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Guide for Inspection of Refinery Equipment

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Appendix—Inspection of Welding

FOURTH EDITION, SEPTEMBER 1985



American Petroleum Institute
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Guide for Inspection of Refinery Equipment

Appendix—Inspection of Welding

Refining Department

FOURTH EDITION, SEPTEMBER 1985

**American
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PREFACE

This chapter is one of a series that make up the manual *Guide for Inspection of Refinery Equipment*. It is based on the accumulated knowledge and experience of engineers and other personnel in the petroleum industry. All users are invited to submit suggested revisions to the director of the Refining Department, American Petroleum Institute, 1220 L Street, Northwest, Washington, D.C. 20005.

The information contained in this publication has been arranged in its present form as a means of facilitating continuity of presentation and convenience of reference. It does not constitute, and should not be construed to be, a code of rules, regulations, or minimum safe practices. It is not intended that practices described in this publication supplant practices that have proven satisfactory. Nor is it intended that this publication discourage innovation and originality in the inspection of refineries. Users of the publication are reminded that no book or manual is a substitute for good judgment.

The *Guide for Inspection of Refinery Equipment* is subdivided as follows:

Chapter I	Introduction
Chapter II	Conditions Causing Deterioration or Failures
Chapter III	Inspection Planning
Chapter IV	Inspection Tools
Chapter V	Preparation of Equipment for Safe Entry and Work
Chapter VI	Pressure Vessels (Towers, Drums, and Reactors)
Chapter VII	Heat Exchangers, Condensers, and Cooler Boxes
Chapter VIII	Direct-Fired Boilers and Auxiliary Equipment
Chapter IX	Fired Heaters and Stacks
Chapter X	Pumps, Compressors, and Blowers and Their Drivers
Chapter XI	Pipe, Valves, and Fittings
Chapter XII	Foundations, Structures, and Buildings
Chapter XIII	Atmospheric and Low-Pressure Storage Tanks
Chapter XIV	Electrical Systems
Chapter XV	Instruments and Control Equipment
Chapter XVI	Pressure-Relieving Devices
Chapter XVII	Auxiliary and Miscellaneous Equipment
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Guide for Inspection of Refinery Equipment

APPENDIX—INSPECTION OF WELDING

A.1 Scope

This chapter of the *Guide for Inspection of Refinery Equipment* covers the subject of welding procedures and the inspection necessary to ensure that welding conforms to procedures. The objectives of inspecting welding are to ascertain:

1. That welded joints are of acceptable quality.
2. That welded joints comply with the requirements prescribed by the contract or the job specifications and with the welding procedure prescribed by the applicable code.

A welded joint consists of the weld metal and the adjacent base metal, including the heat-affected zone. Therefore, the scope of inspection must include all factors influencing the parts of the welded joint.

A.2 Standards and Publications

The information in this appendix covers some of the important criteria concerning weld inspections that welding inspectors must observe. To ensure that the inspection is complete and the inspector competent, a total understanding of and compliance with the latest editions of the following standards and publications is mandatory.

ANSI¹

- B31.1 *Power Piping*
- B31.3 *Chemical Plant and Petroleum Refinery Piping*

API

- 510 *Pressure Vessel Inspection Code*
- Std 1104 *Standard for Welding Pipelines and Related Facilities* (This standard is of limited applicability as defined in ANSI B31.3.)

ASME²

- Boiler and Pressure Vessel Code*, Section I, "Power Boilers," Section VIII, "Pressure Vessels," and Section IX, "Welding and Brazing Qualifications"

AWS³

- Welding Handbook*, Volume I, "Fundamentals of Welding"
- A3.0 *AWS Welding Terms and Definitions*
- A5.1 *Specification for Steel, Carbon, Covered Arc Welding Electrodes*

- B2.1 *Standard for Welding Procedure and Performance Qualification*

- D1.1 *Structural Welding Code—Steel*

- D10.4 *Recommended Practices for Welding Austenitic Chromium Nickel Stainless Steel Piping and Tubing*

- D10.8 *Recommended Practices for Welding of Chromium-Molybdenum Steel Piping and Tubing*

- D10.9 *Specification for Qualification of Welding Procedures and Welders for Piping and Tubing*

- D10.10 *Local Heat Treatment of Welds in Piping and Tubing*

- D10.11 *Recommended Practices for Root Pass Welding and Gas Purging*

NBBPVI⁴

National Board Inspection Code

A.3 Procedures for Producing Suitable Welds

The suitability of the base metal for a welding process (such as oxyacetylene, shielded metal arc, gas tungsten arc, or gas metal arc) is of primary importance; however, many factors affect the production of a satisfactory weld. To ensure that a satisfactory welded metal joint is produced, a welding procedure must be developed. For guidance in the development of welding procedures for pressure-containing equipment, refer to the standards and publications listed in A.2.

A.3.1 WELDING PROCEDURES

A welding procedure is a detailed plan developed by the fabricator to achieve sound welds meeting the requirements of the applicable codes, specifications, and contractual documents. It shall provide clearly understandable instructions to the welders, supervisors, and inspectors. The welding

¹American National Standards Institute, 1430 Broadway, New York, New York 10018.

²American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.

³American Welding Society, 550 N.W. Lejeune Road, Miami, Florida 33135.

⁴National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229.

procedure should stand alone, and users of the procedure should not have to rely upon other documents that may not be readily understandable or obtainable. In addition, the welding procedure shall include qualification test results as required by the applicable variables. The procedure qualification tests must be accomplished and found to be acceptable prior to the start of any welding. The person performing the welding for the qualification test automatically becomes qualified to execute that procedure in the position or positions in which he qualified; however, any other person welding to that procedure must pass a welder performance qualification test for that procedure and in the position or positions he is going to weld before he does any welding using the qualified procedure.

A.3.2 BASIC PRINCIPLES OF WELDING PROCEDURES

The basic requirements for welding procedures and welder qualification have been continually updated by the American Society of Mechanical Engineers and are set forth in Section IX of the *ASME Boiler and Pressure Vessel Code* (commonly called the ASME Code). The American Welding Society has also developed recommended practices and reports for the welding of several groups of materials that can be used in developing satisfactory welding procedures.

The basic purpose of a welding procedure specification is to define welding parameters that would, if they varied, affect the deposited weld and heat-affected zone in any of the following areas: strength, ductility, toughness, chemistry, and soundness.

Section IX of the ASME Code discusses the factors that can affect the weld as either essential or nonessential variables. The ASME Code defines nonessential variables as those in which a change, as described in the specific variables, may be made in the welding procedure specification without requalification of the procedure.

A.4 Qualification of a Welding Procedure

A welding procedure is qualified by establishing the suitability of that procedure in obtaining consistent and acceptable weld quality. The qualification test measures the various mechanical and chemical attributes of the weld resulting from a welding procedure so that they may be compared with service or code requirements. Some of those attributes and the tests that measure them are discussed here:

1. The strength of the weld, which is evaluated using the reduced section tensile test, must meet certain minimum levels. Generally, the weld should be of the same strength level as that of the weakest of the materials being welded.
2. Ductility and soundness of the weld are evaluated by the guided bend test.

3. Toughness of the weld, the fusion zone, and the adjacent heat-affected zones are measured using the Charpy V-notch impact test, the drop weight test, or both. Toughness in this context means the ability to resist brittle fracture in low temperature service or in other services such as hydrogen or cyclic service.

4. Fillet weld tests are designed to prove strength, soundness, and ductility.

5. Various chemical tests such as the Huey test, Strauss test, and others are sometimes added to test the resistance of the weld metal to corrosion.

6. In the case of overlay cladding, chemical analysis of as-deposited weld metal is required to prove that excessive dilution has not occurred. Since no chemical tests are required for welds other than overlay cladding, such tests, which are often valuable quality assurance tools, must be specified by the purchaser when desired.

7. The position in which the qualification test is made is particularly important. When impact tests are required, the procedure qualification test must be run in the same position as production welding. For impact tested procedures, which are qualified to the supplemental essential variables, separate qualifications are required for each subgroup of the P-number (called the group number in Section IX of the ASME Code). Deviations from essential variables, as listed in ASME Section IX, require requalification. The welding procedure applies to one metal or group (P-number) of metals that have similar welding characteristics as specified in Section IX of the ASME Code. The material to be welded must be of a type included in the proposed welding procedure. The type of welding filler metal, its cleanliness, and its condition must also meet the specifications.

A.5 Qualification of Welders

Section IX of the ASME Code includes requirements for qualifying welders and welding operators. These tests are designated as "performance qualifications." An inspector must assure himself that each welder's ability has been demonstrated in accordance with these tests.

The inspector must also be familiar with any state and local code requirements. Of particular importance are those requirements dealing with the position of the weld during test and the type of weld. A welder required to weld groove welds in every orientation would have to qualify in the 6G position or would have to qualify in both the 2G and 5G positions. Concerning the type of weld, a welder qualified in the 6G position or both 2G and 5G positions for groove welds is automatically qualified for fillet welds in all positions. A welder qualified only for fillet welds is not qualified for groove welds.

Section IX of the ASME Code does not address the subject of accessibility limits. Since restricted access welding

requires higher skill levels, the use of a qualification test simulating production welding should be considered.

A.6 Preparation for Welding

The material to be welded and the welding consumables must be checked for conformity to the welding procedure. Preparation of the base metal for welding, groove shape, and fit-up must also come within the tolerances established by the procedure specifications and applicable codes. Visual inspection of welding groove surfaces, particularly after thermal cutting, may expose discontinuities in the base metal (such as cracks, laminations, segregations, or inclusions) that may be detrimental to the weld and would require repair or rejection of the faulty material. It is often necessary to perform a magnetic-particle or dye-penetrant examination of the edge surface in addition to the visual check.

A.7 Inspection During the Welding Operation

During the progress of the work, periodic inspection shall be performed to determine whether the provisions of the procedure specifications are being met by each welder. Weld inspection starts with inspection of the fit-up of the weld joint and the tacking of the joint to maintain alignment. Fit-up check points may include but are not limited to those described in A.7.1 through A.7.17.

A.7.1 Prior to starting the inspection, the inspector shall understand the requirements of the drawing, specification, welding procedures, and codes applicable to the job. A complete knowledge of the meaning of weld symbols is required on the part of the inspector. If the drawings or specifications do not clearly show the weld sizes, lengths, or other requirements, the inspector must get these things clarified before allowing the welding to proceed.

A.7.2 Weld area cleanliness must be checked and all dust, rust, oil, paint, and so forth should be cleaned off of the weld area prior to welding.

A.7.3 The physical dimensions of the joint must be checked; that is, root spacing and offset must be held to close tolerances and the condition and suitability of the joint edges must be checked and found acceptable prior to welding.

A.7.4 Tacks to hold the alignment of the joint must be checked for soundness. The tacks should be well down into the root if they are to become a part of the finished weld, otherwise they should be removed. Tacking left in the weld must be done by qualified welders in accordance with the welding procedure and must be of the same quality as the root pass. Procedures for certain materials will not allow

tacks to become part of the finished weld, or tacks may not be permitted at all as they often initiate cracks.

A.7.5 All welding procedure requirements specified for preheating prior to welding must also be applied to any thermal cutting, tacking, or welding on of temporary attachments. The specified minimum preheat temperature should be maintained during all welding activities. For most materials, the weldment should be cooled slowly and uniformly after welding has been completed.

A.7.6 Any procedural requirements or limitations concerning concurrent heat or interpass temperatures must be monitored by the inspector. The root pass should be inspected for cracks and porosity, and any cracks, blow holes, and porosities must be ground out or removed prior to the continuation of welding. The weld must be checked for appearance and all slag must be removed from the weld surface prior to depositing additional weld metal.

A.7.7 On double butt welds, the grinding, gouging, or arcing of the root pass to sound metal must be inspected and found acceptable before backside welding is started.

A.7.8 Any requirements for nondestructive testing (such as magnetic-particle inspection of the root pass) must be monitored, and necessary repairs must be made prior to continuation of the welding.

A.7.9 On multipass welds, bead configuration must be carefully watched and the welding stopped if there is evidence of rropy, piled-up beads or if there is evidence of bead roll-over that could trap slag.

A.7.10 The welding parameters set forth by the procedure specification must be checked closely throughout the welding operation. These parameters include amperage, voltage, wire speed, travel speed, and so forth. Amperage should be checked using a tong ammeter positioned as close to the arc as possible, since the instrumentation on the welding machine may not show what the amperage at the arc actually is. Particular care must be exercised to ensure that welding cables are of the proper size and are not longer than necessary to avoid excessive voltage drop.

A.7.11 The physical setup for welding should be checked prior to the start of welding and throughout the welding. This check includes examining the affixing of cables to the machine, the affixing of ground cables to the work, and the physical condition of cables and connectors. Excessive cable length and poor grounding can be major problems.

A.7.12 The inspector must watch that a welder or welding operator does not change the procedural amperage, wire feed,

or stick out to reduce spatter or to make a smoother weld bead appearance since this can affect other things such as penetration and dilution.

A.7.13 After completion of the welding, the weld and the area adjacent to the weld must be visually inspected. All undercut exceeding the requirements of the applicable specification must be repaired by blend grinding or, in very bad situations, by the addition of more filler metal.

A.7.14 The inspector must check the weld reinforcement height on groove welds to make sure it is not excessive. Both the ASME Code and ANSI B31.3 have specific limitations on reinforcement height as does API Standard 1104.

A.7.15 The area where fit-up lugs were attached or where handling lugs, machining blocks, or other temporary attachments were welded on must be checked carefully after the attachment is removed. The area must be ground smooth and any pits or tears filled in with weld metal and ground. In the case of air-hardening materials or any material requiring preheat, the area must be preheated before thermal cutting is performed to remove attachments. Also, the preheat must be maintained for any repair welding. Most procedures require magnetic-particle evaluation of such areas.

A.7.16 Fillet welding must be inspected for size and appearance. The edges where the fillet legs blend into the base metal must be inspected carefully for toe cracks. The throat of the fillet is susceptible to cracking and must be closely inspected visually or by any other means specified. Cracks are likely to be found in areas of starts and stops in the welding process and in junctures of welds, which may be highly stressed. Stitch or intermittent fillets are particularly susceptible to crater cracks.

A.7.17 Welding sequence is generally not watched carefully enough and is not thought through properly. An improper welding sequence can result in locked up stresses that may result in severe cracking. In principle, the most restrained joint should be made first; this joint will allow some small amount of movement and thus relaxation of some stress. The lesser restrained joints should then be made in a logical sequence to allow for as much movement and stress relaxation as possible while still avoiding warpage and distortion.

A.8 Inspection on Completion of Welding

Close inspection is required of completed welds for appearance and compliance with specification requirements for the welder's identification stamp. Reinforcement and merge of weld and base metal must be checked. The weld

must be clean and free from defects—such as porosity, slag inclusions, cracks, incomplete penetration, lack of fusion, or icicles—to the degree specified in the applicable code or specification. It is very important that:

1. Repairs be made carefully by a qualified welder or welding operator using qualified welding procedures.
2. Repaired welds be subjected to the same preweld, concurrent, and postweld heat treatment and testing requirements originally specified.
3. Full penetration and fusion, to the degree originally specified, be obtained without any objectionable defects being present.

To further ensure that the welding is in accordance with the specification, an inspector shall witness or perform any additional operations required by the specification. Operations may include review of the heat treatment, radiographic examination, ultrasonic examination, hardness testing, chemical analysis, magnetic-particle or dye-penetrant testing, and pressure testing.

A.9 Method of Inspection

The aids to visual inspection of welding are the same as for other surface inspections of metals under similar circumstances. Good lighting is the prime prerequisite at all times. The area under inspection must be cleaned to a degree that will remove any substance covering a defect. Occasionally a magnifier is necessary for positive identification of a condition. Devices utilizing lights, mirrors, and optical systems should be considered for inspection of locations that are otherwise inaccessible.

A.10 Materials and Welding

Welding inspection can be complete and faultless and yet the welds may be worthless if the materials of construction are not correct. P1 materials (carbon steel) inadvertently welded into high-temperature, high-pressure lines where P5 (4-6 percent chromium) material is required can and has resulted in catastrophic failure. P5 material welded into a P1 line where hydrogen can cause stress corrosion cracking can and has resulted in failure because of the high-strength, high-hardness resulting from the dilution of the chromium into the carbon steel weld.

A welding inspector must be familiar with and use all available methods to ensure that the base materials being welded are what they are supposed to be. Magnets, spark tests, chemical spot-check tests, X-ray fluorescence, light emission spectrography, and various other means can all be used to check the correctness of materials.

Materials should also be checked for their condition, size, weight, and thickness. The condition of the plate's surface

or structural members can indicate potential problem areas. The following are some examples:

1. Any evidence of slivers on the surfaces of plates or structural members must be investigated. Generally they are only rolling slivers with little depth, length, and width; however, they can go as deep as the centerline of the plate and be of such magnitude that repair is impossible.
2. Excessive pitting can be found by close visual examination and must be investigated. If the material is in a corrosive environment, it might fail prematurely. There is considerable difference between the kind of pitting caused by rust and the pitting resulting from rolled in scale, which is a mill defect. This latter type of pitting is more nearly a pock marking, and frequently its depth is undeterminable since the scale may not be easy to remove by mechanical means such as scraping, pounding, or chipping. In this case and where heat is not injurious to the material, it is sometimes possible to make that type of scale pop out by local heating with a rose bud or other high-output torch.
3. Any swells or bulges on a plate, pipe, or section surface must be investigated because they are generally indications of a lamination. If a lamination is suspected or known to exist, its extent can be determined by ultrasonic evaluation. Since laminations and segregations are common plate defects and are occasionally found in rolled sections and seamless pipe, all cut edges or ends should be visually inspected for such defects.

A.11 Welding Defects and Their Relationship to Weld Processes

A.11.1 DEFECTS COMMON TO ALL PROCESSES

Each of the various welding processes has its own typical defects. Defects listed below may be found in welds made by almost any process. Each process, however, has susceptibilities to particular problems because of the nature of the process. Common defects include:

1. Cracks in the weld metal.
 - a. Longitudinal cracks, surface and subsurface.
 - b. Transverse cracks, surface and subsurface.
 - c. Crater cracks (starts and stops).
 - d. Cracks associated with trapped slag or internal porosity.
 - e. Underbead cracks.
2. Porosity and blow holes in the weld metal.
3. Slag inclusions in the weld metal.
4. Inclusions other than slag in the weld metal.
5. Cracks in the base metal adjacent to the weld or propagating from or into the weld.
6. Lack of side-wall fusion or lack of bead-to-bead fusion.
7. Incomplete penetration.
8. Excessive penetration.

9. Undercut.
10. Excessive spatter.
11. Excessively rough weld surface.
12. Delayed cracking of weld or heat-affected zone (that is, cracking that occurs minutes or hours after a weld is completed).
13. Pin holes at the termination or the crater of a weld. These are most frequently encountered in austenitic stainless steel and nonferrous material welds and in gas tungsten arc welds made with insufficient or no filler metal.

A.11.2 DEFECTS IN PARTICULAR PROCESSES

Although welding is the most common, satisfactory means of economically joining structural elements, problems may be encountered in the form of serious defects. Various welding processes are listed in A.11.2.1 through A.11.2.6. Following each process is a brief description of the type of defect to which that particular process is most susceptible and the cause of that susceptibility.

A.11.2.1 Shielded Metal Arc Welding

Shielded metal arc welding (AWS Code SMAW), commonly called manual stick welding, is a process susceptible to all types of cracks, porosity, slag, lack of fusion, incomplete penetration, excessive penetration, undercut, excessive spatter, excessively rough surfaces, and delayed cracking.

Low hydrogen electrodes are susceptible to moisture pick-up, which can impart hydrogen to the molten weld metal. Such electrodes must be stored in a dry and warm environment unless they are stored in hermetically sealed, unopened, and undamaged containers. This requirement does not apply to high cellulose coated electrodes since hot storage can damage the coating. Such electrodes should be stored in a clean environment (see Appendix A of AWS A5.1). The imparting of hydrogen to the molten weld pool can cause cracking of all kinds, porosity, and blow holes.

Since this process is strictly a manual process and is dependent on the welder's dexterity, slag entrapment, lack of fusion, incomplete penetration, excessive penetration, undercut, and spatter can all be major problems.

Excessive spatter and excessively rough surface of welds made by this process can be caused by either incorrect current density or the welder not maintaining a correct arc length for the particular rod coating and size, or both. Excessive weaving causes slag entrapment and rough surfaces.

A.11.2.2 Submerged Arc Welding

Submerged arc welding (AWS Code SAW) is susceptible to porosity and blow holes, slag inclusions, poor penetration, and excessive penetration. It is also susceptible to crack-

ing to a relatively low degree due to weld joint restraint. In general, these defects are the result of improper machine settings involving the wire speed, travel speed, and current density relationships. Since this is an automatic process, any defect will continue until the above parameters are changed. Welding flux must be protected from moisture since damp flux can impart hydrogen to the weld.

A.11.2.3 Gas Metal Arc Welding

Gas metal arc welding (AWS Code GMAW), commonly called MIG, has its own characteristic problems including cracking in all its forms as listed above, porosity and blow holes, and lack of side-wall and bead-to-bead fusion. Poor penetration, excessive penetration, undercutting, excessive spatter, and excessively rough weld surface are other characteristics of the process.

The biggest problems with this process arise from the variables resulting from the infinite number of combinations of shielding gas composition, wire stick out, voltage, and wire feed speed, which determines the amperage.

Lack of side-wall fusion and bead-to-bead fusion is more prevalent in this process than in any other process. The primary reason for this lack of fusion relates to the fact that short-circuiting mode gas metal arc welding is inherently a cold process. Consequently, welder technique is especially important.

Various gases, either singly or mixed, are used as a shielding medium for the arc and weld pool. When the shielding gas is diverted from protecting the weld puddle by the wind, drafts, or partial plugs of the torch gas orifices, excessive porosity will result.

Lack of side-wall fusion is very difficult to detect by nondestructive means such as radiographic testing, dye-penetrant testing, or magnetic-particle examination. Lack of fusion may be detected by ultrasonic testing or visually as welding progresses in that the arc will tend to be somewhat more erratic than usual. In the case of gross oxidation, there may be visual evidence. It follows, therefore, that the work area where this process is being used must be protected from strong drafts or wind. This is true both indoors and outdoors. The above is particularly true in the short-circuiting mode of metal transfer, which is run at low amperage (100 to 130 amperes).

Another defect typical of the GMAW process is porosity. Porosity can occur because of a bad bottle of gas (that is, one that has too much moisture in it). However, more often it is the result of the welder turning up the gas flow to a level higher than it should be. This excessive flow can result in the deposition of frost inside the regulator from what little moisture is present in the gas. This frost will melt when welding is stopped for any significant period of time. When welding is started, the water from the frost will be carried

through the gas hose to the torch and will contribute water to the shielding gas stream. This water, after dissociation in the arc, will impart hydrogen and oxygen to the molten weld metal, which will be oxidized as it flows across the arc and into the weld pool. This can result in hydrogen-induced cracking, excessive porosity at the start of the weld bead, and lack of fusion. This problem will generally clear up as soon as all of the accumulated moisture is dispelled. It is quite normal to have a certain amount of condensation on the outside of the regulators, particularly in humid weather. However, if there is frost on the outside of the gas regulators, there is probably internal frost and the resulting problem can be expected.

Poor penetration can be the result of too low a voltage setting and/or too low a feed rate affecting the amperage, insufficient gas flow, an improper gas or gas combination, or a combination of these causes.

Excessive penetration, undercut, excessive spatter, and an excessively rough weld surface can be the result of too high a voltage setting and/or too high a feed rate affecting the amperage, too high gas flow, improper gas or gas mixture, or a combination of these. Inclusions are possible with this process even though there is no flux or coating involved. Inclusions come from the interaction of the shielding gas and the molten metal and appear as a sort of a black glass, which must be removed before depositing the next bead.

GMAW is a high-deposition welding process. It can be used in all positions and is suitable for welding both carbon steel and other materials. However, it is operator dependent and current densities, type of gas, gas flow, wire stick out, and wire feed (which controls amperage) must all be correct.

A.11.2.4 Flux Cored Arc Welding

Flux cored arc welding (AWS Code FCAW) is basically the same as GMAW, the difference being that the weld wire for GMAW is solid and the wire for FCAW is tubular and contains fluxes, alloy additions, or both. Some flux cored wires are designed to be run without shielding gas since the shielding of the arc and weld pool is provided by the flux. The flux also provides a small amount of slag so this process can have all the problems that the GMAW process has with slag entrapment as well. Those flux cored wires that are self shielding (that is, can be run without shielding gas) have the advantage of being more tolerant of drafts and wind. The flux cored wire with shielding gas can be expected to produce welds with better mechanical properties—especially notch ductility—than without shielding gas.

A.11.2.5 Gas Tungsten Arc Welding

Gas tungsten arc welding (AWS Code GTAW), commonly called TIG, is a very high-quality welding process when

properly used. It has very low deposition rates because filler metal must be manually applied when the torch is manually controlled. Since this is a gas shielded process, extreme care must be taken to protect the weld area from drafts.

This is a totally operator dependent welding process, and when properly applied, the welder can obtain excellent welds. It is susceptible to cracking at stops and starts and at tack beginnings and terminations if the tacks are not down into the root of the weld and if the ends are not feathered. This process is susceptible to tungsten inclusions if the electrode is touched to the weld puddle or if current densities are too high and tungsten composition is incorrect. Root penetration can be excellent with good backside reinforcement and without excessive drip through with welding being done by a qualified welder without the use of consumable inserts. The use of a consumable insert can result in a perfect root bead but requires intensive welder training.

A.11.2.6 Other Welding Processes

There are many other welding processes as listed below

that are not normally used in refinery construction or maintenance. The inspector should be familiar with their peculiarities when and if they are to be used.

1. Plasma arc welding (AWS Code PAW).
2. Electro-slag welding (AWS Code ESW).
3. Electro-gas welding (AWS Code EGW).
4. Resistance welding.
 - a. Resistance spot welding (AWS Code RSW).
 - b. Projection welding (AWS Code RPW).
 - c. Resistance seam welding (AWS Code RSEW).
 - d. Flash welding (AWS Code FW).
5. Oxyfuel welding (AWS Code OFW).
6. Diffusion welding (AWS Code DFW).
7. Friction welding (AWS Code FRW).
8. Electron beam welding (AWS Code EBW).
9. Laser beam welding (AWS Code LBW).

Definitions pertaining to welding terminology can be found in AWS 3.0.