

API RP 577

weld inspection and Metallurgy

1. Scope of application

- This recommended practice provides guidance to the API authorizing the welding inspector on inspection in the fabrication and repair of refinery and chemical plant equipment and piping.
- Common welding processes, welding procedures, welder qualification, metallurgical effects of welding, and inspection techniques described to assist the inspector in fulfilling his or her mandate to enforce API 510, API 570, API Std. 653, and API RP 582.

2. References

2.1 Codes and Standards

• The following codes and standards are referenced in this recommended practice. All codes and standards are subject to periodic review, and the most recent revision available must be used.

API

- API 510 Pressure Vessel Inspection Code: Maintenance, Inspection, Rating, Repair, and Alteration.
- API 570 Piping Inspection Code: Inspection, Repair, Alteration, and Rerating of In-Service Piping Systems.
- RP 578 Material Verification Program for New and Existing Alloy Piping Systems.

ASME

- B31.3 Process Piping: Boiler and Pressure Vessel Code Section V, Nondestructive Examination; Section VIII, Rules for Construction of Pressure Vessels, Section IX, Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators.
- Practical Guide to ASME Section IX— Welding Qualifications.

ASNT

- ASNT Central Certification Program.
- CP-189, Standard for Qualification and Certification of Nondestructive Testing Personnel.
- SNT-TC-1A, Personnel Qualification and Certification in Nondestructive Testing.

3. Definitions

Here are some definitions that apply for the purposes of this publication:

- **Defect:** The term designates rejectability.
- **Direct Current Electrode Negative (DCEN):** Commonly known as straight polarity.
- **Discontinuity:** It is an interruption of the typical structure of a material, such as the lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect.

3. Definitions (cont.)

ÿ **Fusion line:** A non-standard term for the weld interface.

ÿ **Heat affected zone (HAZ):** The portion of the base metal whose mechanical properties or microstructure have been altered by the heat of welding and thermal cutting.

ÿ **Recordable indication:** Recording in a data sheet of an indication or condition that is not necessarily superior to the rejection criteria, but in terms of code, contract or procedure it will be documented.

ÿ **Notification indication:** Recording on a data sheet of an indication that exceeds the size of the failure, rejects the criteria and needs not only documentation, but also notification to the competent authority that must be corrected. All reportable cues are recordable cues, but not vice versa.

4. Weld inspection

. 4.1 Overview

- ÿ Weld inspection is a critical part of an overall weld quality assurance program . This includes much more than just the non-destructive examination of the finished weld.
- ÿ Other important issues, such as specification revision, joint design, cleaning procedures, and welding procedures.

4.2 Pre-welding tasks

• The importance of tasks in the welding planning and preparation phase should not be underestimated. Many welding problems can be avoided at this stage when it is easier to make changes and corrections, rather than after the weld is in progress or complete. These tasks may include:

4.2.1 Drawings, codes and standards

- Review of plans, standards, codes and specifications, thus understanding both the requirements for welding and detecting any inconsistencies.

4.2.1.1 Quality control elements to be evaluated:

- a. Weld symbols and weld sizes clearly specified (see Appendix A).
- b. Welded joint designs and dimensions clearly specified (see Appendix A).
- c. The needs of the established base material
(as the use of ductile impact-proof materials is a requirement in low- temperature service).

4.2.1.1 Quality control elements to evaluate (contd):

- a. Maintain inspection points and defined NDT requirements.
- b. Additional needs, such as the production of weld coupons, clearly specified.
- c. pressure testing requirements, clearly specified.

4.2.1.2 Inspector of possible actions:

- a. Identify and clarify details and information.
- b. Identify and clarify missing sizes of welding, dimensions, tests and any additional requirements.
- c. Identify and clarify contradictions with standards, codes and specification requirements.

4.2.2 Welding requirements

ÿ Examine welding needs

with the personnel involved with the execution of the work such as the design engineer, the welding engineer, and the inspection organization.

4.2.2.1 Quality control elements to be evaluated:

- a. The competence of the welding organization to perform welding activities in accordance with codes, standards and specifications.
- b. The competence of the inspection organization to perform specified inspection tasks.
- c. The independence of the production inspection organization is clear and demonstrated.

4.2.2.2 Potential Inspector Actions: Highlight deficiencies and problems with organizations for appropriate personnel.

4.2.3 Qualification procedures and records .

- Review WPS(s) and Welder Performance Qualification Record(s) (WPQ) to ensure they are acceptable for the job.

4.2.3.1 Quality control elements to evaluate:

- a. WPS(s) are properly qualified and meet the codes, standards and specifications for the job.
- b. Procedure Qualification Records (PQR) tasks to be performed properly and support the WPS(s).
- c. Welder Performance Qualifications (WPQ) meet the requirements for WPS.

4.2.3.2 Inspector possible actions:

- a. Obtain acceptable WPS(s) and PQR(s) for the job.
- b. Qualify WPS(s) where necessary and witness rating effort.
- c. Qualify or requalify welders when necessary necessary and witness a percentage of the welder's qualifications.

4.2.4 NDT information

- Confirm the examiner(s), procedure(s) and inspection organization's NDT team are acceptable for the engagement.

4.2.4.1 Quality control elements to evaluate:

- a. END examiners are duly certified.
- b. END procedures are current and accurate.
- c. END equipment calibration is current.

4.2.4.2 Inspector of possible actions:

- a. Identify and correct deficiencies in certifications and procedures.
- b. Get the equipment calibrated.

4.2.5 Welding of Equipment and Instruments

- ÿ Confirm welding equipment and that instruments are calibrated and operational.

4.2.5.1 Quality control elements to evaluate:

- a. Welding machine calibration is current.
- a. Instruments such as ammeters, voltmeters, contact pyrometers, are calibrated.
- a. Storage furnaces to operate with automatic control welding consumables
visible heat and temperature indication.

4.2.5.2 Inspector of possible actions:

a. Recalibrate equipment and instruments. b.

Replace faulty equipment and instruments.

4.2.6 Heat treatment and test pressure

ÿ Confirm heat treatment and pressure testing procedures and associated equipment are acceptable.

4.2.6.1 Quality control elements to evaluate:

- a. Available and appropriate heat treatment procedure .
- b. The available pressure test procedures and detailed test requirements.
- c. Updated PWHT equipment calibration.
- d. Pressure test equipment and gauges calibrated and meet proper testing requirements.

4.2.6.2 Inspector of possible actions:

- a. Identify and correct deficiencies in procedures.
- b. Get a calibrated computer.

4.2.7 Materials

- ÿ Ensure all filler metals, base materials, and backing ring material are properly marked and identified, and if necessary, perform PMI to verify material composition.

4.2.7.1 Quality control elements to evaluate:

- a. Material test certifications are available and items marked appropriately (including backups if ring is used).
- b. Electrode marking, bare wire flagtags, identification on cable reels, etc.
- c. Filler material brands are traceable to a filler material certification.
- d. Base metal markings originate from a material certification.

4.2.7.2 Inspector of possible actions:

- a. Reject non-traceable or bad materials marked.
- b. Reject inappropriate materials.

4.2.8 Weld preparation

- ÿ Confirm weld preparation, joint fit up, and acceptable and correct dimensions.

4.2.8.1 Quality control elements to evaluate:

- a. Preparation of weld surfaces that are free of common metal contaminants and defects, such as flakes and cracks.
- b. Preheat, if necessary, applied to thermal break.
- c. Hydrogen bake -out heat treatment, if necessary, carry out the procedure.
- d. Welded joint that is free of oxide and sulfur scales, hydrocarbon residues, and any excessive buildup of solder through primers.

4.2.8.2 Potential Inspector Actions: Reject material and correct deficiencies.

4.2.9 Preheating

- Confirm the preheat equipment and temperature.

4.2.9.1 Quality control elements to evaluate:

- a. Warm up equipment and technique are acceptable.
- b. Preheat topping and correct temperature.
- c. Reheat, if necessary, applies to thermal break operations.
- d. Preheat, if necessary, applied to remove moisture.

4.2.9.2 Potential inspector actions:

- ÿ Identify and correct deficiencies in preheating operations.

4.2.10 Welding consumables

- ÿ Confirm electrode, filler wire, flows, and inert gases are as specified and acceptable.

4.2.10.1 Quality control elements to evaluate:

- a. Filler metal type and size are correct per process.
- b. Filler metal are properly handled and stored.
- c. Filler metal is cleaned and rid of contaminants. d.

Coating of non-film-coated electrodes
are neither damaged nor damp.

and. Flux is appropriate for the soldering process and should be handled properly. F. Inert gases, if necessary.

4.2.10.2 Potential Inspector Actions:

- a. Reject inappropriate materials.
- b. Identify and correct deficiencies.

4.3 Tasks during welding operations.

ÿ During the welding inspection, these must include the audit parameters to check if the welding is carried out according to the procedures.

These tasks may include the following:

4.3.1 Quality Control

ÿ Establish a quality assurance and quality control umbrella with the welding organization.

4.3.1.1 Quality control elements to evaluate:

- a. The Welder is responsible for craftsmanship and the quality of welds
- b. Welder meets qualification requirements
- c. The welder understands the welding procedure and the requirements for the job.

4.3.1.2 Inspector of possible actions:

- a. Review welder performance with welding organization.
- b. See Appendix B.

4.3.2 Welding - Parameters and Techniques

ÿ Confirm the welding parameters and techniques listed on the WPS and WPQ.

4.3.2.1 Quality control elements to evaluate:

a. The essential variables that are met during welding.

Yo. Backfill material, flows and inert gas composition / flow.

ii. Blowdown technique, flow rate, O2 analysis , etc. iii.

Power heater furnaces, or when the heaters are not in use, the welder adjusts to the furnace's maximum exposure times to the electrodes.

4.3.2.1 Quality Control Items to Evaluate (cont.):

- b. Welding mock-up, if necessary, meets the requirements of welder and welding engineer.
- c. The Welder must show confidence and adhere to good welding practices.

4.3.2.2 Inspector of possible actions:

- a. Revision of mock-up welding problems with welding engineer.
- b. Quality review with the welding organization.
- c. See Appendix B.

4.3.3 Weld test

ÿ Complete physical checks, visual examination, and in process of
END

4.3.3.1 Quality control elements to evaluate:

- a. Weld points to be incorporated into the weld are of acceptable quality. b. The weld root has adequate penetration and

quality.
- c. Cleaning between weld passes and d any back-gouged of
acceptable surfaces.

4.3.3.2 Potential Inspector Actions: Reject unacceptable workmanship.

4.4 Functions after welding is finished

- The final tasks at the end of the weld must include all those that guarantee the quality of the final weld before placing the weld in service.

4.4.1 Appearance and Finish

ÿ Check after welding acceptance, the appearance and finishing of welded joints.

4.4.1.1 Quality control elements to evaluate:

- a. Size, length and location of all welds conform to Drawings and Specifications/Code.
- b. No welds added without approval. c.

Dimensional and visual verification of the weld that identifies weld discontinuities, excessive distortion and poor workmanship.

4.4.1.2 Inspector Possible Actions: Redo existing welds, remove welds, and make weld repairs as needed.

4.4.2 NDT review

- Verify END that is performed at selected locations and the results of the examiner's review.

4.4.2.1 Quality control elements to evaluate:

a. Specific locations examined. b.

Specified frequency of examination. c.

END is done after the final PWHT. d. Work

of each welder included in the random examination techniques.

and. RT film quality, IQI placement, IQI visibility, etc. and that it complies with the standards.

4.4.2.2 Inspector of possible actions:

- a. Require additional ENDs to address gaps in results.
- b. Verification of cracking in the thickness section, very limited and material with high bond strength.
- c. Repeat missing or unacceptable exams. d. Correct discrepancies in the records test.

4.4.3 Post-weld Heat Treatment

ÿ Verify post-weld heat treatment is performed to the procedure and produces acceptable results.

4.4.3.1 Quality control items to assess:

- a. Paint marking and other detrimental contamination removed.
- b. Temporary attachments removed.
- c. Machined surfaces protected from oxidation.
- d. Equipment internals, such as valve internals, removed to prevent damage.

4.4.3.2 Inspector of possible actions:

- a. Temperature calibration of surveillance equipment.
- b. Correct deficiencies before treatment

thermal.

- c. Repeat the heat treatment cycle.

4.4.4 Pressure test

- ÿ Verify the pressure test that is carried out to
The procedure.

4.4.4.1 Quality control elements to evaluate:

- a. Pressure test that meets the specification.
- b. Test duration is as specified.
- c. The metal temperature of the components meet the minimum and maximum requirements.
- d. Pressure drop or decay is acceptable per procedure.

4.4.4.2 Potential Inspector Actions:

- a. Correct deficiencies either before or during pressure testing, as appropriate.
- b. Repeat test if necessary.
- c. Develop a repair plan if the defects are identified.

4.4.5 Audit documentation

• Conduct a final audit of the inspection file to identify inaccuracies and incomplete information.

4.4.5.1 Quality control elements to evaluate:

- a. All checks in the quality plan are executed correctly.
- b. Inspection reports are complete, accepted and signed by the responsible parties.
- c. Inspection reports, NDT examiners from interpretations and conclusions are accurate.

4.4.5.2 Inspector of possible actions:

- a. Require additional inspection verification to address deficiencies in results.
- b. Repeat missing or unacceptable exams.
- c. Correct discrepancies in exam records.

4.5 Non-conformities and defects

ÿ At any time during the welding inspection , in the event of defects or non- conformity to the specifications that are identified, they must be brought to the attention of those responsible for the work or corrected before additional welding inputs.

4.6 END examiner certification

- Reference to codes or standards may require that the examiner be qualified in accordance with a specific code and certification that meet the requirements. ASME Section V, Item 1, when referenced code is specified, requires qualified personnel, with END being one of the following:
 - a. ASNT SNT-TC-1A
 - b. ANSI/ASNT CP-189

4.7 Safety precautions

• Hazards most frequently encountered by the inspector in welding include arc radiation, air pollution, airborne debris, and heat.

5. Welding processes

5.1 Overview

- The inspector must understand the basic arc welding processes most commonly used in the manufacture and repair of refinery and chemical process equipment.
- These processes include gas metal arc welding (SMAW), gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), submerged arc welding (SAW), and stud arc welding (SW).

5.2 Metal Arc Welding (SMAW)

- SMAW is the most widely used of the various arc welding processes. SMAW uses an arc between a covered electrode and the weld pool.
- A constant current (DC) power supply is preferred. See figures 1 and 2 schematic of the SMAW circuit and welding process.

5.2.1 Electrode Coverage

Depending on the type of electrode used, the cover performs one or more of the following functions:

- a. Provides a gas to shield the arc and prevent excessive atmospheric contamination of the filler metal molten.
- b. Provides scavengers, deoxidizers, and fluxing agents to clean the weld and prevent excessive grain growth in the weld metal.
- c. Sets the electrical characteristics of the electrode.

5.2.2 Advantages of SMAW

• Some of the commonly accepted advantages of the SMAW process include:

- a. The equipment is relatively simple, cheap and laptop.
- b. The process can be used in areas of limited access.
- c. The process is less sensitive to wind and draft than other welding processes.

5.2.3 Limitations of SMAW

• Limitations associated with SMAW are:

- a. Deposit rates are lower than for other processes, such as GMAW.
- b. Dross should normally be removed at shutdowns and starts, and before depositing a weld bead next to or on a previously deposited weld bead.

5.3 Gas Tungsten Arc Welding (GTAW)

- GTAW is an arc welding process that uses an arc between a non-consumable tungsten electrode and the weld bead.
- The DC type power supply can be used with either DC or AC, the choice largely depends on the metal to be welded. Welding current is typically electrode negative (DCEN polarity).

5.3 Gas Tungsten Arc Welding (GTAW) cont.

• DCEN welding offers the advantages of greater penetration and higher welding speed. Alternating current provides sputtering that removes refractory oxides from the surface of the brazed joint, which is necessary for welding aluminum and magnesium.

• See figures 3 and 4.

5.3.1 Advantages of GTAW

• Some of the commonly accepted advantages of the GTAW process include:

- a. Produces high purity solders, generally free of defects.
- b. Some post weld cleaning is necessary.
- c. Allows excellent root pass control of weld penetration.
- d. It can be used with or without filler metal, depending on the app.

5.3.2 GTAW Limitations

Limitations associated with the GTAW process are:

- a. Deposit rates are lower than electrode consumption rates possible with arc welding processes.
- b. It has a low tolerance for contaminants in filler material or base metals.
- c. Difficult to adequately protect the weld area in draughty environments.

5.4 Gas Metal Arc Welding (GMAW)

- GMAW is an arc welding process that uses an arc between the continuous filler metal electrode and the weld bead.
- Employs a constant voltage (CV) power supply, and uses either the short circuiting, globular, or spray methods for transferring metal from the electrodes to the work:

• The type of transfer is conditioned by a series of factors. The most influential are:

- a. Magnitude and type of welding current.
- b. Electrode diameter.
- c. electrode composition.
- d. Electrode extension.
- and. Shielding gas.

• See Figures 5 and 6 GMAW schematics

5.4.1 Short Circuit Transfer (GMAW-S)

- GMAW-S, covers the lower range of electrode welding currents and diameters associated with the GMAW process.

5.4.2 Globular transfer

• This process covers relatively low current (less than 250 A). The globular transfer mode is characterized by a drop size with a diameter greater than that of the electrodes. In general, this process is limited to the flat position and can cause spattering.

5.4.3 Spray Transfer

• Splash is negligible. Due to their high arc forces at high current, applying this process to thin sheets can be difficult.

• Pulsed GMAW is a variation of GMAW in the that the current is pulsed to get the advantage of spray transfer in medium average currents than spray transfer mode.

5.4.4 Advantages of GMAW

- Some of the commonly accepted advantages of the GMAW process include:
- a. The consumable single electrode process that can be used to weld most commercial metals and alloys.
 - b. Deposit rates are significantly higher than those obtained with SMAW.
 - c. Minimal post-weld cleanup is necessary due to the absence of slag

5.4.5 GMAW Limitations

Limitations associated with GMAW are:

- a. The welding equipment is more complex, more expensive, and less portable than SMAW.
- b. The welding arc must be protected from air currents that disperse the shielding gas.
- c. When the GMAW-S process is used, the weld is more prone to lack of proper fusion.

5.5 Flow cored arc welding (FCAW)

- FCAW is an arc welding process that uses an arc between the continuous tubular metal filler electrode and the weld bead. The process is used with shielding gas from a flow contained in the tubular electrode.
- The recommended power supply is of the constant voltage DC-type, similar to the supplies used for GMAW. Figures 7, 8 and 9 show a schematic of FCAW.

5.5.1 Advantages of FCAW

Some of the commonly accepted advantages of the process FCAWs include:

- a. The metallurgical benefits that can be derived from a flux.
- b. Dross that supports and shapes the weld bead.
- c. High deposition and productivity rates than other processes such as SMAW.
- d. Shielding is produced on the surface of the weld which makes it more tolerant of stronger drafts than GMAW.

5.5.2 FCAW Limitations

Limitations associated with the FCAW process are:

- a. Self-shielding FCAW generates large volumes of welding fumes, and requires suitable exhaust equipment.
- b. Requires slag removal between passes.
- c. Backing material is required for root pass welding.

5.6 SUBMERGED ARC WELDING (SAW)

- Submerged arc welding is an arc welding process that uses an arc or arcs between a bare metal covered electrode flux and the weld bead.
- Either CV or CC power supply can be used. SAW is widely used in pressure vessel manufacturing and pipe manufacturing. Figure 10 shows a schematic of the SAW process.

5.6.1 Advantages of SAW

• Some of the commonly accepted advantages of the process include:

- a. Provides very high deposition rates
high metal.
- b. Produces repeatable high quality welds for
large welds and repetitive short welds.

5.7 STUD welding arc (SW)

- SW is an arc welding process that uses an arc between a piece of metal or the like and the work piece. Or shielding gas flow may or may not be used.
- Direct current is typically used for SW with the gun stud connected to the negative (DCEN) terminal. The power source is a DC type.

5.7.1 Advantages of SW

Some of the commonly accepted advantages of the process of SW include:

- a. High productivity rates compared to stud de manual welding of base metal.
- b. Considered as a position process.

5.7.2 SW limitations

SW limitations are as follows:

- a. The process is mainly suitable for carbon steel and low alloy steels.
- b. The process is specialized for some applications.

6. Welding procedure

6.1 Overview

- Qualified welding procedures are necessary for welding fabrication and repair of pressure apparatus, piping, and tanks.
- Details the steps necessary to make a specific weld and usually consists of a written description, details of the weld joint and welding process variables, and test data to demonstrate the procedure produces welds that meet specifications. design requirements.

6.1 General (contd)

- It is important to differentiate PQR and welder qualification (WPQ).
- The purpose of the WPQ is to establish whether the welder is capable of contributing a quality to the weld through the welding procedure.

6.2 Welding Procedure Specification (WPS)

- ASME Section IX requires each fabricator and contractor to develop welding procedures.
- ASME B31.3 allows qualification of the welding procedure by others, provided it is acceptable to the inspector and meets certain conditions.

- The complete WPS for a welding process of all essential directions, non-essential and essential complementary variables, when notch toughness is required. Essential variables affect the mechanical properties of the weld.
- **Nonessential** variables do not affect the mechanical properties of the weld.

6.2.1 Types of essential variables

ÿ The WPS must contain, as a code requirement, the following information as a minimum:

a. Process.	h. Assembly and alignment.
b. base metal.	Yo. Back of the joint.
c. Filler metal (and/or flux).	j. Peening.
d. welding current.	k. Preheating.
and. Welding position.	he. Post-heat treatment of the weld.
F. Shielding gas, if used.	m. Welding technique.
g. Base metal preparation.	

6.2.2 Other requirements

• The WPS should also reference the supporting PQR(s) used to qualify the welding procedure.

These may include:

- a. Hardness of metals, weld metal, and
MAKE.
- b. Limitations of the welding process.

c. Limitations of filler metals and fluxes. d.
Critical joint geometries. and. Preheat
limitations.

- The WPS format.
- A sample form is available in ASME
Section IX, Appendix B.

6.3 Registration Qualification Procedure (PQR)

- Section IX requires that the fabricator or contractor must supervise the production of test welds and certify that the PQR correctly qualifies the welding procedure.
- Section IX. Tensile testing to determine the breaking strength of a groove weld, guided bends test to determine the degree of strength and ductility of a groove weld, notch strength tests are typically included where strength requirements are imposed. strength and hardness measurements when we define the constraints on hardness.

6.3 Procedure for Qualification of Registration (PQR) (cont.)

- A sample form is available in ASME Section IX, Appendix B.
- One PQR can support several WPSs.

6.4 Review of WPS and PQR

ÿ Inspectors shall review the WPS and PQR to verify that they are acceptable for welding. While there are many ways to review a welding procedure, the most effective uses a systematic approach that ensures a complete and thorough review of the WPS and PQR to verify that all Section IX, and manufacturing and repair code requirements have been met. .

6.4.1 Topics to be included in the WPS

6.4.2 Topics to be included in the PQR

ÿ Appendix C provides an example of using a WPS and PQRS review checklist.

7. Welding of materials

7.1 Overview

- Welding materials refers to the many materials involved in welding including base metal, filler metal, fluxes and gases, if any.
Each of these materials has an impact on WPS and welding properties.
- Understanding the conventions used by ASME Section IX is necessary to properly review qualified welding procedures.

7.2 P-number assignment to base metals

- **Base** metals are assigned P-numbers in ASME Section IX to reduce the number of welding procedure titles needed. For base non-ferrous metals with specified impact tests, group numbers are assigned within P-numbers.
- These assignments are based on the characteristics of the comparable base metal, such as composition, weldability, and mechanical properties.

ÿ Table 1

7.3 F number assignment to filler metals

• The F number is based primarily on usability characteristics.

• For example, a welder who has qualified with an E-7018 is qualified to weld with all F-4 electrodes, plus all F-1, F-2, and F-3 electrodes (considering certain limitations).

7.3 F-number assignment to filler metals (cont'd).

• Compatibility of base and filler metals should be considered from the perspective of metallurgical properties, post weld heat treatment, design and service, and mechanical properties.

• A complete list of welding rod and electrode F numbers is given in ASME Section IX, Table QW-432.

7.4 AWS Classification of Filler Metals

• AWS classification numbers are specified in ASME Section CII under their SFA number as per specification. ASME Section IX Table QW-432 lists the AWS classification numbers.

• ie, AWS classifications E6010, E7010, E8010, E9010, and E10010 are all covered by the F-3 (EXX10) number.
Appendix A

7.5 A-NUMBER

- To minimize the number of welding procedure headings, steel and alloy steel filler metals are also grouped according to their number.
- ASME Section IX, table QW-442 is based on the chemical composition of the weld metal deposited.

7.6 METAL SELECTION FILLING

Inspectors must verify the selection of filler metal is suitable for the base metal where they are to be welded. Some considerations in the selection are:

- a. Chemical composition of the filler metal.
- b. Tensile strength of filler metal and base metal.
- c. Dilution of base metal alloying elements.
- d. Filler metal hardenability.
- e. Susceptibility to hot cracking.
- f. Corrosion resistance of the filler metal.

See Appendix D

7.7 Conservation and handling consumables.

• Particularly prone to moisture pickup are low hydrogen electrode coatings and stainless steel electrodes.

The moisture can be a source of hydrogen.

• Any electrodes or fluxes that have become wet should be discarded.

8. Welder Qualification

8.1 Overview

- Qualifying the welder's performance is to establish the welder's ability to deposit sound weld metal.
- A welder can be qualified by the coupon x-ray test of an initial production weld or by the flexure tests of a coupon test.

8.1 General (contd)

- ÿ Some end users and codes limit or restrict the use of radiography for this purpose, radiographic testing is not allowed for GMAW-S and ASME Section IX.
- ÿ Responsibility for welder qualification is limited to the contractor or fabricator employing the welder and cannot be delegated to another organization. Subcontracting of sample preparation and END is authorized .

8.2 Welder Performance Qualification (WPQ)

- The WPQ addresses all essential variables listed in ASME Section IX QW-350.
- QW-352 through QW-357 in ASME Section IX, the list of essential variables and reference Code paragraphs for different welding processes.
- The WPQ test record includes all essential variables, test type and test results, and scored ranges.
- A sample form is available in ASME Section IX-Form QW-484 in nonmandatory Appendix B.

8.2 Welder Performance Qualification (WPQ) (cont.)

- If radiological examination is used for qualification, the minimum coupon length to be examined is 6 inches (152.4 mm), and includes the full circumference of pipe weld coupons. Coupons are required to pass visual examination and physical tests, if used.
- Welding operator classification standards using radiography requires 3 feet (0.91 m) of length to be examined.

8.2 Welder Performance Qualification (WPQ)(cont.)

- Welder performance rating expires if the welding process is not used for a period of six months. The welder's qualification may be revoked if there is reason to question his ability to weld.
- A welders log or continuity report can be used to verify that a welder's qualifications are current.

8.3 Review of a WPQ

8.3.1 Pre-weld review

Before any welding, inspectors should review welders' WPQ to verify that they are qualified to perform the weld given their position and process. When examining a WPQ, items to check include:

- a. Welders name and number on the stamp.
- b. Welding process and type.
- c. WPS ID used to get a trial coupon welding.
- d. Backup (if used). and. P-number(s) of base metal joints.

When examining a WPQ, items to check include (cont):

F. Base metal thickness and tube diameter. **g.** SFA filler metal number. **h.** F number of filler metal. **Yo.** Insert consumables (if used). **j.** Deposited thickness (for each process used). **k.** Welding position on the coupon. **he.** The progression of vertical welding. **m.** Gas track used. **no.** Metal transfer mode (if GMAW).

When examining a WPQ, items to check include (cont):

either. Weld current type / polarity (if GTAW). **p.** If welded machine refer to QW-484 for values additional required. **Q.**

Test guided curve type and results, if used. **r.** The results of the visual examination.

s. The additional needs of the manufacturing code. **t.**

Organization of proofs of identification, signature and date. **or.**
X-rays if used.

8.3.2 Qualification Range Verification

§ ASME Section IX, the following references should be used to verify qualification range:

- a. Base Metal Qualification-QW-QW-423.1 and 403.15. b. Backing-QW-350 and QW-402.4. c. Deposited for qualification of weld thickness of metal QW-452.1 (transverse bending tests) and QW-404.30. d. Groove Limits Welding Small Diameter-QW-QW 452.3 and 403.16.
- and. Position and diameter limits-QW-461.9, QW-QW-405.3 and 403.16.
- F. Number F-QW-433 and QW-404.15.

9. Non-destructive tests

9.1 Discontinuities

• Non-destructive testing (NDT) is defined as inspection methods, which will allow materials to be examined without modifying or destroying their usefulness.

END is an integral part of the quality assurance program.

- The inspector should choose an NDT method capable of detecting discontinuity in the type of joint weld due to configuration. Table 2 and Figure 11 list the common types and locations of discontinuities and illustrate their positions within a butt weld.
- The most commonly used END methods used during weld inspection are shown in Table 3. Used during weld inspection are shown in Table 3.

ÿ Table 4 lists the different types of welded joints and the common NDT methods available for inspecting their configuration. Table 5 new lists the detection capabilities of the most common END methods.

ÿ Table 6 is a summary of these discontinuities, potential NDT methods, and possible solutions for the welding process.

9.2 IDENTIFICATION OF MATERIALS

- This may include checking material certificates, checking component seals or markings, or requiring PMI (Positive Material Identification) testing.
- Guidelines for material control and its verification are set out in API RP 578.

9.3 VISUAL EXAMINATION (VT)

9.3.1 Overview

- Visual testing is the most widely used NDT method for welds. It includes both direct and indirect observation of the exposed surfaces of the weld and the base metal.
- Direct Visual Testing is performed when access is sufficient to place vision 6 inches - 24 inches (150 mm - 600 mm) from the surface to be examined and at an angle of not less than 30 degrees to the surface as described. illustrated in Figure 12.

• ASME Section V, Article 9, (Part T-940) lists the requirements for visual examination.

• Some of the requirements listed in this article are:

a. The written procedure required for examinations. b. The minimum amount of information that must be included in the written procedure. c. Demonstration of the adequacy of the inspection procedure. d. Personnel who are required to demonstrate the Jaeger 1 near vision acuity test each year.

- and.** Direct visual examination requires access to allow the eye to be within 6 inches - 24 inches (150 mm - 600 mm) of the surface, at an angle of not less than 30 degrees. **F.** The minimum necessary illumination of the object during the exam will be 1000 Lux.
- g.** Indirect visual examination allows the use of remote visual examinations.
- h.** The evaluation of the indications will take into account the limits of acceptance / rejection of the reference code / standard.

9.3.2 Visual Inspection Tools

• Listed below are some commonly used tools with VT or welding methods:

9.3.2.1 Optical aids

- a. Illumination: Illumination of the inspection surface is extremely important.
- b. Mirrors-Valuable for the inspector allowing them to see inside pipes, threaded holes and bore holes, inside castings and at corners if necessary.
- c. Magnifying glasses-useful to take to observe the small details and defects.
- d. Borescopes and Fiberscopes-Widely used for the examination of tubes, deep bores, long bores, and curved pipes, having internal surfaces not accessible to direct vision .

9.3.2.2 Aids Mechanics

- a. Steel ruler available in a wide selection of sizes and graduations to meet the needs of the inspector (considered a medium precision instrument).
- b. Vernier or caliper - A precision instrument, capable of measuring in units of decimal value in a precision factor that can vary between 0.1 to 0.01 mm.

- c. Combination square set, consists of a blade and a set of three heads: Square, Center and protractor.
- d. Feeler Gauge - Commonly called a "Feeler" gauge is used to measure the distance between objects.
- and. Levels - tools designed to test whether a plane or surface is truly horizontal or vertical.

9.3.2.3 Examination of welding devices

Typical inspection tools for weld inspection include:

- a. Inspector Kit (see Figure 13)
- b. Measure CAM Bridge (see figure 14)
- c. Fillet weld gauge (see Figures 15, 16, 17 and 18),
- d. Measure weld size (see Figure 19)
- e. Hi-lo weld width (see Figure 20)

9.4 QUIZ Magnetic Particles (MT)

9.4.1 Overview

- Magnetic particle examination is effective in locating surface or near -surface discontinuities in ferromagnetic materials. It is most commonly used to evaluate the weld joint on surfaces, intermediate checks of weld layers, and back-gouging of finished weld surfaces.
- The types of discontinuities that can be detected are cracks, laminations, laps, and seams. (Fig. 21, 22,23, 24 and 25).

9.4.2 Magnetic flux direction indicator

• The direction of the magnetic flux direction can be confirmed by the use of various indicators. One of the most popular gauges is the foot gauge. It consists of eight low carbon steel segments, welded together to form an octagonal plate that is copper coated on one side to hide the hinge lines (see Figure 27).

9.4.3 Demagnetization

• When residual magnetism in the part could interfere with further treatment or use, demagnetization techniques should be used to reduce the residual magnetic field to within acceptable limits. Care must be taken when performing the MT examination of a weld during the welding process.

9.5 Alternating current field of measurement (CCGP)

- The ACFM technique is a non-contact electromagnetic technique that is capable of detecting the size and area of breaking defects in a range of different materials and coatings across varying thicknesses.
- ACFM is used for evaluation and monitoring of existing cracks.
- ACFM uses a probe similar to an eddy current probe and an alternating current is introduced into a thin skin near the surface of any conductor.

Two components of the magnetic field are measured: B_x over the duration of the defect, which responds to changes in surface current density and gives an indication of depth when the reduction is greatest; and B_z , which gives a negative and positive response of the defect caused by the current poles generated by providing an indication of longitude.

9.6 Liquid Penetrant Test (PT)

- PT is able to detect surface discontinuities in ferrous and non-ferrous alloys. The Liquid Penetrant test can be used to examine the welded joint surface, intermediate controls of the different weld passes, finished weld.
- PT is commonly used on austenitic stainless steels where magnetic particle examination is not possible.

- During the PT, the test surface is cleaned and covered with a penetrating liquid, which seeks to connect the discontinuities in the surface.
- After the excess liquid surface penetrant is removed, a powder base slurry solvent (developer) is normally applied by spraying.

• Three different methods of penetrating liquids are available for use with the two techniques, including:

- a. Washable with water.
- b. Post-emulsifiable.
- c. Solvent removable.

9.7 Eddy Currents (ET)

- Eddy Current inspection is used to detect surface discontinuities, and in some cases, subsurface discontinuities in pipe, tube, wire, rod, and bar action. ET has limited its use in weld inspection.
- Eddy currents can be used as a quick test to ensure that components joined during welding have the same material properties, and as a quick check for defects on welded joint faces.
- More information can be found in ASME Section V, Article 8, which deals with Current Eddy Current Testing of Tubular Products.

9.8 RADIOGRAPHIC INSPECTION (RT)

9.8.1 Overview

- RT is a volumetric examination method capable of examining the entire sample and not just the surface. It is the historical approach to examine welds for complete surface and subsurface discontinuities. The method uses the change in radiation absorption of solid metal and in one of the discontinuity zones.
- The transmitted radiation reacts with the film, a latent image is captured, and when the film is processed (developed) it creates a permanent image (x-rays) of the weld.

- The NDT examiner performing film interpretation, evaluation, and reporting must be certified to a minimum of ASNT Level II requirements. However, all personnel performing radiography are required to attend radiation safety training and comply with applicable regulatory requirements.
- The exposure and processing of a radiograph is considered acceptable as long as it meets the required quality characteristics in terms of sensitivity and density.

9.8.2 Image Quality Indicators (Penetrameters)

- Standards for industrial radiography require the use of one or more Image Quality Indicators (IQIs) to determine the required sensitivity.
- Errors with IQIs (penetrameters) can have a much greater impact in thin-walled tubing, where passing large root imperfections can significantly reduce the strength and integrity of a weld.

• IQIs (penetrameters) are tools used in industrial radiography to establish the level of quality of the radiographic technique.

• There are two types of IQIs (penetrometers) in use today:

- a. Wire-IQIs type (ASTM E-747)
- b. Hole-type IQIs (ASTM E - 142)

- IQIs (penetrameters) are selected based on the thickness of the base material plus reinforcement. Wire-type IQIs (penetrometers) are most often placed perpendicular to the center line of the weld with the necessary sensitivity based on the thickness of the weld.
- Hole-type IQIs (penetrameters) are placed next to the weld either in the original material or in a wedge with a thickness equivalent to the accumulated weld.

Table 7 ASTM 142

- The hole that is required to be visible on an acceptable radiograph is called the essential hole.
- For example, a No. 10 IQI (Penetrameter) is 0.010 inches (0.25 mm) thick while the No. 20 is 0.020 mm thick (0.51 mm).

9.8.3 Radiographic film

• Class I or II radiographic film are acceptable for use. The film is required to be of sufficient length and width to allow a minimum of 1 inch (25 mm) on consecutive circumferential exposures , and 3/4 inch (19 mm) coverage on both sides of the weld.

9.8.4 Selection of radioactive source

- For weld inspection, radioactive isotopes of iridium 192 or cobalt 60 are usually used. X-ray machines may also be used.
- Iridium 192 is typically used for radiography of steel with a thickness range of 0.25 inches - 3.0 inches (6.3 mm - 76.2 mm). Cobalt 60 is used for steel, the thickness of 1.5 inches - 7.0 inches (38 mm - 178 mm).

9.8.5 Film processing

• Movies exposed can be processed by hand, or the examiner may use an automatic processor.

Normal development time is five to eight minutes at 68 ° F (20°C).

9.8.6 Surface preparation

- Where a surface condition, which could mask a defect, is visually detected by the radiologist prior to radiography, the surface condition must be remedied prior to exposure.
- Weld waves or other irregularities inside both must be eliminated to the extent that they can either mask or they can be confused with the image of a discontinuity.

9.8.8 Radiological techniques

- The most effective technique is one in which the radiation passes through a single thickness of the material to be radiographed and the film is in contact with the surface of the opposite side of origin.
- The IQI (penetrameter) placement should be as close to the weld as possible, without interfering with the weld image.

9.8.8.1 Single wall technique

• A single wall exposure technique should be used for practical radiography.

In the single wall technique, radiation passes through a single wall of material or weld, which is considered acceptable on radiography (see Figure 31).

9.8.8.2 Single wall display

- For materials, and for welds on components, a technique that can be used where radiation passes through two walls and only the weld (materials) on the film sidewall is seen for acceptance.
- A minimum of three exposures taken to each 120° other should be made.

9.8.8.3 Double wall technique

- When it is not practical to use a single wall technique, a double wall technique should be used. For materials and welds on 3.5-inch (88.9 mm) components.
- (See Figure 32). When full cover is required a minimum of two exposures taken at 90° to each other should be of each weld joint. Alternatively, the radiographed with the radiation beam positioned such that the two walls overlap.
- When full coverage requires a minimum of three together. Exposures taken at any one of 60 should be made or 120° for each welded joint.

9.8.9 Radiographic Evaluation

- The final step in the process is radiographic evaluation of the radiograph. Accurate film interpretation is essential, and it requires hours of examination and understanding of the different types of images and associated conditions in industrial radiography.
- The interpreter should be aware of the different welding processes and the discontinuities associated with those processes.

9.8.9.1 Viewing radiography services

- Equipment used to view the interpretation radiographs will provide a light source sufficient for the essential IQI (penetrameter) information visible for the specified density range.
- Low power magnification devices (1.5x - 3X) can also be used to aid in film interpretation and evaluation.

9.8.9.2 Quality of radiographs

• Radiographs must be free of mechanical, chemical or other defects.

A radiograph with stains in the area of interest should be discarded and the area re-radiographed.

9.8.9.3 Radiographic density

- Exposed film that allows 10% of incident light to pass through and has a film density of 1.0. The film density transmitted through the radiographic image through the body of the hole type IQI (penetrometer), or adjacent to wire IQI (penetrometer), in the area of interest should be within the range of 1.8 to 4.0 for X-rays and 2.0 -- 4.0 for Gamma rays.
- A comparison film densitometer or wedge is used to measure and calculate the darkness (density) of the film.

9.8.9.4 Excessive Backscatter

- A lead letter "B" with a minimum dimension of 1/2 inch (12.7 mm) and 1/16 inch (1.55 mm) thick is usually adhered to the back of each film/film backing. cassette during an exposure to determine if radiation backscatter is the film exposure.
- If a light image of the letter "B" appears on any radiograph against a dark background, the protection against scattered radiation is considered insufficient and the radiograph is considered unacceptable.

9.8.9.5 Interpretation

- Radiographic interpretation is the art of extracting the maximum information from a radiographic image. This requires subjective judgment on the part of the interpreter and is influenced by the knowledge of the interpreters:
- a. The characteristics of the radiation source and energy level(s) with respect to the material being examined;
 - b. The characteristics of the recording media in response to the selected radiation source and energy level(s);

- c. The treatment of recording media with respect to the image quality;
- d. The shape of the product (object) is radiographed;
- and. The possible and most probable types of discontinuities that can occur in the test object.
- F. The possible variations of the images of the discontinuities depending on the radiographic geometry, and other factors.

ÿ See Figure 33 to 44.

9.8.10 Radiographic Examination Records

- A report of the sample radiograph is provided in Appendix E.

9.9 Ultrasonic Inspection (UT)

- UT is able to detect surface and subsurface discontinuities. A sound beam in the ultrasonic frequency range ($> 20,000$ cycles per second) travels in a straight line through metal and is reflected at an interface.
- Straight beam techniques are used for thickness evaluation or to check for laminations, and/or other conditions, that may prevent the beam angle from interrogating the weld.

• The A-scan, as shown in the Figure 45,

• The B-scan (see figure 46).

• The C-scan (see Figure 47).

- ASME Section V, Article 4, lists the general requirements for ultrasound examination.
- ASME B31.3 and ASME Section VIII, Division 1 require an ultrasound examination to be performed in accordance with Article 4.

9.9.1 Ultrasonic Calibration Inspection System.

- Ultrasonic inspection system calibration is the process of adjusting the controls of the ultrasonic apparatus so that the UT display shows a linear sound wave response.
- The inspection system includes the test, ultrasonic instrument, wiring, search unit, including wedges or shoes, coupler, and a reference standard/procedure.
- The ultrasound instrument is required to meet or exceed the requirements of ASME Section V, Article 5, Part T-530,

- Calibration system checks should be performed before and during the performance of an examination.
- The temperature of the calibration standard should be within 25 °F (14 °C) from the area to be examined.
- System checks are typically performed at a minimum of every four hours during the testing process, but may be done more often when a malfunction is suspected.
- If during a system calibration check, it is determined that the ultrasound equipment is not working properly, all areas tested since the last successful calibration should be re-examined.

9.9.1.1 Echo Assessment with CAD

• Distance Amplitude Correction (CAD) curve allows simple echo evaluation of unknown reflectors by comparison of echo height to DAC (% DAC).

• See figure 48 and 49

9.9.2 Surface preparation

• Prior to UT examination, all surface analysis should be free of weld spatter, surface irregularities, and foreign material that could interfere with the test.

9.9.3 Deck examination

• Each transducer step overlaps the previous step by 10% of the transducer element dimension. The drive seek movement rate should not exceed 6 inches (152 mm) per second unless calibration is verified at a higher rate.

9.9.4 Straight Beam Test

• A straight beam test should be performed next to the weld to detect reflectors that may interfere with the angled beam from examining the weld as a sheet on the base material. All areas that have this type of reflector must be registered.

9.9.5 Angular beam test

- Typically, there are two different angle beam tests performed on a weld. A search for reflectors that are oriented parallel to the weld, and a search for reflectors that are oriented transverse to the weld.
- In both cases, the scan should be performed at a gain value at least twice the sensitivity of the reference level established during calibration.

9.9.6 Automated Ultrasonic Testing (AUT)

- a. Pulse-echo Raster Scanning: This technique inspects with zero degree of compression and two angle beam transducers interrogating the weld from both sides simultaneously.
- b. Pulse-echo by inspection zones: The zoning inspection is a scan line technique.
- c. Time of Flight Diffraction (TOFD): This is a line scanning technique used in the transmit and receive mode.

9.9.7 The discontinuity of evaluation and size

- Normally, any imperfection that causes an indication to exceed a certain percentage of the DAC curve should be investigated in terms of acceptance standards.
- One of the commonly used sizing techniques is called the “Intensity drop” technique. This technique uses the size of the spread beam to determine the reflector edges. The 6 dB drop technique is commonly used to determine the reflector length.
- Using this technique, the transducer is placed on the part in such a way that the amplitude of the reflector is maximized. This point is marked with a greasy pencil. The UT instrument is set to set the signal to 80% of full screen height (FSH).

9.9.7.1 The Creeping Wave identification method

• The Creeping ID wave method uses the effects of multiple sound modes, such as longitudinal waves to size a defective shear

• Three specific waves are presented with the Creeping ID wave method:

- a. Longitudinal wave high refraction angle of about 70° .
- b. direct of 30° S-wave, which converts to a 70° refracted longitudinal wave mode.
- c. Indirect shear or "head" wave which mode converts on the inside diameter of a surface to a longitudinal wave, and moves along the surface.

9.9.7.2 Tip of the Diffraction Method

• Tip of the Diffraction Methods are very effective in sizing flaws which are open to the surface of the inner or outer diameter and are shallow to mid-wall.

9.9.7.3 The Longitudinal High Angle Method

• The method of high refractive angle of longitudinal waves is very effective for very deep defects.
Dual Element, Centered, 60, 70, and Wave Progressive OD is used to examine the exterior of an average thickness of component material.

9.9.7.4 The Bimodal Method

• The bimodal method is a dual element probe together with the transducer crystals positioned opposite each other.

9.10 Hardness test

- Testing of weld hardness and size is often necessary to ensure the welding process and any PWHT resulting in an acceptable "soft" result.
- API RP 582 details the hardness test requirements for PQRS and production welds.

9.11 PRESSURE AND LEAKAGE TEST (LT)

- API Standards 510 and 570, API RP 574, and ASME B31.3 provide guidance on the application of pressure tests. Pressure testing should be carried out at the proper temperature for the material of manufacture to prevent brittle fracture.
- The test should be considered long enough for a complete visual inspection to identify potential leaks. Typically a pressure test should be held for at least 30 minutes.

- Pneumatic pressure tests often require special approvals and considerations due to the amount of energy stored in the system.
- ASME Section V, Article 10, addresses leak test methods and indicates different test systems to be used for both open and close units.
- If the unit is found to be under pressure to leak, it should be de-pressured, the leaks repaired per Administration code , and the test repeated.

9.12 Inspection of welds data recording

9.12.1 Information details

- The results of the welding inspection must be completely and correctly documented. The inspection report, in many cases, will become a permanent record that is maintained and referenced for the life of the weld or part being inspected.
- The information included in an inspection report is:
General information, inspection information and inspection results.

9.12.2 Terminology

ÿ When reporting the results of an inspection, it is important to use standard terminology. Examples of standard terminology are shown in tables 8, 9 and 10.

10. Metallurgy

10.1 GENERAL

Metallurgy is a complex science, but a general understanding of the major principles is important to the inspector because of the wide variety of metals that can be welded together during equipment repair, and the significant impact on the resulting metals . of the welding process.

10.2 The structure of metals and alloys

- The physical properties of metallic materials such as strength, ductility, and toughness can be attributed to the chemical composition and orderly arrangement of these atoms.
- Metals in molten or liquid states do not have an ordered arrangement of atoms contained in the molten mass.

10.2.1 The Casting Structure

- The general arrangement of grains, grain boundaries and phases present in the casting is called the microstructure of the metal.
- Due to the casting used in the refinery industry they are generally alloyed, containing two or more microstructural phases. A phase is any structure that is different in physique and composition. As the chemical composition is altered or the temperature changes, new phases or stages can form and begin to disappear.

- In general, it is desirable to keep the size of the grains small, which improves strength and toughness. This can be achieved by maximizing the cooling rate or minimizing heat input (in the case of welding).
- As the melt cools, these elements are eventually contained in microstructural phases that last solidify in the spaces between grains.

- Welds are particularly prone to hydrogen cracking from trapped gases.
- This problem can be avoided by careful cleaning of weld bevels to remove hydrocarbons and moisture, the use of low hydrogen electrodes, proper storage or in the electrode furnace, and the use of proper off-gas cleaning techniques. high quality weld

10.2.2 The structure of wrought materials

- The vast majority of metallic materials used to manufacture refinery plant equipment and chemicals used in forging form gypsum.
- Single phase materials are often strengthened by adding alloying elements which lead to the formation of metallic or intermetallic precipitates.
- In general, greater strengthening occurs with the fine distribution of precipitates.

10.2.3 Metallurgical Welding

- Welding metallurgy is concerned with melting, solidification, gas-metal reactions, slag metal reactions, surface phenomena, and base metal reactions.
- The parts of a weld are made up of three zones, the weld metal, the heat affected metal (zone), and the base metal.
- Consequently, the weld will be less homogeneous than the base metal, which can affect the mechanical properties of the weld.

10.2.3 Welding Metallurgy

- The heat affected zone (HAZ) is adjacent to the weld and is the part of the base metal that has not melted, but whose mechanical properties or microstructure have been altered by the preheat temperature and the heat of the weld.
- There is normally a change in grain size or grain structure and hardness in HAZ steel.
- For carbon steels, the HAZ includes regions that are heated to more than 1350 F (700°C).

10.2.3 Metallurgical Welding (cont'd)

There are many sources of hydrogen. In SMAW or SAW, hydrogen may be present as water in the flux or electrode coating. Hydrogen can also come from lubricants, water on the work piece, surface oxides, or moisture or rain.

10.2.3 Metallurgical Welding (cont'd).

- A reactive gas such as carbon dioxide can decompose at temperatures in the arc of carbon and oxygen. This is not a problem in carbon and low alloy steels. However, with highly alloyed and reactive metals, this can cause an increase in carbon content and the formation of oxides that can decrease the corrosion resistance properties of the weld.
- High alloy materials in gas shielded welding processes often employ inert gas shielding or mixtures with only small additions of reactive gases to promote arc stability.

10.3 PHYSICAL PROPERTIES

• The physical properties of a metal or alloy are those that are relatively insensitive to structure and can be measured without the application of force. Some examples of the physical properties of a metal are melting temperature, thermal conductivity, electrical conductivity, coefficient of thermal expansion, and density.

10.3.2 Thermal Conductivity

Materials with high thermal conductivity require higher heat inputs for welding than those with lower thermal conductivity and may require preheating. Steel is a poor conductor of heat, compared to aluminum or copper. As a result, less heat is needed to melt the steel.

This ability of aluminum to transfer heat so efficiently makes it more difficult to weld with low temperature heat sources.

10.3.3 Electrical conductivity

- One can then deduce that steel heats up with lower heat inputs than necessary for aluminum or copper due to its lower measure of electrical conductivity and higher electrical resistance.
- The thermal conductivity of a material decreases when the temperatures rise.
- A material that has had significant alloying elements added would have a low thermal conductivity and low fire are the inputs necessary to raise the material to a desired temperature.

10.3.4 Coefficient of Thermal Expansion

• This coefficient of thermal expansion may not be constant throughout a given temperature range because of the phase changes a material experiences at different temperatures and the increases or decreases in volume that accompany these phase changes.

10.3.4 Coefficient of thermal expansion

- This coefficient of thermal expansion cannot be constant over a range of temperatures because of the phase changes that a material undergoes at different temperatures and the increases or decreases in volume that accompany these phase changes.
- **Joining** metals where their coefficients of thermal expansion are very different can also contribute to thermal fatigue conditions, and as a result premature component failure. Welding procedures are often employed that specify special filler metals that minimize adverse effects caused by inherent differences between the metals to be joined.

10.3.5 Density

The **density** of a material is defined as its mass per unit volume. Cast, welded and therefore are usually less dense than wrought material of similar composition.

• A gas with a higher density is more efficient as a shielding gas than one with a lower density, since it protects the welding environment longer before dispersion.

10.4 MECHANICAL PROPERTIES

• The tests carried out to verify the value of those properties. This is one of the fundamental principles of the weld qualification testing procedure. Some examples of the mechanical properties of metals and alloys, tensile strength, yield strength, ductility, hardness and strength

10.4.1 Stress and yield

- The tensile test is used to determine metals tensile strength, yield strength, elongation, and surface reduction.
- The nominal stress of a metal is equal to the tensile strength.
- Stress is defined as the amount of deformation, change in shape. Stress is expressed as the length of the elongation divided by the original length of the specimen before being stressed.

10.4.2 Ductility

- In tensile strength tests, ductility is defined as the ability of a material to deform plastically without cracking, as measured by elongation or reduction in area.
- A material subjected to loads beyond its elastic limit may be strain hardened, or work hardened.
- Some of the materials also deteriorate in terms of ductility due to thermal cycling in service. Reduced ductility in these cases can fall so far that seamless repair welding services are very difficult if not impossible. This is sometimes experienced during repair welding of complex alloy tube plate heat exchangers.

10.4.3 Hardness

The **hardness** of a material is defined as its resistance to plastic deformation by indentation

- Hardness measurements can provide information about changes caused by metallurgical welding. In alloy steels, a high hardness measurement could indicate the presence of loose martensite in the weld or heat-affected zone, while low hardness can indicate over-tempering.
- There are often service degradation requirements, which are related to hardness. For example, the susceptibility to H₂S wet cracking in carbon steel is reduced if levels are maintained below 22 HRC hardness.

10.4.4 Resistance

Strength is the ability of a metal to absorb energy and deform plastically before fracturing. An important material property for a pressure tank and vessel design is the "fracture strength" of a metal which is defined as the ability to resist fracture or crack propagation under stress. It is usually measured by the energy absorbed in a notch impact test.

10.5 PREHEATING

- The primary purpose for preheating carbon and low-alloy steels is to reduce the tendency for hydrogen-induced retarded cracking. It does this by slowing down the cooling rate, which helps prevent the formation of martensite in the weld and HAZ base metal.
- A good practice is to evenly heat a gap on both sides of the welded joint at a distance of three times the width of the weld. Preheat should be applied and extend to at least 2 inches (50.8 mm) on both sides of the weld to encompass the weld and potential heat affected zone areas.

10.6 POST-WELD HEAT TREATMENT

- Post-weld heat treatment (PWHT) produces both mechanical and metallurgical effects on carbon and low-alloy steels.
- For example, a simple stress relief to reduce residual stresses is performed at a lower temperature than a heat treatment.
- PWHT (stress relief) can be applied by electric resistance heating, furnace heating, or if allowed by code, local flame heating.

10.7 TEMPERING

- Hardening or tempering is defined as the property of an iron alloy that determines the depth and distribution of hardness induced by quenching.
- Hardness depends mainly on the carbon content of the material, while hardenability is strongly affected by the presence of alloying elements, such as chromium, molybdenum, and vanadium, and, to a lesser extent, by the carbon content and alloying elements. alloy such as nickel, copper, and silicon.

ÿ Table 11

10.8 Material test report

- Material Test reports can sometimes be a very valuable tool for the inspector and welding engineer. These are normally notarial declarations and are legally binding. There are generally two types of test reports, a heat analysis and a product analysis. A heat analysis, or factory certificate.
- It is important to note that the materials of the general test reports are not delivered to the buyer, unless requested.

10.9 Weldability of steels

- ÿ There are entire books devoted to the weldability of metals and alloys. Weldability is a complex property that does not have a universally accepted definition. The term is widely interpreted by individual experience.
- ÿ The American Welding Society defines weldability as "the ability of a metal to be welded under the fabrication conditions imposed on a specific structure, properly designed, and to perform satisfactorily in its intended service."

10.9.1 Metallurgy and weldability

- A major factor affecting the weldability of metals and alloys is their chemical composition.
- If these limits are wide, the metal is said to have good weldability. If the limits are narrow, the metal is considered to have poor weldability.
- These are sulfur, phosphorus, tin, antimony and arsenic. These elements are sometimes known as residual elements.

• Several different equations to express carbon equivalent are in use. A common formula is:

$$CE = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Si + Ni + Cu)}{15}$$

• Generally, steels with a CE less than 0.35 do not require preheating. Steels with a CE of 0.35 to 0.55 usually require preheat, and steels with a CE greater than 0.55 require both preheat and a PWHT.

10.9.2 Weldability test

- One of the best means of determining the weldability of a metal or combination of metals is to perform direct weldability tests.
- The simplest weldability tests are those that evaluate the strength and ductility of the weld. Examinations that include tests evaluating weld tensile strength, shear strength, and hardness. The ductility and fracture toughness tests include bending tests and impact tests.

ÿ Table 12

10.10 Weldability and Alloys

• This section will give you information about welding high- alloy metals such as austenitic stainless steels, precipitation hardening stainless alloys, and nickel

10.10.1 Austenitic Stainless Steels

- The most important considerations for welding austenitic stainless steels are; solidification cracks, hot cracking, distortion and maintenance of corrosion resistance.
- The most common measure of weldability and susceptibility to hot cracking is the ferrite number of the weld metal. Austenitic welds require a minimal amount of delta ferrite to resist cracking.

10.10.2 Nickel Alloys

- Nickel alloys, such as Alloy C276 or Alloy 625 suffer from similar problems as austenitic stainless steels.
- This tendency means that the welder must move the weld bead from side to side or in a wobble pattern to ensure good sidewall fusion. If some oscillation is not used, a high convex weld contour will result in possible lack of fusion, weld undercut, or slag inclusions.

11. Welding in Refinery and petrochemical plant

1.1 Overview

ÿ This section provides details of the specific issues raised by the inspector at refinery and petrochemical plants. This section will be completed as more issues reflecting industry experience are added.

11.2 Hot Tapping and In-Service Welding

- API Publ 2201 provides an in-depth review of the safety aspects that must be considered when hot tapping or welding on service and equipment piping.
- Two major concerns to the welding process on pipelines in service and equipment burn through cracks.

11.2.1 Electrode Considerations

• Hot current and on duty welding operations should be carried out only with low hydrogen consumption electrodes (eg E7016, E7018 and E7048). Extra-low-hydrogen consumables such as Exxxx-H4 should be used to weld carbon steels with CE greater than 0.43%, or where the potential for hydrogen-assisted cracking (HAC) exists, such as high-strength cold-worked parts. , and very limited areas.

11.2.2 Flows

- Under most conditions, it is desirable to maintain product flow within any material being welded.
- Flow rates for liquids in pipes should be between 1.3 m/sec. and 4.0 m/sec. (0.4m/sec and 1.3m/sec)
- Because this is not a problem when the tube contains gases, there is no need to specify a maximum velocity.
It is advisable to compensate by preheating the weld area to at least 70 F (20 ° C) and maintain that temperature until the weld is complete.

11.2.3 Other considerations

Many users establish procedures detailing the minimum wall thickness that can be hot tapped or welded in service. See table 13

11.2.4 Inspection

• Inspection tasks typically associated with Hot Tapping or welding on service equipment must include:

- a. Proper wall thickness verification along lengths of welds typically proposed using UT or RT.
- b. Verification of welding procedures. Often plants have qualified welding procedures specifically for taps and in utility welding.
- c. Verification of flow conditions.
- d. Witness leak test, if specified.

11.3 Lack of High Fusion with GMAW-S Processes welding

- A large number of ASTM A 106, Grade B 4-inch by 10-inch pipe were found to be lack of fusion (LOF) after being fabricated using the GMAW-S welding process.

ASME B31.3 LOF considers a defect.

Due to the inherent character of the welding process of the
Section IX of the BPV Code restricts this process:

- a. Require qualification of welders by mechanical testing rather than by radiographic examination.
- b. Limit the thickness of the base metal qualified by the procedure to 1.1 times the thickness of the test for coupons less than 1/2 inch thick (12.7 mm) per variable QW 403.10.
- c. Limit the thickness of weld deposited metal qualified by the procedure to 1.1 times the thickness deposited for coupons less than 1/2 inch thick (12.7 mm) by variable QW-404-32 .
- d. QW-409.2 variable Make an essential variable in the qualification of a welder for the GMAW-S process.