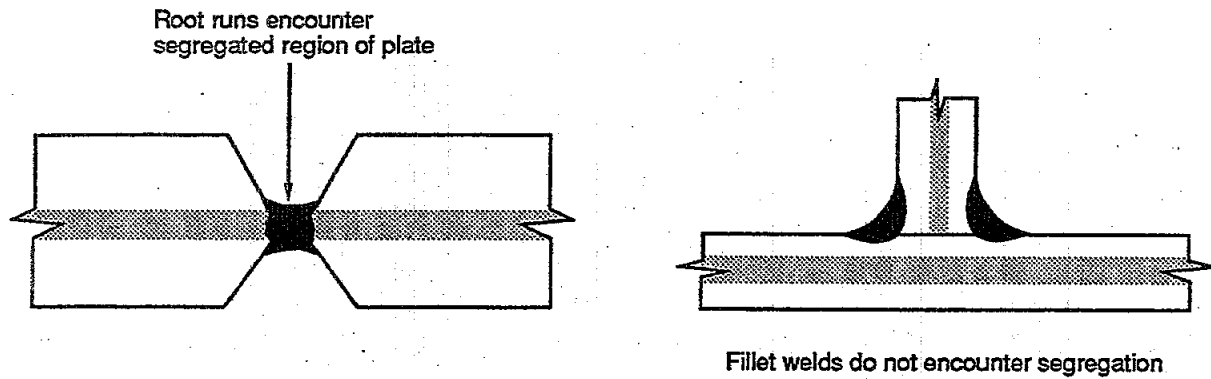


Figure 11. Possible welding problems due to plate segregation in rimmed steel. This is not normally a problem in modern continuously cast steels.

procedures should be followed for this, bearing in mind the greater risk of weld defects. Fig. 11 illustrates a groove weld where problems from segregation in a rimmed steel are possible. With fillet welds, difficulties due to segregation are unlikely.

Rolling direction

When a plate is made, most of the rolling will usually take place in one direction and the metal grains and small non-metallic inclusions will become elongated (Fig. 12). The inclusions may include deoxidation products, such as manganese silicates, and impurities such as manga-

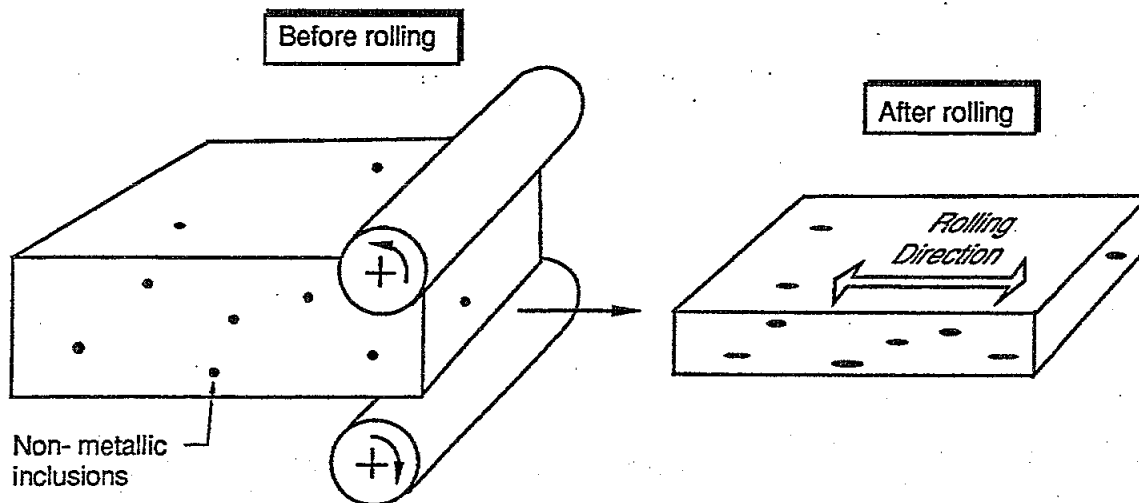


Figure 12. Rolling direction of plate.

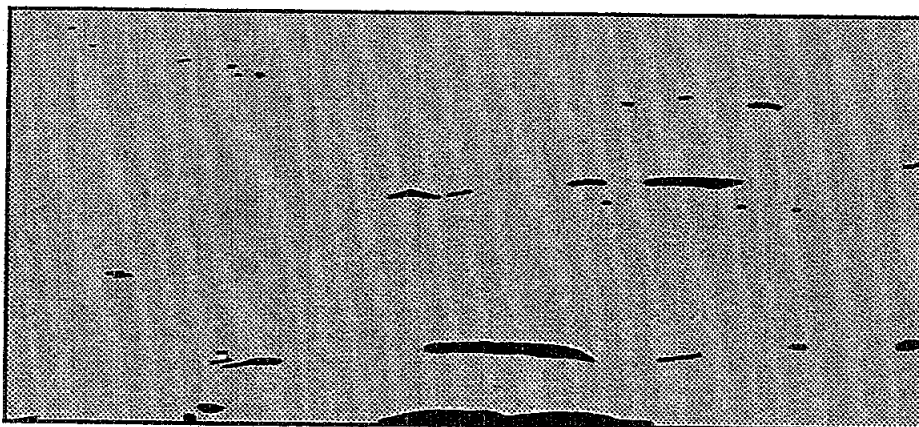
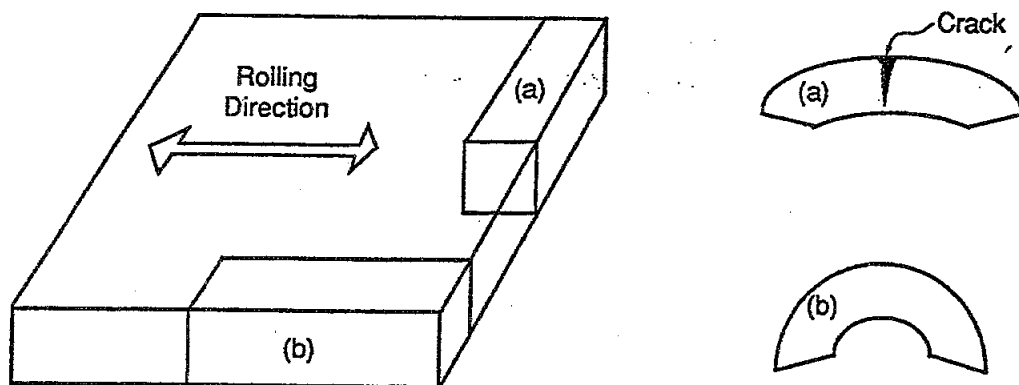


Figure 13. Non-metallic inclusions in a steel plate (magnification X 200).

nese sulphides (see Fig. 13). Sometimes long “stringers” may be formed in the plate. The elongated inclusions give directional properties to the plate. The ductility of the steel when stretched parallel to the rolling direction is usually higher than that transverse to the direction of rolling, (Fig. 14). This may be an important feature when plates are formed during fabrication. For example, when a pressure vessel is made from formed plates they are usually arranged so that the direction of bending and the major stress when the vessel operates is in the most favourable direction (Fig. 15).



Transverse sample (a) would usually show less ductility than a longitudinal sample (b).

Figure 14. In a rolled plate the mechanical properties may depend on the direction of loading.

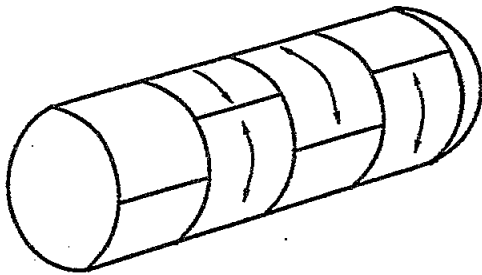
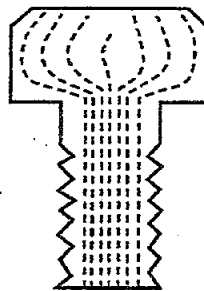


Figure 15. The plates for the shell of a pressure vessel are usually formed with the rolling direction around the circumference.

The ductility measured through the thickness of the plate is usually the lowest of all, and if this direction is strained excessively internal tears may occur. This may happen, for example, in a large, heavily restrained Tee-joint when welded and gives rise to *lamellar tearing*. In cases where excellent ductility is required in all directions, special steel making techniques are used to minimize the number of non-metallic inclusions.

Directional properties are also a characteristic of components made by *forging*. The *fibre direction*, however, tends to follow the shape of the component and for this reason a forged component may be preferred for some applications over one fabricated from plates or machined from solid. Fig. 16 illustrates how the fibre direction of a forged component may improve its mechanical behaviour.

Fibre direction in a bolt with forged head. Favourable fibre direction improves the strength of the head.



Fibre direction in a bolt machined from a bar.

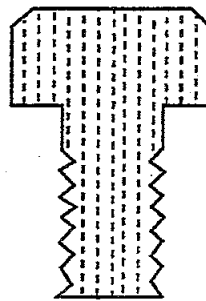


Figure 16. An example of the advantage of forging a component to provide a more favourable fibre direction.

Grain structure

THE STRUCTURE OF IRON AND STEELS

The properties of steel depend upon the structure of the metal and an understanding of this is necessary to appreciate the effects of heating and cooling, particularly from welding. Metals have a *crystalline* structure in which the atoms are arranged in a regular pattern. Usually, the pattern does not extend right across the piece of metal to form one large crystal but rather the piece is made up of a large number of *grains*. Each grain is a crystal with a regular pattern of atoms extending across it. At the junction of two grains, the grain boundary, the pattern of atoms will not match up and there will be a region of disordered atoms. Fig. 17 shows the typical grain structure of a metal.

The size of the grains and the grain boundaries can have important effects on the properties of the metal. In steels, for example, a small grain size increases the strength and toughness of the steel. Many modern steels undergo complex heating and rolling schedules designed to produce a very small grain size and so achieve excellent toughness.

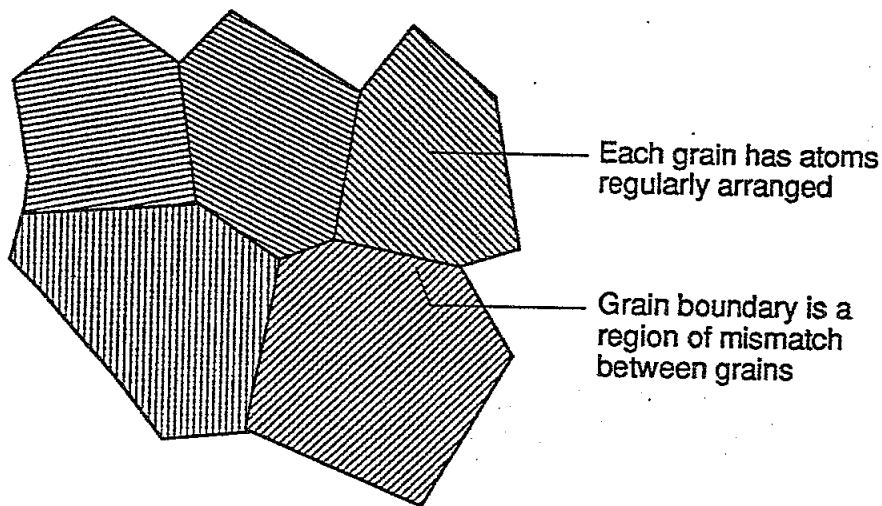


Figure 17. Typical grain structure of a metal.

Crystal structure

Consider now the pattern of atoms formed within a grain. Most metals have one of three basic types of atomic arrangements, but iron has the unique feature of existing in two forms depending on the temperature. At temperatures below 910°C iron exists in the body-centred cubic (bcc) form. This atomic arrangement is illustrated in Fig. 18(a). One atom sits at each corner of a cube and one in the geometric centre of the cube.

In the temperature range 910°C to 1390°C iron exists in the face-centred cubic (fcc) form illustrated in Fig. 18(b). One atom sits at each corner of a cube and one in the centre of each face of the cube.

The atoms in the fcc structure are more closely packed than in the bcc form and when iron changes from fcc to bcc (i.e., when it cools below 910°C it will expand slightly.

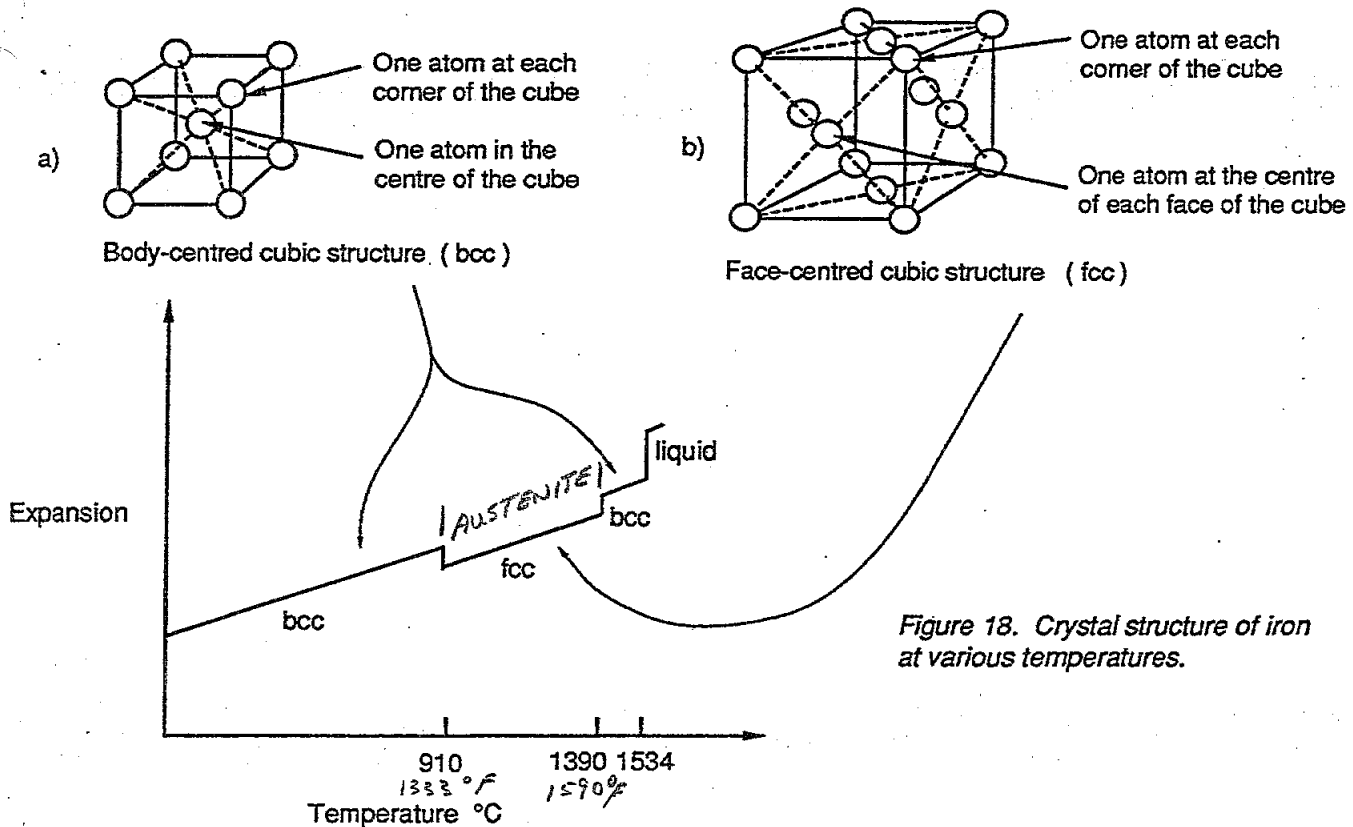


Figure 18. Crystal structure of iron at various temperatures.

Effect of carbon

The ability of iron to change form when it is heated is the fundamental reason why the properties of steel can be changed by heat treatment. For a steel, the temperature at which the changes occur depends on the carbon content. In pure iron the change from fcc to bcc (as the metal cools) occurs at 910°C. If carbon is present this temperature is lowered, but instead of transforming completely at one temperature, transformation now occurs over a range of temperatures. Fig. 19 shows this for carbon contents up to 0.8%. Below 723°C the structure is bcc, but above this temperature there will be a mixture of bcc and fcc forms. These temperatures will vary according to the presence of other elements and the rate of cooling.

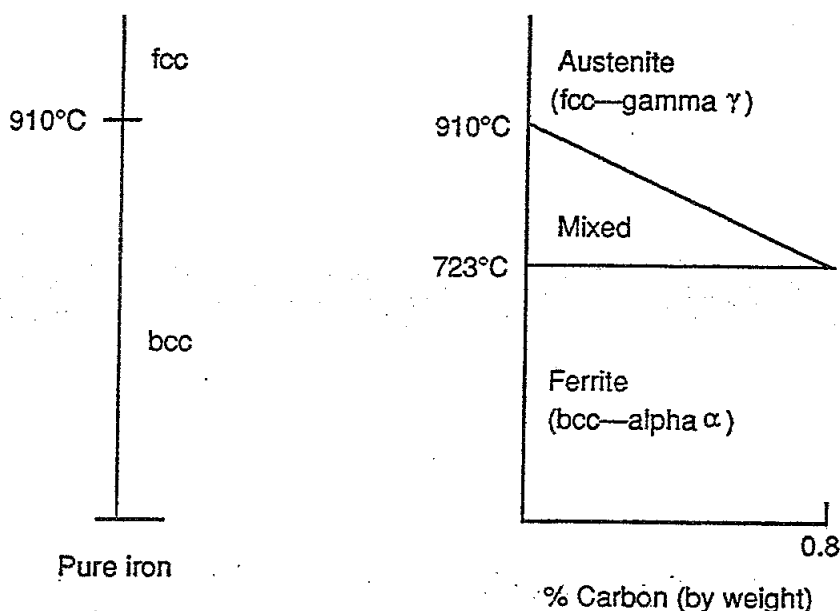


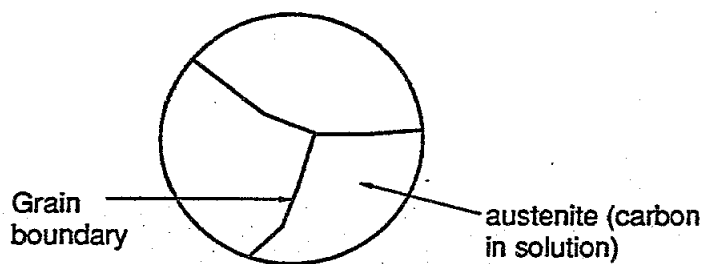
Figure 19. The effect of carbon on the structure of a steel.

Carbon dissolves completely in the fcc structure (up to 1.7% carbon) with the carbon atoms fitting into the spaces between the iron atoms. The fcc iron, with carbon dissolved in it, is known as *austenite* and given the symbol γ (gamma).

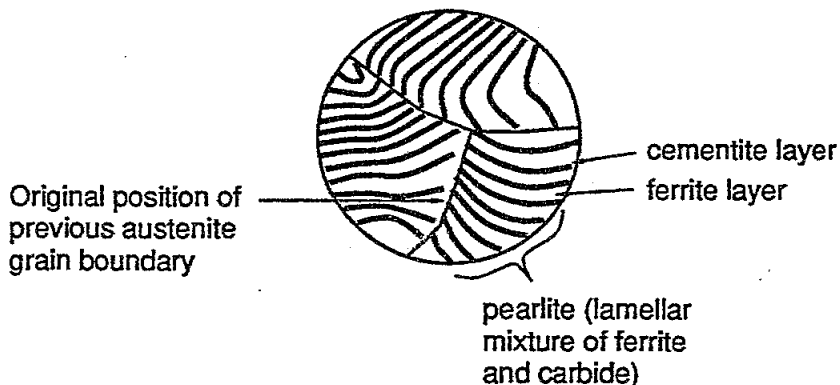
The bcc structure of iron dissolves very little carbon and below 723°C the bcc form is virtually pure iron, called *ferrite*, which is given the symbol α (alpha). Since bcc iron dissolves very little carbon, most of the carbon in a steel (below 723°C) will be present in the form of a

carbide in which carbon is chemically combined with iron. The usual carbide, known as *cementite*, comprises three atoms of iron and one of carbon and may be present in the form of small particles, plates, or layers.

Ferrite, austenite, and cementite are known as "*phases*" and the type of diagram shown in Fig. 19 is known as a *phase diagram*. Consider, for example, what phases may be present in a 0.8% carbon steel. Reference to Fig. 19 shows that above 723°C the steel is completely single phase austenite and will have the appearance of Fig. 20(a). Below 723°C, the steel changes structure to bcc ferrite and most of the carbon forms cementite. Thus below 723°C the steel has a two phase structure and typically would consist of layers of ferrite and cementite as illustrated in Fig. 20(b).



a) Above 723°C the structure is single phase austenite in which all carbon is dissolved.



b) Below 723°C the structure is two phase ferrite and cementite. Typically these would form layers.

Figure 20. Structure of a 0.8% carbon steel.

The layered structure of a 0.8% carbon steel has a "mother-of-pearl" appearance and is known as *pearlite*. If the steel has a carbon content greater than 0.8%, the extra carbon will form cementite and the structure will be a mixture of cementite and pearlite. Similarly, if the carbon content is less than 0.8%, the structure will be a mixture of ferrite grains and pearlite. Fig. 21 shows the appearance of a typical structural steel with about 0.15% carbon comprising ferrite grains and regions of pearlite. The steel has been cooled slowly.



Figure 21. Structure of a typical 0.15% carbon steel cooled slowly (magnification X 1000).

The diagram of Fig. 19 may be extended to carbon contents above 0.8%. Up to 1.7% carbon (the maximum solubility of carbon in austenite) alloys are known as *steels*. Beyond 1.7% C they become *cast irons*. Cast irons are beyond the scope of this module, but, for completeness, the entire iron-carbon diagram is presented in Fig. 22. Some parts of the diagram become quite complex but are not relevant to the present discussion. Notice some extra lines have been drawn in at the low carbon end to account for the very small solubility of carbon in ferrite.

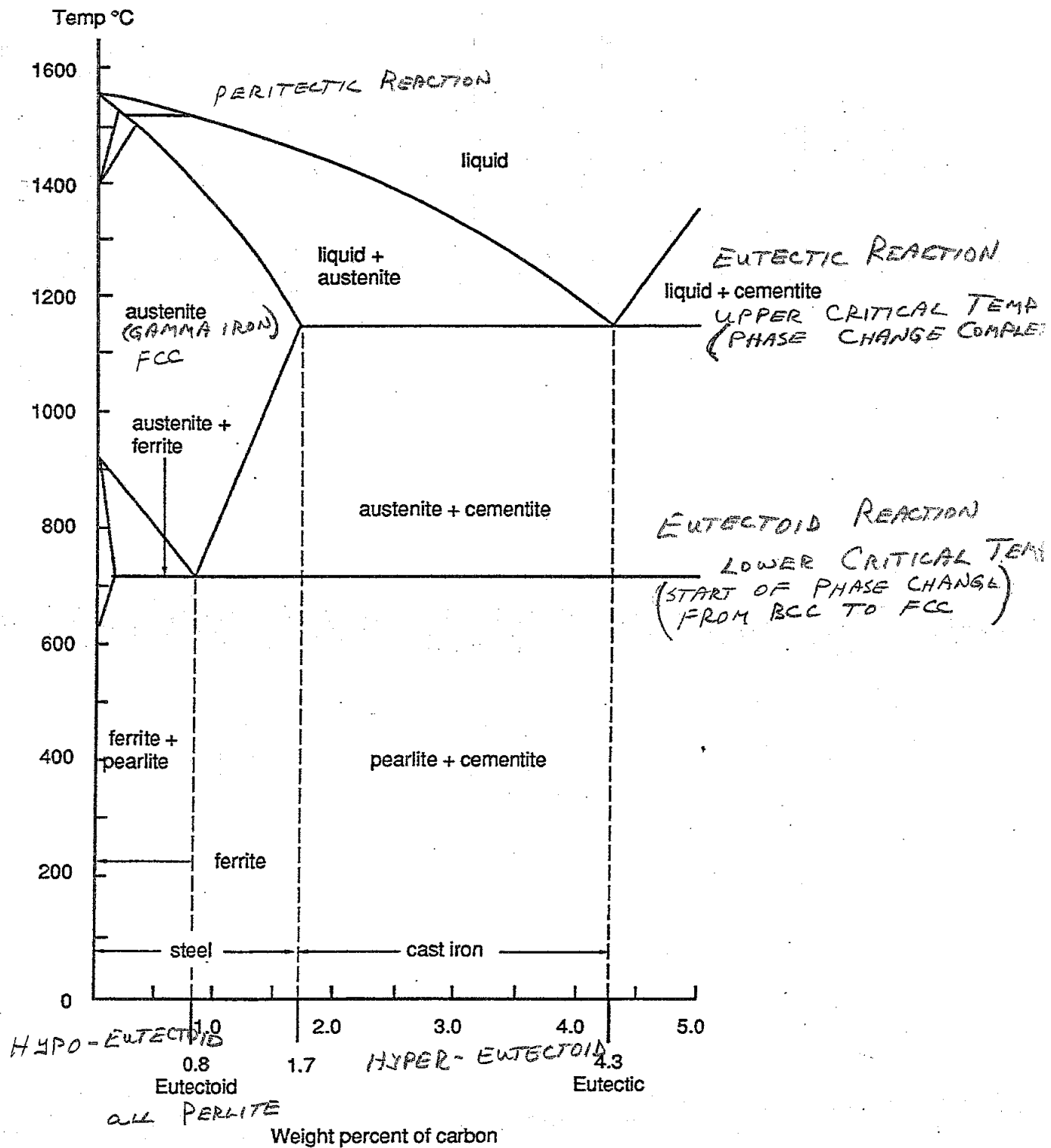
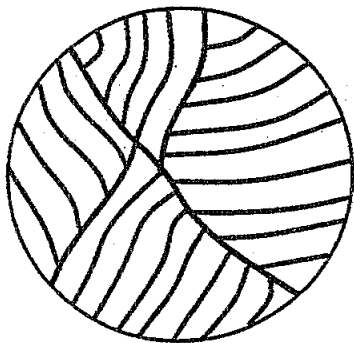


Figure 22. Iron-carbon diagram.

Effect of cooling rate

The phase diagram in Fig. 22 only applies to ideal equilibrium conditions and the structures will only change at the temperatures shown if heating and cooling rates are very slow. If the rate of cooling is increased, transformation occurs at a lower temperature. This will also influence the type of structure produced. Consider, for example, the pearlite structure discussed previously. Under very slow cooling conditions the coarse, layered structure shown in Fig. 20(b) will form. If the cooling rate is faster, the pearlite formed will be finer. With even faster cooling rates there may not be enough time to form layers of ferrite and cementite and the carbide will form as small rods or particles. With the very fast cooling rate of a quench there is not time to form carbides and the carbon gets trapped in the ferrite. Normally, ferrite dissolves only a small amount of carbon and this extra trapped carbon distorts the bcc structure of the ferrite. The result is a very hard needle-like structure called martensite. The progressive change of microstructures formed in steel, when the cooling rate is increased, is shown in Fig. 23.



Coarse Pearlite

Very slow cooling rate



Fine Pearlite

Increased cooling rate



Martensite

Mass of interlocking needles
Very fast cooling rate (quench)

Figure 23. Effect of increasing the cooling rate on the structure of steel.

If the hardness of the structures shown in Fig. 23 were measured, an increase would be found as the cooling rate became faster. The finer pearlite is slightly harder than the coarse pearlite, but the martensite is very much harder (Fig. 24). This ability to form structures of different hardness (and strength) by changing the cooling rate is the basis of the heat treatment of steels. With carbon steels, the increase of hardness is quite rapid when the critical rate to form martensite is exceeded. With alloy steels, the curve is far more gradual.

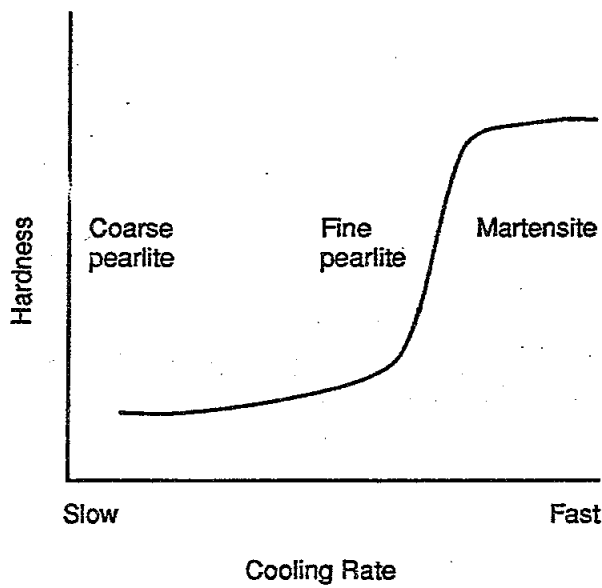


Figure 24. The hardness increases with cooling rate.

Effect of composition

The hardness of martensite depends on the carbon content, but although a high carbon martensite will be extremely hard and strong, it will also be very brittle. Fig. 25 illustrates the increase of martensite hardness with carbon content. Perhaps of more importance than the effect of carbon on martensite hardness, is the effect of carbon and other alloy elements on the critical cooling rate to produce martensite. By adding certain elements such as chromium to the steel, it is found that martensite will form at much slower cooling rates than in a plain carbon

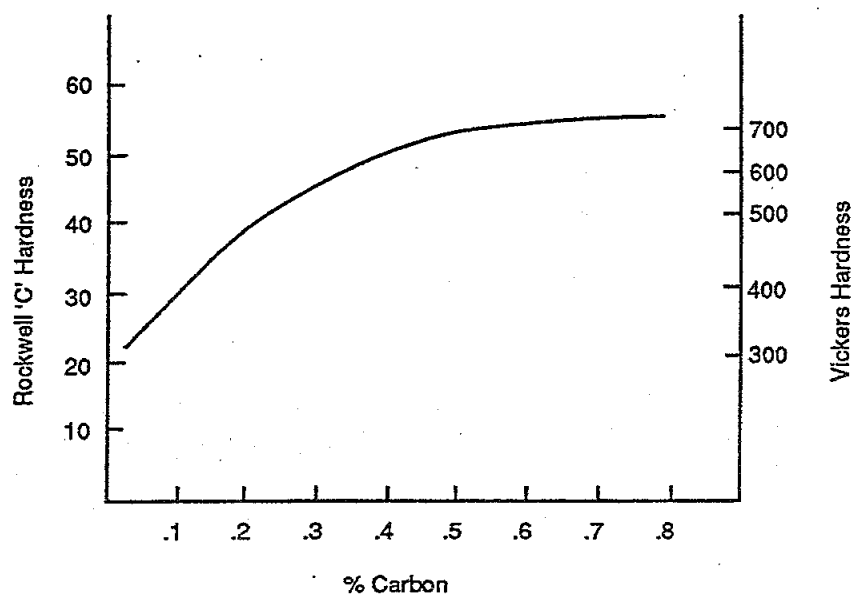


Figure 25. The effect of carbon content on martensite hardness.

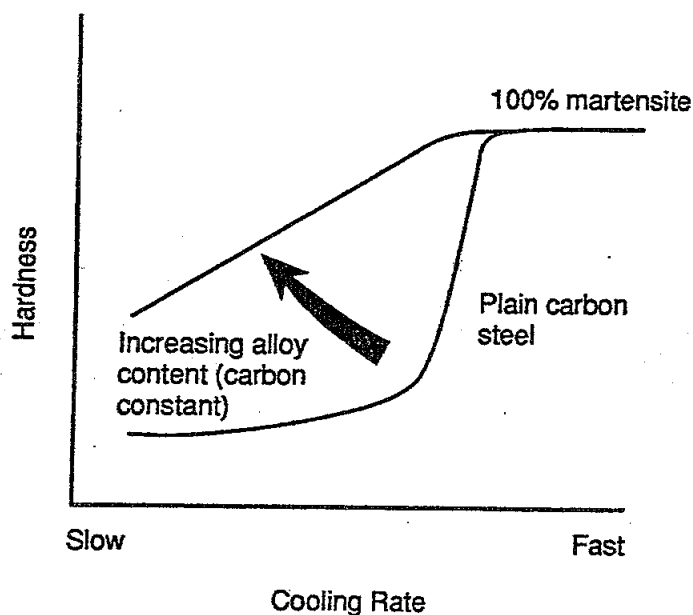


Figure 26. The effect of increasing alloy content on the hardenability of a steel.

steel. In fact, with high levels of alloy elements (e.g., 12% chromium), martensite will form even with an air cool. Combinations of elements have a greater effect than single elements and this has led to a wide range of complex alloys. The ability of the steel to form martensite at a given cooling rate is called *hardenability*. Fig. 26 shows the effect of increasing alloy content on the hardness/cooling rate curve.

When a bar is quenched, the cooling rate is fastest at the surface but the centre of the bar cools more slowly. If it is desired to harden the bar completely through, then the steel must have sufficient hardenability to form martensite at the centre of the bar where it is cooling more slowly. A 25 mm diameter bar of plain carbon steel would only be hardened to a depth of about 6 mm when water quenched, but an alloy steel would easily be hardened right through.

If a steel is being heat treated to produce maximum hardness, it must be heated prior to quenching at a temperature sufficient to remove any ferrite present. For steels less than 0.8% C this must be the fully austenitic region, but for steels above 0.8% C the mixed austenite/cementite region above 723°C is sufficient (see Fig. 27).

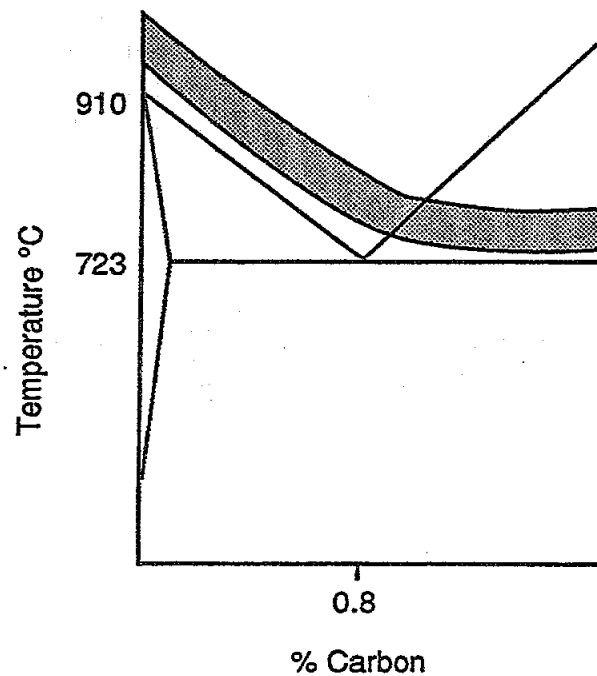


Figure 27. Heating range prior to quenching for full hardening.

Tempering

It was mentioned that martensite, particularly with high carbon, is extremely brittle and would have limited applications. Fortunately, the martensite can be *tempered* to enhance its toughness although there will also be a loss of hardness.

Tempering involves reheating the martensite to a temperature less than 723°C. Thus there will be no change in the crystal structure, but carbon trapped in the martensite can diffuse out and form small carbide particles. The fine particles and small grain size still provide a high strength, but tempered martensite will be much tougher. The loss of hardness and change in other properties will depend on the tempering temperature selected (Fig. 28). It is important that a quenched and tempered steel is never heated during fabrication to a temperature higher than its tempering temperature, otherwise there could be loss of tensile strength.

Example Tempering of AISI 4340

Nominal composition		Heat treatment of test specimens
C	0.38 - 0.43 %	Normalized 871°C Quenched from 843°C in oil and Tempered at 56°C intervals in 13.7 mm rds Tested in 12.8 rounds
Mn	0.60 - 0.80	
P	0.040 max.	
S	0.040 max.	
Si	0.20 - 0.35	
Ni	1.65 - 2.00	
Cr	0.70 - 0.90	
Mo	0.20 - 0.30	

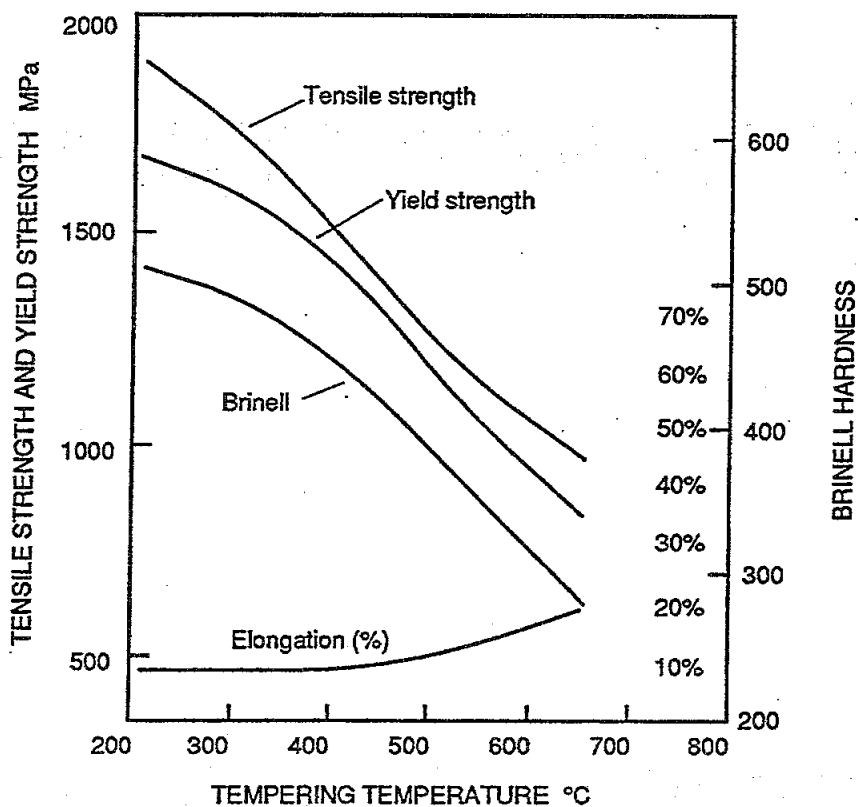


Figure 28. Effect of tempering temperatures on mechanical properties.

When a steel is heated sufficiently to cause the structure to transform, new grains must grow, a process called *recrystallization*. The grains will grow to a size dependent on the temperature, and at high temperatures considerable grain coarsening can occur. Fig. 29 shows the austenite grain size of a steel as a function of temperature. In some steels, certain elements, such as aluminum, are added, forming small particles which can restrict grain growth because they can be heated to a higher temperature before grain coarsening occurs. This is typically referred to as "fine grain practice". However, this should not be confused with the term "fine grain steel" where an actual test is made to determine grain size.

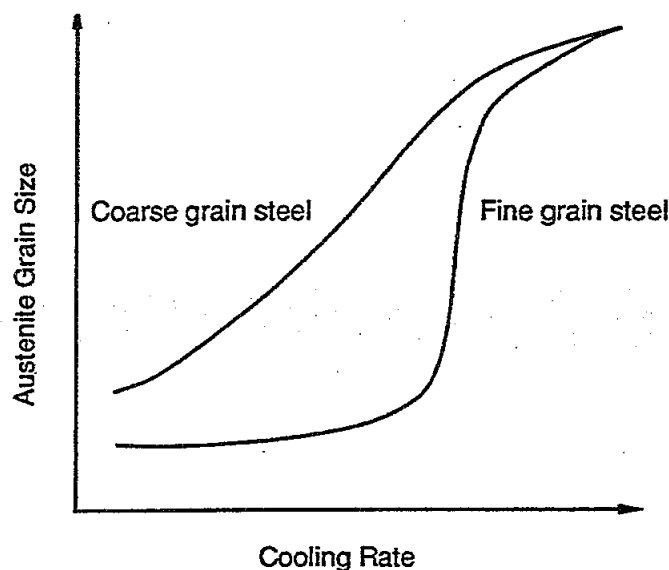


Figure 29. Effect of temperature on the austenite grain size.

Know
NORMALIZING
& ANNEALING.

It was mentioned earlier that a fine grain size improves the toughness of the steel, and hence fine grain steel is often specified. *Normalizing* is a process for refining the grain size of the steel to improve its properties. It entails heating the steel just into the fully austenitic region to allow recrystallization (but not high enough to coarsen the grain) followed by cooling in air. Relatively rapid cooling produces a fine ferrite/pearlite with good toughness. If a furnace cool is used, a coarse pearlite is produced with lower toughness and lower hardness. This process is known as *annealing* (Fig. 30). The temperature range used for normalizing and annealing is shown in Fig. 31.

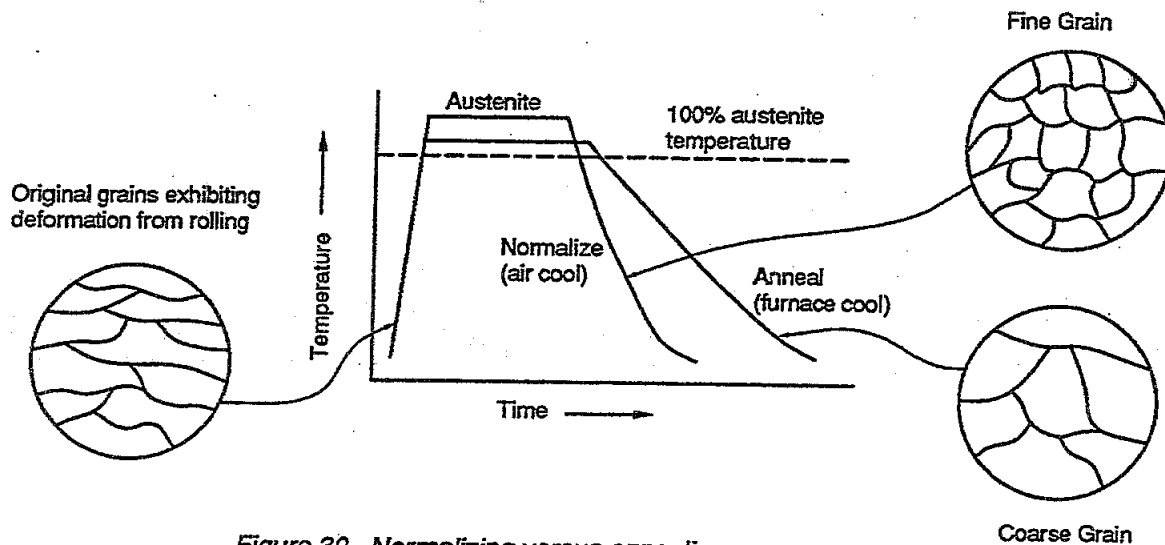


Figure 30. Normalizing versus annealing.

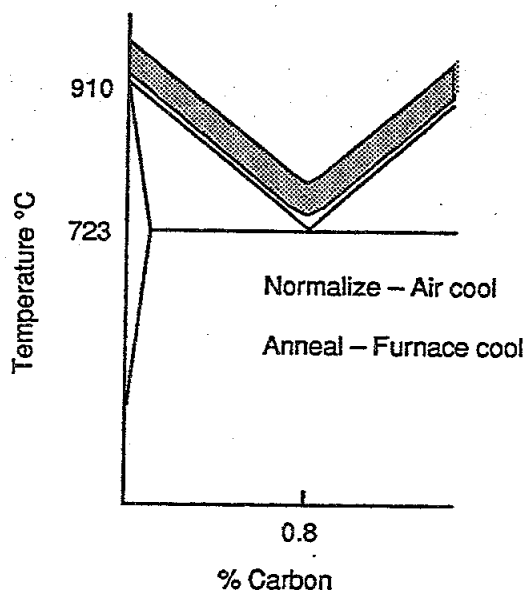


Figure 31. Temperature range for normalizing and annealing.

Sometimes the forming of thick plates is carried out hot and this may be equivalent to a normalizing treatment. To be considered as a normalizing treatment, the temperature for hot forming must not be higher than a normalizing temperature (about 900°C, for a typical 0.25% C steel). If the forming temperature is too high, an additional normalize would be required to restore the fine grain size.

Hot rolling

Hot rolling is carried out in the austenitic region, but the mechanical working constantly breaks up the grains which then recrystallize. Modern controlled rolling methods continue the process to lower temperatures and this results in a very fine grain steel. Sometimes niobium (columbium) is added to further retard recrystallization leading to high strength steels of good toughness. A comparison in the toughness of typical structural steels for normalizing, controlled rolling, and different deoxidation practices is shown in Fig. 32.

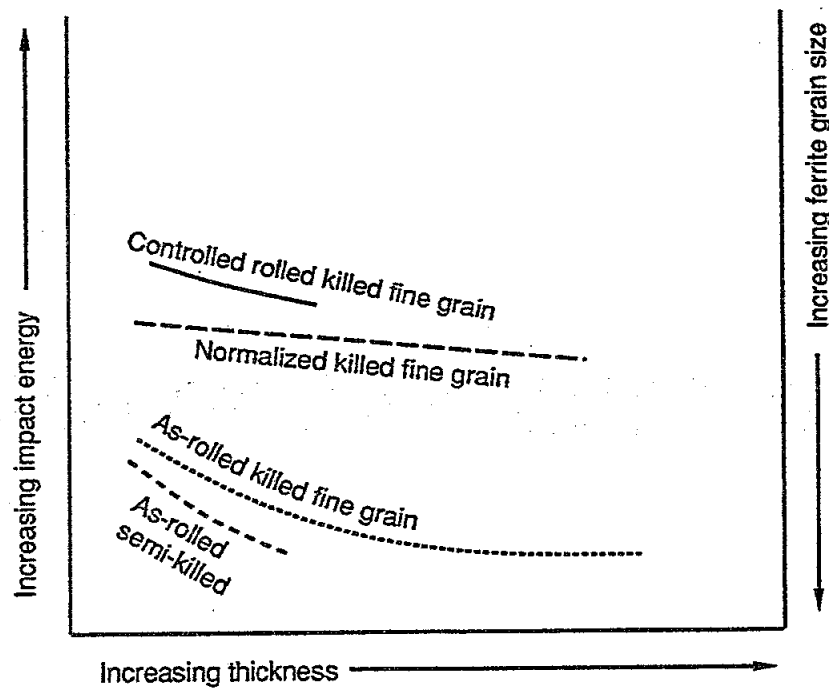


Figure 32. Effect of deoxidation practice and heat treatment on impact energy.

Hot shortness

A material susceptible to cracking during hot working operations is *hot short*. There may be several causes, one being the presence of high sulphur levels. Sulphur in the steel can form liquid films at the grain boundaries which pull apart during working. The presence of manganese counteracts this effect by forming manganese sulphides having a higher melting point.

COULD BE
T.Q

ALSO LEAD

Stress relief

A thermal stress relief treatment is often specified for welded fabrication for several reasons, including dimensional stability during machining, softening of any martensitic areas, and improvement of fracture resistance. A stress relief treatment should not cause any changes in the microstructure of the steel, except for tempering of martensite, and is therefore carried out below the transformation temperature (Fig. 33). Typically, a temperature of about 625°C is used and components are held at temperature for a period of time dependent on thickness. To avoid distortion and reintroducing additional stresses, the heating and cooling rates are very slow.

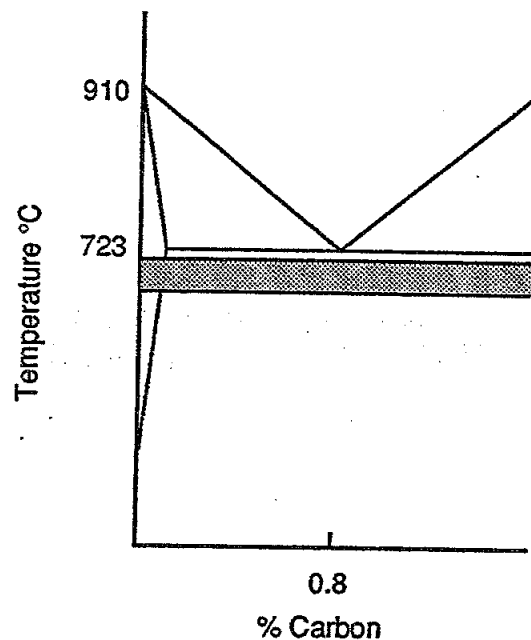


Figure 33. Stress relieving range.

Thermal stress relief is usually avoided on steels that have been quenched and tempered, but if carried out, the temperature must not exceed the tempering temperature.

There may be other heating operations carried out on a steel during fabrication such as flame straightening and preheating for welding. It is important to control these so that excessively high temperatures that could cause changes in the structure and properties, are not applied.

CLASSIFICATION AND SPECIFICATION OF STEELS

It is clear that a very wide range of steels with various compositions and properties can be made. Optimum compositions have been developed for many specific applications and are covered by specifications which serve as a guide to their selection. In this section the characteristics of the various groups of steels will be discussed and the main features of steel specifications will be presented. In a field as broad as this it is impossible to be completely thorough and only the salient points will be touched on.

In the first section of this module a rough grouping of ferrous materials was given. This is expanded here to provide a slightly more detailed grouping of steels. Three major groups are identified:

- Carbon steels
- Low alloy steels
- Alloy steels

The last group, alloy steels, are hard to classify because they are often designed for specific applications, but some of the more important steels are discussed in the following sections.

Carbon steels represent the simplest type but a very wide range of properties are obtainable by varying the carbon content. Their low cost and ability to satisfy a broad spectrum of applications make them the most important group of steels. Table 3 shows the types of applications for carbon steels of various carbon levels. Steels above about 0.30% carbon would often be heat treated to produce high strength. The addition of carbon increases the strength in the as-rolled condition (not heat treated) by increasing the percentage of pearlite in the structure. Fig. 34 shows the increase of tensile strength with carbon content for steels with a fine pearlite structure. Increasing the carbon content will, however, reduce the ductility of the steel as shown in Fig. 35.

Classification
of steels

Carbon steels

Basic Steel Metallurgy and Material Specification

Table 3. Applications of carbon steels.

Know THIS.

Carbon Content %	Typical Uses
0.05 - 0.15	Sheet steel products, nails, tubing
0.15 - 0.30	Structural steel plates, forgings, screws
0.30 - 0.50	Crankshaft forgings, gears, axles
0.50 - 0.80	Rails, drop-forging dies, leaf springs, cold chisels, hammers, band saws
0.80 - 1.0	Coil springs, punches, dies
1.0 - 1.2	Twist drills, taps and dies, lathe tools
1.2 - 1.4	Files, razors, ball races

.3 → .45
MED CARBON
.45 - .75
HIGH CARBON
.75 -
VERY HIGH
CARBON

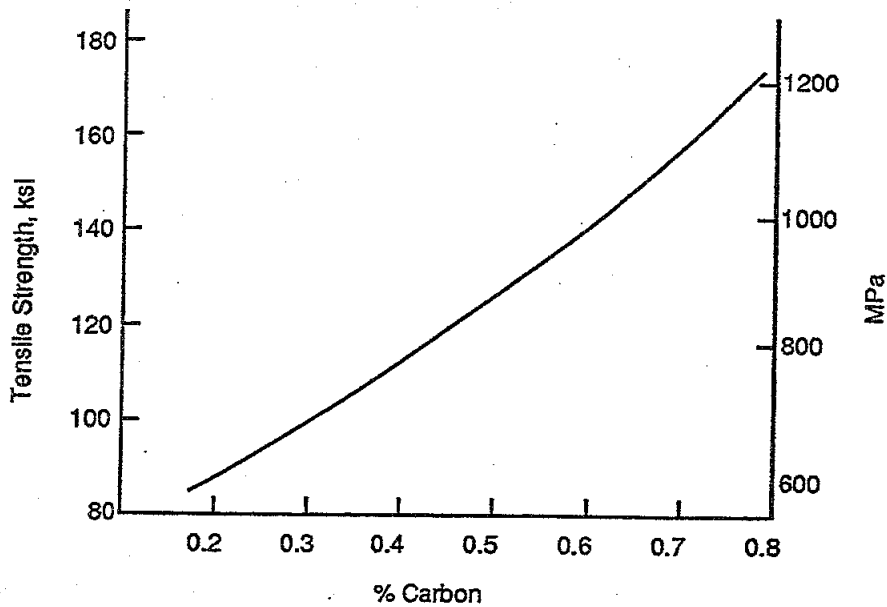


Figure 34. Increase of tensile strength with carbon content.

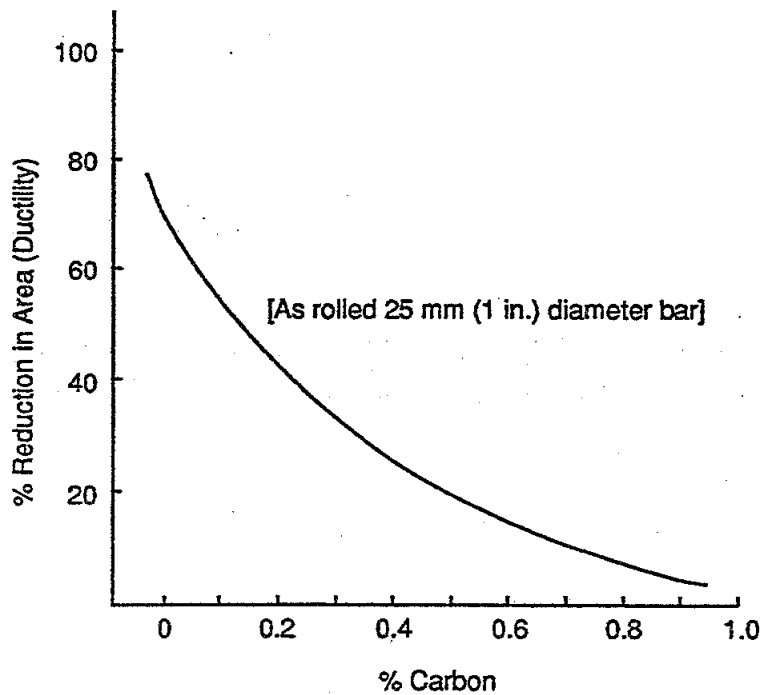


Figure 35. Decrease in ductility with increase in carbon content of plain carbon steels.

The largest tonnage of steel is produced in the form of sheet and strip having a composition in the range:

Carbon	0.03 - 0.12%
Manganese	0.2 - 0.6%
Phosphorus	0.04% max.

with other elements as low as possible. Much of the steel for sheet is made from rimmed steel ingots, since this provides an excellent surface. When steels are intended for deep-drawing applications the carbon and manganese levels are further restricted. To avoid local yielding when deformed they are usually given a slight reduction by cold rolling, known as temper rolling. Temper rolled sheet steels may be susceptible to *strain ageing* and if stored for a period of time, they will show irregular yielding when deformed. Strain ageing is a characteristic of rimmed steels and for extra deep-drawing applications fine grained fully killed steels containing aluminum may be justified.

Carbon steel plates for structural applications are made by hot rolling and have a ferrite-pearlite microstructure. Since a thin plate is deformed more and cools quicker than a thick one, it tends to be stronger for the same carbon content. To adjust for this, thicker plates will generally have a higher carbon content than thin plates. A typical composition of a carbon steel for structural applications is given in Table 4.

Table 4. Typical composition of carbon steel for structural uses.

Plate Thickness	Carbon C	Manganese Mn	Silicon Si	Sulphur S	Phosphorus P
13 mm (1/2 in.)	0.15	1.0	0.05	0.02	0.01
51 mm (2 in.)	0.23	1.0	0.25	0.02	0.01

Deoxidation practice may also vary depending on the thickness of the plate, a thick plate often being fully killed, whereas a thin plate may not be. The percentage of silicon in the steel may give an indication of the deoxidation practice, since a fully killed steel would usually have about 0.15 to 0.3% silicon.

The major group of low alloy steels are those intended for various structural applications and have higher yield strengths than carbon steels, but retain good weldability and formability. They are generally known as *high-strength low alloy steels*, *HSLA* steels. A wide range of such steels is available and many combinations of alloying elements are used. In many cases, high strength can be achieved with low carbon levels which greatly improves the weldability, and there has been a continuing trend, particularly for applications such as pipelines, to reduce the carbon content. Many of these steels achieve a high strength by having a very fine grain size and this provides the added advantage of excellent toughness. A variety of methods are used to achieve fine grain size. Among these are the use of grain refining elements such as aluminum or vanadium, possibly followed by a normalizing treatment. More recently, controlled rolling techniques and the use of niobium (columbium) to retard recrystallization, have been used. An additional benefit of many HSLA steels, particularly those containing copper, is

Low alloy steels

improved resistance to atmospheric corrosion. They may be 4 to 6 times more corrosion resistant than a carbon steel (Fig. 36).

Some low alloy steels are heat treated by quenching and tempering to achieve high strengths (yield strength exceeding 700 MPa. They usually employ boron in small quantities to provide sufficient hardenability to allow plates up to 50 mm, and sometimes more in thickness, to be made. The carbon content is kept low (0.2% maximum) to maintain good weldability and toughness. Typical uses of these steels include earth-moving and mining equipment, pressure vessels and parts of bridges.

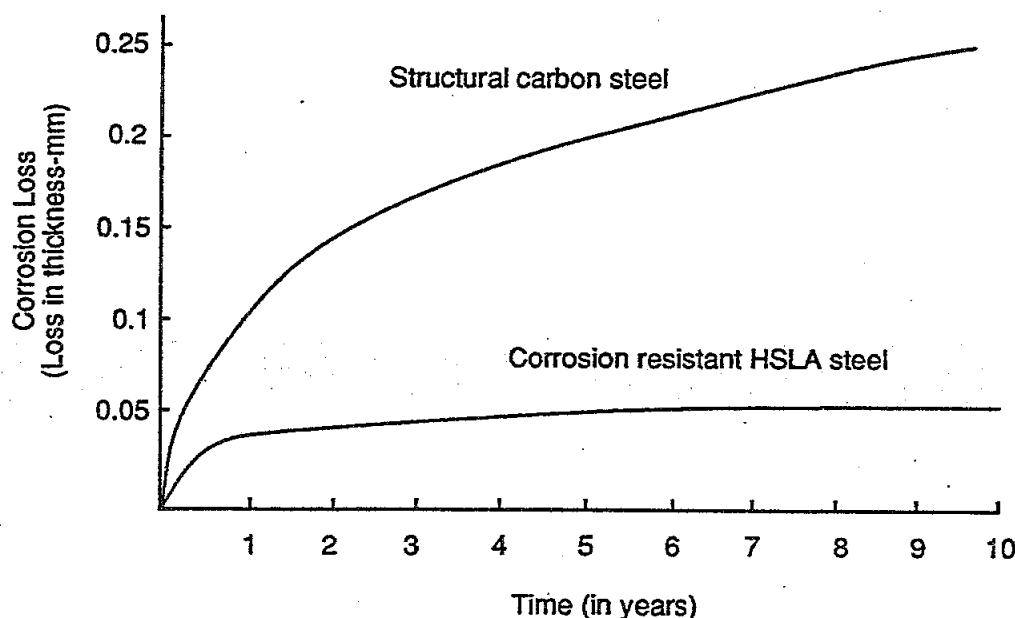


Figure 36. Typical atmospheric corrosion losses in structural carbon and HSLA steels.

Alloy steels

Alloy steels as bars and forgings intended for *heat treating* will contain alloying elements to provide adequate hardenability. The effect of a particular alloying element can be expressed in terms of a *multiplying factor* which relates to the maximum diameter of a bar that could be hardened. The larger the multiplying factor, the more hardenable is the steel and therefore bars of greater diameter could be hardened by quenching. Some multiplying factors for a number of elements are given in Fig. 37. A large number of elements are used to increase hardenability and a combination of several elements is found to be more effective than a large amount of a single element. Some elements are added for their effect on the tempering behaviour of the steel.

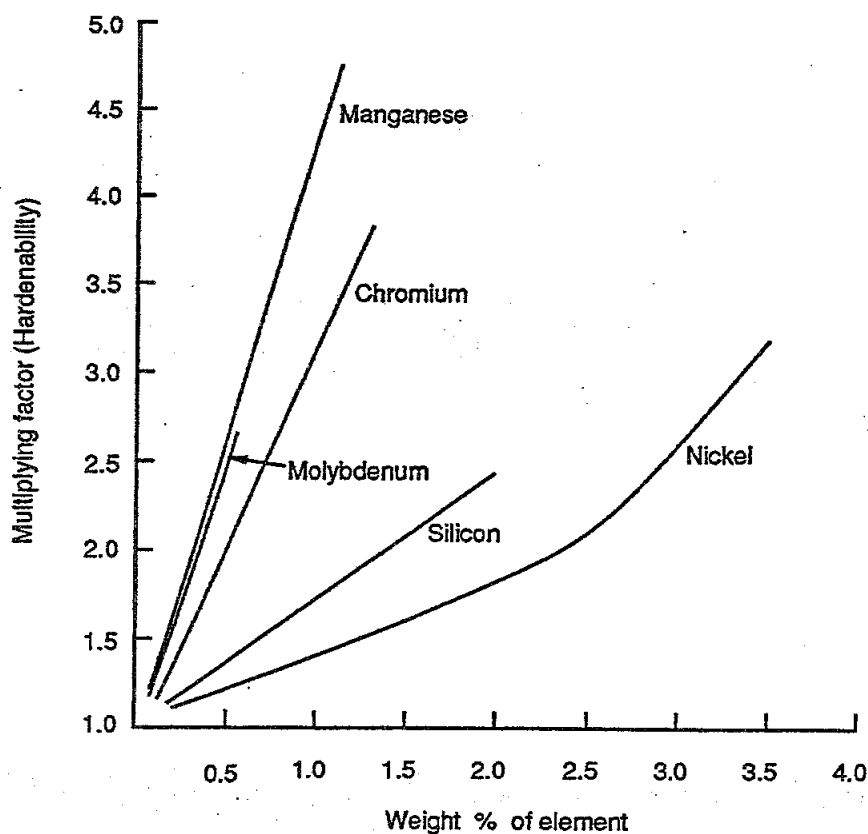


Figure 37. Effect of various alloy elements on hardenability.

Alloy tool steels, in addition to high hardenability, are designed to have good resistance to tempering (retain hardness at high temperatures) and good wear resistance. The chief alloying elements to achieve these properties are chromium (Cr), tungsten (W), vanadium (V) and Cobalt (Co). These elements can form carbides in the steel which are small hard particles that provide wear resistance and limit tempering.

Other alloying systems have been developed for specific applications and will not be discussed here. The specific effects of a few other alloying elements will be mentioned.

Sulphur is normally regarded as an impurity and is kept as low as practicable. In excessive amounts it may lead to hot shortness, and the presence of manganese sulphide inclusions may reduce the ductility and cold formability of the steel. Sulphur does, however, along with lead (Pb), have a beneficial effect on machining and is deliberately added in free machining steels.

Silicon has been discussed as a deoxidizing element when used in small quantities and in this role has a small effect on hardness. Greater levels of silicon affect the electrical and magnetic properties of steel, and steels with 0.5 to 5% silicon are widely used in the electrical industry in such things as transformer cores.

Chromium's effect on hardenability has been mentioned but a major property is its effect on corrosion resistance. For this purpose it is used in amounts (typically 18%) in stainless steels.

Nickel is also used in stainless steels (typically 8%) because it allows the steel to exist in the austenitic (fcc) form at room temperature. In smaller quantities it is used in structural steels to obtain excellent toughness at low temperatures.

Manganese is beneficial at levels up to about 2.0% to improve strength, increase hardenability and reduce the detrimental effects of sulphur. At higher level, like nickel, it has the ability to form an austenitic structure at room temperature and such steels containing 10 - 14% manganese have excellent resistance to impact and abrasion. They are used in mining equipment, shovel teeth, etc.

A number of organizations issue specifications for steel. These have become essential in the purchasing process and assuring the quality of materials used in fabrication. Different industries have developed their own specifications for their particular needs and they differ substantially in detail. Simple specifications cover only the chemical composition range of the steel, whereas those that are more complex include the steel making method, heat treatment, composition, mechanical properties and many other requirements.

For the purchaser, the specification is a description of what is being bought, but it may not cover all the properties and characteristics of the steel. It is important that the purchaser does not make incorrect assumptions regarding properties not covered by the specification. If the additional properties are required (e.g., toughness) they must be specified separately. A further point is that there may be tolerances on the values quoted which may be included in a separate document, such as a specification covering general requirements, common to many steel specifications.

Steel specifications

Professional societies, standards associations, government agencies, etc., all write specifications and it is not possible to cover all of them here. The main organizations involved in steel specifications are listed in Table 5 and it will be seen that several of them use the same numbering system.

The organizations that usually write the specifications for steel products in particular are shown in Table 6. Those that are most widely encountered by welding personnel are the ASTM and CSA specifications which will be discussed more fully later.

Table 5. Major organizations issuing specifications for steels.

SHOULD KNOW THESE ABBREVIATIONS

CSA Canadian Standards Association	Issues a wide variety of standards including one which covers structural quality steels, G40.21.
SAE Society of Automotive Engineers	A professional society of engineers in the field of ground, air and space transportation. Originated the SAE system of steel specifications.
AISI American Iron and Steel Institute	An association of steel producers which issues steel specifications and co-operates with SAE in using the same numbering system.
ASME American Society of Mechanical Engineers	A professional society of mechanical engineers that issues codes for boilers and pressure vessels. The ASME co-operates closely with ASTM in issuing steel specifications.
ASTM American Society for Testing and Materials	Writes specifications for a wide range of materials and the ASTM steel specifications are extensively used in the steel fabrication industry.

Table 6. Main organizations issuing specifications for steel products.

Steel Product	Main Organization Issuing Specification
Structural Steel Plates and Shapes	CSA, ASTM
Steel Sheets	AISI
Steel Bars	SAE, AISI

The SAE and AISI system

KNOW THIS SYSTEM

The system of classification adopted by SAE and AISI is based on a code that indicates the composition range of the steel. It is not a detailed specification, but rather a steel designation. The system adopted by SAE is essentially the same as AISI differing only in minor details. Each steel in the system is given a numerical index that relates to its composition. Most indexes use four digits as follows:

- First digit indicates the major class
- Second digit indicates the sub-class (often the percentage of the major alloy element)
- Third and fourth digits indicate the carbon level (in hundredths of a percent)

TYP T.9. WHAT IS CARBON CONTENT OF 1020 STEEL.

Table 7.

First Digit -- Major Class:	Alloy Type
1	Carbon Steel
2	Nickel Steel
3	Nickel-Chromium Steel
4	Molybdenum Steel
5	Chromium Steel (not stainless)
6	Chromium - Vanadium Steel
7	Tungsten-Chromium Steel
8	Nickel-Chromium-Molybdenum Steel
9	Silicon-Manganese and Other Complex Steels

Table 7. (cont)

Sub Classes:	Alloy Type
10 11 12 13	Plain carbon Plain carbon resulphurized Plain carbon resulphurized and rephosphorized Plain carbon with additional manganese
21 23 25	1% Nickel 3.5% Nickel 5% Nickel
31 33	1.25% Nickel – 0.65% Chromium 3.5% Nickel – 1.55% Chromium
40 41 43, 47 46, 48	0.25% Molybdenum Chromium-Molybdenum Nickel-Chromium-Molybdenum Nickel-Molybdenum
50 51	Low Chromium 1% Chromium
61	Chromium-Vanadium
81, 86, 87, 88	Nickel-Chromium-Molybdenum
92 93	0.85% Manganese – 2% Silicon Nickel-Chromium-Molybdenum

Carbon content
(last two digits)

The alloy types in the SAE system are shown in Table 7. This covers the main examples, but is not a complete listing.

The nominal carbon content in hundredths of a percent is usually given by the last two digits. For example:

1020 is a carbon steel with 0.20% carbon

4340 is a Ni-Cr-Mo steel with 0.40% carbon

The actual range of carbon depends on the level of carbon and varies somewhat with the steel. For example, a 1010 steel has a carbon in the range 0.08 to 0.13%, but a 1060 steel has a range 0.55 to 0.65% carbon.

ASME system

- The prefix "E" denotes steel made in the electric furnace, e.g., E4340
- The letter "B" (between 2nd and 3rd digit) denotes boron, e.g., 51B60
- "BV" denotes boron-vanadium and L is a leaded steel
- Steels with a specified hardenability have the suffix "H"

ASME uses the same designation as ASTM for steel specifications. Section IX of the ASME has adopted a grouping system for the purposes of welding procedure qualification allowing a number of different steels to be considered under one group. A welding procedure qualified on one steel is then valid for all steels in that group. The grouping is based on the "P" number classification as shown in Table 8.

Table 8. "P" grouping of steels according to ASME Section IX (refer to ASME for details).

P1	Carbon-manganese steels [45 to 90 ksi (310 - 621 MPa) minimum specified UTS]
P3	Alloy steels with 0.5 % molybdenum and total alloy content not exceeding about 2%
P4	Alloy steels with chromium 0.5% to 2% and total alloy content not exceeding about 2.75%
P5	Alloy steels with chromium 2.25 - 9% and total alloy not exceeding about 10%
P6	High alloy stainless steels—martensitic
P7	High alloy stainless steels—ferritic
P8	High alloy stainless steels—austenitic
P9	Nickel alloy steels
P10	Other alloy steels (P10 steels require separate welding qualification for each material)
P11	High strength nickel alloy steel High strength manganese molybdenum nickel steel High strength chromium molybdenum steel

ASTM system

This is the most extensive system for materials specification and is the most important for welding personnel. The specification number provides no information on the material itself (as in the case with the SAE-AISI system) but the first letter does indicate the class of material. Ferrous materials (steels etc.) begin with the letter "A". Sometimes the

year of adoption or most recent revision is included as a suffix. A typical ASTM specification would include the following:

- A reference to another specification covering general requirements (ordering information, quality, dimensional tolerance, etc.). For structural steel this is A6/A6M and for pressure vessel steel A20/A20M.
- Process for steel making (e.g., open hearth, basic oxygen, etc.) and whether the steel is fine grained.
- Any requirements for heat treatment (e.g., normalizing).
- Chemical composition requirements. This is usually given in a table of maximum (and/or minimum) values for various elements. Sometimes a number of grades are included.
- Mechanical property requirements.
- Other requirements such as Charpy impact tests and supplementary requirements that may be included at the option of the purchaser (e.g., vacuum treatment, ultrasonic inspection, etc.).

A brief list of some of the more important ASTM steel specifications is given in Table 9.

It is recommended that anyone using ASTM specifications read thoroughly the specifications for general requirements. These are:

A6/A6M General requirements for rolled steel plates, shapes, sheet piling, and bars for structural use.

A20/A20M General requirements for steel plates for pressure vessels.

These two differ substantially in detail particularly in regard to the quality of the plate. A6/A6M allows certain defects to be repaired by welding at the discretion of the producer, whereas A20/A20M allows repair welding only with the agreement of the purchaser. A6/A6M contains a table of tolerances on chemical composition. For example, a structural steel with a specific maximum carbon level of 0.20% may have up to 0.24% when a check on the product composition is made. Significantly, there is no limitation on carbon, phosphorus and sulphur

General
requirements

READ ONLY
PP 42-45

Table 9. Brief list of some important ASTM steel plate specifications.

Type of Product	ASTM Specification	General Description
Structural Steel (A6/A6M applies)	A36	Carbon steel for general construction.
	A242	High strength low alloy steel. Some of the alloying elements used are specified. Good atmospheric corrosion resistance.
	A441	HSLA steel employing manganese, vanadium, and copper.
	A514	High yield strength steel. Quenched and tempered. Fully killed fine grain steel.
	A572	HSLA steel using niobium (columbium) and/or vanadium.
	A588	HSLA steel. Several grades with various alloy contents. Achieves 345 MPa yield point to 100 mm thick.
	A633	Normalized HSLA steel. A fine grain steel with good low temperature toughness.
	A710	High yield strength, low carbon age-hardening steel.
Pressure Vessel Steels (A20/A20M applies)	A387	Chromium-molybdenum alloy steel for elevated temperature use in boilers and pressure vessels.
	A515	Carbon steel, usually coarse grain, for intermediate and higher temperature service. Plates over 50 mm are normalized.
	A516	Carbon steel, fine grain, for moderate and lower temperature service. Plates over 38 mm are normalized.
	A533	Quenched and tempered alloy steel. Has been used in nuclear reactor vessels.
	A537	Carbon-manganese-silicon steel in either normalized or quenched and tempered condition.

CSA standards

for rimmed or capped steels when a product analysis is undertaken because of segregation, even though the heat analysis (i.e., samples taken from the ladle before the ingot is poured) is specified. A20/A20M does not contain a table of tolerances on composition since they are generally contained within the steel specification itself.

Both specifications contain considerable information on dimensional tolerances, standard product sizes, identification, marking, etc.

The Canadian Standards Association issues standards for structural steels, but CSA Standards do not cover pressure vessel steels. As with the ASTM system, a separate standard covers the general requirements.

CSA G40.20-M92 General requirements for rolled or welded structural quality steel.

CSA G40.21-M92 Structural quality steels.

The CSA Standards include a large number of grades covering a wide range of structural steels within the standard.

The general requirements cover tolerances on composition, dimensions, etc., and also include mechanical testing requirements. An important general requirement is identification. Plates must be marked with:

- The heat number and producer's name or brand
- Steel material standard designation and grade
- The size and thickness (or nominal mass, when so ordered)

The methods for marking the plate are specified in a table in the standard.

There are eight types of steel covered by the CSA G40.21M Standard and these are listed in Table 10. This grouping becomes useful in design since the steel type with the appropriate properties may readily be selected. As with all steels, the welding procedures must be suitable for the material and the intended application. When a notch tough grade (T) is selected, a category specifying test temperature must be specified. For each of the six types of steels there are a number of grades covering a range of yield strength levels.

Table 10. Types of steels covered in CSA G40.21M.

Type	General Description
G	General Construction Steel. Primarily designed for bolted applications but can be welded under controlled conditions. Usually a semi-killed steel.
W	Weldable Steel. For general welded construction where notch toughness at low temperatures is not a prime consideration. Usually semi-killed, up to 40 mm and fully killed over 40 mm.
WT	Weldable Steel. For welded construction where good low temperature toughness is a prime consideration. Toughness category must be specified by the purchaser. Usually killed fine grain.
R	Atmospheric Corrosion-Resistant Structural Steel. For welded construction where toughness at low temperature is not a prime consideration e.g., unpainted light structural members.
A	Atmospheric Corrosion-Resistant Structural Steel. For welded construction, low temperature toughness is not a prime consideration.
AT	Atmospheric Corrosion-Resistant Weldable Notch Tough Steel. For welded construction, low temperature toughness is a design consideration. Toughness category must be specified.
Q	Quenched and Tempered Low Alloy Plate. High yield strength steels. Welding procedure is critical if the properties of the plate are not to be adversely affected.
QT	Quenched and Tempered Low Alloy Notch Tough Steel Plate. Toughness category must be specified. Welding procedure is critical if the properties of the plate are not to be adversely affected.

The foregoing is intended only as a brief introduction to steel specifications and the specifications themselves should be studied for further information.

Additional Resources

The Making, Shaping and Treating of Steel. Published by United States Steel. (A comprehensive reference work on all aspects of steel making).

Metallurgy for Engineers, Rollason. Published by Edward Arnold.

American Society for Metals Handbook, Volume I.

GUIDES AND EXERCISES

MODULE 8

BASIC STEEL METALLURGY AND MATERIAL SPECIFICATION

BASIC STEEL METALLURGY AND MATERIAL SPECIFICATION

MODULE 8

Guides & Exercises

To obtain maximum benefit from this module we suggest that you follow this guide and complete the exercises as indicated. It is important that you work through the text methodically, studying each section thoroughly before moving on. The exercises are designed to give you an indication of whether you have learned the material and can move on or whether you need to go back and study the section again.

Do the exercises honestly. They will not help you unless you take them seriously. If you get a question wrong go back through the text until you understand where you have gone wrong and know the correct answer.

The length of time required to complete the module will vary from student to student. Find your own pace. Do not rush. Remember you are trying to learn something, not win a race.

Some people like to underline sections when they read a text. We suggest that you use caution if you do this. What you think is important first time you read it may be different after reading it three times. We suggest you read a section three times thoroughly before highlighting anything.

The last exercise is designed to give you an indication of whether you are ready to take the closed-book exams. The exercise questions are of a similar standard to the official exams. Do not take the exam until you feel you are ready and you may wish to study several Modules before taking the exams on each. The details of the examination procedures are on a separate sheet.

If you have any difficulties with this Module do not hesitate to ask for help. You may find you learn more by attending seminars which are given periodically, and you should also contact your local WIC Chapter to see if they can be of assistance. Remember, if you fail the examination you can always try again later.

After working through each guide, check your answers (on page 54) for accuracy. If any of your answers are wrong, restudy the guide subject matter in the text until you understand it before moving on to the next guide.

Guide 1

Read carefully pages 1 to 5 and answer the following questions:

1. From the following, select the ferrous metals.

- a) Wrought iron
- b) Copper
- c) Aluminum
- d) Carbon steel
- e) Stainless steel

2. What is taconite?

- a) Aluminum alloy
- b) Stainless steel
- c) Pig iron
- d) Iron ore
- e) Low alloy steel

3. True or false?

"Limestone is a fluxing agent that removes impurities to form a slag."

4. In the basic oxygen furnace what does the term "basic" refer to:

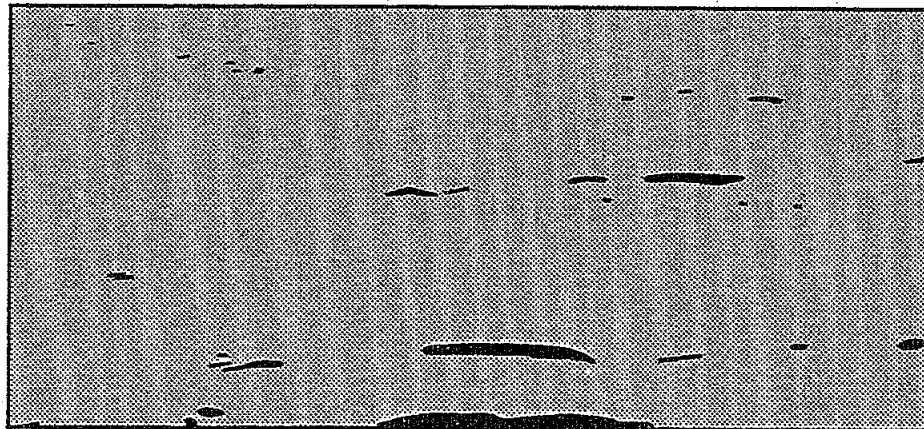
- a) The chemical nature of the molten steel
- b) The chemical nature of the refractory lining of the furnace
- c) The chemical nature of the steel after pouring

Guide 2

Read carefully pages 7 to 15 and answer the following questions:

1. In the electric furnace, what provides the heat to melt the metal charge?
2. What are the advantages of continuous casting over ingot casting?
3. When making semi-killed steel what is the usual deoxidizing material which is added to the melt?
 - a) Magnesium
 - b) Silicon
 - c) Aluminum
 - d) Manganese
4. True or false?

"Alloy steels and steels with greater than 0.3% carbon are fully killed."
5. What does the illustration depict?



Guide 3

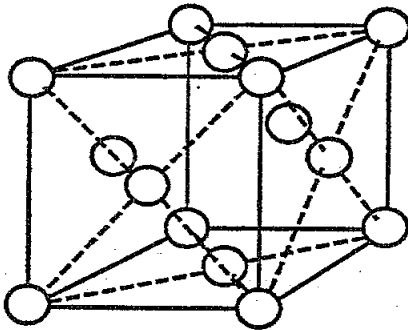
Read carefully pages 16 to 23 and answer the following questions:

1. True or false?

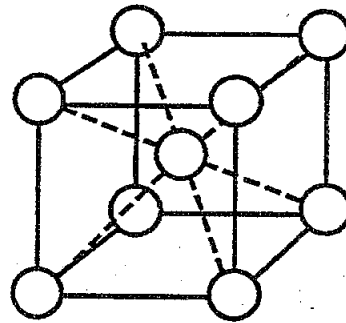
"Metals have a crystalline structure in which the atoms are arranged in an *irregular pattern*."

2. Apply the correct description to each of the illustrations:

(a)



(b)



3. Ferrite, austenite, and cementite are known as:

- a) Particles
- b) Elements
- c) Phases

4. Which is the harder—martensite or fine pearlite?

Guide 4

Read carefully pages 23 to 34 and answer the following questions:

1. Complete the following sentence—

If a steel is being heat treated to produce maximum hardness, it must be heated prior to quenching at a temperature sufficient to remove any.....present.

2. Martensite is extremely brittle. Can martensite be tempered to enhance its toughness?
3. When steel is normalized how is the steel cooled?
4. What are the three major groups of steels?

Guide 5

Read carefully pages 34 to 46 and answer the following questions:

1. Chromium has an effect on hardenability, what other major property does it affect?
2. In the SAE and AISI system of steel classification what does the designation 1020 signify?
3. Section IX of the ASME code has adopted P number groupings. For the purpose of welding procedure qualification, what is the P number for carbon steels (310 to 621 MPa minimum specified UTS)?
4. Which of the following ASTM specifications are for pressure vessel steels?
 - a) A516
 - b) A36
 - c) A533

ANSWERS

Guide 1

1. a), d), e)
2. d)
3. True
4. b)

Guide 2

1. An arc between carbon electrodes and the metal
2. Less segregation, less rolling required, less cost
3. b)
4. True
5. Nonmetallic inclusions in a steel plate

Guide 3

1. False
2. a) Face-centred cubic (fcc)
b) Body-centred cubic (bcc)
3. c)
4. Martensite

Guide 4

1. Ferrite
2. Yes
3. In air
4. Carbon steels, low alloy steels, alloy steels

Guide 5

1. Corrosion resistance
2. Carbon steel with 0.20% carbon
3. P1
4. a) and c)

MODULE 8

TEST

This test is designed to determine whether you are ready to attempt the formal examination.

Complete the ANSWER SHEET and compare the results with the TEST KEY. If you score less than 70% we suggest you restudy the material.

1. In steels, a small grain size will:
 - a) change the atomic arrangement from face-centred cubic to body-centred cubic
 - b) decrease the strength and toughness
 - c) increase the strength and toughness
 - d) decrease the carbon content
 - e) affect the chemical analysis
2. Which of the following processes produces most of the world's steel?
 - a) electric furnace
 - b) blast furnace
 - c) open hearth furnace
 - d) basic oxygen furnace
 - e) none of the above
3. At what point does the carbon content indicate that the material is no longer steel but cast iron?
 - a) beyond 1.7%
 - b) beyond 17%
 - c) beyond 7.1%
 - d) beyond 0.71%
 - e) beyond 0.17%
4. One of the causes of hot shortness in steel is the presence of:
 - a) high cobalt
 - b) high chromium
 - c) high manganese
 - d) high sulphur
 - e) high silicon
5. Rimmed steels—
 - a) are alloy steels with greater than 5% chromium
 - b) are vacuum degassed
 - c) have a layer of pure iron on the surface
 - d) are fully austenitic
 - e) are fully deoxidized

Basic Steel Metallurgy and Material Specification

6. What is the typical stress relief temperature specified for welded steel fabrication?
- a) 510°C
 - b) 625°C
 - c) 900°C
 - d) 955°C
 - e) 1066°C
7. The elements in alloy tool steels can form small hard particles which provide wear resistance and limit tempering. What is the name of the particles?
- a) eutectoids
 - b) carbides
 - c) sulphides
 - d) cementite
 - e) pearlite
8. The plates for pressure vessel are usually formed with the direction:
- a) around the circumference
 - b) parallel to vessel axis
 - c) diagonal to the axis
 - d) opposed to the direction of the hoop stress
 - e) none of the above
- 9) What is the usual charge in an electric furnace?
- a) pig iron and limestone
 - b) pig iron and chromium
 - c) molten pig iron and scrap
 - d) pig iron and manganese
 - e) completely scrap
10. To what types of steel is sulphur deliberately added?
- a) austenitic stainless steels
 - b) ferritic stainless steels
 - c) free machining steels
 - d) casting steels
 - e) pressure vessel carbon steels

Basic Steel Metallurgy and Material Specification

Complete the "Answer Sheet" and compare the results with the "Test Key". If you have a pass mark less than 70%, you are advised to re-study the material.

Please circle only ONE letter corresponding to the answer you think is most correct.

QUESTION	ANSWERS				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

The answer key below is provided for your use in the event that you wish to retest yourself.

QUESTION	ANSWERS				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

Basic Steel Metallurgy and Material Specification

Compare your answer sheet to this key.

QUESTION	ANSWERS				
1	a	b	(c)	d	e
2	a	b	c	(d)	e
3	(a)	b	c	d	e
4	a	b	c	(d)	e
5	a	b	(c)	d	e
6	a	(b)	c	d	e
7	a	(b)	c	d	e
8	(a)	b	c	d	e
9	a	b	c	d	(e)
10	a	b	(c)	d	e