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Procurement Guidelines for Metallic Materials

ASME

SETTING THE STANDARD

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FOREWORD

The scope of this document is to discuss the requirements in the ASME Codes and in the ASME material specifications for metallic materials, to address the various issues that affect the materials, and to provide guidelines for evaluating materials manufacturers and for preparing materials specifications that include the requirements for procuring material for ASME Code construction.

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1 INTRODUCTION

The ASME Boiler and Pressure Vessel Codes (BPVC) typically use ASME material specifications in practice, whereas, the ASME Piping Codes use ASTM material specifications. The ASME material specifications used in BPVC construction are based on the American Society for Testing Materials (ASTM), American Welding Society (AWS), or other international material specifications for metallic materials. The material specifications include mandatory requirements for manufacturing, testing and inspecting material, and may include a number of supplementary requirements, which are only used when specified by the purchaser. The specifications may also contain requirements pertaining to ordering and supplying of the materials.

ASTM and ASME material specifications generally do not include requirements that address fabrication effects on materials, except for statements that the material is suitable for welding construction. The BPVC and the ASME B31 Pressure Piping Codes do include certain requirements for fabrication effects, such as forming strains, tests on representative test coupons to simulate fabrication heat treatments, impact test requirements for materials and welded joints, and inspection requirements. Where these additional requirements are mandated by the ASME Codes, it is generally the responsibility of the vessel or piping designer/purchaser to specify these requirements when specifying/purchasing raw materials.

The ASME Codes and the various material specifications also do not generally include special requirements for environmental effects on the materials. The 2013 edition of the BPVC Section II, Part D includes an expanded Non-mandatory Appendix A that describes various materials degradation mechanisms for materials that are used in ASME Code construction. Generally, it is the responsibility of the user or designer to identify service related material requirements for vessels and piping. It is the responsibility of the vessel or piping manufacturer to specify these requirements when procuring materials.

Frequently, ASME material requirements or service related conditions are not properly identified, or communicated between the parties involved during design, specification, procurement, and fabrication of vessels and piping, This document is intended to highlight common problems associated with the specification and procurement of materials for ASME Code construction. The relevant ASME Codes in this document include BPVC Section I, BPVC Section IV, BPVC Section VIII, BPVC Section XII, B31.1 Power Piping Code (ASME B31.1), and B31.3 Process Piping Code (ASME B31.3). The information in this report may also be applicable to other codes; however, such other codes have not been evaluated for inclusion in this document.

2 SCOPE

The ASME Codes and material specifications include specific requirements for use of the materials in ASME Code construction. However, they do not address all requirements. It is the responsibility of the user to specify service related requirements to prevent in-service degradation of the materials. It is the responsibility of the vessel manufacturer to account for materials degradation during fabrication and to include all necessary requirements in the raw material purchase specifications for ASME Code construction.

The scope of this document is to discuss the requirements in the ASME Codes and in the ASME material specifications for metallic materials, to address the various issues that affect the materials, and to provide guidelines for evaluating materials manufacturers and for preparing materials specifications that include the requirements for procuring material for ASME Code construction.

Some of the sections in this document pertain only to ferrous materials (carbon steels, low alloy steels and high alloy steels) because many of the past problems have been related to these materials (refer to Section 4 and Section 11 herein). However, most of the issues and considerations discussed in this document also pertain to nonferrous materials, particularly Sections 12 – 14 herein.

3 ASME ADOPTION OF MATERIAL SPECIFICATIONS

ASME material specifications are those that are published in the BPVC Section II, Parts A, B and C. The majority of ASME material specifications are based on ASTM or AWS specifications.

ASME ferrous material specifications are identified by the letters "SA" as the first characters in the specification number. For example, SA-106 refers to an ASME specification, whereas A106 refers to an ASTM specification. ASME nonferrous material specifications are identified by the letters "SB" as the first characters in the specification number. For example, SB-366 refers to an ASME material specification, whereas, B366 refers to an ASTM material specification. ASME welding rod, filler metal, and electrode material specifications are identified by the letters "SFA" as the first characters in the specification number. For example, SFA-5.1/SFA-5.1M refers to an ASME specification, whereas, A5.1/A5.1M refers to an AWS welding material specification.

As ASME adopts ASTM and other acceptable international material specifications for pressure vessel construction, the requirements in the ASME specification generally will be the same as those in the adopted ASTM or the acceptable international specification. However, some of the ASME material specifications include a statement underneath the title of the specification that lists the exceptions from the ASTM (or international) specification, or additional ASME requirements. Users should consult the appropriate specification to determine the differences between the ASME and the ASTM/AWS (or other international) specifications.

3.1 ASME Material Specifications

In general, materials used for ASME BPVC construction are required to be ASME materials. The BPVC Section II, Part D, Tables 1A, 1B, 2A, 2B, C, 5A and 5B list all materials that may be used for ASME Code construction. Materials that have a temperature listed in the column titled "Applicability and Maximum Temperature Limits" may be used for ASME Code construction within the indicated temperature range for the applicable BPVC Section. Materials that have "NP" listed in this column may not be used for construction under that Section. Materials that are not listed in the BPVC Section II, Part D, may be used for ASME Code construction if permitted by an ASME Code Case.

The materials used for ASME Code construction must be furnished in accordance with the specifications listed in BPVC, Section II. The materials for Code use shall be ordered, produced, and documented in accordance with either the ASME specification in Section II (except as limited by the rules of the applicable construction code), or with an ASTM specification listed in Table II-200-1, or with a specification issued by other acceptable non-ASTM (international) specifications listed in Table II-200-2, or in a ASME Code Case for the construction code(s) listed in the ASME Code Case.

The ASME SA material specifications include a statement under the title of the specification that identifies the related ASTM or the international material specification. Many ASME SA material specifications are identical with a particular edition of the same ASTM specification, in which case the ASME SA specification states that the ASME SA specification is identical with the ASTM or the international material specification, and lists the year date of the publication of that specification that is used for adoption of it as the ASME SA material specification. However, not all of the ASME SA material specifications are identical with the ASTM or the related international material specification. In such cases the statement under the title of the ASME SA specification also lists the exceptions, or modifications, or additional requirements to the adopted specification for use in ASME Code construction. For example, the ASME SA specification SA-335 adds hardness requirements for Grades P23 and P911 pipes. Another example is fusion welded pipes under specifications SA-671 and SA-672 that include an additional statement that limit fabrication of such pipe for ASME Section III construction to Manufacturers holding the appropriate ASME Certificate of Authorization and Certification Mark.

Also the ASME SB nonferrous material specifications include a statement under the title of the specification that identifies the related ASTM or the international material specification. Some of the ASME SB material specifications are identical with a particular edition of the same ASTM specification, in which case the ASME SB specification states that the ASME SB specification is identical with the ASTM or the international material specification, and lists the date of publication of that specification that is used for adoption of it as the ASME material specification. However, most of the ASME SB nonferrous material specifications are not identical with the ASTM or related international material specification because many do not include the mandatory requirement for a certification and test report. In such cases the statement under the title of the ASME SB specification also lists the exceptions, modifications, or additional requirements, and includes the statement that certification and test reports have been made mandatory for the adopted specification for use in ASME Code construction.

3.2 ASTM Material Specifications

In general, materials used for ASME B31 Pressure Piping Code designs must be ASTM materials. The B31 Pressure Piping Codes contains table listings of ASTM materials that are for use within the scope of that Code. Each ASME Code also includes rules for the use of unlisted materials, whether such materials are ASTM, ASME, or produced to another material specification.

For BPVC applications, BPVC Section II, Part A, Table II-200-1 and Section II, Part B, Table II-200-1 list the dates of the latest adopted ASTM material specifications and other acceptable ASTM specification editions that may be used in lieu of the corresponding ASME specifications, provided the additional requirements referenced in the subtitle are met. Likewise, Tables II-200-2 in Section II, Part A and in Part B list the latest and other acceptable editions of non-ASTM specifications that may be used in lieu of the corresponding ASME specifications, provided the additional requirements listed in the ASME specifications are met.

ASTM specifications may be used if listed in BPVC Section II, Part A, Table II-200-1, except as limited by rules in the applicable construction code. If the BPVC Data Report is registered with National Board, material specifications must be in accordance with ASME SA specifications.

3.3 Dual Marked Materials

Occasionally, users may come across items that are marked as both ASME and ASTM materials. For example, a pipe may be marked as “A/SA-106” or “SA-106/A-106”, which indicates that the material complies with the requirements of both the ASTM specification and the corresponding ASME specification. Materials marked in this fashion may be used in applications requiring either ASME or ASTM materials.

4 GENERAL REQUIREMENTS IN MATERIAL SPECIFICATIONS FOR VARIOUS PRODUCT FORMS

A material specification for a product (plate, forging, pipe, etc.) includes the specific requirements for materials produced to that specification, and often includes the following:

- Types, grades, or classes of material covered by the specification.
- General requirements and ordering information.
- Manufacturing practice.
- Heat treatment.
- Chemical composition requirements.
- Mechanical properties.
- Supplementary requirements considered applicable to the materials produced under that specification.

Common requirements that are applicable for a particular product form (such as plate, forging, pipe, etc.) are frequently referenced in the general requirements section of a material specification. These general requirements specifications provide additional information that may not be stated in the specific material specification. General requirements specifications may typically include the following:

- Material specifications covered by the general requirements specification.
- Ordering information that should be specified by the purchaser.
- Manufacturing requirements for the material.
- Heat treatments.
- Chemical composition (by heat and product analysis).
- Metallurgical structure.
- Quality requirements.
- Test methods.
- Tension test requirements.
- Notch toughness test requirements.
- Identification of the product forms (e.g., plates).
- Permissible variations in dimensions or mass.
- Inspection and testing.
- Provisions for retest.
- Provisions for re-heat treatment.
- Notch toughness test requirements.
- Rejection.
- Test reports.
- Marking.

In some cases there are differences between the requirements of a material specification and the referenced general requirements specification. In these cases, the requirements of the specific material specification will prevail.

The general requirements specifications also include a list of the supplementary requirements that are considered suitable for use with the specific product specifications. The product specifications may include additional supplementary requirements that are suitable for a particular product specification. The general requirements specifications form an integral part of the specification of a material, and it is important that ASME Code users understand what is in these specifications, and how they impact the specification and procurement of materials. The following sections highlight some of the general requirements specifications for ferrous materials (carbon, low alloy, and high alloy steels) that ASME Code users should be familiar with.

4.1 SA-20, General Requirements for Steel Plates for Pressure Vessels

SA-20 includes general requirements for pressure vessel plate specifications that are listed in the Scope. That includes requirements for terminology, ordering information, materials and manufacture, heat treatment, chemical composition, metallurgical structure, quality, test methods, tension tests, notch toughness tests, identification of plates, permissible variations in dimensions or mass, inspection and testing, retests, retreatment, rejection, test reports, and packaging, marking, and loading for shipment. The following are comments on several of these requirements:

(a) *Manufacture* **-** Practically all steel in modern steel mills is now produced by strand casting. However, ingots are still used for producing thick plates. Strand cast slabs are limited to about 10 to 12 inches maximum thickness, which limits the final plate thickness to about 4 inches after reduction. SA-20 contains alternative rules that may be used to produce plate using strand cast slabs in thicknesses to about 6 inches.

(b) *Heat Treatment* **-** The heat treatment (normalizing, quenching and tempering, thermomechanical processing) is specified in the general product specification. ASTM and ASME specifications do not consider "normalized rolling" (permitted by the European (EN) specifications for pressure vessel plates) to be an acceptable substitute for "normalizing".

(c) *Chemical Composition* **-** In addition to the elements specified in the applicable product specification, SA-20 requires determination of the content of the following elements: carbon, manganese, phosphorus, sulfur, silicon, nickel, chromium, molybdenum, copper, vanadium, columbium, and in some cases aluminum or other austenitic grain refining element.

The chemical composition may include other unspecified elements that may not be listed in the chemical composition tables of the product specification but, if present in excessive amounts can increase hardenability or decrease weldability. SA-20 imposes maximum limits (SA-20 specifications, Table 1) for certain elements (copper, nickel, chromium, molybdenum, vanadium, columbium, titanium, and boron) that may be present but are not listed in the product specification. Excessive amounts of these elements can cause martensitic hardening in heat affected zones during postweld heat treatment with a corresponding loss of notch toughness and can lead to an increased risk of hydrogen-delayed cracking.

(d) *Tension and Impact Testing* **-** SA-20 includes detailed requirements for tension testing and impact testing most of which is referenced in the product specifications and is referred to the general requirements specification for testing requirements.

(e) *Quality* **-** SA-20 includes specific requirements for defects and states that plates shall be free of injurious defects. It goes on to state that injurious surface imperfections shall be removed by the manufacturer or processor. Unfortunately, SA-20 does not define "injurious defects", however it is generally understood that a plate with an "injurious defects" is not suitable for the intended service. Code users may want to consider adding a definition of injurious surface imperfections to their material specifications if it is critical to their application. SA-20 also includes acceptance criteria for edge defects.

(f) *Repair by Welding* **-** SA-20 includes specific requirements for repair welding. Repair welding is not permitted unless approved the purchaser.

(g) *Identification of Plates* **-** SA-20 includes requirements for marking of plates. Heat treated plates shall be marked with the letters "MT" and "green" plates (to be heat treated by others) be marked with the letter "G". SA-20 also specifies the types of required marking and location of markings.

(h) *Test Reports* **-** The manufacturer or processor shall report the results of all tests required by the applicable product specification, the applicable supplementary requirements, and the purchase order. The test report shall clearly identify the organization submitting the test report. Copies of the original manufacturer's test report shall be included with any subsequent test report. Test reports may be provided in electronic form.

(i) *Supplementary Requirements* **-** The following is a list the supplementary requirements in SA 20 that may be invoked by the purchaser:

S1. Vacuum Treatment.

S2. Product Analysis.

S3. Simulated Postweld Heat Treatment of Mechanical Test Coupons.

S4. Additional Tension Test.

S5. Charpy V-Notch Impact Test.

S6. Drop-weight Test for Plates 0.625 inches (in.) (16 millimeters (mm)) and Over in Thickness.

S7. High temperature Tension Test.

S8. Ultrasonic Examination in Accordance with A435/A435M.

S9. Magnetic Particle Examination.

S10. Charpy V-Notch Impact Transition Curve.

S11. Ultrasonic Examination in Accordance with A577/A577M.

S12. Ultrasonic Examination in Accordance with A578/A578M.

S13. NDT Temperature Determination.

S15. Reduction of Area Measurement.

S16. Thermal Stress Relief of Mechanical Test Coupons.

S17. Vacuum-Carbon Deoxidized Steel.

S19. Restricted Chemical Requirements.

S20. Maximum Carbon Equivalent for Weldability.

S21. Restricted Limits on Elements.

S22. Through Thickness tension Tests.

S24. Strain Age Test.

S25. Weldability.

S26. Low-Sulfur Steels.

S27. Restricted Plate Flatness.

S28. Heat Treatment in the Working Zone of a Surveyed Furnace.

Not all of the Supplementary Requirements listed in SA-20 are deemed to be suitable for all product specifications listed in SA-20. For example, SA-516 lists the following Supplementary Requirements:

S1. Vacuum Treatment.

S2. Product Analysis.

S3. Simulated Postweld Heat Treatment of Mechanical Test Coupons.

S4.1. Additional Tension Test.

S5. Charpy V-Notch Impact Test.

S6. Drop-weight Test for Plates 0.625 in. (16 mm) and Over in Thickness.

S7. High temperature Tension Tests.

S8. Ultrasonic Examination in Accordance with A435/A435M.

S9. Magnetic Particle Examination.

S11. Ultrasonic Examination in Accordance with A577/A577M.

S12. Ultrasonic Examination in Accordance with A578/A578M.

S17. Vacuum-Carbon Deoxidized Steel.

However, additional Supplementary Requirements from SA-20 can be specified for SA-516 plates by the purchaser, subject to agreement with the plate manufacturer.

4.2 SA-788, General Requirements for Steel Forgings

SA-788 includes common requirements for forgings. This includes requirements for terminology, ordering information, melting process, forging, cooling prior to heat treatment, chemical composition, heat treatment, mechanical testing, reheat treatment, repair welding, dimensions and finish, inspection, rejection, certification, packaging and package marking. The following are comments on several of these requirements:

(a) *Chemical Composition* **-** The chemical composition limits are listed in each individual product specification. SA-788 does not prescribe limits for elements which are not specified by the product specification, unless Supplementary Requirement S1 is specified.

(b) *Repair Welding* **-** Repair welding of forgings is not permitted unless specifically allowed by the product specification. The individual forging specifications that are listed in SA-788 and are permitted for ASME Code construction, require the repair welding to be made in accordance with the BPVC Section IX.

(c) *Mechanical Testing* **-** Mechanical testing requirements are specified in the individual product specifications. This includes test frequency, test specimen location and orientation, and heat treatment. Most specifications include three options for mechanical testing:

- *Testing of separately forged test block* - The separately forged test block must be of the same heat of material, shall be subjected substantially the same reduction and working as the production forging, and shall be of the same nominal thickness as the production forging. (NOTE: Not meeting these requirements introduces uncertainty that the test blocks may not be forged substantially to the same level of reduction as the production forging, which may result in better impact test energy values in the test block that in a test specimen take from the actual forging.)
- *Testing of forging prolongations (with or without thermal buffers*) - The test specimen are to be taken from the ¼ t x t location of the forging.
- *Testing of specimens taken from t x 2t location in the forging* - Where "t" corresponds to the distance from the area of significant stress to the nearest heat treated surface and at least twice this distance from any second surface. The test depth shall not be nearer to one heat treated surface than ¾ inches and to second heat treated surface than 1¼ inches.

(d) *Heat Treatment* **-** The required forging heat treatments are specified in the individual product specifications.

(e) *Examination* **-** The examination requirements are specified in the individual product specifications. For example, low alloy steel forgings such as SA-336, heat treated by quenching and tempering, must be examined by the magnetic particle (MT) method in accordance with A/SA-275.

(f) *Supplementary Requirements* - The following is a list of the supplementary requirements that may be invoked by the purchaser's purchasing documents.

S1. Residual Elements.

S2. Unspecified Elements.

S3. Sequential or Continuous Strand Casting.

S4. Intercritical Heat Treatment.

S5. Straightening of Forgings.

S6. Post-Heat Treatment Straightening of Forgings.

S7. Fracture Toughness Test.

S8. Vacuum Degassing.
S9. Vacuum Carbon Deoxidation.
S10. Restricted Phosphorus and Sulfur, Level A or B.
S11. Restricted Copper, Level A or B.
S12. Tension Specimens for Hubbed Flanges and Tube Sheet.
S13. Charpy V-Notch Impact Transition Curve.
S14. Charpy Impact Tests.
S15. Grain Size.
S16. Rough Machining and Boring.
S17. Simulated Post-Weld Heat Treatment of Mechanical Test Samples.
S18. Magnetic Particle Examination.
S19. Liquid Penetrant Examination.
S20. Ultrasonic Examination.
S21. Additional Test Coupon Heat Treatment.
S22. Ultrasonic Examination from Bore Surface.
S23. Magnetic Particle Examination Using AC Current.
S24. J-factor.
S25. Positive Material Identification.
S26. Pressure Equipment Directive – Mechanical Testing.
S27. Heat Analysis for Re-melted Ingots.

4.3 SA-961, Common Requirements for Steel Flanges, Forged Fittings, Valves, and Parts for Piping Applications

SA-961 includes the common requirements that apply to steel flanges, forged fittings, valves and parts for piping applications. This includes requirements for terminology, ordering information, melting process, manufacture, heat treatment, chemical requirements, mechanical requirements, hardness requirements, tensile requirements, impact requirements, hydrostatic test requirements, rework, finish and appearance, repair by welding, inspection, rejection and rehearing, certification, marking and packaging, and loading for shipment. The following are comments on several of these requirements:

(a) *Chemical Composition* - The heat analysis limits for the listed elements are given in the product specifications. If product analysis is performed, the product analysis tolerances are given in Table 1 (for higher alloy and stainless steels) and in Table 2 (for carbon and low alloy steels) of SA-961.

(b) *Repair by Welding* - Repair welding is permitted at the discretion of the supplier, unless the purchaser requires prior approval of the proposed weld repairs by invoking Supplementary Requirement S58. The welding procedure and welders shall be qualified in accordance with the BPVC Section IX.

(c) *Certification* - Not all product specifications referenced by A961 require test reports. For example, A105 forgings only require test reports when specifically requested by the purchaser. Purchasers who require test reports should carefully verify the requirements of the product specification to determine whether or not these need to be specified in the purchase order.

(d) *Supplementary Requirements* - The following is a list of the supplementary requirements in SA-961 that may be invoked by the purchaser:

S50. Macroetch Test.
S51. Heat Analysis.
S52. Product Analysis.

S53. Tension Test.
S54. Impact Test.
S55. Magnetic Particle Examination.
S56. Liquid Penetrant Examination.
S57. Hydrostatic Testing.
S58. Repair Welding.
S59. Electro polished Austenitic and Ferritic-Austenitic Grades.
S60. Positive Material Identification Examination.
S61. Heat Treatment in the Working Zone of a Surveyed Furnace.
S62. Requirements for Carbon Steel Products for Concentrated Hydrofluoric Acid Service.
S63. Pressure Equipment Directive – Mechanical Testing.

The individual product specifications listed in SA-961 can have additional Supplementary Requirements. For example, SA-350 lists the following Supplementary Requirements:

S1. Impact Test Temperature.
S2. Stress Relieved Test Specimens.
S3. Lateral Expansion.
S4. Vacuum Carbon-Deoxidized Steel.
S5. Special Impact Test Requirements for Flanges.
S6. Carbon Equivalent.

(e) *Separately Forged Test Blanks* **-** This specification permits the use of either production forgings or separately forged test blanks for mechanical testing. It further specifies that if separately forged test blanks are used, they must be of the same heat of steel, be subjected to substantially the same reduction and hot working as the production forging they represent, be heat treated in the same furnace charge under the same conditions as the production forging, and be of the same nominal thickness as the maximum heat treated thickness of the production forging. However, it is difficult to verify that a separately forged test blank has been subjected to the same reduction and hot working as a production forging. Past experience indicates that often separately forged test blanks of carbon and of alloy steel forgings are subjected to more work and reduction than the actual forgings, which significantly increases the notch toughness of the test blanks, therefore, the impact test values reported taken from the actual forging may be significantly less than those from the actual forging. The only way to verify the test results is to test the actual forging, or a prolongation of it. This specification recognizes this and includes supplementary requirements for tension testing (S53) and impact testing (S54) of a production forging from each heat of steel.

4.4 SA-530, General Requirements for Specialized Carbon and Alloy Steel Pipe

SA-530 includes general requirements that apply to specialized carbon and alloy steel piping. This includes requirements for process, chemical composition, mechanical requirements, tensile requirements, permissible variation in weight, permissible variations in wall thickness, permissible variations in inside diameter, permissible variations in outside diameter, permissible variations in length, standard weight, ends, straightness, repair by welding, retests, retreatment test specimens, flattening test requirements, hydrostatic test requirements, certified test reports, inspection, rejection, product marking, packaging, marking, loading, and government procurement. The following are comments on several of these requirements:

(a) *Applicability of Requirements* - This general specification has requirements that are mandatory dependent upon what the product specification requires. For example, the requirements for product analysis and flattening tests are mandatory if the product specification requires product analysis or flattening tests. The requirements for hydrostatic testing are mandatory only where the product specification requires hydrostatic testing, but does not define the test parameters. The purchaser should carefully review the scope of SA-530 to determine if requirements apply to their situation.

(b) *Chemical Composition* - SA-530 does not explicitly impose limits on unspecified elements; for stainless steels, unspecified elements may not be present in such an amount that the material may qualify for another grade of material.

(c) *Repair Welding* - Repair welding of seamless pipe and welded pipe shall be permitted, subject to approval by the purchaser and with the understanding that the deposited filler metal shall be suitable for the composition being welded. Repair welding shall be done using welding procedures and welders or welding operators that have been qualified in accordance with the BPVC Section IX.

(d) *Certification* - When specified in the purchase order or contract, the producer or supplier shall furnish certified test reports.

(e) *Supplementary Requirements* - SA-530 does not include a list of Supplementary Requirements. However, the individual product specifications list Supplementary Requirements that may be specified by the purchaser. For example, SA-106 lists the following supplementary requirements that apply to that specification:

S1. Product Analysis.
S2. Transverse Tension Test.
S3. Flattening Test, Standard.
S4. Flattening Test, Enhanced.
S5. Metal Structure and Etching Test.
S6. Carbon Equivalent.
S7. Heat Treated Test Specimens.
S8. Internal Cleanliness – Government Orders.
S9. Requirements for Carbon Steel Pipe for Hydrofluoric Acid Alkylation Service.

4.5 SA-450, General Requirements for Carbon and Alloy Steel Tubes

SA-450 includes general requirements for carbon, ferritic alloy, and austenitic alloy steel tubes. This includes requirements for process, chemical composition, tensile properties, standard weights, permissible variations in wall thickness, permissible variations in outside diameter, permissible variations in length, permissible variations in height of flash on electric resistance welded tube, straightness and finish, repair by welding, retests, retreatment, test specimens, method of mechanical testing, flattening tests, reverse flattening tests, flaring tests, flange tests, hardness tests, hydrostatic tests, air underwater pressure tests, nondestructive examination, certified test reports, inspection, rejection, product marking, packaging, marking and loading, and government procurement. The following are comments on several of these requirements:

(a) *Applicability Requirements* **-** This general specification has requirements that are mandatory depending on what the product specification requires. For example, the requirements for product analysis, tensile properties, standard weights, flattening tests, reverse flattening tests, flaring tests, flange tests, hardness tests, hydrostatic test, and air underwater tests are mandatory only if the product specification states requirements for these. The purchaser should carefully review the scope of SA-450 to determine if requirements apply to their situation.

(b) *Chemical Composition* **-** The chemical composition by heat analysis, or that determined by product analysis shall conform to the requirements in product specification. For stainless steel ordered to the product specification, the steel shall not contain an unspecified element, other than nitrogen for the ordered grade, to the extent that the steel conforms to another grade.

(c) *Repair Welding* - Repair welding is permitted only with the prior approval of the purchaser. The tube shall be marked with the letters "WR". The welding procedure and welders shall be qualified in accordance with the BPVC Section IX.
(d) *Certification* - When specified in the purchase order or contract, the producer or supplier shall furnish certified test report.
(e) *Supplementary Requirements* - SA-450 does not include a list of Supplementary Requirements.

4.6 SA-703, General Requirements for Steel Castings for Pressure-Containing Parts

SA-703 includes common requirements for steel castings for pressure-containing parts. This includes requirements for terminology, materials and manufacture, chemical composition, mechanical test methods, tensile requirements, repair by welding, flanges, quality, hydrostatic tests, workmanship, finish and appearance, retests, inspection, rejection and rehearing, certification, and product marking. The following are comments on several of these requirements:

(a) *Chemical Composition* - The chemical composition limits are listed in each individual product specification. SA-703 does not prescribe limits for elements, which are not specified by the product specification, unless Supplementary Requirement S1 is specified. Additionally, for stainless steels and nickel alloys, unspecified elements may not be present in such an amount that the material may qualify as another grade of material.
(b) *Repair by Welding* - Repair by welding may be made without consent of the purchaser. Where Supplementary Requirement S12 has been specified, major weld repairs shall require prior approval. This specification does not require that weld repairs shall be performed in accordance with the BPVC Section IX, but rather in accordance with ASTM A488/A488M.
(c) *Quality* - SA-703 states that the casting surface shall be free of adhering sand, scale, cracks, hot tears as determined by visual examination and other surface discontinuities shall meet the visual acceptance standards specified in the order. Purchasers may want to explicitly reference Practice A802/A802M or other visual standards. This may be used to define acceptable surface discontinuities and finish. Unacceptable visual surface discontinuities shall be removed and their removal verified by visual examination of the resultant cavities. Castings shall not be peened, plugged, or impregnated to stop leaks or to disguise rejectable indications. Internal chills and chaplets may be used in the manufacture of castings. However, the chills, chaplets, and affected cast material must be completely removed.
(d) *Hydrostatic Test* - Each casting shall be tested after machining to the hydrostatic test pressures prescribed in ASME B16.5 Piping Code [10] for the applicable steel rating for which the casting is designed; castings shall show no leaks. Where a casting has not been ordered to a standard ANSI rating, test pressure shall be agreed to between the manufacturer and the purchaser, and this shall be noted in the order.
(e) *Certification* - For all orders, the manufacturer shall provide certification of compliance with product specification, including chemical analysis and mechanical property test results.
(f) *Supplementary Requirements* - The following is a list of the supplementary requirements that may be invoked by the purchaser:

S1. Unspecified Elements.

S2. Destruction Tests.

S3. Bend Test.

S4. Magnetic Particle Inspection.

S5. Radiographic Inspection.

S6. Liquid Penetrant Inspection.

S7. Ultrasonic Inspection.

S8. Charpy Impact Test.

S9. Drop Weight Test.
S10. Examination of Weld Preparation.
S12. Prior Approval of Major Repairs.
S13. Hardness Test.
S14. Tension Test from Each Heat and Heat Treatment Charge.
S15. Quench and Temper Heat Treatment.
S17. Tension Test from Castings.
S18. Tension Test for Castings Each Weighing 10,000 lb (4500 kg) or more.
S20. Weld Repair Charts.
S21. Heat Treatment Furnace Record.
S22. Heat Treatment.
S23. Macroetch Test.
S24. Specified Ferrite Content Range.
S25. Heat Treatment Certification.
S26. Alternate Tension Test Coupons and Specimen Location for Castings.
S27. Hot Isostatic Pressing (HIPing).
S28. Cleaning of Stainless Steels.

4.7 SA-480, Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip

SA-480 includes the general requirements for flat rolled stainless and heat resisting steel plate, sheet, and strip. This includes requirements for terminology, ordering information, heat analysis, product analysis, material test reports and certification, permitted variations in dimensions and weight, workmanship, finish for sheet, finish for strip, finish for plates, edges for cold-rolled strip, heat treatment, number of tests, test specimens, special tests, test methods, retests and retreatment, repair of plates by welding, inspection, rejection, rehearing, packaging, marking, and loading. The following provides comments on several of these requirements:

(a) *Heat Treatment* **-** This general requirements specification includes the required heat treatments for austenitic stainless steels, duplex types, and martensitic and ferritic types of stainless steels, unless otherwise specified in the applicable material specification. Austenitic stainless steels shall be solution annealed, unless otherwise specified in the applicable material specification.

(b) *Chemical Composition* - The chemical composition limits are listed in each individual product specification. SA-480 does not prescribe limits for elements which are not specified by the product specification. However, unspecified elements may not be present in such an amount that the material may qualify as another grade of material.

(c) *Workmanship* – SA-480, Paragraph 10.1 requires the plates to be of uniform quality consistent with good manufacturing and inspection practices. The steel shall have no imperfections of a nature or degree that will adversely affect the stamping, forming, machining, or fabrication of finished parts.

(d) *Repair Welding* **-** Repair of surface defects of a plate by welding is permitted unless prohibited by other specifications or purchase order requirements. Where repair welding is performed, the repair welding shall be in accordance with the BPVC Section IX.

(e) *Identification of Plates* **-** Sheet, strip, and plate shall be marked on one face with the specific designation number, type of steel (type or UNS designation), material identification number, and the name or mark of the manufacturer. Flat sheet, strip in cut lengths, and plate with length and width dimensions less than 24 inches, shall be marked with type of steel and material identification number.

(f) *Test Reports* **-** A report of the results of all the tests required by the product specification shall be supplied to the purchaser. The test report shall list the melting process when this is required by the purchase order.

(g) *Supplementary Requirements* **-** This specification has no supplementary requirements. However, supplementary requirements are included in the applicable material specifications (e.g., SA-240).

4.8 SA-1016, Specification for General Requirements for Ferritic Alloy Steel, Austenitic Alloy Steel, and Stainless Steel Tubes

SA-1016 includes general requirements for ferritic alloy steel, austenitic alloy, and stainless steel tubes. This includes requirements for terminology, manufacturing, ordering requirements, chemical composition, tensile properties, permissible variations in wall thickness, permissible variations in outside diameter, permissible variations in length, permissible variations in height of flash on electric resistance welded tube, straightness and finish, repair by welding, retests, retreatment, test specimens, method of mechanical testing, flattening tests, reverse flattening tests, reverse bend test, flaring tests, flange tests, hardness tests, nondestructive information, hydrostatic tests, air underwater pressure tests, certified test reports, inspection, rejection, product marking, packaging, marking and loading, and government procurement. The following are comments on several of these requirements:

(a) *Application* **-** This general specification has requirements that are mandatory, depending on what the product specification requires. Some requirements, such as product analysis, tensile properties, standard weights, Vickers hardness tests, hydrostatic test, and air underwater tests are mandatory only if the product specification or the purchaser states requirements for these. In general, this specification has more specific requirements than SA-450. The purchaser should carefully review the scope of SA-1016 to determine whether some of the requirements in this general specification apply to their situation.

(b) *Chemical Composition* **-** The heat analysis limits for the listed elements are given in the product specifications. SA-1016 does not prescribe limits for elements which are not specified by the product specification. The steel shall not contain an unspecified element, other than nitrogen for stainless steels, for the ordered grade to the extent that the steel conform to the requirements of another grade for which that element is a specified element having a required minimum content.

(c) *Repair Welding* **-** Repair welding is permitted only with the prior approval of the purchaser. The tube shall be marked with the letters "WR". The welding procedure and welders shall be qualified in accordance with the BPVC Section IX.

(d) *Certification* **-** The producer or supplier shall furnish a certificate of compliance. In addition to the certificate of compliance, the manufacturer shall furnish test reports that include the following information and test results, where applicable:
- Heat number.
- Heat analysis.
- Product analysis, when specified by the purchaser.
- Tensile properties.
- Width of the gage length (when longitudinal strip tension test specimens are used).
- Flattening test acceptable.
- Reverse flattening test acceptable.
- Flaring test acceptable.
- Flange test acceptable.
- Hardness test acceptable.
- Hydrostatic test pressure.
- Nondestructive electric test method.
- Impact test results.

- Any other test results and information required to be reported by the product specification or the purchase order.

(e) Supplementary Requirements - SA-1016 does not include a list of Supplementary Requirements.

4.9 SB-248 General Requirements for Wrought Copper and Copper-Alloy Plate, Sheet, Strip and Rolled Bar

SB-248 includes general requirements for plate, sheet, strip, and rolled bar specifications that are listed in the Scope. That includes requirements for terminology, materials and manufacture, dimensions, weights, and permissible variations, workmanship, finish and appearance, sampling, number of tests and retests, specimen preparation, test methods, significance of numerical limits, inspection, rejection and rehearing, certification, mill test report, and packaging and package marking.

Supplementary Requirements – SB-248 does not include a list of Supplementary Requirements.

4.10 SB-249/SB-249M General Requirements for Wrought Copper and Copper-Alloy Rod, Bar, Shapes, and Forgings

SB-249/SB-249M includes general requirements for rod, bar, shapes and forgings specifications that are listed in the Scope. That includes requirements for terminology, materials and manufacture, chemical composition, dimensions, mass and permissible variations, workmanship, finish and appearance, sampling, number of tests and retests, specimen preparation, test methods, significance of numerical limits, inspection, rejection and rehearing, certification, mill test report, and packaging and package marking.

Supplementary Requirements – SB-249/SB-249M does not include Supplementary Requirements unless it is specified by the purchaser in the inquiry, contract, or order for agencies of the U.S. Government. However, Supplementary Requirements are included in the applicable material specification (e.g. SB-283).

4.11 SB-251, General Requirements for Wrought Seamless Copper and Copper-Alloy Tube

SB-251 includes general requirements for wrought seamless tube specifications that are listed in the Scope. That includes requirements for terminology, materials and manufacture, chemical composition, dimensions and permissible variations, workmanship, finish and appearance, sampling, number of tests and retests, test specimens, test methods, significance of numerical limits, rejection and rehearing, certification, packaging and package marking and mill test report.

Supplementary Requirements – SB-251 does not include Supplementary Requirements unless it is specified by the purchaser in the inquiry, contract, or order for agencies of the U.S. government.

4.12 SB-751, General Requirements for Nickel and Nickel-Alloy Welded Tube

SB-751 includes general requirements for welded tube specifications that are listed in the Scope. That includes requirements for terminology, dimensions and permissible variations, workmanship, finish, and appearance, test requirements, sampling, retests and retreatment, specimen preparation, inspection, rejection and rehearing, certification and product marking.

Supplementary Requirements – SB-751 does not include a list of Supplementary Requirements. However, supplementary requirements are included in the applicable material specifications (e.g., SB 468).

4.13 SB-775, General Requirements for Nickel and Nickel-Alloy Welded Pipe

SA-775 includes general requirements for pressure vessel welded pipe specifications that are listed in the Scope. That includes requirements for terminology, test requirements, dimensions and permissible variations, workmanship, finish, and appearance, sampling, retests and retreatment, specimen preparation, inspection, rejection and rehearing, certification and product marking.

Supplementary Requirements – SB-775 does not include a list of Supplementary Requirements.

4.14 SB-824, General Requirements for Copper Alloy Castings

SA-824 includes general requirements for copper casting specifications that are listed in the Scope. That includes requirements for terminology, materials and manufacture, chemical composition, mechanical property requirements, other requirements, dimensions, mass and permissible variations, workmanship, finish and appearance, sampling, number of tests and retests, specimen preparation, test methods, significance of numerical limits, inspection, rejection and rehearing, certification, test report, and packaging and package marking.

Supplementary Requirements – This specification does not include supplementary requirements unless it is specified by the purchaser in the inquiry, contract, or order for agencies of the U.S. government.

4.15 SB-829, General Requirements for Nickel and Nickel Alloys Seamless Pipe and Tube

SA-829 includes general requirements for pressure vessel seamless pipe and tube specifications that are listed in the Scope. That includes requirements for terminology, chemical composition, test requirements, dimensions and permissible variations, workmanship, finish, and appearance, sampling, retests and retreatment, specimen preparation, inspection, rejection and rehearing, certification, product marking, packaging and package marking.

Supplementary Requirements – SB-829 does not include a list of Supplementary Requirements.

4.16 SB-906, General Requirements for Flat-Rolled Nickel and Nickel Alloys Plate, Sheet and Strip

SA-906 includes general requirements for plate, sheet and strip specifications that are listed in the Scope. That includes requirements for terminology, ordering information, chemical composition, sampling, number of tests and retests, specimen preparation, test methods, finish for sheet, finish for strip, finish for plates, edges for cold-rolled strip, workmanship, repair of plate by welding, inspection, rejection, rehearing, material test report and certification and packaging, marking and loading.

Supplementary Requirements – SB-906 does not include a list of Supplementary Requirements.

5 ADDITIONAL CONSIDERATIONS FOR MATERIAL SPECIFICATIONS

5.1 Clad Plates

Clad plates may be produced to the following ASME specifications:

- SA-263, Specification for Stainless Chromium Steel-Clad Plate.
- SA-264, Specification for Stainless Chromium-Nickel Steel-Clad Plate.
- SA-265, Specification for Nickel-Base-Alloy-Clad Steel Plate.

(a) *Supplementary Requirements* - The above clad plate specifications include the several supplementary Requirements:

S2. Product Analysis

S3. Simulated Post-weld Heat Treatments of Mechanical Test Coupons

S5. Charpy V-Notch Impact Test

S12. Ultrasonic Examination in Accordance With Specification A578/A578M

(b) *Bond Quality* - Clad plates with total composite thickness of 3/8 inches (10 mm) and thicker, and when specified by the purchaser, thinner than 3/8 inches (10 mm) must be ultrasonically examined. The extent of ultrasonic examination shall be at the discretion of manufacturer and shall be adequate for the quality level specified by the purchaser. The purchaser may specify 100% coverage in accordance with SA-578 and to one of the following quality levels:

- Class 1 – No single unbonded area exceeding 1 inch in its longest dimension with total unbonded area not exceeding 1% of the total cladded surface area.
- Class 3 – No single unbonded area exceeding 3 inches in its longest dimension with total unbonded area not exceeding 3% of the total cladded surface area.
- Class 5 – No single unbonded area exceeding 9 square inches with total unbonded area not exceeding 5% of the total cladded surface area.

(c) *Manufacturing* - Clad plates typically are produced by roll-bond cladding or by explosion bonding. It is generally more practical to produce clad plates by the roll bonding process in thicknesses up to about 2 inches. Thicker plates usually are produced by the explosion bonding process.

5.2 Limitations on Thickness, and Weight

Some of the ASME and ASTM product specifications include limitations on size, weight or thickness, based on the capabilities of the material to meet the specified mechanical properties, or based on the intended use of the material. For example, ASME SA-537 limits the maximum thickness of normalized Class 1 plates to 4 inches. As compared with SA-516, Grade 70, both materials have the same specified minimum tensile strength of 70 kilopounds per square inch (ksi), but SA-516, Grade 70 has a specified minimum yield strength of 38 ksi and SA-537, Class 1 has a specified minimum yield strength of 50 ksi.

A commonly used ASME carbon steel forging specification for flanges, fittings, valves and similar parts is SA-105. This specification limits maximum weight of forgings made to this specification to 10,000 pounds. Larger forgings may be ordered to the following specifications:

- SA-350, Specification for Carbon ad Low Alloy Steel Forgings Requiring Notch Toughness Testing for Piping Components
- SA-266, Specification for Carbon Steel Forgings for Pressure Vessel Components,
- SA-765, Specification for Carbon Steel and Low-Alloy Steel Pressure-Vessel-Component Forgings with Mandatory Toughness Requirements.

Where users require material larger or thicker than typically permitted by ASME/ASTM product specifications, the BPVC Section VIII, Division 1, paragraph UG-4, permits the use of materials outside the limits of size and /or thickness given in the specification, if the material meets all other requirements of the specification and there are no size or thickness limitation given in the stress tables of Section II, Part D stress tables.

5.3 Certification

For ferrous materials, some material specifications require material to be supplied with certified mill test reports (e.g., pressure vessel; plates). Some other specifications permit certificates of compliance (COCs) (e.g., piping, tubing, stainless steel plates and sheets). For non-ferrous materials, all material specifications require that the material be supplied with both a material certification and a test report. Certification of materials for ASME Code construction is mandatory.

The manufacturer of a vessel or piping system is responsible for verifying that the materials used in construction meet the requirements of the design. Specific requirements in this regard are included in the ASME Construction codes (e.g., UG-93 in BPVC Section VIII, Division 1; and BPVC Section VIII, Division 2, Paragraph 3.2.6). ASME Section VIII, Division 3 also includes specific requirements for certification by materials manufacturers. It is common practice by vessel and piping manufacturers to specify test reports for all pressure retaining components. For critical components or chemistries, it is good practice specify certified mill test reports.

(a) Certified Mill Test Reports - A certified test report is a document that presents the applicable qualitative or quantitative results obtained by one or more tests. The certifying organization is the entity responsible for the conformance and certification of the product to the specification requirements. The manufacturer or processor shall report in the certified test report the results of all tests required by the applicable product specification, the applicable supplementary requirements, and the purchase order. The test report should include the following:

- The heat treatment of the material.
- The results of all mechanical tests. (including test specimen type and size, location and direction tension tests and Charpy V-notch impact tests and test temperature)
- The extent of and the results of all examinations. (e.g., ultrasonic examination)
- Other information, as required by the applicable product/general specification.

(b) Certificates of Compliance - A certificate of compliance is a document that states that the product was manufactured, sampled, tested and inspected in accordance with the requirements of the specification (including year of issue) and any other requirements specified in the purchase order or contract and has been found to meet such requirements. A certificate of compliance does not typically include results of testing or inspection.

(c) Test Reports - Product or general specifications may require test reports, but make no mention of certification. These reports will generally include the same information as a certified mill test report, but will not be certified.

Regardless of what reports are requested, when inspecting documentation, purchasers who have specified any non-standard requirements should make special note that any certified reports can be traced back to the purchase order, and that the certification explicitly states that all requirements of the purchase order have been met. If the certification cannot be traced to a purchaser's order, it may have minimal value to the purchaser.

6 API 5L SPECIFICATION FOR LINE PIPE

(a) *General* - This American Petroleum Institute (API) specification includes requirements for the manufacture of seamless and welded steel pipe in two product levels, PSL 1 and PSL 2. API 5L, Table 1 lists the various steel grades that are available as PSL 1 and as PSL 2 pipes and the delivery conditions (as rolled, thermomechanical rolled, normalized, normalized and tempered, etc.) for each steel grade. The delivery condition for PSL 1 pipes is at the option of the pipe manufacturer, unless the delivery condition is specified in the purchase order. For PSL 2 pipe, the delivery condition is in accordance with the purchase order, as applicable in Table 1. PSL 2 pipe is subject to additional mandatory requirements for chemical composition, including carbon equivalent, notch toughness, strength properties, and nondestructive examination.

(b) *Quality System* - This specification states that, "A quality system shall be applied to assist compliance with the requirements of this standard". It does not state that the quality system shall be mandatory. This specification references International Organization for Standardization (ISO)/TS 29001 for sector-specific guidance on quality management systems.

(c) *Manufacturing* - The acceptable processes of manufacture and product specification levels are listed in API Specification 5L, Table 2 for both PSL 1 and PSL 2 pipe. Table 3 lists the acceptable manufacturing routes for PSL 2 pipe.

(d) *Acceptance Criteria* - The general technical delivery requirements shall be in accordance with ISO 404.

(e) *Traceability* - The manufacturer shall establish and follow documented procedures for maintaining

  (1) The heat identity until all related chemical tests are performed and conform to the specified requirements.

  (2) The test-unit identity until all related tests are performed and conform to the specified requirements.

(f) *Surface Conditions, Imperfections and Defects* - All pipes shall be free from defects, cracks, sweats, and leaks. Section 9.10 of API 5L includes detailed requirements for other defects, such as undercuts, arc burns, laminations, geometrical deviations, surface imperfections, dimensions, mass, and tolerances.

(g) *Inspection* - For PSL 1 pipe, material test reports are only provided if specified by the purchaser. Material test reports are provided for all PSL 2 material. This specification references ISO and European (EN) standards for information to be included in test reports, and if specific information is desired, the purchaser must carefully specify what type of test report they desire.

(h) *Annexes* - The API 5L specification several mandatory (normative) and nonmandatory (informative) Annexes. The following lists normative requirements:

- Annex A, Specification for Welded Jointers
- Annex B, Manufacturing Procedure Qualification for PSL 2 Pipe
- Annex C, Treatment of Surface Imperfections and Defects
- Annex D, Repair Welding Procedure
- Annex E, Non-destructive inspection for other than sour service or offshore service.
- Annex F, Requirements for couplings PSL 1 only)
- Annex G, PSL 2 pipe with resistance to ductile fracture properties
- Annex H, PSL 2 pipe ordered for sour service
- Annex I, Pipe ordered as "Through the Flowline" (TFL) pipe
- Annex J, PSL 2 pipe ordered for offshore service
- Annex K, Non-destructive inspection for pipe ordered for sour service and/or offshore service

7 ASME CODE REQUIREMENTS

7.1 BPVC Section I, Rules for Construction of Power Boilers [2]

General – BPVC Section I specifically lists the material specifications that have been approved for use for each product form and/or component type in PG-6, PG-7, PG-8, PG-9, PG-13, and PG 14. Material for pressure parts must conform to one of the ASME material specifications listed in BPVC Section II, and shall be limited to those that are listed in the Tables of BPVC Section II, Part D, except as otherwise permitted in PG-8.2, PG-8.3, PG-10, and PG11. Materials are not to be used at temperatures above those for which stress values are listed for BPVC Section I in the Tables of BPVC Section II, Part D. Additional requirements in Section I include the following:

- Specific requirements for P-15E materials
- Size limits and tolerances
- Requirements for all new materials to be considered for use (Appendix 5 of BPVC Section II, Part D)
- Rules for the use of materials that have been identified or produced to a specification that is not permitted and materials that are not fully identified (PG-10)
- Rules for miscellaneous pressure parts and water level indicators and associated connector material (PG-11 and PG-12)

7.2 BPVC Section IV, Rules for Construction of Heating Boilers [5]

General - BPVC Section IV includes rules for heating boilers constructed of the following materials:

- Part HF, Boilers Constructed of Wrought Materials
- Part HF, Subpart Part HW, Boilers Fabricated by Welding
- Part HF, Subpart HB, Boilers Fabricated by Brazing
- Part HC, Boilers Constructed of Cast Iron
- Part HA, Boilers Constructed of Cast Aluminum
- Part HLW, Requirements for Potable-Water Heaters

Materials subjected to pressure stress shall conform to the specifications listed in BPVC Section II and must be listed in the allowable stress tables, Table HF-300.1 (for ferrous materials), and in Table HF-300.2 (for nonferrous materials).

Specific requirements for materials for the various types of heating boilers are listed in the Parts of the BPVC pertaining to the specific type of construction:

- Part HG, paragraphs HG-200 and HG-201
- Part HF, paragraphs HF-200 through HF-210
- Part HF, Subpart HW, paragraphs HW-500 through HW-502
- Part HF, Subpart HB, paragraphs HB-1100 through HB-1103
- Part HC, paragraphs HC-200 through HC-215
- Part HA, paragraphs HA-200 through HA-203
- Part HLW, paragraphs HLW-200 through HLW-205

Materials are not restricted as to the method of production unless stated so in the product specification. Also, materials with thicknesses outside of the limits stated in the product specification may be used in construction, provided they comply with the other requirements of the specification and all thickness requirements in BPVC Section IV. Materials not listed in Section II shall not be used unless approved by the Boiler and Pressure Vessel Committee in accordance with BPVC Section II, Part D, Mandatory Appendix 5. The following lists several additional considerations for materials:

- Material test reports are required for all pressure retaining plates and forgings.
- Stainless steels shall be fully annealed.
- Materials for non-pressure parts need not conform to the specifications they are attached to or to the material specifications permitted in HG-200, HC-200, or HLW-205, but if welded, they shall be of weldable quality.

7.3 BPVC Section VIII, Division 1, Rules for Construction of Pressure Vessels [6]

(a) *General* - Material for pressure parts must conform to the one of the ASME material specifications listed in BPVC Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, including all applicable notes in the tables, and are limited to those listed in the tables of the applicable part of Subsection C of BPVC Section VIII, Division 1. The permissible materials and grades are listed in Tables UCS-23, UNF-23, UHA-23, UCI-23, UCD-23, UHT-23, and ULT-23. The BPVC Section VIII accepts the ASTM and international specifications, including quality requirements, and lists the additional ASME Code requirements or restrictions at the beginning of the specification.

(b) *Paragraph UG-4(f)* - Recommends that the user or the designated agent assure that the materials used for construction of the vessels will be suitable for the intended service with respect to retention of satisfactory mechanical properties, and resistance to corrosion, erosion, oxidation, and other deterioration during their intended service life.

(c) *Paragraph UG-6(a)* - Permits the use of forged material in pressure vessel construction, provided the material has been worked sufficiently to remove coarse ingot structure.

(d) *Paragraph UG-93* - Includes requirements for inspection of materials. For plates, the vessel Manufacturer must obtain the materials test report or certificate of compliance as provided for in the material specification and shall determine that it represents the material and meets the requirements of the material specification. For all other product forms, the material shall be accepted as complying with the material specification if the material specification provides for the marking of each piece with the specification designation, including the type, grade, and class if applicable, and each piece is so marked.

(e) *Paragraph UCS-6* - Permits the use of several structural plate specifications provided the material is not used in lethal service (liquid or gaseous), is not used for construction of steam boilers, and the thickness does not exceed 5/8 inches (16 mm).

(f) *Paragraphs UCS-8, UNF-8, and UHA-8* - Require all castings used in welded construction to be of weldable grade.

(g) *Notch Toughness Requirements* - The notch toughness requirements for BPVC Section VIII, Division 1 are given in the following Division 1 paragraphs and Tables:
   - UG-84 and Fig. UG-84.1, Charpy V-Notch Impact Test Requirements for Full Size Specimens for Carbon and Low Alloy Steels, Having a Specified Minimum Tensile Strength Less Than 95 ksi
   - UCS-66, Materials
   - UHA-51, Impact Tests (stainless steels)
   - UHT-6, Test Requirements

(h) *Appendix 10, Quality Control System* - Requires the vessel manufacturer to have a Manufacturer's Quality Control System which will ensure that the material received is properly identified and that the documentation includes the required COCs or Material Test Reports (MTRs) to satisfy the BPVC requirements.

7.4 BPVC Section VIII, Division 2, Alternative Rules [7]

(a) General - Material for pressure parts must conform to the one of the ASME material specifications listed in BPVC Section II, Part D, Subpart 1, Tables 3, 5A and 5B, including all applicable notes in the tables and are limited to those listed in the tables of the applicable part of BPVC Section VIII, Division 2. The permissible materials and grades are listed in Tables 3.A.1 through 3.A.11.

(b) Certification - The materials manufacturer shall verify that all the requirements of the material specification and all special requirements of Part 3 of Division 2, which are to be fulfilled by the materials manufacturer, are complied with. The certification shall include certified reports of the numerical results of all required tests and examinations, or certificates of compliance, and shall certify that that all required inspections and repairs have been performed on the materials.

(c) Examination of Ferrous Materials:

(1) Ultrasonic Examination **-** Paragraph 3.3.3 of Division 2 requires ultrasonic examination of all plates 2 inches and over in nominal thickness. The acceptance standard is Level B of SA-578. Paragraph 3.3.4 of Division 2 requires ultrasonic examination of forgings 2 inches and over in thickness in accordance with SA-388.

(2) Magnetic Particle and Liquid Penetrant Examination (Division 2, Paragraph 3.3.5) - All accessible surfaces of thick or complex forgings, such as contour nozzles, thick tubesheets, flanges, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, shall be examined by the magnetic particle method in accordance with Test Method A 275/A275M or by the liquid penetrant method in accordance with Practice E165.

(d) Examination of Nonferrous Materials:

(1) Division 2, Paragraphs 3.6.2 and 3.6.3, Ultrasonic Examination - All plates 2 inches (50 mm) and over an inch nominal thickness shall be ultrasonically examined in accordance with the applicable requirements of the following ASTM standards and ASME specifications: SE-114, E214, E127, and SB-548.

Essentially the entire volume of the forging metal shall be ultrasonically examined at some state of the manufacture. Insofar as practicable, all solid rectangular forgings shall be examined by straight beam techniques from two directions at approximately right angles. Hollow forgings, including flanges and rings 2 inches (50 mm) and over in nominal thickness shall be examined using the angle beam technique either by the contact method or the immersion method. Disk forgings shall be examined from one flat side and from the circumferential surface.

(e) Paragraph 3.6.4, Liquid Penetrant Examination of Forgings - All accessible surfaces of thick or complex forgings, such as contour nozzles, thick tubesheets, flanges, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, shall be examined by liquid penetrant method in accordance with Practice E165.

(f) Examination of Bolting:

(1) All bolts, studs, and nuts over 1 inches (25 mm) nominal bolt size shall be examined by the magnetic particle method or by the liquid penetrant method in accordance with Paragraph 3.7.2(b) of Division 2.

(2) All bolts studs, and nuts greater than 2 inches (50 mm) nominal thickness shall be ultrasonically examined over the entire surface prior to threading in accordance with the requirements of paragraph 3.7.2(c) of Division 2. All bolts, studs, and nuts greater than 4 inches (100 mm) nominal thickness shall be ultrasonically examined over the entire end surface before and after threading in accordance with the requirements of Paragraph 3.7.2(d) of Division 2.

(g) *Notch Toughness Requirements* -The notch toughness requirements for BPVC Section VIII, Division 2 are given in the following Paragraphs and Tables:
- BPVC Section 3.11.2, Carbon and Low Alloy Steels.
- BPVC Section 3.11.3, Quenched and Tempered Steels.

(h) *Quality Control System (Annex 2.E)* - The manufacturer shall have a system of receiving control that will ensure that the material received is properly identified and has documentation including required material certification or material test reports to satisfy ASME Code requirements as ordered. The system of material control shall ensure that only the intended material is used in ASME Code construction.

7.5 BPVC Section VIII, Division 3, Alternative Rules for Construction of High Pressure Vessels [8]

(a) *General* - The materials for pressure parts are listed in Table KCS-1 and must conform to the requirements of Part KM.

(b) *Mechanical Property Test Requirements for Materials (Article KM-2)* - Article KM-2 includes requirements for impact testing of various product forms (plates, forgings, etc.), the test specimen locations and the acceptance criteria for all materials for Division 3 construction.

(c) *Certification* - The Materials manufacturer shall certify that all requirements of the applicable material specifications in BPVC Section II, all special requirements of Part KM in BPVC Section VIII, Division 3 which are to be fulfilled by the Materials Manufacturer, and all supplementary requirements specified by the User's Design Specification have been complied with. The certification shall consist of Materials Manufacturer's certified materials test report showing numerical results of all required tests, and shall certify that all required examinations and repairs have been performed on the materials. The certified results of these tests and examinations shall be documented in the Manufacturer's Construction Records.

(d) *Procedure for Obtaining Test Specimens and Coupons* - Paragraph KM-211 includes requirements for taking test specimens from plates, forgings, pipe, and bars and bolting materials that are in addition to those required by the applicable material specification.

(e) *Quality Control System (Mandatory Appendix 2)* - The manufacturer shall have a system of receiving control that will ensure that the material received is properly identified and has documentation including required material certification or material test reports to satisfy ASME Code requirements as ordered. The system material control shall ensure that only the intended material is used in ASME Code construction.

(f) *Examination (Article KE-2)* - The requirements in Article KE-2 apply to Materials Manufacturer and Manufacturer. Detailed examination requirements for the various product forms are included in the Division 3 paragraphs listed below:
(1) KE-201 - Examination after Quenching and Tempering.
(2) KE-211 - Elimination of Defects by Blend Grinding.
(3) KE-212.4 - Examination of Repair Welds.
(4) KE-213 - Repairs of Cladding.
(5) KE-220 - Examination and Repair of Plate.
(6) KE-230 - Examination and Repair of Forgings and Bars.
(7) KE-240 - Examination and Repair of Seamless and Welded (Without Filler Metal) Tubular Products and Fittings.
(8) KE-250 - Examination and Repair of Tubular Products and Fittings Welded With Filler Metal.
(9) KE-260 - Examination of Bolts, Studs, and Nuts.

7.6 BPVC Section XII, Rules for Construction and Continued Service of Transport Tanks [9]

(a) General - Materials for pressure parts and for attachments that are essential to structural integrity of the pressure vessel shall conform to the specifications listed in BPVC Section XII, Tables TM-130.2.1 through TM-130.2-7 and the requirements in BPVC Section II, including the applicable notes to the allowable stress tables in BPVC Section II, Part D. The material requirements for BPVC Section XII transport tanks are essentially the same as for BPVC Section VIII, Division 1 vessels. Materials other than those allowed by BPVC Section XII are not permitted, unless data are submitted to and approved by the Boiler and Pressure Vessel Committee.

Materials used for construction of vessels and appurtenances must be suitable for the modal applications and the conditions specified by the purchaser. Specific requirements for the various product forms (plate, forgings, etc.) are listed in TM-110.

(b) Forgings - Paragraph TM-110.2 permits the use of forged material in pressure vessel construction, provided the material has been worked sufficiently to remove coarse ingot structure.

(c) Castings - Castings shall meet the additional requirements in TM-190.

(d) Inspection of Materials - Paragraph TM-140 includes requirements for inspection of materials. For plates, the vessel Manufacturer must obtain the materials test report or certificate of compliance as provided for in the material specification and shall determine that it represents the material and meets the requirements of the material specification. For all other product forms, the material shall be accepted as complying with the material specification if the material specification provides for the marking of each piece with the specification designation, including the type, grade, and class if applicable, and each piece is so marked.

(e) Fabrication Heat Treatment of Materials and Test Coupons for Carbon and Alloy Steels - The materials shall be represented by test specimens, which have been subjected to the same manner of heat treatment including postweld heat treatment as the base metal. Carbon steels with ASME P-number designations; P No. 1, Groups No. 1 and 2 are exempted from this requirement when the heat treatment during fabrication is limited to postweld heat treatment below the lower transformation temperature.

(f) Notch Toughness Requirements - The notch toughness requirements for all steel products used in BPVC Section XII vessels are listed in Article TM-2. The impact test exemption curves are shown in Fig. TM-240.1-1 for nominal thicknesses up to 3 inches (75 mm).

7.7 ASME B31.1, Power Piping [11]

(a) General - Materials conforming to ASME SA or ASME SB specifications may be used interchangeably with ASTM A or ASTM B specifications of the same number except for boiler external piping as described in Paragraph 123.2.

(b) Mandatory Appendix J (Quality Control Requirements for Boiler External Piping) - Includes specific requirements for material control. The manufacturer or assembler shall include a system of receiving control which will insure that the material received is properly identified and has the necessary documentation, including required material certifications or material test reports, to satisfy ASME Code requirements as ordered.

7.8 ASME B31.3, Process Piping [12]

(a) General - Chapter III of ASME B31.3 states the limitations and the required qualifications for materials based on their inherent properties. The permissible ASTM material specifications and grades are listed in Appendix A. Users should pay particular attention to the notes

associated with Appendix A, which may impose specific manufacturing requirements upon a material.

(b) *Unlisted Materials* - ASME B31.3 permits the use of unlisted materials, and provides the designer with rules for the use of these materials

(c) *Code Cases* - ASME B31.3 permits users to submit materials to the committee for evaluation and issuance of a Code Case

(d) *Low Temperature Toughness Requirements* - ASME B31.3 Tables A-1 and A-1M contain information on the minimum temperature for which materials may be used; however, not all materials may be used at these temperatures without additional requirements being specified by the purchaser. Purchasers should consult ASME B31.3 Para. 323.2.2 and Table 323.2.2 to determine if additional toughness testing is required for materials, especially in the following cases:

- For all piping and piping components that contain welds made by the manufacturer; with a design temperature lower than -29°C (-20°F); and made of carbon steel, low- and intermediate-alloy steels, high-alloy ferritic steels, duplex stainless steels, and austenitic stainless steels, ASME B31.3 may require additional impact testing of weld metal and the heat affected zone.
- For all piping and piping components that contain welds made by the manufacturer; made of aluminum, aluminum alloys, copper, copper alloys, nickel, nickel alloys or unalloyed titanium; and where the filler metal composition is outside the range for the base metal composition, ASME B31.3 requires that the designer specify suitable testing to assure that the welds and heat affected zone will be suitable at the design minimum temperature.
- For all austenitic stainless steels; where the design temperature is lower than -29°C (-20°F); and where the carbon content is greater than 0.1% or the material is not in the solution heat treated condition, ASME B31.3 may require additional impact testing of the base material.

(e) *Certification* – Except where ASME B31.3 or the engineering design requires the material manufacturer to perform additional impact testing (beyond that required by the material specifications), is required by the Code or the engineering design, certified reports of impact testing shall be obtained, there are no explicit requirements for the owner to obtain material test reports. There is a requirement, however, where the fabricator's examiner must be assured that the materials used meet the specified grade. To assist with this, it is common practice to simply require test reports for all pressure containing materials.

(f) *Appendix Q* - Includes a Quality System Program which states "Design, construction, inspection, examination, testing, manufacture, fabrication, and erection of piping in accordance with this Code shall be performed under a Quality System Program following the principles of an appropriate standard such as the ISO 9000 series. The details describing the quality system shall be documented and shall be available upon request. A determination of the need for registration and/or certification of the quality system program shall be the responsibility of the owner". Appendix Q applies only when specified by the owner.

8 FABRICATION EFFECTS

8.1 Forming

The ASME Codes provide rules for calculating the maximum forming strains and for limitations of the maximum forming strains above which some type of heat treatment of the fabricated component is required. The following are references of the requirements in BPVC Section VIII, Divisions 1 and 2, and in BPVC Section I regarding limitations on maximum forming strains:

(a) The BPVC Section VIII, Division 1 requirements are given in:
- UG-79, Forming Pressure Parts, and Table UG-79-1 (forming strain formulas)
- UCS-79, Forming Pressure Parts (including limitations on forming strains for carbon and low alloy steels), and Table UCS-79-1 (Post-Forming Strain Limits and Heat Treatment Requirements for P-No. 15E Materials)
- Table UHA-44, Post Fabrication Strain Limits and Required Heat Treatment (for stainless steels
- UNF-79, Requirements for Post fabrication Heat Treatments Due to Straining (for Ni alloys)

(b) The BPVC Section VIII, Division 2 requirements are given in:
- Table 6.1, Equations for Calculating Forming Strains
- Table 6.2.A, Post Cold-Forming Strain Limits and Heat-Treatments for P-No. 15E Materials
- Table 6.2.B, Post Fabrication Strain Limits and Required Heat Treatment for High Alloy Materials

(c) The BPVC Section I requirements are given in:
- PG-17, Cold Forming of Austenitic Materials (also lists the forming strain formulas)
- Table PG-19, Post Cold-Forming Strain Limits and Heat Treatment Requirements (for high alloy steels)
- PG-20, Cold Forming of Creep Strength Enhanced Ferritic Steels

8.2 Postweld Heat Treatment (PWHT) of Ferrous Materials

8.2.1 PWHT Requirements.

ASME Codes typically require postweld heat treatment (PWHT) of P-No. 1 carbon steel vessel when the nominal thickness of welded joints exceed the following thicknesses P-No. 1 materials:
- BPVC Section I: ¾ inches (19 mm), or 1½ inches (38 mm) if the base metals and the preheat meet the additional requirements in Table PW-39-1.
- BPVC Section VIII, Divisions 1 and 2: 1¼ inches (32 mm), or 1½ inches (38 mm) if the welded joints over 1¼ inches (32 mm) to 1½ inches (38 mm) in thickness are preheated at 200 °F (95 ^{0}C).
- BPVC Section VIII, Division 3: 1¼ inches (32 mm).
- ASME B31.3: 3/4 inches (19 mm).

The ASME Codes typically require PWHT P-No. 3, P-No. 4, and P-No 5 low alloy steels of all thicknesses, unless specially exempted by notes in the PWHT requirements tables (e.g., small diameter and thin wall pipe for certain materials).

Note: The need to differentiate PWHT requirements by P-No. is one reason why the unspecified elements restrictions in SA-20 is required for ASME work.

8.2.2 Test Coupons.

The following ASME Codes do require test coupons to simulate vessel fabrication heat treatments:

- BPVC Section VIII Div. 1 - All carbon and low alloy steels (except P-No. 1 Groups 1 and 2) subject to heat treatments above 900°F (482°C).
- BPVC Section VIII Div. 2 - All carbon and low alloy steels subject to heat treatments above 900°F (482°C).
- BPVC Section VIII Div. 3 - All carbon and low alloy steels subject to heat treatments.

8.2.3 PWHT Effect on Materials.

It is well known that stress relieving high PWHT temperatures or with long hold times may reduce the strength and notch toughness (e.g., in terms of impact test energy values) of carbon and low alloy steel materials. Although there are no specific provisions in ASME Codes for evaluating the combined effects of time and temperature on strength and of materials by use of the Larson-Miller Parameter (LMP) parameter this is frequently done by steel manufacturers to evaluate the effect of materials due to long time PWHT, or when the PWHT is done at high temperatures for certain service applications. The LMP is a combination of the time during tempering of the material, including postweld heat treatment cycles and intermediate heat treatments above 900 °C (482 °C). The LMP is defined as follows:

$$\text{LMP} = T \text{ x } (\text{C} + \log t)$$

T is temperature in °R, where °R = °F + 460, or in °K, where °K = °C + 273
t is the time at temperature in hours
C is the constant (typically 20 for carbon and low alloy steels)

8.3 Postweld Heat Treatment of Nonferrous Materials

(a) Postweld heat treatment of nonferrous materials is not normally necessary or desirable.

(b) Except as in *(c)*, *(d)* or *(e)* below, no postweld heat treatment shall be performed except by agreement between the User and the Manufacturer. The temperature, time and method of heat treatment shall be covered by agreement.

(c) If welded, castings of SB-148, Alloy CDA 954 shall be heat treated after all welding at 1,150°F to 1,200°F (620°C to 650°C) for 11/2 hour at temperature for the first inch of cross section thickness plus 1/2 hour for each additional inch of section thickness. Material shall then be air cooled.

(d) Within 14 days after welding, all products of zirconium Grade R60705 shall be heat treated at 1,000°F to 1,100°F (540°C to 595°C) for a minimum of 1 hour for thicknesses up to 1 inch (25 mm) plus 1/2 hour for each additional inch of thickness. Above 800°F (425°C), cooling shall be done in a closed furnace or cooling chamber at a rate not greater than 500°F/hour (278°C/h) divided by the maximum metal thickness of the shell or head plate in inches, but in no case more than 500°F/hour (278°C/h). From 800°F (425°C), the vessel may be cooled in still air.

(e) Postweld Heat Treatment of UNS Nos. N08800, N08810, and N08811 Alloys

(1) Pressure boundary welds and welds to pressure boundaries in vessels with design temperatures above 1000°F (538°C) fabricated from UNS No. N08800 (Alloy 800), UNS No. N08810 (Alloy 800H), and UNS No. N08811 (Alloy 800HT) shall be postweld heat treated. The postweld heat treatment shall consist of heating to a minimum temperature of 1,625°F (885°C) for 11/2 hour for thicknesses up to 1 inch (25 mm), and for 1 1/2 hour plus 1 hour/inch of thickness for thicknesses in excess of 1 inch (25 mm). Cooling and heating rates shall be by agreement between the user or his designated agent and the Manufacturer. As an alternative, solution annealing in accordance with the material

specification is acceptable. Postweld heat treatment of tube-to-tubesheet and expansion bellows attachment welds is neither required nor prohibited.

(2) Except as permitted in *(3)* below, vessels or parts of vessels that have been postweld heat treated in accordance with the requirements of this paragraph shall again be postweld heat treated after welded repairs have been made.

(3) Weld repairs to the weld metal and heat affected zone in welds joining these materials may be made after the final PWHT, but prior to the final hydrostatic test, without additional PWHT. The weld repairs shall meet the requirements of *(i)* through *(iv)* below.

(i) The Manufacturer shall give prior notification of the repair to the user or to the designated agent and shall not proceed until acceptance has been obtained.

(ii) The total repair depth shall not exceed ½ inch (13 mm) or 30% of the material thickness, whichever is less. The total depth of a weld repair shall be taken as the sum of the depths for repairs made from both sides of a weld at a given location.

(iii) After removal of the defect, the groove shall be examined. The weld repair area must also be examined. The liquid penetrant examination method, in accordance with Mandatory Appendix 8, shall be used.

(iv) The vessel shall be hydrostatically tested after making the welded repair.

(f) Postweld heat treatment of UNS R31233 is required prior to cold forming when the cold forming bend radius at the weld is less than 4 times the thickness of the component. Postweld treatment shall consist of annealing at 2,050°F (1,121°C) immediately followed by water quenching.

9 MATERIALS DEGRADATION MECHANISMS

9.1 BPVC Section II, Part D [4], Appendix A

Nonmandatory Appendix A (Issues Associated with Materials Used in ASME Code Construction) includes an expanded listing of materials degradation mechanisms that affect various materials and the recommended precautions to avoid corrosion or embrittlement, or cracking of materials during fabrication or while in service. Any restrictions based on concerns over material degradation related to fabrication or to service generally should be specified by the owner of the equipment or included User's Specifications. However, a knowledgeable vessel manufacturer can also help to avoid service related problems by proper selection of materials and optimizing fabrication procedures for the materials involved.

10 OTHER CODES AND STANDARDS, OR RECOMMENDED PRACTICES

Some organizations (e.g., API, Technological Association of the Pulp and Paper Industry (TAPPI), NACE International (NACE)) publish recommended practices or guidelines for specific materials and vessels to avoid service damage and improve performance in certain aggressive environments.

10.1 API Recommended Practices for CR – MO Steels

These API Recommended Practices include special chemical composition restrictions, heat treatment (including PWHT) requirements, materials testing, toughness, inspection, and other requirements, that need to be included in the material purchase specification, in addition to the ASME Code requirements to ensure materials degradation. For example, API RP 934 A includes special chemical composition and testing requirements for 2¼ Cr – 1 Mo and 3 Cr – 1Mo materials to avoid the risk of temper embrittlement, and API 934E includes additional requirements to avoid the risk of creep embrittlement when used at temperatures above 825 °F (441 °C).

The following are several API Recommended Practices for use of Cr-Mo materials in oil refinery service:

- API RP 934 A, Materials and Fabrication of 2¼ Cr-1Mo, 2¼ Cr-1Mo-1/4 V, 3Cr-1Mo, 3Cr-1Mo- ¼V Steel Heavy Wall Pressure Vessels for High Temperature, High Pressure Hydrogen Service [15]
- API TR 934 B, Fabrication Considerations for ¼ Vanadium Steel Heavy Wall Pressure Vessels for High Temperature, High Pressure Hydrogen Service [16]
- API TR 934D, Materials and Fabrication of 1¼ Cr-1/2 Mo Steel Heavy Wall Pressure Vessels for High Pressure Hydrogen Service Operating at or Below 825 °F (441 °C) [18]
- API RP 934 C, Technical Report on the Materials and Fabrication Issues of 1¼ Cr – ½ Mo and 1 Cr – ½ Mo Steel Pressure Vessels [17]
- API RP 934E, Recommended Practice for Materials and Fabrication of 1¼ Cr-1/2 Mo Steel Pressure Vessels for Service above 825 °F (441 °C) [19]

10.2 API Recommended Practices to Avoid Damage in Certain Service Environments

API has published several reports, standards, and recommended practices that address specific damage mechanisms and recommended practices to avoid damage to pressure equipment while in service. These generally include restrictions on the use of specific types of materials, or include additional restrictions or supplemental requirements for materials that should be included in the material purchase specifications. The following lists some of such API documents:

- API RP 941, Steels in Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants [20]
- API RP 945, Avoiding Environmental Cracking in Amine Units [21]
- API RP 571, Damage Mechanisms Affecting Fixed Equipment in the Refining and Petrochemical Industries [14]

10.3 NACE Standards

NACE has published numerous standards related to materials damage from various service conditions. These standards also include recommendations for use of material in certain service environments, as well as recommended practices for avoidance of material degradation in specific service environments (e.g., material requirements, hardness, PWHT, or testing). Some commonly used NACE standards are listed below:

- NACE MR0103, Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments
- NACE 8X194, Materials and Fabrication Practices for New Pressure Vessels Used in Wet H_2S Refinery Service [22]
- NACE SP0403, Avoiding Caustic Stress Corrosion Cracking of Carbon Steels Refinery Equipment and Piping [23]
- NACE SP0472, Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments [24]
- NACE MR0175 / ISO 15156, Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production (Possibly the most widely used NACE Standard, and the only one that is legally required in some jurisdictions)

10.4 TAPPI TIPS

TAPPI has published several "Technical Information Publications" ("TIPS") related to use of materials. Because they address topics of general interest, they are used far beyond the pulp and paper industries. Two are listed below:

- TIP 0402-23, Welding of duplex stainless steels
- TIP 0402-35, Post Fabrication Cleaning of Stainless steel in the pulp and paper industry

11 PAST MATERIALS PROBLEMS

There have been a number of cases that have resulted in unacceptable material performance and even premature shop and field failures.

Most of these problems have resulted from poor manufacturing practices by the material producer. Some users and vessel manufacturers specify additional requirements (e.g., additional examinations or testing, purchase materials from their approved suppliers, hire third party inspectors) to ensure that the material meets the specified requirements and quality. This generally adds to the cost of the material.

The following sections list some of the more common materials problems that have been encountered in the past for different product forms. Material purchasers should consider these problems and develop strategies to prevent these from occurring along with other problems.

11.1 All Product Forms

(a) *Mechanical Properties* - The steel manufacturer only has an obligation to meet the required properties in test coupons taken from prescribed locations. It is generally recognized that mechanical properties do vary within the product, and small variations are not a cause for rejection.

(b) *Unspecified Elements* - Product specifications list the minimum and maximum contents of specified elements. However, materials also contain other elements that are not controlled by the material specification under the assumption that they will not be present at levels deleterious to the material. However, excessive amounts of some of these elements may be detrimental to weldability, notch toughness, or cause excessive hardness in the heat affected zones. This may increases the risk of heat affected zone (HAZ) cracking during and after welding and in certain service conditions. Some examples are listed below:
- Hydrogen induced cracking in the presence of wet H_2S may occur as a result of excessive amounts of H_2S and excessive hardness.
- Excessive amounts of columbium or vanadium may also promote carbide formation in the HAZ and loss of toughness after stress relieving (PWHT).
- Some elements, such as copper and excessive amounts of phosphorus, may also cause reheat cracking of low alloy steel weldments as a result of PWHT.

(c) *Weldability* - Chemical composition and strength can have a significant effect on weldability. Steels with higher carbon contents and more alloying elements (such as Mn, Cr, Mo, V, B, etc.) require higher preheat temperatures and post heating after welding to minimize the risk of hydrogen cracking in the welds.

A commonly used formula for weldability is the IIW Carbon Equivalent (CE) formula:

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}, \%$$

Boron is not included in the CE formula, above, but it is included in another carbon equivalent formula by Ito and Bessyo, called Pcm, which is generally considered more suitable for weldability of steels with carbon content less than 0.18%, where

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B, \%$$

High CE or Pcm values may require more preheat and modified welding practices to avoid hydrogen cracking. Consideration should be given to including additional requirements (e.g., a limitation on maximum carbon equivalent, higher preheat temperature, low hydrogen welding materials) to avoid cracking problems during fabrication.

For example, a vessel fabricator experienced hydrogen cracking after welding 2 inch thick SA-537 Class 2 plates in a field constructed vessel. The material had carbon equivalent over 0.54% and required a preheat higher than that recommended in ASME Section VIII, Division 1, Appendix R, blend grinding of welds, and wet magnetic particle examination of welds to check for hydrogen cracking, all of which significantly increased the cost.

Some material specifications include Supplementary Requirements that can be specified by the purchaser to improve weldability of the steel. For example, SA-516, Supplementary Requirement S54. lists a maximum carbon equivalent, CE = 0.43 for plate thicknesses less than or equal to 1 inch (25 mm) and CE = 0.45% for plate thicknesses greater than 1 inch (25 mm). Also, SA-20, Supplementary Requirement S20. includes Table S20.1 that lists maximum carbon equivalent values that can be specified for carbon steels.

(d) *Test Coupons* - ASME Codes do require test coupons for the following situations:
- Sections I and IV.
- Section VIII Div. 1 - All carbon and low alloy steels (except P-No. 1 Groups 1 and 2) are subject to heat treatments above 900°F (482°C).
- Section VIII Div. 2 - All carbon and low alloy steels are subject to heat treatments above 900°F (482°C).
- Section VIII Div. 3 - All carbon and low alloy steels are subject to heat treatments. This is an important consideration as excessive amounts of PWHT (cycles and PWHT temperature) do decrease strength and notch toughness in most carbon and low alloy steels.

(e) *Certification* - Many product specifications require certified test reports. When required, the materials manufacturer or processor shall report the results of all tests required by the applicable product specification, applicable supplementary requirements, and any additional requirements in the purchase order. These reports are to be certified by the manufacturer.

Some product specifications do not mandate material test reports, but require COCs. A COC just states that the material is manufactured, sampled, tested and inspected in accordance with the material specification. The purchaser does not know the actual chemical composition or the actual mechanical properties without a test report. A certified test report includes information on actual chemical composition, tensile strength, heat treatments, or examinations that may be important in fabrication of the vessel or piping.

Some forging specifications (SA-105, etc.) and most fitting specifications (SA-234, etc.), pipe and tube specifications (SA-333, SA-334, SA-213, etc.), high alloy steel specifications (SA-312, etc.), and similar international product specifications permit certificates of compliance. A test report will be provided only if specified in the purchase order.

If a purchaser wishes to have test reports for all materials, and if the Code does not mandate that such reports be provided for a particular material, then the purchaser must add a line on the purchase order requiring test reports for all materials.

Several general requirements specifications (e.g., A/SA-530, A/SA-530) allow the producer or the supplier to furnish a certified test report. Some other specifications (e.g. A/SA-20) allow the manufacturer or the processor to issue a test report, but require copies of the original manufacturer's test report to be included with any subsequent test report. There have been cases where the supplier has recertified the original product to a different specification/grade without the knowledge of the purchaser, or has certified a material based on an acceptable test result of a single test while ignoring other provisions for retest in the applicable product specification.

(f) *Documentation* - Inadequate or falsified documentation is probably the most common complaint with materials produced and supplied from some international producers. Some examples are:

(1) An international materials manufacturer vendor supplied carbon steel flanges to a USA vessel fabricator. The test reports appeared to be in order however, the vessel manufacturer experienced cracking problems when welding these flanges. Hardness testing and product analysis of the chemical composition of about 200 – 300 flanges indicated that several of these flanges were made from high carbon tool steel. The problem was discovered when cracks were found after welding.

(2) A vendor supplied "carbon steel" (ASTM A27 and similar) castings to a contractor in the USA for use in storage tanks. These castings turned out not to be weldable. The chemical analysis of the castings gave a chemical composition of about 0.57% C, 2.25% Mn, and 1.72% Si. The problem was discovered when cracks were found after welding.

(3) Several purchasers have received test reports from international suppliers that included only partial or incomplete information or wrong information on the test reports.

(4) A contractor required a rush order on some duplex stainless steel bolting for installation in a seawater system in the Middle East. Several suppliers were found, and quotes were obtained. One supplier was about a third of the cost of the others. Despite having serious questions about how one supplier could be so much cheaper than the others, a decision was made to go with the low cost supplier. Prior to shipment, the contractor's engineer required supply of material test reports, which stated that the materials were a duplex stainless steel. Upon receipt of the product, the contractor immediately performed Positive Material Identification (PMI) on the bolts, and determined that they were not duplex stainless steel, but austenitic stainless steel. The materials were rejected and proper materials were procured from another source.

Where a purchaser is using an unfamiliar supplier, or where a supplier is able to supply a non-standard material in a much shorter timeframe or for a much lower cost than their competitors, a purchaser may want to specify some product testing to confirm the validity of the certification/documentation that has been provided. A random PMI check of materials against their markings can be a very cost effective way to screen for materials that are grossly out of compliance with their product specifications. For critical applications, 100% PMI might be specified. See Section VIII, Division 2, Annex 6-A, Positive Material Identification Practice.

11.2 Plates

(a) *Unspecified Elements* - ASME SA-20 includes Table 1 which lists the maximum permissible contents by heat and by product analysis for elements that are not listed in the chemical composition table in the material specification. However, the footnotes to Table 1 permit higher amounts of some of these elements when agreed to by the purchaser and the steel producer (e.g., Cb, V, Ti).

The following describes several problems encountered by one vessel fabricator with excessive amounts of micro alloying elements:

(1) A/SA-516 does not list micro alloying elements (Cb, V, Ti, or B) in the chemical composition requirements and it is normally made without deliberate additions of any of these elements; however, in one case it was supplied with 0.03 – 0.04% Cb from an international steel producer. The vessel manufacturer could not use the intended welding process (electro gas welding) and meet the required energy values at the specified test

temperature. This required the use of a costlier welding process with lower heat inputs to meet the required impact test requirements.

(2) A/SA-737, Gr. B permits a maximum Cb content of 0.05% by heat and by product analysis. A vessel manufacturer purchased this material for low temperature service with impact test requirement of 20 ft-lb at -50 °F but was not able to meet the impact test requirement in welded joints after PWHT (in HAZ and in weld metal due to Cb pickup in weld metal by dilution with the base metal). The plates contained 0.05% – 0.06% Cb by product analysis. The actual Cb contents in the plates caused loss of toughness in the HAZ and in the weld metal. For certain applications, such as described above, the Cb content should have been restricted to a lower value than permitted by the SA-737 product specification, or a different material should have been considered for this application.

(3) A steel plate specification produced by one of the European countries permitted up to 0.18% vanadium for a normalized high strength steel and was typically supplied with more than 0.12% V content. Tests on stress relieved welded joints indicated excessive loss of notch toughness (impact test values) in heat affected zones after PWHT.

(4) In another example, a stress relieved LPG sphere (in Far East) suffered extensive hydrogen induced cracking in heat affected zones, whereas an adjacent LPG sphere connected to the same LPG system did not. The materials had similar strength, heat treatment, and chemical composition, except that the material in the sphere with cracks was a micro alloyed steel with Cb, and the other sphere did not contain any significant amounts Cb or V.

(5) Reports that indicate deliberate addition of boron to carbon steels being shipped to USA from international sources. Boron decreases weldability and increases hardenability, which is undesirable for certain applications. SA-20, Table 1 now includes a maximum limit on boron content when it not one of the specified chemical components in the material specification.

(b) *Surface Defects in Plates* - Surface defects (such as blisters scabs, slivers, seams, pits), can be caused by improper pouring, casting, or rolling. Surface and internal defects can also be caused by improper adjustments of the continuous caster and thermal gradients during continuous casting. Mill scale can be caused during heat treatment and inadequate controls during rolling of the plate. Mill scale hides surface defects. Plates with mill scale should generally be descaled to permit proper surface inspection. Of particular concern are low alloy nickel bearing plates (such as 9% Ni and 5% Ni plates), which typically have a thick tenacious mill scale after heat treatment. "AISC Steel Plates Manual Plates, Rolled Floor Plates, Carbon, High Strength Low Alloy, and Alloy Steel" [1] includes photographs of various surface defects.

(c) *Segregations and Laminations* - Segregations and laminations are internal defects that are generally caused by inadequate control of process variables in melting, casting, and cutting. These plate defects can render the plate unsuitable for fabrication (welding) or for use in structures. Of particular concern are large laminations that are not parallel to plate surface. These defects can increase crack propagation rates and the risk of brittle fracture.

In one example of this problem, two rail car manufacturers purchased large quantities of carbon steel plates from an international material manufacturer. The plates met the product specifications ultrasonic testing acceptance criteria, but could not be welded because of an extensive amount of segregations at mid-thickness of the plate. The materials manufacturer refused to accept any responsibility for the problem. An independent investigation concluded that the segregations were the result of improper process controls with the continuous caster. The rail car manufacturers rejected all plates from this material manufacturer and purchased new plates from another steel producer.

(d) *Edge Defects in Plates* - Edge defects are caused by internal defects or cutting of plate edges. They are undesirable because they can cause welding problems and leave defects in heat affected zones of welded joints, thereby increasing the risk of brittle fracture.

(e) *Plates Produced From Coils* - Plates produced from coils can have poor flatness, wavy edges, poor edge camber, welded splices, and distortions after cutting and welding because of locked up thermal stresses due to uneven cooling rates at ends, edges, and in the middle of the coil. Vessel and storage tank constructors have experienced flat spots, poor appearance, and difficulties in meeting geometric tolerance requirements when using plates from coil, unless additional precautions are taken (e.g., temper rolling of the coil before cutting into plates).

Plates from coils are also likely to have non-uniform properties, mainly due to unidirectional rolling and uneven cooling rates of the coiled product.

11.3 Forgings

(a) *Use of Separately Forged Test Blanks for Forgings* - Most forging specifications permit the use of separately forged test blanks instead of testing the forging, or a prolongation of the forging (with or without the use of thermal buffers). These specifications also require the separately forged test blanks to be reduced by forging in a manner similar to that of the forging itself, to receive approximately the same hot working and reduction, and the same heat treatment as the finished forging. It is difficult to verify these requirements (particularly the amount of hot working), and consequently, the test results from the separately forged test blanks may not be representative of the actual forging. In one case, a vessel and storage tank manufacturer had to reject a large amount of ASTM A350 Gr. LF2 flanges (in one case about 1800 flanges) after they tested the flanges. In each case, the test results from the separately forged test blanks had acceptable impact results at -50 °F (-46 °C), whereas the test results from the actual forgings had only a few ft-lbs (in some cases as low as 2 ft-lbs at -50 °F). The product specification required at least 15 ft-lb at -50 °F (-46 °C).

(b) *Poor Weldability* - Most forging specifications do not specify limitations on unspecified elements. This is also not covered in the general requirements specifications. High levels of unspecified elements (such as columbium, vanadium, or boron) have been known to result in cracking problems due to insufficient preheat.

(c) *Improper Use of Forging Specifications* - Some forging specifications (e.g., SA-105, SA-182) are intended for piping applications and not for large and heavy forgings. The following gives an example of misapplication of forging specifications. In one case this resulted in costly rejection of thick SA-350 Gr. LF2 tube sheets as the material was not capable of meeting the toughness requirement. The SA-350 Gr. LF2 tube sheets were replaced with SA- 765 Gr. IV material, a forging specification that is generally intended for larger forgings than SA-350.

11.4 Welded Pipe and Tubes

Problems have been reported with low frequency welded ASTM A53 ERW pipe that have resulted in leaks during hydrostatic testing and expansion of the pipe. These problems have been significantly reduced by use of high frequency Electric Resistance Welding (ERW). Also normalizing of the pipe after ERW improves the properties of the pipe. Purchasers may want to restrict the use of A53 ERW piping to sizes NPS 2 and larger, where full examination of the weld seam is required by the manufacturer.

A 178 and SA-178 includes a supplementary requirement S1 that have provisions UT examination of the ERW pipe.

11.5 Castings

(a) *Product Quality* - Several purchasers and users have encountered problems with valves. One user encountered leaks in several castings during hydrostatic tests or in service. These were attributed to improper casting practices (e.g., pouring the casting too fast or letting it cool too fast), resulting in shrinkage cracks, improper heat treatment, and welded repairs. Another user purchased 90 control valves of which 63 were recalled by the vendor. The problems included casting defects, lack of control of manufacturing procedures leading to improper assembly, and lack of proper QA/QC records.

A construction company purchased 620 valves from a supplier. The valves were produced by a valve manufacturer in Asia. Many of the cast valves were unsound and leaked which led to all valves to be rejected and replaced.

(b) *Cracks* **-** Surface flaws have been detected by magnetic particle testing that, when explored further, have resulted in large repairs. In one case these flaws were attributed to segregation of tramp elements (typically Pb, Sn, Sb, As, P, and S) at the solid/liquid interface, usually at the top of the casting during pouring, which resulted in very tight cracks between the final casting grains.

(c) *Welded Repairs* - The casting manufacturer should not perform welded repairs unless permitted by the product specification and unless approved by the purchaser. However, welded repairs have been reported where the repairs were made without the knowledge of the purchaser, by unqualified welders, and were masked by paint. In one case the casting passed the hydrostatic test but later failed in high pressure high temperature service.

11.6 Use of Wrong Materials

In some cases wrong materials have been supplied and wrong welding materials have been used for welding of vessel components. This could lead to failures when used in certain service conditions. Of particular concern are materials in high or low temperature service and if used in service environments that can cause embrittlement and cracking.

In one case, carbon steel welding material was inadvertently used for welded joint in a Cr-Mo vessel in high temperature service that could have resulted in premature failure. Positive material identification after completion of fabrication using portable field equipment identified the weld as carbon steel, which was replaced with the appropriate Cr-Mo material.