

Installation of Thin Metallic Wallpaper Lining in Air Pollution Control and Other Process Equipment

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Foreword

Extremely corrosive conditions are encountered by certain types of air pollution control equipment. Such equipment is subject to wide temperature fluctuations and formation of condensates containing sulfuric, sulfurous, and other acids. Flue gas desulfurization (FGD) slurry environments may contain significant aggressive contaminants of halides and oxidizing ions (e.g., Fe). High-performance metals and alloys are being used to resist these environments. The application of these materials to a carbon steel or other substrate as thin metallic linings is commonly called wallpapering. Wallpapering has been identified as a practical and effective method of providing anticorrosive linings in both new equipment and retrofit installations. Wallpapering is widely applied in response to power industry (utility) FGD experiences, and is equally applicable to use in other air pollution control and process equipment subject to corrosive conditions.

This standard practice provides technical and quality assurance guidelines for handling and installing nickel alloy, stainless steel, and titanium linings in air pollution control equipment (e.g., FGD systems, ducts, and stacks). The concepts and guidance included in this standard may also be useful in other process industries, but may require modification to meet the requirements of a particular process. This standard is intended to be a basis for preparation of a specification to be agreed on by contracting parties for the installation of wallpaper lining in air pollution control and other process equipment. It is the responsibility of users of this standard to determine the suitability of specific procedures, metals, and alloys for particular applications.

This standard practice is intended for use by those specifying and installing thin metallic linings (nickel alloy, stainless steel, and titanium) in air pollution control and other process equipment subject to corrosive conditions.

In AMPP standards, the terms *shall* and *must* are used to state requirements and are considered mandatory. The term *should* is used to state something that is recommended, but is not considered mandatory. The term *may* is used to state something considered optional.

Section 1: General

- 1.1 This standard provides technical and quality assurance guidelines for handling and installing nickel alloy, stainless steel, and titanium linings in air pollution control equipment such as FGD systems, ducts, and stacks.
- 1.2 The guidelines in this standard are also applicable to installation of thin, high-performance metallic linings in a wide variety of other process equipment. However, titanium welding procedures contained herein are only applicable to seal welds in air pollution control equipment.
- 1.3 It is the responsibility of users of this standard to determine the suitability of construction materials specified for particular applications.
- 1.4 This standard is applicable to wallpapering materials of 1.6 to 3.2 mm (0.063 to 0.13 in) thickness applied as linings over new or existing metallic structures. General safety requirements to perform this work are beyond the scope of this standard. It is assumed that users will incorporate specific safety requirements in accordance with their individual needs.
- 1.5 New and improved welding techniques as well as new alloys applicable to wallpaper installation are being developed. References to specific weld designs and techniques in this standard are not intended to preclude the use of newer technology. Use of alternative techniques shall be mutually agreed on by all contractual parties after adequate engineering analysis.
- 1.6 The corresponding ASME⁽¹⁾ material specifications may be used instead of the ASTM⁽²⁾ material specifications cited in this standard.
- 1.7 While the techniques described in this standard have demonstrated high levels of success, some extreme environmental and/or design conditions encountered in the use of air pollution control equipment can result in corrosive conditions so severe that even the most corrosion-resistant construction material will occasionally fail. Such failures generally affect a relatively small percentage of the total lined surface and may require periodic maintenance.

Section 2: Installation of Nickel Alloy Linings

2.1 Materials

- 2.1.1 Nickel alloy lining materials with a nominal content of at least 9% molybdenum (Mo) shall be selected in accordance with the requirements of the particular application and ASTM specifications. Superaustenitic stainless steels are addressed in [Section 3](#).
- 2.1.2 The nickel alloy lining materials and copies of the certified mill test reports shall be supplied in accordance with purchase orders.

2.2 Storage and Handling

- 2.2.1 All nickel alloy lining materials shall be stored and handled in a manner that does not result in damage to or contamination of the nickel alloys.
- 2.2.2 All nickel alloy lining materials (including cut or formed pieces) shall be marked to maintain material identity and separation. These identifying marks shall not be made in such a way as to contribute to corrosion of the nickel alloy.

⁽¹⁾ ASME, Two Park Avenue, New York, NY 10016-5990, www.asme.org.

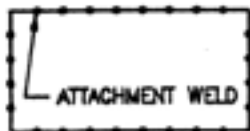
⁽²⁾ ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959, www.astm.org.

2.3 Design Factors/Fabrication of Nickel Alloy Lining Sheets

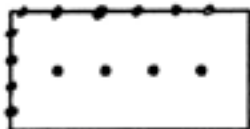
- 2.3.1** Certified mill test reports for all nickel alloy lining materials, including welding filler metals, shall be reviewed by the purchaser before acceptance and use for traceability, identification, and conformance to specifications and standards.
- 2.3.2** All nickel alloy lining sheet installation details shall be approved by the purchaser before work begins. A complete layout plan shall be reviewed, and pieces shall be marked according to the plan. Figures 1 through 5 illustrate layout and installation details. Nickel alloy lining sheets shall be sized to facilitate handling and minimize welding.
- 2.3.3** All internal structural attachments shall be made to the existing substrate. The nickel alloy lining sheets shall not be used to support any internal components or temporary supports.
- 2.3.4** Joints between nickel alloy lining sheets shall be lap joints (see [Figures 1](#) and [2](#)). Lap joints shall have a nominal 25 mm (1.0 in) overlap. The overlap shall not be less than 6.3 mm (0.25 in).
- 2.3.5** Joining nickel alloy lining sheets in corners shall be avoided because corner seal welds are difficult to make and to properly inspect. The technique to be used shall be agreed on by the purchaser and installer. Two techniques that have been used to avoid this problem are illustrated in [Figures 3, 4, and 5](#).



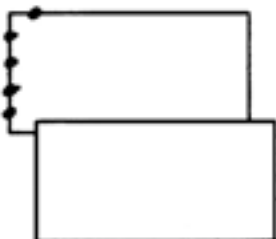
1. Tack weld first lining sheet to substrate (tack welds not shown).



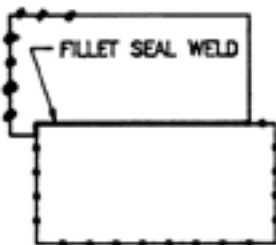
2. Attachment weld first lining sheet to substrate (welds exaggerated).



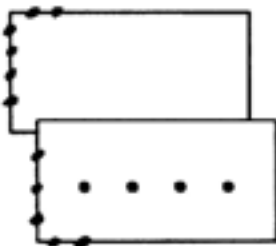
3. Make intermediate lining sheet attachment welds (if required, various patterns).



4. Lap second lining sheet over first lining sheet, tack weld (tack welds not shown).



5. Attachment weld second lining sheet and fillet seal weld to first lining sheet.



6. Make intermediate lining sheet attachment welds (if required, various patterns).

7. Repeat Steps 4, 5, and 6 for each subsequent lining sheet.

Figure 1: Lining Sheet Installation Sequence (Nickel Alloy and Stainless Steel)

NOTE: Only new welds are shown at each step. Offsetting each lining sheet is optional. The sequence of tack welds and seal welds is optional.

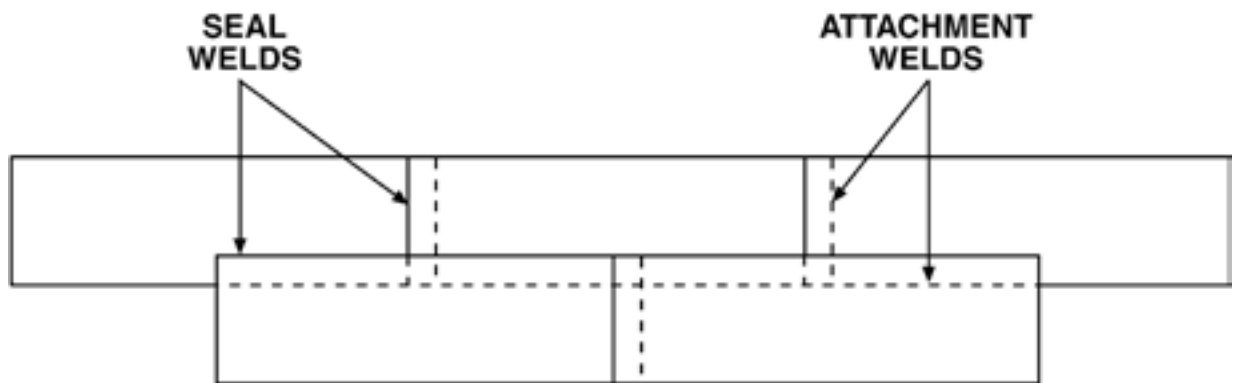


Figure 2: Typical Layout for Installation of Lining Sheets

NOTE: Staggered lining sheet pattern with overlapping, seal-welded sheet edges is shown.

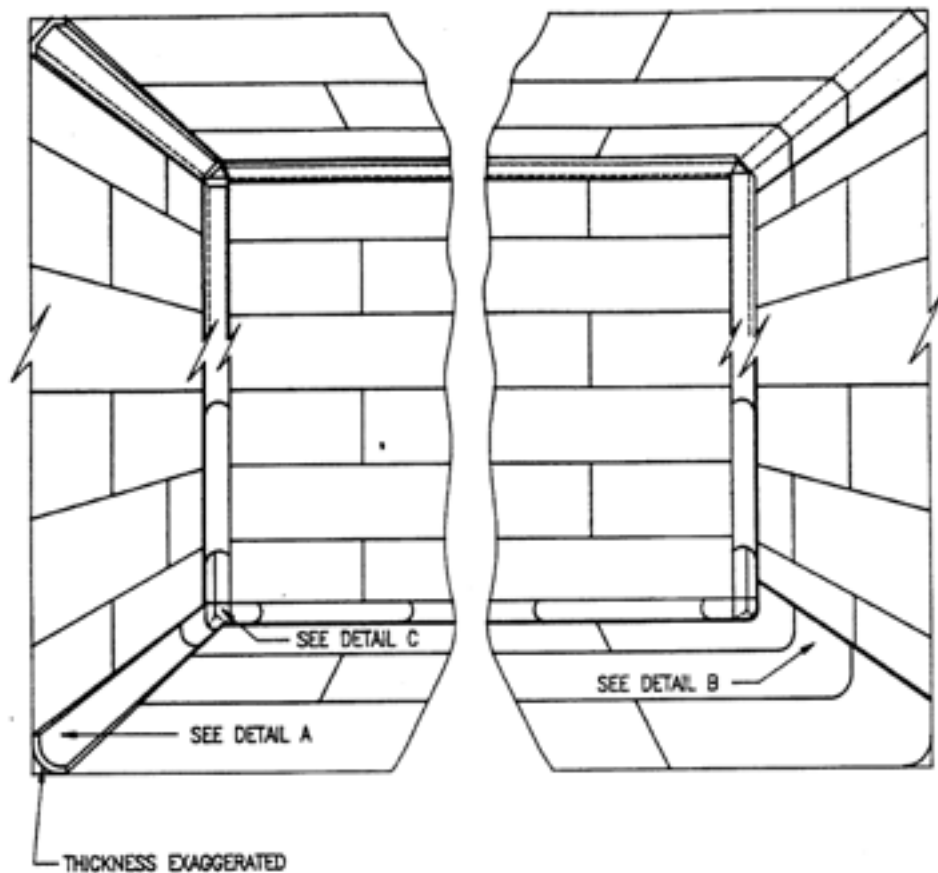


Figure 3: Typical Lining Sheet Installation

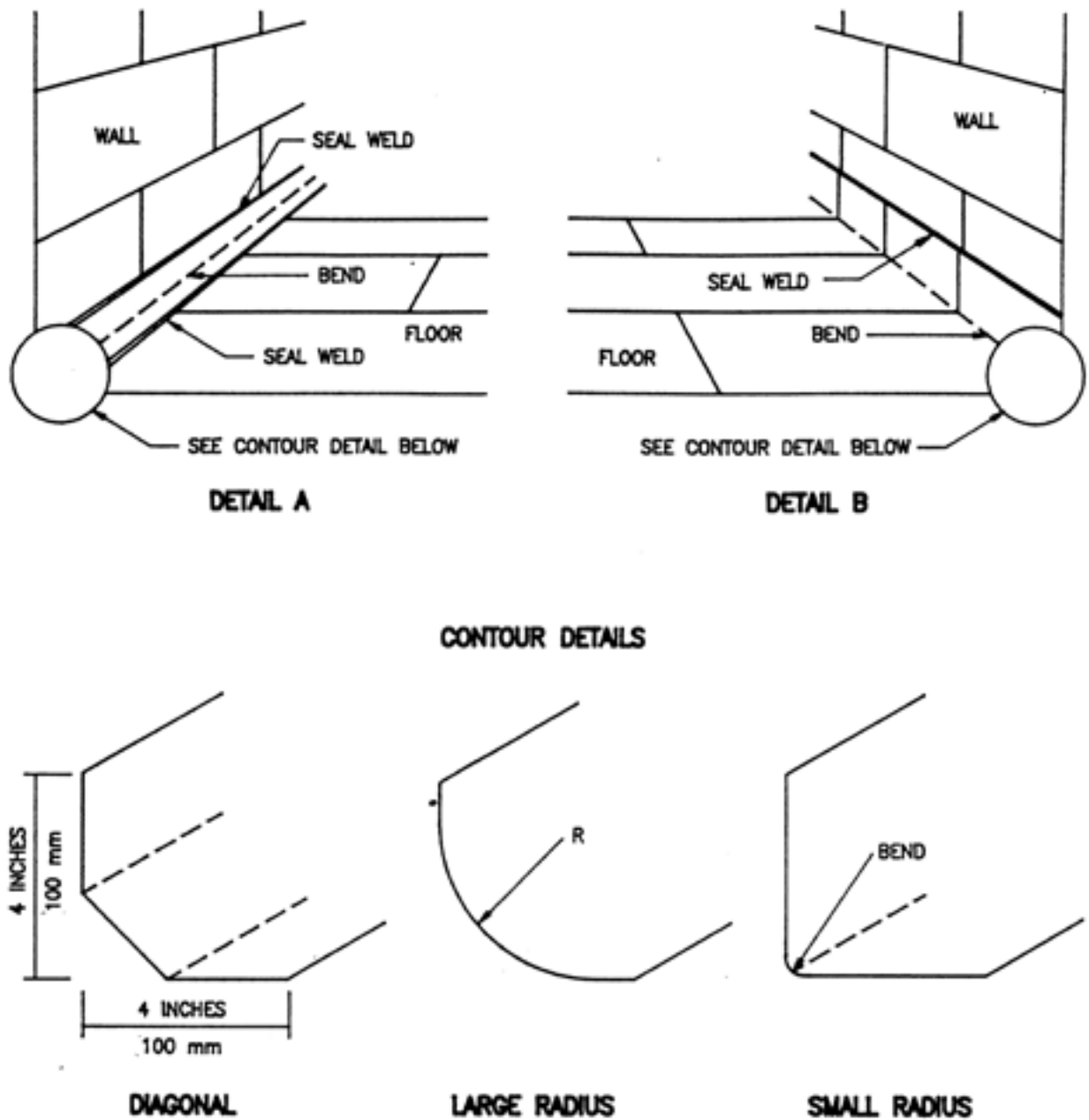


Figure 4: Two-Plane Corner Details

NOTE: A diagonal or large-radius corner provides suitable clearance for reinforced carbon steel weld in corner of the substrate, facilitating fit-up and eliminating need to grind weld.

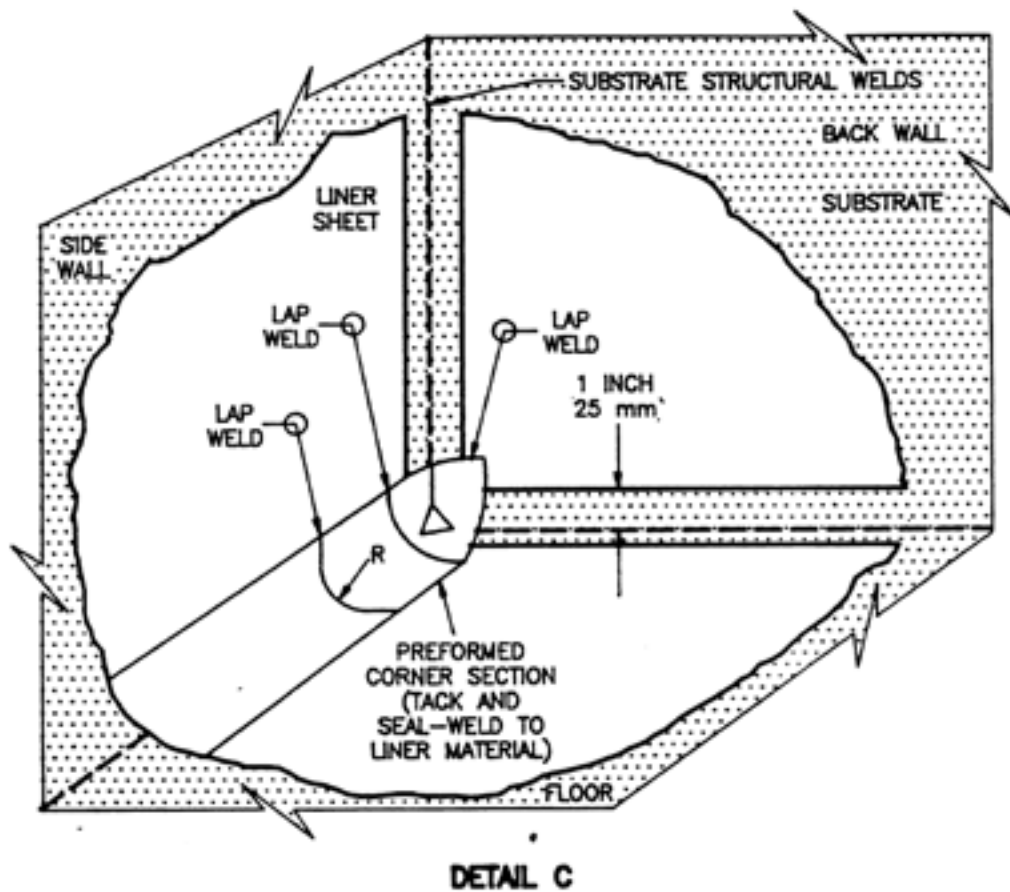
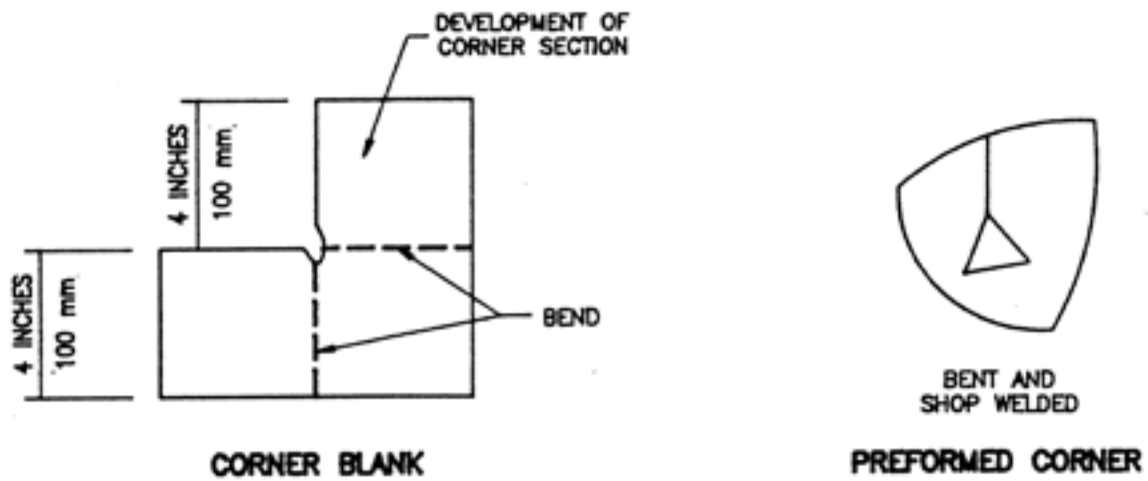


Figure 5: Three-Plane Corner Details

2.3.5.1 The edge of the nickel alloy lining sheet may be bent to fit around the corner, making the overlap on the next sheet on the flat plane away from the corner. (See [Figure 4](#)).

2.3.5.2 The nickel alloy lining sheet on each side of the corner may stop short of the corner. A nickel alloy sheet may be bent to form an angle to fit into the corner. Each edge of the angle sheet is seal welded to the adjacent nickel alloy lining sheets on the flat plane away from the corner. (See [Figure 5](#)).

2.3.6 The nickel alloy lining sheets may be preformed and cut as required to match existing substrate surfaces to be lined. Measurements shall be taken whenever possible to verify existing dimensions prior to cutting and fitting the lining sheets.

NOTE: Original design drawings indicate theoretical or approximate dimensions and elevations (not “as-built” dimensions). Existing substrate surfaces may be out-of-square, out-of-plumb, wavy, and/or misaligned.

2.3.7 Nickel alloy lining sheets shall be cut to size as required by methods such as shearing, abrasive cutting, or plasma-arc cutting. The nickel alloy lining sheets shall be sized to facilitate handling and to minimize welding. Air carbon arc and oxy-fuel cutting shall be prohibited. All thermal cuts shall be ground back as necessary to remove dross. Shears shall be clean and free of filings or oil.

2.3.8 Weld size shall be agreed on by the contracting parties. Weld reinforcement and undercut acceptance criteria are provided in [Appendix A](#) (mandatory).

2.3.9 Some sheet-lining designs provide for “weep holes” through the substrate to detect leaks in the lining during service or to aid in performing leak tests on the lining seal welds.

2.4 Substrate Preparation

2.4.1 The responsibility for preparation of the substrate surfaces prior to the nickel alloy lining installation should be clearly assigned. For retrofit installations, all existing nonmetallic lining materials and any nonmetallic lining-related materials should be removed from the substrate surface as necessary. Disposal of all materials removed should be approved by the purchaser.

2.4.2 The substrate shall be inspected for damage. The purchaser and installer shall determine whether repair is required. Repair work shall be performed to an agreed-on standard. Protrusions must be ground as necessary to ensure proper fit of the lining sheets.

2.4.3 The substrate must be clean and free of oxide or mill scale, corrosion products, oil, grease, and other foreign matter in the area of the lining-to-substrate welds as necessary to obtain a mechanically sound weld. Abrasive blasting with clean abrasive or grinding may be used for surface cleaning as necessary. The substrate surface should be sufficiently smooth and free of protrusions or depressions (e.g., pits) to allow close contact with the lining sheet. A rust-preventive compound may be applied after cleaning if rerusting is likely. Substrate preparation should be completed prior to installation of the nickel alloy lining sheets.

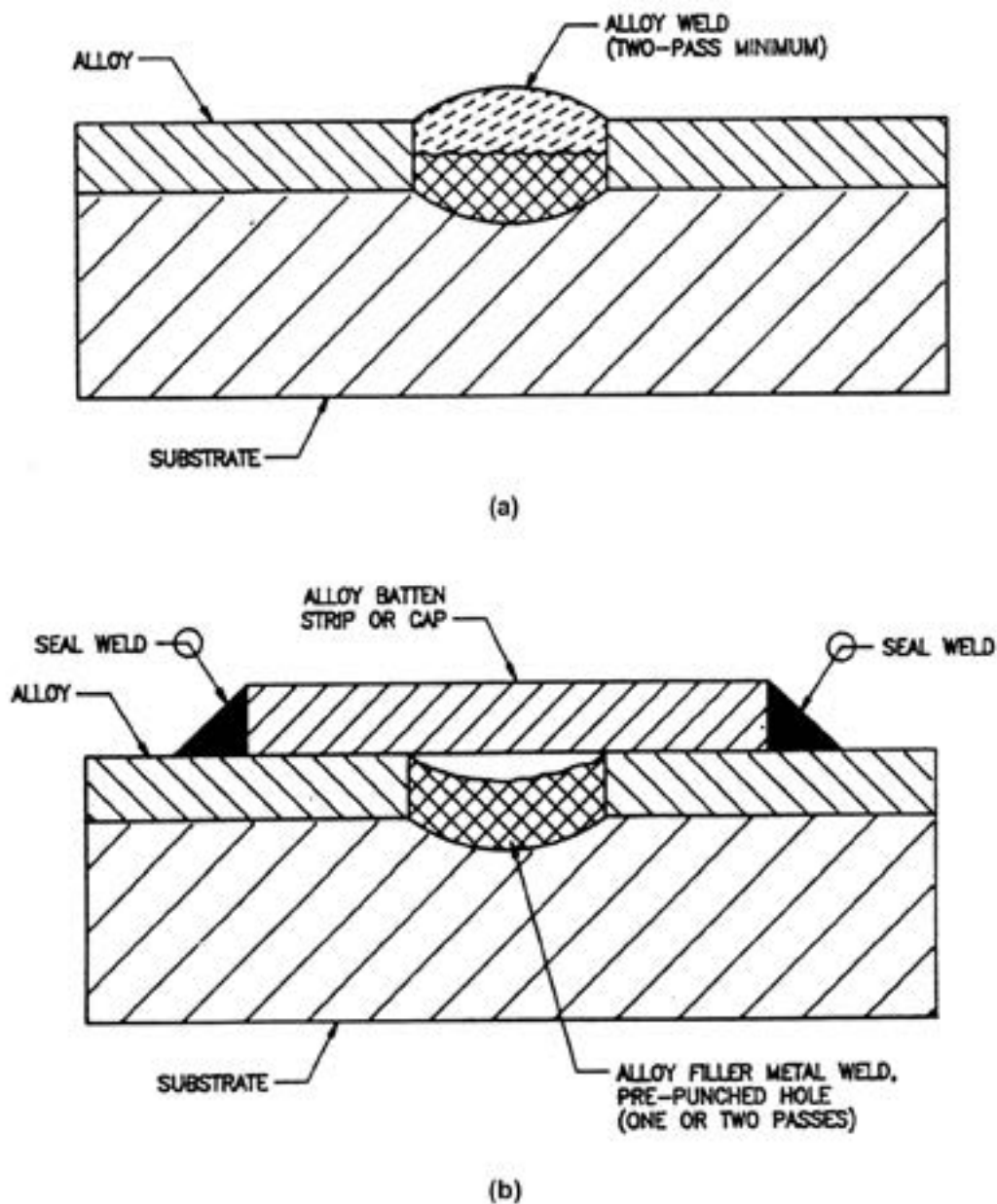
2.4.4 Materials may be brought into the work area through existing or temporary openings. All temporary openings should be approved by contracting parties prior to cutting. The openings should be repaired after the lining is completed by mutually agreed-on procedures.

2.5 Installation of Nickel Alloy Lining Sheets

2.5.1 Nickel alloy lining sheets should be pressed against the existing substrate surface to ensure close contact wherever possible. Edges of the lining sheets at weld seams shall have close contact with the substrate.

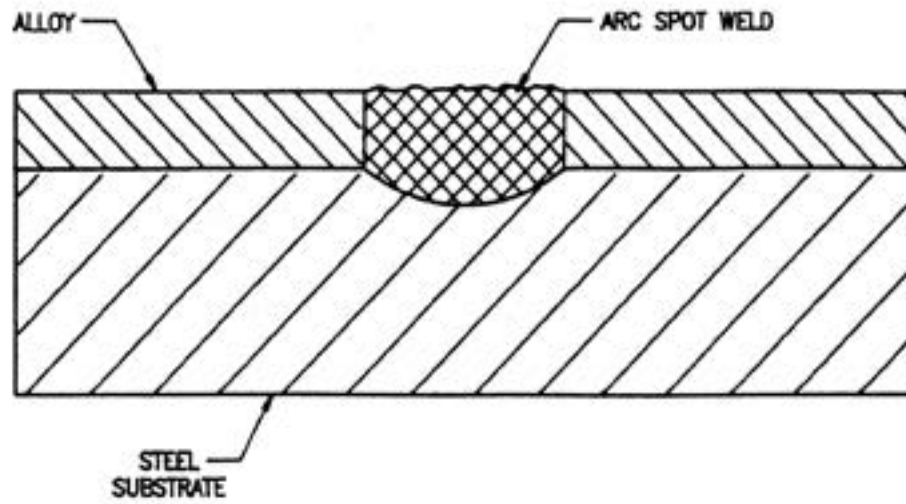
2.5.2 The nickel alloy lining sheets forming a lap joint shall be held in as close contact as possible during welding, and the separation shall not be more than 1.6 mm (0.063 in). To achieve the maximum 1.6 mm (0.063 in) lap separation with lining sheets greater than 1.6 mm (0.063 in) thick, some forming of the overlapping sheet may be necessary. This forming should be done using procedures and tooling that will not damage or contaminate the nickel alloy lining sheet being formed.

- 2.5.3** Staging or scaffolding shall be installed in a manner that prevents mechanical damage to the nickel alloy lining.
- 2.5.4** All existing hardware (e.g., bolts, brackets, angles) exposed to corrosive media shall be replaced by purchaser-approved nickel alloy hardware, or covered with purchaser-approved nickel alloy lining materials.
- 2.5.5** Small tack welds may be used to hold nickel alloy lining sheets in position before the attachment welds are made. Tack welds may be used around the perimeter of the lining sheet to maintain contact with the edges before seal welding. Tack welds shall be as small as possible to prevent cracking.
- 2.5.6** Attachment welds are those joining the edges of the nickel alloy lining sheet to the substrate. The length of the attachment fillet welds shall be left to the discretion of the purchaser. Generally, 25 mm (1.0 in) attachment fillet welds on approximately 150 mm (6.0 in) spacing centers have proved sufficient. Welding sequence shall minimize distortion of the lining sheets.
- 2.5.7** To provide additional attachment or prevent vibration or flexing of the nickel alloy lining sheet, intermediate attachment welds such as plug welds or gas-metal arc spot welds may be used. (See [Figure 1](#)).
- 2.5.7.1** Precut or prepunched holes for plug welds should be 9.0 to 25 mm (0.35 to 1.0 in) in diameter. Elongated slots 25 to 50 mm (1.0 to 2.0 in) long and sufficiently wide for three weld beads may be used. A minimum of two weld layers shall be used to avoid substrate dilution unless the welds are capped. Overmatching composition welding consumables should be used for plug welds and spot welds. [Figure 6](#) illustrates two plug weld designs and [Figure 7](#) illustrates two arc spot weld designs.
- 2.5.7.2** Plug welds or gas-metal arc spot welds used to prevent vibration or flexing of the lining sheets may be capped for additional corrosion protection, as shown in Figures 6(b) and 7(b), respectively.
- 2.5.8** All welded joints that will be exposed to corrosive media must be leak-tight

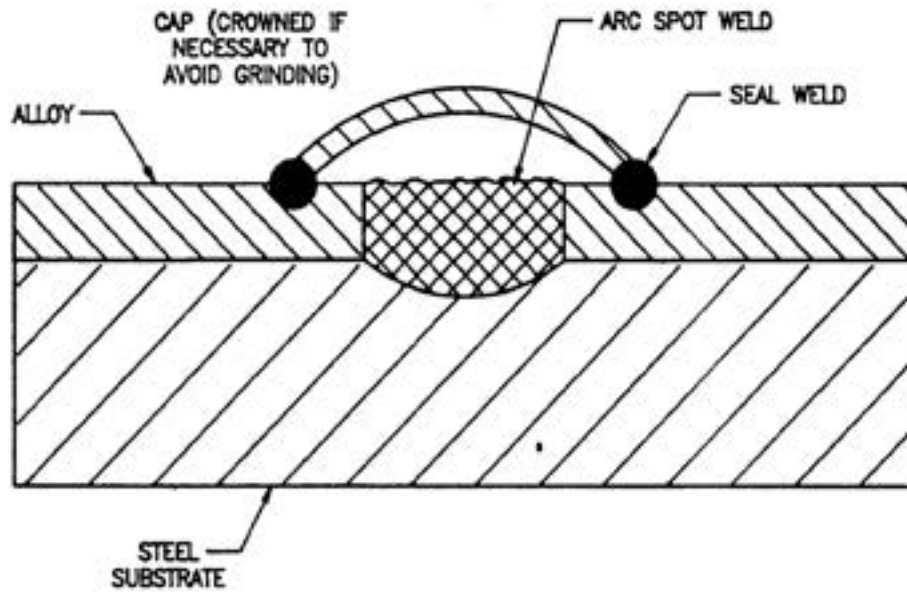


NOTE: Flat cap illustrated; crowned cap may be used. Care should be taken to avoid porosity in cap seal welds associated with expansion of air inside the cap.

Figure 6: Plug Weld Designs for Nickel Alloy and Stainless Steel Lining Sheets Using Precut or Prepunched Holes or Elongated Slots



(a)



(b)

NOTE: Care should be taken to avoid porosity in cap seal welds associated with expansion of air inside the cap.

Figure 7: Arc Spot Weld Designs for Nickel Alloy and Stainless Steel Lining Sheets Using the Melt-Through Procedure

2.6 Welding—General

- 2.6.1 All welding shall be performed in accordance with welding procedures approved by the purchaser. [Appendix E](#) (nonmandatory) provides descriptions of thin-sheet wallpaper lining welding processes.
- 2.6.2 All welding materials shall be stored in a clean, dry area. If coated electrodes are used, they shall be stored as recommended by the coated electrode supplier. Damaged materials shall not be used.
- 2.6.3 Mechanically cut edges shall be clean and free of filings and oils. If necessary, thermal-cut edges shall be ground to bright metal to remove dross from cutting. All weld surfaces shall be clean and dry prior to welding.
- 2.6.4 Preheating is not required except to bring the metal in the area to be welded to room temperature or to a typical shop temperature to prevent condensation of moisture on the nickel alloy lining materials. When heating is necessary, it shall be accomplished by a technique that will not result in contamination of the nickel alloy surface. Some acceptable techniques are indirect natural gas, propane, or infrared heating. Fuel oil or oxy-fuel heaters shall not be allowed.
- 2.6.5 Pulse-mode gas metal arc welding (GMAW) has historically yielded the most consistent results. Conventional short-circuiting GMAW has been used in the past but new technologies have achieved more consistent weld quality. Gas tungsten arc welding (GTAW) and shielded metal arc welding (SMAW) are considered acceptable welding processes. Precautions shall be taken in selecting electrodes for out-of-position SMAW because some welding consumables may not be acceptable.

2.7 Welding Procedure Qualification

- 2.7.1 The installer shall develop welding procedure specifications and perform procedure qualification tests for all welds intended to be made. The welding procedure specifications and procedure qualification records shall be submitted to the purchaser for approval upon request.
- 2.7.2 [Appendix B](#) (nonmandatory) contains recommended relevant welding variables for nickel alloys in addition to the essential and nonessential variables described in AWS⁽³⁾ D9.1M/D9.1,¹ AWS B2.1,² or ASME Boiler and Pressure Vessel Code, Section IX.³
- 2.7.3 [Appendix C](#) (nonmandatory) contains recommended procedures for use in conjunction with the weld procedure specifications within this standard.

2.8 Welding Performance Qualification

- 2.8.1 All welders, welding operators, spot welders, and tack welders shall be qualified by the installer as agreed on by the contracting parties.
- 2.8.2 Procedures for use in conjunction with the welder performance qualifications within this standard are covered in [Appendix D](#) (mandatory). Further guidelines for welder qualification are in ASME Boiler and Pressure Vessel Code, Section IX, AWS B2.1, or AWS D9.1M/D9.1. Areas of particular concern are addressed by the following requirements:
 - 2.8.2.1 Each welder shall qualify for each welding procedure specification he/she will be required to use. The welder shall use the same type of equipment for qualification as will be used for field welding. Welders who have not engaged in a particular process for a period of 12 months preceding the start of fabrication and welders/welding operators whose ability is subject to question for some specific reason shall be requalified.

⁽³⁾ American Welding Society (AWS), 8669 NW 36th St., Ste. 130, Miami, FL 33166-6672, www.aws.org.

- 2.8.2.2** Butt-weld qualifications shall not suffice for fillet welding. Each joint design requires a separate test for welder qualification.
- 2.8.2.3** Each welder shall be tested in accordance with the approved welding procedures for each welding process to be used in the various positions encountered.
- 2.8.2.4** Test specimens shall meet the weld-quality requirements in Paragraph 2.9.
- 2.8.2.5** Consideration shall be given to the extra time and quantity of nickel alloy lining material needed to perform welder qualification tests.

2.9 Weld Quality

- 2.9.1** Seam welds, capped plug welds, and uncapped plug welds shall be smooth and visually free from cracking, porosity, pinholes, and lack of fusion.
- 2.9.2** Welds must meet the acceptance criteria for weld reinforcement and undercut presented in [Appendix A](#). The development of agreed-on workmanship and weld-profile standards prior to production welding is encouraged to avoid misunderstanding regarding weld acceptability.

2.10 Inspection

- 2.10.1** Lining leaks occurring in service are very difficult to locate, and thus repair. Therefore, the inspection process is extremely important, given the reality that later repair is very difficult.
- 2.10.2** Because the nickel alloy lining is a corrosion barrier, any indication of a leak path in a weld between the lining and the substrate is cause for rejection of the weld. A gas-leak test using a vacuum-box method is preferred because it gives the best practical indication of whether a defect penetrates the lining. Alternative testing methods using helium or other gases with an approved gas-leak sniffer, detection of interspace air pressure decay, or acoustical emission may be considered and used after agreement between the contracting parties.
- 2.10.3** Inspection procedure specifications shall be submitted to the purchaser for approval. The inspecting organization shall be responsible for the qualification of inspectors. Methods of inspection and qualification of inspectors shall be agreed on by the contracting parties before the job begins.
- 2.10.4** Materials, certified mill test reports, purchase orders, and workmanship shall be subject to inspection by the purchaser.
- 2.10.5** Nickel alloy lining material shall be completely visually inspected for handling, erection, and/or contamination damage.
- 2.10.6** A visual inspection of all final seal welds in the as-welded condition shall be made by the installer's welding inspector for conformance to the requirements in Paragraph 2.9. The purchaser also retains the right to inspect all welds at this time. Following visual inspection and necessary repairs, seal welds may be inspected by a leak-test method such as the vacuum box technique, helium, or a similarly approved gas-leak detection method mutually agreed on. Seal welds shall be inspected/tested as soon as practical after the final welds have been made to identify seal weld problems.
- 2.10.7** Vacuum box technique for leak testing of seal welds shall be performed in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 10,⁴ AWWA⁽⁴⁾ D100, Section 11.12,⁵ or other applicable codes. Acceptance criteria shall be agreed on by the contracting parties.
- 2.10.8** Helium or similar approved gas-leak testing shall be performed in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 10, Appendixes 4 and 5. Acceptance criteria shall be agreed on by contracting parties.

⁽⁴⁾ American Water Works Association (AWWA), 6666 W. Quincy Ave., Denver, CO 80235, www.awwa.org.

2.10.9 Liquid penetrant examination may be used to supplement visual inspection in areas that are not accessible by other methods, or in areas where linear indications are suspected. Liquid penetrant examinations shall be performed in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 6⁶ or other applicable codes. Acceptance criteria shall be agreed on by contracting parties.

2.10.10 All surface defects shall be suitably marked or identified to make them readily apparent for repair. The markings shall not be made in such a way as to contribute to corrosion of the nickel alloy.

2.11 Repair of Defective Welds

2.11.1 Weld repair procedures shall be developed and qualified by the installer, approved by the purchaser, and shall include a method for documenting the repair made, its location, the name of the welder making the repairs, and the inspector's approval of the repaired weld.

2.11.2 The installer shall repair all welds found to be defective. Weld defects shall be removed by grinding followed by solvent cleaning, then by rewelding with the qualified filler metal. If patches are welded over defective welds, the patch shall be large enough so that a minimum overlap of 25 mm (1.0 in) around the perimeter of the defective weld is achieved. Flame or arc gouging of defective welds shall not be permitted.

2.11.3 Cracks shall be ground out and rewelded. Cracks or other defects shall not be repaired by remelting weld beads or covering with additional weld metal.

2.12 Postweld Cleaning

2.12.1 Acid cleaning of nickel alloy lining materials for the removal of heat tint or surface contamination generally is neither necessary nor recommended.

2.12.2 Passivation treatments are not required for nickel alloy lining materials.

Section 3: Installation of Stainless Steel Linings

3.1 Materials

3.1.1 Stainless steel lining materials shall be selected in accordance with the requirements of the particular application and ASTM specifications. Superaustenitic stainless steels are included in this section.

3.1.2 The stainless steel lining materials and copies of the certified mill test reports shall be supplied in accordance with the purchase orders.

3.2 Storage and Handling

3.2.1 All stainless steel lining materials shall be stored and handled in a manner that does not result in damage to or contamination of the stainless steels with dirt, grease, oils, corrosives, or iron. Indoor storage is preferred, but if outdoor storage is necessary, stainless steels shall be covered with clear polyethylene or polytetrafluoroethylene (PTFE) sheet for long-term storage. Adequate ventilation should be provided and all contact with carbon steel and moisture-absorbent materials (e.g., paper, cardboard) shall be avoided.

3.2.2 The surfaces of stainless steel lining materials may be rinsed with clean water to determine whether organic contaminants are present. Water does not coat the stainless steel with a uniform film if the surface is not clean. If organic contaminants are present, a nonchlorinated solvent shall be used to remove them.

3.2.2.1 The presence of rust streaks after exposure to water indicates the presence of embedded or smeared iron. Test methods for the presence of iron are listed in ASTM A380.⁷ Removal of this iron can be achieved by acid cleaning with, for example, nitric and citric acid solutions as described in ASTM A967⁸ or oxalic and phosphoric acids, or blasting with glass beads or other suitable media containing less than 0.01% iron. Proper safety precautions shall be adhered to when any acids are handled.

3.2.2.2 Dirt may be removed with a mild abrasive and a detergent.

3.2.3 All stainless steel lining materials (including cut or formed pieces) shall be marked so that they are distinguishable from other alloys or carbon steels. The markings shall be made with a chloride-free substance that does not contribute to corrosion of the stainless steel.

3.2.4 Handling equipment (e.g., slings, hooks, and forklifts) shall be covered with wood, cloth, or plastic to reduce contact with carbon steel surfaces. Alternatively, stainless steel hooks and nonmetallic materials may be used. Stainless steel wire brushes and hand tools that have been used on carbon steel shall not be used on stainless steel lining materials.

3.3 Design Factors/Fabrication of Stainless Steel Lining Sheets

3.3.1 Certified mill test reports for all stainless steel materials, including welding filler metals, shall be reviewed by the purchaser before acceptance and use for traceability, identification, and conformance to specifications and standards.

3.3.2 All stainless steel lining sheet installation details shall be approved by the purchaser before work begins. A complete layout plan shall be reviewed, and pieces shall be marked according to the plan. Figures 1 through 5 illustrate layout and installation details. Stainless steel lining sheets shall be sized to facilitate handling and minimize welding.

3.3.3 The stainless steel lining sheets may be preformed and cut as required to match the substrate surfaces to be lined. Measurements shall be taken whenever possible to verify the existing dimensions prior to cutting and fitting the lining sheets. If stainless steel lining sheets are roll-formed, all forming lubricants and any iron contamination resulting from the forming operation must be removed before use.

NOTE: Original design drawings indicate theoretical or approximate dimensions and elevations (not “as-built” dimensions). Existing substrate surfaces may be out-of-square, out-of-plumb, wavy, and/or misaligned.

3.3.4 Stainless steel lining sheets shall be cut to the required size by appropriate methods such as shearing, abrasive cutting, or thermal cutting using plasma-arc cutting. Shears shall be clean and free of filings or oils. Tool steel shear blades shall be ground with lip clearances as great as can be maintained without chipping. All thermal cuts shall be ground as necessary to remove dross. Cutting techniques that contaminate the metal with hydrocarbon compounds and/or carbon steel shall be avoided.

3.3.5 Joints between stainless steel lining sheets shall be lap joints (see [Figures 1](#) and [2](#)). Lap joints shall have a nominal 25 mm (1.0 in) overlap. The overlap shall not be less than 6.3 mm (0.25 in).

3.3.6 Joining stainless steel lining sheets in corners shall be avoided because seal welds are difficult to make and properly inspect. The technique to be used shall be agreed on by contracting parties. Two techniques that have been used to avoid this problem are illustrated in [Figures 3](#), [4](#), and [5](#).

3.3.6.1 The edge of the stainless steel lining sheet may be bent to fit around the corner, making the overlap on the next sheet on the flat plane away from the corner. (See [Figure 4](#)).

3.3.6.2 The stainless steel lining sheet on each side of the corner may stop short of the corner. A stainless steel sheet may be bent to form an angle to fit into the corner. Each

edge of the angle sheet is seal welded to the adjacent stainless steel lining sheets on the flat plane away from the corner. (See [Figure 5](#)).

- 3.3.7** All internal structural attachments shall be made to the existing substrate. The stainless steel lining sheets shall not be used to support any internal components or temporary supports.
- 3.3.8** Weld size shall be agreed on by the contracting parties. Weld reinforcement and undercut acceptance criteria are provided in [Appendix A](#) (mandatory).
- 3.3.9** Some sheet-lining designs provide for “weep holes” through the substrate to detect leaks in the lining during service or to aid in performing leak tests on the lining seal welds.

3.4 Substrate Preparation

- 3.4.1** The responsibility for preparation of the substrate surfaces prior to the stainless steel lining installation should be clearly assigned. For retrofit installation, all existing lining material and any lining-related materials should be removed as necessary from the existing surface to allow proper fit-up. The substrate around the area of any stainless-steel-to-substrate welds may be cleaned according to the guidelines in NACE No. 3/SSPC-SP 6.⁹ Disposal of all materials removed should be approved by the purchaser.
- 3.4.2** The substrate shall be inspected for damage. The purchaser and the installer shall determine whether repair is required. Repair work shall be performed to an agreed-on standard. Protrusions must be ground flush where required to ensure proper fit of the lining sheets.
- 3.4.3** The substrate must be clean and free of oxide or mill scale, corrosion products, oil, grease, and other foreign matter in the area of the lining-to-substrate welds as necessary to obtain a mechanically sound weld. Abrasive blasting with clean abrasive or grinding may be used for surface cleaning as necessary. The substrate surface should be sufficiently smooth and free of protrusions or depressions (e.g., pits) to allow for close contact with the lining sheet. A rust preventative may be applied after cleaning if rerusting is likely. Substrate preparation should be completed prior to installation of the stainless steel lining materials. Care shall be taken to avoid any contamination of the stainless steels.
- 3.4.4** Materials may be brought into the work area through existing or temporary openings. All temporary openings should be approved by the contracting parties prior to cutting. The openings should be repaired after the lining is completed by mutually agreed-on procedures.

3.5 Installation of Stainless Steel Lining Sheets

- 3.5.1** Stainless steel lining sheets should be pressed against the existing substrate surface to ensure close contact wherever possible. Edges of the lining sheets at weld seams shall have close contact with the substrate.
- 3.5.2** The stainless steel lining sheets forming a lap joint shall be held in as close contact as possible during welding, and the separation shall not be more than 1.6 mm (0.063 in). To achieve the maximum 1.6 mm (0.063 in) lap separation with lining sheets greater than 1.6 mm (0.063 in) thick, some forming of the overlapping sheet may be necessary. This forming should be done using procedures and tooling that will not damage or contaminate the stainless steel lining sheet being formed.
- 3.5.3** Staging or scaffolding shall be installed in a manner that prevents mechanical damage to the stainless steel lining.
- 3.5.4** All existing hardware (e.g., bolts, brackets, angles) exposed to corrosive media shall be replaced by purchaser-approved stainless steel hardware or covered with purchaser-approved stainless steel lining materials.

- 3.5.5** Small tack welds may be used to hold stainless steel lining sheets in position before the attachment welds are made. Tack welds may also be used around the perimeter of the lining sheet to maintain contact with the edges before seal welding. Tack welds shall be as small as possible to prevent cracking.
- 3.5.6** Attachment welds are those joining the edges of the stainless steel lining sheet to the substrate. The length of the attachment fillet welds is left to the discretion of the purchaser. Generally, 25 mm (1.0 in) attachment fillet welds on approximately 150 mm (6.0 in) spacing centers have proved sufficient. Welding sequence shall minimize distortion of the lining sheets.
- 3.5.7** To provide additional attachment or prevent vibration or flexing of the stainless steel lining sheet, intermediate attachment welds such as plug welds or gas-metal arc spot welds may be used. (See [Figure 1](#)).
 - 3.5.7.1** Precut or prepunched holes for plug welds should be 9.0 to 25 mm (0.35 to 1.0 in) in diameter. Elongated slots 25 to 50 mm (1.0 to 2.0 in) long and sufficiently wide for three weld beads may be used. A minimum of two weld layers shall be used to avoid substrate dilution unless the welds are capped. Overmatching composition welding consumables should be used for plug welds and spot welds. Figure 6 illustrates two plug weld designs and [Figure 7](#) illustrates two arc spot weld designs.
 - 3.5.7.2** Plug welds or gas-metal arc spot welds used to prevent vibration or flexing of the lining sheets may be capped for additional corrosion protection, as shown in Figures 6(b) and 7(b), respectively.
- 3.5.8** All welded joints that will be exposed to corrosive media must be leak-tight.
- 3.5.9** Carbon steel brackets shall not be welded to stainless steels. Brackets or fit-up materials must be of the same stainless steel as the lining alloy. Exceptions to this requirement must be approved by the purchaser.
- 3.5.10** All tools used on stainless steel shall be distinctively marked and used only on stainless steel. No tools previously used on carbon steel shall be used on stainless steels. The installer shall protect completed stainless steel lining from damage.
- 3.5.11** Grinding wheels, abrasive discs, and abrasive belts shall be of silicon carbide, alumina abrasive, or zirconia abrasive. Wheels, discs, and belts shall be dedicated to stainless steel use to avoid iron contamination. Power wire brushes shall not be permitted.

3.6 Welding—General

- 3.6.1** All welding shall be performed in accordance with welding procedures approved by the purchaser. [Appendix E](#) provides descriptions of thin-sheet wallpaper lining welding processes.
- 3.6.2** All welding materials shall be stored in a clean, dry area. If coated electrodes are used, they shall be stored as recommended by the coated electrode supplier. Damaged materials shall not be used.
- 3.6.3** Mechanically cut edges shall be clean and free of filings and oils. If necessary, thermal cut edges shall be ground to bright metal to remove dross from cutting. All weld surfaces shall be clean and dry prior to welding.
- 3.6.4** Preheating is not required except to bring the metal in the area to be welded to room temperature or to a typical shop temperature to prevent condensation of moisture on the stainless steel lining materials. When heating is necessary, it shall be accomplished by a technique that will not result in contamination of the stainless steel surface. Some acceptable techniques are indirect natural gas, propane, or infrared heating. Fuel oil or oxy-fuel heaters shall not be allowed.

- 3.6.5** GMAW has been used almost exclusively for structural intermittent fillet welding, seal fillet welding, spot welding, and plug welding. GTAW and SMAW are considered acceptable alternate welding processes. Precautions shall be taken in selecting electrodes for out-of-position SMAW because some welding consumables may not be acceptable.

3.7 Welding Procedure Qualification

- 3.7.1** The installer shall develop welding procedure specifications and perform procedure qualification tests for all welds to be made. The welding procedure specifications and procedure qualification records shall be submitted to the purchaser for approval upon request.
- 3.7.2** [Appendix B](#) contains recommended relevant welding variables for stainless steels in addition to the essential and nonessential variables described in AWS D9.1M/D9.1, AWS B2.1, or ASME Boiler and Pressure Vessel Code, Section IX.
- 3.7.3** [Appendix C](#) contains recommended procedures for use in conjunction with the weld procedure specifications within this standard.

3.8 Welder Performance Qualification

- 3.8.1** All welders, welding operators, spot welders, and tack welders shall be qualified by the installer as agreed on by the contracting parties.
- 3.8.2** Procedures for use in conjunction with the welder performance qualifications within this standard are covered in [Appendix D](#). Further guidelines for welder qualification are in ASME Boiler and Pressure Vessel Code, Section IX, AWS B2.1, and AWS D9.1M/D9.1. Areas of particular concern are addressed by the following requirements:
- 3.8.2.1** Each welder shall qualify for each welding procedure specification he/she will be required to use. The welder shall use the same type of equipment for qualification as will be used for field welding. Welders who have not engaged in a particular process for a period of 12 months preceding the start of fabrication and welders/welding operators whose ability is subject to question for some specific reason shall be requalified.
- 3.8.2.2** Butt-weld qualifications shall not suffice for fillet welding. Each joint design requires a separate test for welder qualification.
- 3.8.2.3** Each welder shall be tested in accordance with the approved welding procedures for each welding process to be used in the various positions encountered.
- 3.8.2.4** Test specimens shall meet the weld quality requirements in Paragraph 3.9.
- 3.8.2.5** Consideration shall be given to the extra time and quantity of stainless steel lining material needed to perform welder qualification tests.

3.9 Weld Quality

- 3.9.1** Seam welds, capped plug welds, and uncapped plug welds shall be smooth and visually free from cracking, porosity, pinholes, and lack of fusion.
- 3.9.2** Welds must meet the acceptance criteria for weld reinforcement and undercut presented in [Appendix A](#). The development of agreed-on workmanship and weld-profile standards prior to production welding is encouraged to avoid misunderstandings regarding weld acceptability.

3.10 Inspection

- 3.10.1** Lining leaks occurring in service are very difficult to locate, and thus repair. Therefore, the inspection process is extremely important, given the reality that later repair is very difficult.
- 3.10.2** Because the stainless steel lining is a corrosion barrier, any indication of a leak path in a weld between the lining and the substrate is cause for rejection of the weld. A gas-leak test using a vacuum-box method is preferred because it gives the best practical indication of whether a defect penetrates the lining. Alternative testing methods using helium or other gases with an approved gas-leak sniffer, detection of interspace air pressure decay, or acoustical emission may be considered and used after agreement between the contracting parties.
- 3.10.3** Inspection procedure specifications shall be submitted to the purchaser for approval. The inspecting organization shall be responsible for the qualification of inspectors. Methods of inspection and qualification of inspectors shall be agreed on by the contracting parties before the job begins.
- 3.10.4** Materials, certified mill test reports, purchase orders, and workmanship shall be subject to inspection by the purchaser.
- 3.10.5** Stainless steel lining materials shall be completely visually inspected for handling, erection, and/or contamination damage.
- 3.10.6** A visual inspection of all final seal welds in the as-welded condition shall be made by the installer's welding inspector for conformance to the requirements in Paragraph 3.9. The purchaser also retains the right to inspect all welds at this time. Following visual inspection and necessary repairs, seal welds may be inspected by a leak-test method such as vacuum box technique, helium, or a similar approved gas-leak detection method mutually agreed on. Seal welds shall be inspected/ tested as soon as practical after the final welds have been made to identify seal weld problems.
- 3.10.7** Vacuum box technique for leak testing of seal welds shall be performed in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 10, AWWA D100, Section 11.12, or other applicable codes. Acceptance criteria shall be agreed on by the contracting parties.
- 3.10.8** Helium or similar approved gas-leak testing shall be performed in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 10, Appendixes 4 and 5. Acceptance criteria shall be agreed on by the contracting parties.
- 3.10.9** Liquid penetrant examination may be used to supplement visual inspection in areas that are not accessible by other methods, or in areas where linear indications are suspected. Liquid penetrant examinations shall be performed in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 6, or other appropriate codes. Acceptance criteria shall be agreed on by the contracting parties.
- 3.10.10** All surface defects shall be suitably marked or identified to make them readily apparent for repair. The markings shall not be made in such a way as to contribute to corrosion of the stainless steel.

3.11 Repair of Defective Welds

- 3.11.1** Weld repair procedures shall be developed and qualified by the installer, approved by the purchaser, and shall include a method for documenting the repair made, its location, the name of the welder making the repairs, and the inspector's approval of the repaired weld.
- 3.11.2** The installer shall repair all welds found to be defective. Weld defects shall be removed by grinding followed by solvent cleaning, then by rewelding with the qualified filler metal. If patches are welded over defective welds, the patch shall be large enough so that a minimum overlap of 25 mm (1.0 in) around the perimeter of the defective weld is achieved. Flame or arc gouging of defective welds shall not be permitted.
- 3.11.3** Cracks shall be ground out and rewelded. Cracks or other defects shall not be repaired by remelting weld beads or covering with additional weld metal.

3.12 Postweld Cleaning

- 3.12.1** Studies have shown that the presence of heat tint can lead to crevice corrosion of the stainless steel in the surrounding area. Heat tint should be removed by appropriate means as agreed on by the contracting parties.
- 3.12.2** Postweld surface cleaning such as acid pickling, acid cleaning, and mechanical cleaning procedures shall be as agreed on by the contracting parties.

Section 4: Installation of Weld-Attached Titanium Composite Linings

4.1 Materials

4.1.1 Titanium Composite Liner (TCL) Products

- 4.1.1.1** TCL products are 1.6 mm (0.063 in) nominal or other thickness titanium sheet permanently bonded, generally by proprietary processes, to a nontitanium backing metal that is weldable to the intended substrate. The backing metal protrudes from two or more edges of the titanium sheet when viewed from the side exposed to a corrosive environment.
- 4.1.1.2** Based on the engineering requirements of the specific application, backing metal may be attached across the entire area of the titanium, in strip around the four sides in a picture-frame design, or in strip across an adjacent length and width of the titanium sheet in a half-frame configuration (see [Figure 8](#)). For TCL applications over rigid substrates in the absence of significant vacuum, the half-frame configuration with 1.6 mm (0.063 in) backing metal strip is the most common.
- 4.1.1.3** During installation, the backing metal strip at the edges of the TCL sheet shall be welded directly to the substrate. Design is generally such that the exposed backing metal/substrate welds of each TCL sheet are subsequently covered by titanium from subsequent TCL sheets. The titanium-titanium overlaps shall be seal welded (see [Paragraph 1.2](#)). Any remaining exposed backing metal shall be covered by seal-welded titanium sheets (see [Figure 8](#)).
- 4.1.2** Titanium sheet, strip, plate, and weld filler metals shall be in accordance with the requirements of ASTM. Copies of certified mill test reports for all titanium materials, including weld filler metals, shall be provided for review by the purchaser as a condition for acceptance.
- 4.1.3** The backing metal for most applications is carbon steel. Other backing metals may be specified if TCL is to be installed over a stainless steel or other substrate. In such cases, the decision to specify compatible stainless steel or other backing metal should be tempered by consideration that the backing metal/substrate welds will not be exposed to the corrosive environment, and do not therefore require a high degree of corrosion resistance.

4.2 Storage and Handling

- 4.2.1** All TCL materials shall be stored and handled in a manner that does not result in damage or contamination of the TCL.
- 4.2.2** All TCL materials (including cut or formed pieces) shall be marked to maintain traceability.

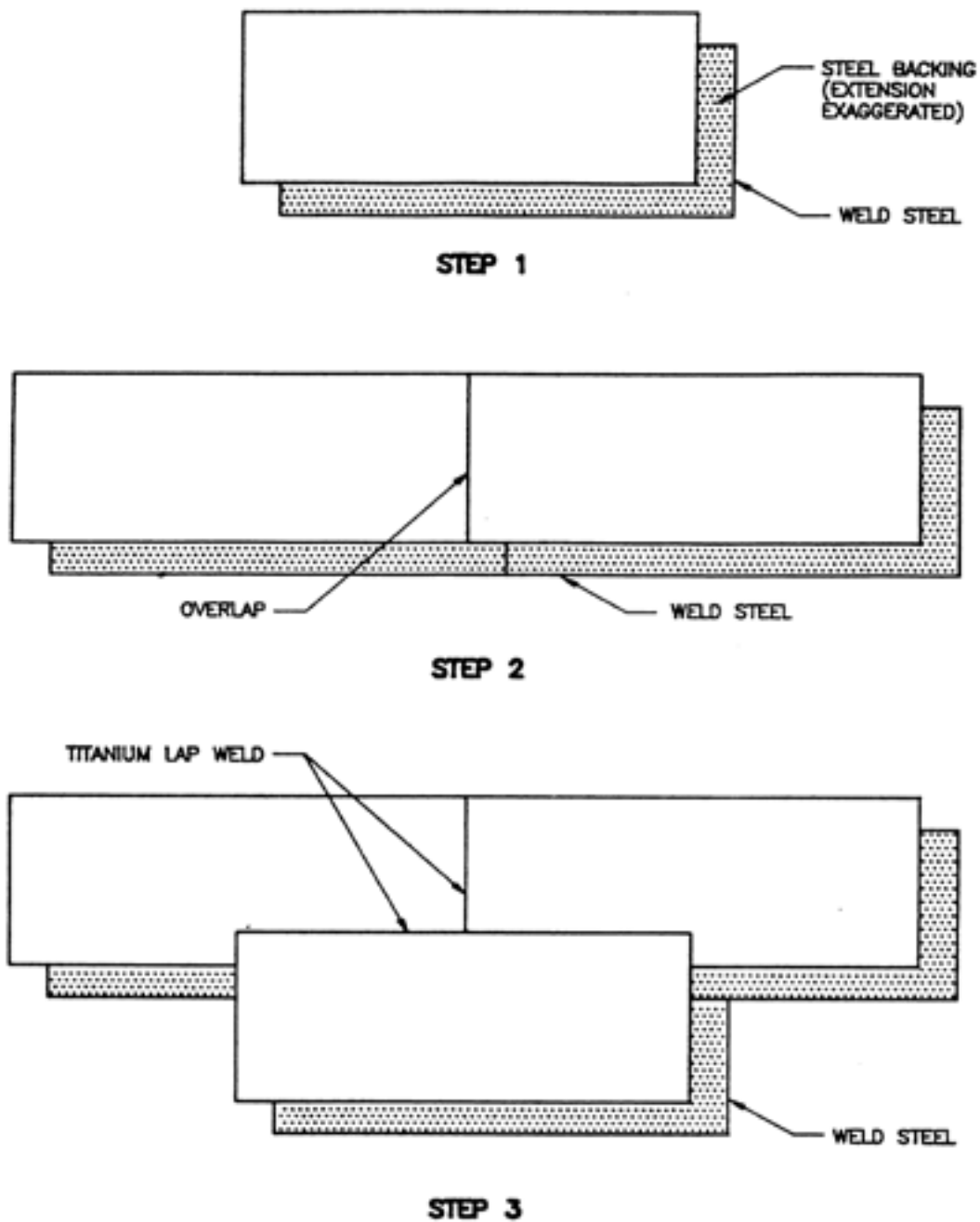


Figure 8: Typical Overlap Design for Titanium Composite Liner Sheets

4.3 Design Factors/Fabrication of TCL Sheets

- 4.3.1** Certified mill test reports for all TCL materials, including weld filler metals, shall be reviewed by the purchaser before acceptance and use for traceability, identification, and conformance to specifications and standards.

- 4.3.2** All TCL sheet installation details shall be approved by the purchaser before work begins. A complete layout plan shall be reviewed, and pieces marked according to the plan. [Figures 3, 4, and 5](#) illustrate typical layouts and methods of finishing corners. [Figure 8](#) illustrates the typical overlap design for TCL sheets.
- 4.3.3** The TCL sheets may be preformed and cut as required to match the substrate surfaces to be lined. Measurements shall be taken whenever possible to verify existing dimensions prior to cutting and fitting lining materials. **NOTE:** Original design drawings indicate theoretical or approximate dimensions and elevations (not “as-built” dimensions). Existing surfaces may be out-of-square, out-of-plumb, wavy, and/or misaligned.
- 4.3.4** The design layout shall use a nominal 25 to 150 mm (1.0 to 6.0 in) overlap of the titanium to permit flexibility during installation. The titanium-to-titanium overlap shall be a minimum of 25 mm (1.0 in).
- 4.3.5** TCL sheets shall be cut to the required size by shearing or thermal cutting using a plasma-arc or oxy-fuel torch. Shears shall be clean and free of filings and oils. It is very difficult to remove all contamination from a thermally cut edge. It is recommended that thermally cut edges be ground back 3.2 mm (0.125 in) for oxyfuel cut edges and 1.6 mm (0.063 in) for plasma cut edges. Thermal cutting raises the metal temperature of titanium to over 1,650 °C (3,000 °F), which results in severe air contamination and embrittlement of the cut metal edge. This contaminated metal edge must be removed to ensure ductile seal welds along these edges.

4.4 Surface Preparation

- 4.4.1** Any existing lining materials should be removed from the substrate surface as necessary in the areas where the backing metal of the TCL sheet is to be welded to the substrate surface. In all other areas, existing lining should be removed to a thickness of 1.6 mm (0.063 in) or less if specified. (The TCL sheet will be attached to the existing substrate by the backing metal strips as shown in [Figure 8](#), and therefore the titanium sheet will be 1.6 mm (0.063 in) away from the substrate).
- 4.4.2** The substrate surface shall be inspected for damage. The purchaser shall determine whether repair is required. Repair work shall be performed in accordance with an agreed-on standard.
- 4.4.3** At the points where the TCL backing metal strips will be welded to the substrate, the substrate surfaces may be prepared by grit blasting to a surface condition as defined by NACE No. 2/SSPC-SP 10.¹⁰ Alternatively, grinding or power wire brushing may be used to provide a surface condition suitable for welding. It is not necessary to clean the substrate beyond what is normally practiced when carbon steel is welded to carbon steel.
- 4.4.4** Materials may be brought into the work area through existing or temporary openings. All temporary openings shall be approved by the purchaser before the opening is cut and repaired after the work is completed.

4.5 Installation of TCL Sheets

- 4.5.1** The TCL sheets shall be pressed against the substrate to ensure close contact wherever possible. The TCL backing strip edges shall have close contact with the substrate.
- 4.5.2** The fit between adjacent TCL sheets should be as close as possible during welding, and the separation shall not be more than 1.6 mm (0.063 in).
- 4.5.2.1** To obtain proper fit, tack welds shall be from 25 to 75 mm (1.0 to 3.0 in) apart, depending on substrate surface conditions.
- 4.5.2.2** To achieve the maximum 1.6 mm (0.063 in) fit-up separation, some forming of the overlapping TCL sheets may be necessary. This forming should be done using procedures and tooling that will not damage or contaminate the TLC sheet being

formed. TCL sheets shall not be hot formed, but may be warm formed at temperatures less than 425 °C (800 °F).

- 4.5.3 All existing hardware (e.g., bolts, brackets, angles) exposed to the corrosive media shall be replaced by or covered with titanium materials.
- 4.5.4 Staging or scaffolding shall be installed in such a manner as to prevent mechanical damage to the titanium.
- 4.5.5 Clips or attachments shall not be welded to the titanium for the purpose of aligning or flattening the TCL sheet.
- 4.5.6 All welded titanium joints that will be exposed to the corrosive media shall be leak-tight.

4.6 Welding—General

- 4.6.1 All welding shall be performed in accordance with approved welding procedures and agreed on by the contracting parties.
- 4.6.2 Standard practices for welding of titanium require specific inert gas shielding including back-shielding on the reverse side of the material being welded, as well as trailing inert gas shielding. These procedures are essential for all titanium structural welds. Best-quality seal welds are also obtained by using this standard.
- 4.6.3 Backshielding is not practical when TCL sheets are installed in FGD ducts and stacks. Adequate seal welds for the application have been made without backshielding, provided that the titanium sheet is in close contact with the other titanium sheet and that all other standard titanium welding practices are followed. This is the prevailing practice for FGD outlet ducts and stacks.
- 4.6.4 Titanium welding shall be performed by the GTAW/metal inert gas (TIG) process.
- 4.6.5 Titanium shall not be welded to carbon steel, stainless steel, or nickel alloys.
- 4.6.6 All welding filler metals shall be in accordance with the appropriate AWS, ASME, or comparable standards.
- 4.6.7 All weld surfaces shall be clean and dry just prior to welding.
- 4.6.8 Warming may be required to prevent the formation of condensate on the TCL sheets. Warming shall be accomplished by a method that will not result in contamination of the titanium or backing metal surfaces. Some acceptable techniques are indirect natural gas, propane, or infrared heating. Fuel oil heaters or oxy-fuel heating shall not be allowed.

4.7 Welding Procedure Qualification

- 4.7.1 Installer-qualified welding procedure specifications approved by the purchaser should address all essential and nonessential variables described in AWS D9.1M/D9.1 (backing metal), AWS B2.1, or ASME Boiler and Pressure Vessel Code, Section IX.
- 4.7.2 [Appendix C](#) contains recommended procedures for use in conjunction with the weld procedure specifications within this standard.

4.8 Welder Performance Qualification

- 4.8.1 All welders and tack welders shall be qualified by the installer in accordance with ASME Boiler and Pressure Vessel Code, Section IX, AWS D9.1M/D9.1 (backing metal), or other applicable codes, and [Appendix D](#) of this standard. Additional requirements are stated below:

- 4.8.1.1 Each welder shall be tested on each welding process in the various positions encountered in accordance with the approved welding procedure specifications that he/she will be required to use.
 - 4.8.1.2 Butt-weld qualifications shall not suffice for fillet welding. Each joint design requires a separate test for welder qualification.
- 4.8.2 Each welder shall prepare one specimen for each type and position that he/she will be required to weld. Test specimens shall meet the weld quality requirements in Paragraph 4.9.
 - 4.8.2.1 Each specimen shall be sectioned, polished, and etched to clearly show the demarcation between the fusion zone and the base metal. To qualify, the specimen shall exhibit, under visual examination without magnification, complete fusion, complete penetration, and no cracking. Melt-through in excess of 0.25 mm (0.010 in) on 1.6 mm (0.063 in) thick titanium sheet shall be cause for rejection.
 - 4.8.2.2 Each specimen to be qualified shall be sectioned, polished, and etched to show clearly the demarcation between the fusion zone and the base metal. To qualify, the specimen shall show, under visual examination with 10 times magnification, complete fusion, complete penetration, and no cracks. Pores, pinholes, and nonmetallic inclusions shall be causes for rejection.
- 4.9 **Weld Quality**
 - 4.9.1 Titanium surfaces to be seal welded shall be cleaned free of dirt, debris, and grease for a distance sufficient to prevent contamination of the weld joint. This shall be achieved by wire brushing with clean, stainless steel wire brushes, followed by solvent cleaning. These brushes shall be used only on the titanium materials; brushes that have been used on carbon steel or other materials shall never be used on titanium.
 - 4.9.2 A technique for avoiding crater cracks at all stops shall be used during welding.
 - 4.9.3 Welds shall be smoothly blended into base metal until there is no lack of fusion or rough edges, depressions, crevices, cold laps, voids, undercuts, pinholes, or surface porosity. Silver, straw, gold, or light-blue single-pass welds or heat-affected zones (HAZs) are generally considered acceptable. However, dark-blue, iridescent, gray, or white titanium weldments are probably heavily contaminated and must be rejected. All such irregular conditions shall be repaired by grinding and rewelding. In addition, there shall be no excessive reinforcement, slag inclusions, cracks, or weld spatter. Acceptance criteria for weld reinforcement and undercut are presented in [Appendix A](#). See also AWS G2.4/G2.4M:2014 Guide for the Fusion Welding of Titanium and Titanium Alloys.¹¹
- 4.10 **Inspection**
 - 4.10.1 Because the titanium lining is a corrosion barrier, any indication of a leak path in a weld between the lining and the substrate is cause for rejection of the weld. A gas-leak test using a vacuum box technique is preferred because it gives the best practical indication of whether a defect penetrates the lining. Alternative testing methods using helium or other gases with an approved gas-leak sniffer, detection of interspace air-pressure decay, or acoustical emission may be considered and used after agreement between the contracting parties.
 - 4.10.2 Methods of inspection and qualification of inspectors shall be agreed on by the contracting parties before the job begins.
 - 4.10.3 Materials, certified mill test reports, purchase orders, and workmanship shall be subject to inspection by the purchaser.
 - 4.10.4 TCL materials shall be completely visually inspected for handling, erection, and/or mechanical damage.

- 4.10.5** All welds shall be visually inspected. Note: wire brushing of titanium welds prior to visual inspection may disguise indications of poor quality welds and therefore shall not be permitted.
- 4.10.6** The installer's welding inspector shall visually inspect and require repair of all welds prior to leak testing by the vacuum box technique.
- 4.10.7** Final inspection of seal welds shall be by a vacuum box technique. Assessment of titanium tack-weld or seal-weld quality in the field is achievable through a combination of several basic methods: close visual inspection, weld-surface color, tungsten-rod scratching test, vacuum box technique, and liquid penetrant examination. After inspection, the welds shall be wiped with acetone or methyl ethyl ketone solvents.
- 4.10.8** Vacuum box technique for leak testing of seal welds shall be performed in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 10, AWWA D100, Section 11.12, or other applicable codes. Acceptance criteria shall be agreed on by the contracting parties.
- 4.10.9** It is recommended that liquid dye penetrant examination be performed on all welds, though liquid dye penetrant examination may be used to supplement visual inspection in areas that are not accessible by other methods, or in areas where linear indications are suspected. Liquid penetrant examinations shall be in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 6 or other appropriate codes. Acceptance criteria shall be agreed on by the contracting parties.
- 4.10.10** Helium or similar approved gas-leak testing shall be performed in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 10, Appendixes 4 and 5. Acceptance criteria shall be agreed on by the contracting parties.
- 4.10.11** All defects shall be suitably marked to make them readily apparent for repairs. Marks shall not contribute to corrosion of the titanium.

4.11 Repair of Defective Welds

- 4.11.1** Weld repair procedures shall be developed and qualified by the installer, approved by the purchaser, and shall include a method for documenting the repair made, its location, the name of the welder making the repairs, and the inspector's approval of the repaired weld.
- 4.11.2** The installer shall repair all welds found to be defective. Weld defects shall be removed by grinding followed by solvent cleaning, then by rewelding with the qualified filler metal. If patches are welded over defective welds, the patch shall be large enough so that a minimum overlap of 50 mm (2 in) around the perimeter of the defective weld is achieved. Flame or arc gouging of defective welds shall not be permitted.
- 4.11.3** Cracks shall be ground out and rewelded. Cracks or other defects shall not be repaired by remelting weld beads or covering with additional weld metal.

Section 5: Installation of Mechanically Fastened/Bolted Titanium Linings

5.1 Materials

- 5.1.1** Titanium sheet, strip, and plate materials shall be in accordance with the requirements of the appropriate ASTM specifications (see [Paragraph 1.6](#)).
- 5.1.2** Titanium bolts shall be Grades 2, 3, 7, or 16 in accordance with ASTM specifications.
- 5.1.3** Titanium materials and copies of certified mill test reports shall be supplied in accordance with approved purchase orders.

5.2 Storage and Handling

5.2.1 All titanium materials shall be stored and handled in a manner that does not result in mechanical damage to or contamination of the titanium.

5.2.2 All titanium materials shall be marked to distinguish them from other alloy or carbon steel materials.

5.3 Design Factors/Fabrication of Titanium Lining Sheets

5.3.1 Certified mill test reports for all titanium materials, including weld filler metals, shall be reviewed by the purchaser before acceptance and use for traceability, identification, and conformance to specifications and standards.

5.3.2 Titanium lining sheet installation details shall be approved by the purchaser before the installer proceeds with the work. Complete titanium sheet layout drawings shall be made, and pieces shall be marked according to the drawings.

5.3.3 Titanium lining sheets may be preformed and cut as required to match substrate surfaces to be lined. Measurements shall be taken whenever possible to verify existing dimensions prior to cutting and fitting the titanium sheets.

NOTE: Original drawings indicate theoretical or approximate dimensions and elevations (not “as-built” dimensions). Existing substrate surfaces may be out-of-square, out-of-plumb, wavy, and/or misaligned.

5.3.4 Any field-applied structural attachments shall be made to the existing substrate. The titanium lining sheet shall not be used to support any external loads.

5.3.5 The design layout shall use a nominal 50 mm (2.0 in) overlap of the titanium to permit flexibility during the installation. The titanium-to-titanium overlap shall be a minimum of 50 mm (2.0 in).

5.3.6 Titanium lining sheets should be cut to size as required by shearing or thermal cutting using plasma-arc cutting or an oxy-fuel torch. Shears shall be clean and free of filings and oils. It is very difficult to remove all contamination from a thermally cut edge. It is recommended that thermally cut edges be ground back 3.2 mm (0.125 in) for oxyfuel cut edges and 1.6 mm (0.063 in) for plasma cut edges. Thermal cutting raises the metal temperature of titanium to over 1,650 °C (3,000 °F), which results in severe air contamination and embrittlement of the cut metal edge. This contaminated metal edge must be removed to ensure ductile seal welds along these edges.

5.4 Surface Preparation

5.4.1 Any existing lining materials should be completely removed, and substrate surfaces shall be prepared by grit blasting, wire brushing, or grinding. Protrusions shall be ground as necessary to ensure proper fit of the titanium lining materials.

5.4.2 The existing substrate surface shall be inspected for damage. The purchaser shall determine whether repair is required. Repair work shall be performed in accordance with the contract.

5.4.3 Materials may be brought into the work area through existing or temporary openings. All temporary openings shall be approved before the opening is cut and shall be repaired after the work is completed as agreed on by the contracting parties.

5.5 Installation of Mechanically Fastened/Bolted Titanium Lining Sheets

5.5.1 Titanium lining sheets shall be predrilled in locations where fastening is required in accordance with design drawings. Each titanium sheet shall be held in place in staggered position with overlapping edges as depicted in [Figure 2](#). Although common high-speed tool steel drills may be used to drill titanium, significant improvement in drill-bit life can be expected from carbide-tipped bits.

- 5.5.2** One of the two following mechanical fastening methods shall be used to attach the titanium lining sheets to the substrate:
- 5.5.2.1** Titanium bolts may be tapped and threaded into the substrate wall, or drilled through and anchored with steel hex-head nuts or toggle heads (if there is accessibility to the other side of the substrate wall). The titanium bolt heads shall be seal welded to the titanium sheet. (See Figure 9).
- 5.5.2.2** Threaded steel studs may be stud welded to the steel substrate, fastened with steel washers and nuts, and subsequently covered with a seal-welded titanium sheet cap. Self-tapping steel screws, or stud bolts with external hex-head nuts or anchors, may also be used with a seal-welded titanium sheet cap. (See Figure 10).
- 5.5.3** The titanium lining sheets shall be pressed against the existing substrate to ensure close contact wherever possible. Edges of the titanium lining sheets at weld seams shall have close contact.
- 5.5.4** The fit between adjacent titanium lining sheets should be as close as possible during welding and in no instance shall the separation be more than 1.6 mm (0.063 in). Depending on substrate surface conditions, tack welds shall be from 25 to 75 mm (1.0 to 3.0 in) apart to obtain proper fit.
- 5.5.5** All existing hardware (e.g., bolts, brackets, angles) exposed to the flue gas corrosive media shall be replaced by or covered with titanium materials.
- 5.5.6** Staging or scaffolding shall be installed in such a manner as to prevent mechanical damage to the titanium.
- 5.5.7** Clips or attachments shall not be welded to the titanium for the purpose of aligning or flattening the titanium lining sheets.
- 5.5.8** All welded joints that will be exposed to corrosive media shall be leak-tight.
- 5.5.9** Transitions from titanium to other metals and alloys shall be made only at the titanium supplier's recommendation.

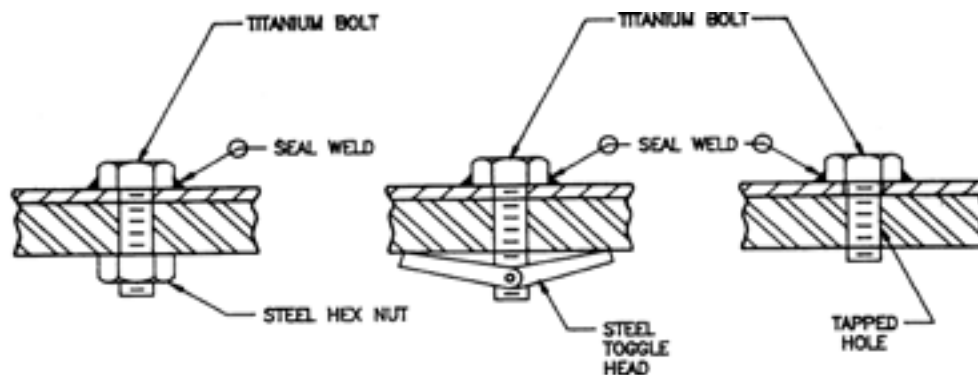


Figure 9: Methods for Fastening Titanium Sheet to Steel Wall Substrates Using Titanium Bolts

NOTE: The titanium bolt head is seal welded to the titanium sheet.

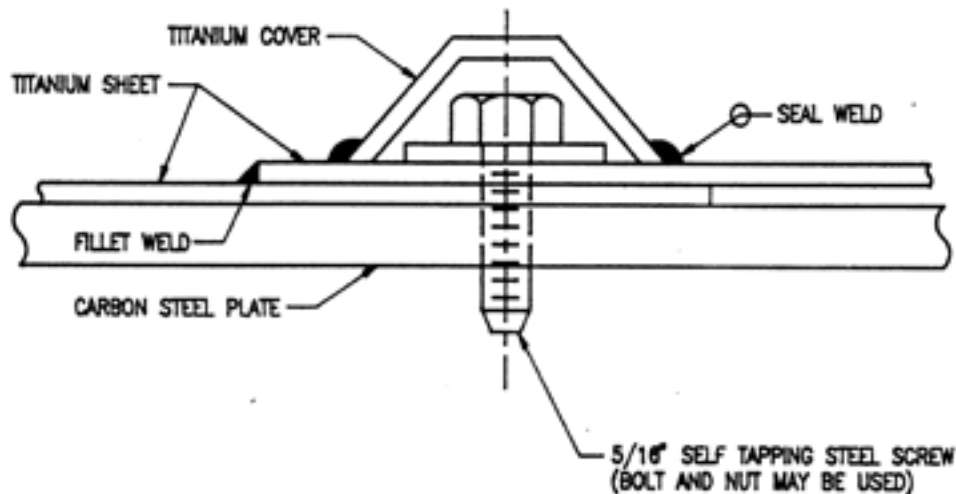
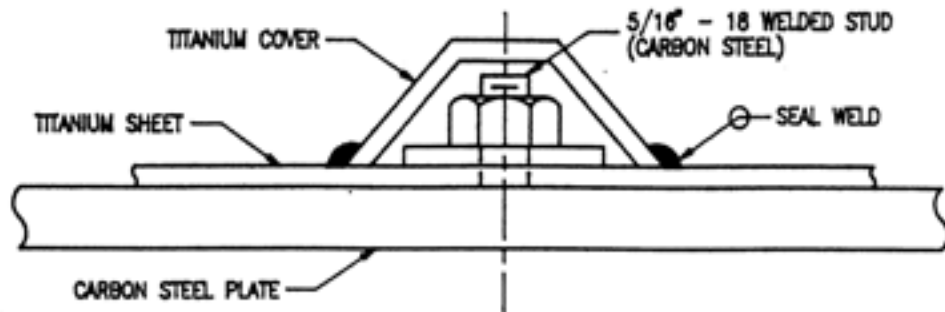


Figure 10: Methods for Fastening Titanium Sheet to Steel Substrates Using Threaded Steel Studs or Screws

NOTE: Titanium sheet cap to cover the steel stud or screw is seal welded to the titanium sheet.

5.6 Welding—General

- 5.6.1 All welding shall be performed in accordance with approved welding procedures agreed on by the contracting parties.
- 5.6.2 Standard practices for welding of titanium require specific inert gas shielding including backshielding on the reverse side of the material being welded, as well as trailing inert gas shielding. These procedures are essential for all titanium structural welds. Best-quality seal welds are also obtained by using this standard.

- 5.6.3** Backshielding is not practical when titanium lining sheets are installed in FGD ducts and stacks. Adequate seal welds for the application have been made without backshielding, provided that the titanium sheet is in close contact with the other titanium sheet and that all other standard titanium welding practices are followed. This is the prevailing practice for FGD outlet ducts and stacks.
- 5.6.4** Titanium welding shall be performed by the GTAW/TIG process.
- 5.6.5** Titanium shall not be welded to carbon steel, stainless steel, or nickel alloys.
- 5.6.6** All welding filler metals shall be in accordance with the appropriate AWS, ASME, or comparable standards.
- 5.6.7** All weld surfaces shall be clean and dry just prior to welding.
- 5.6.8** Warming may be required to prevent the formation of condensate on the titanium lining sheets. Warming shall be accomplished by a method that will not result in contamination of the titanium surface. Some acceptable techniques are indirect natural gas, propane, or infrared heating. Fuel oil heaters or oxy-fuel heating shall not be allowed.

5.7 Welding Procedure Qualification

- 5.7.1** Installer-qualified welding procedure specifications should address all essential and nonessential variables described in AWS B2.1 or ASME Boiler and Pressure Vessel Code, Section IX. Inappropriate essential and nonessential variables should be denoted as such and not be left unaddressed.
- 5.7.2** Welding procedure specifications shall be approved by the purchaser.

5.8 Welder Performance Qualifications

- 5.8.1** All welders and tack welders shall be qualified by the installer in accordance with ASME Boiler and Pressure Vessel Code, Section IX. Additional requirements are stated below:
 - 5.8.1.1** Each welder shall be tested on each welding process in the various positions encountered in accordance with the approved welding procedure specifications that he/she will be required to use.
 - 5.8.1.2** Butt-weld qualifications shall not suffice for fillet welding. Each joint design requires a separate test for welder qualification.
- 5.8.2** Each welder shall prepare one specimen for each type and position that he/she will be required to weld. Test specimens shall meet the weld quality requirements in Paragraph 5.9.
 - 5.8.2.1** Each specimen shall be sectioned, polished, and etched to clearly show the demarcation between the fusion zone and the base metal. To qualify, the specimen shall exhibit, under visual examination without magnification, complete fusion, complete penetration, and no cracking. Melt-through in excess of 0.25 mm (0.010 in) on 1.6 mm (0.063 in) thick titanium sheet shall be cause for rejection.
 - 5.8.2.2** Each specimen to be qualified shall be sectioned, polished, and etched to show clearly the demarcation between the fusion zone and the base metal. To qualify, the specimen shall show, under visual examination with 10 times magnification, complete fusion, complete penetration, and no cracks. Pores, pinholes, and nonmetallic inclusions shall be causes for rejection.

5.9 Weld Quality

- 5.9.1** Titanium surfaces to be seal welded shall be cleaned free of dirt, debris, and grease for a distance sufficient to prevent contamination of the weld joint. This shall be achieved by wire brushing with clean, stainless steel wire brushes followed by solvent cleaning. These brushes shall be used only on the titanium materials. Brushes that have been used on carbon steel or other materials shall never be used on titanium.
- 5.9.2** A technique for avoiding crater cracks at all stops shall be used during welding.
- 5.9.3** Welds shall be smoothly blended into the base metal so that there is no lack of fusion or rough edges, depressions, crevices, cold laps, voids, undercuts, pinholes, or surface porosities. Silver, straw, gold, or light-blue single-pass welds or HAZs are generally considered acceptable. However, dark-blue, iridescent, gray, or white titanium weldments are probably heavily contaminated and must be rejected. All such irregular conditions shall be repaired by grinding and rewelding. In addition, there shall be no excessive reinforcement, slag inclusions, cracks, or weld spatter. Acceptance criteria for weld reinforcement and undercut are presented in [Appendix A](#).

5.10 Inspection

- 5.10.1** Because the titanium lining is a corrosion barrier, any indication of a leak path in a weld between the lining and the substrate is cause for rejection of the weld. A gas-leak test using a vacuum box technique is preferred because it gives the best practical indication of whether a defect penetrates the lining. Alternative testing methods using helium or other gases with an approved gas-leak sniffer, detection of interspace air-pressure decay, or acoustical emission may be considered and used after agreement between the contracting parties.
- 5.10.2** Methods of inspection and qualification of inspectors shall be agreed on by the contracting parties before the job begins.
- 5.10.3** Materials, certified mill test reports, purchase orders, and workmanship shall be subject to inspection by the purchaser.
- 5.10.4** Titanium materials shall be completely visually inspected for handling, erection, and/or mechanical damage.
- 5.10.5** All welds shall be visually inspected. Note, wire brushing of titanium welds prior to visual inspection may disguise indications of poor quality welds and therefore shall not be permitted.
- 5.10.6** The installer's welding inspector shall visually inspect and require repair of all welds prior to leak testing by the vacuum box technique or liquid penetrant examination.
- 5.10.7** Final inspection of seal welds shall be by the vacuum box technique or liquid penetrant examination. Assessment of titanium tack-weld or seal-weld quality in the field is achievable through a combination of several basic methods: close visual inspection, weld surface color, tungsten-rod scratching test, vacuum box technique, and liquid penetrant examination. The vacuum box technique is preferred. After inspection, the welds shall be wiped with acetone or methyl ethyl ketone solvents.
- 5.10.8** Vacuum box technique for leak testing of seal welds shall be performed in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 10, AWWA D100, Section 11.12, or other applicable codes. Acceptance criteria shall be agreed on by the contracting parties.
- 5.10.9** Liquid penetrant examination may be used to supplement visual inspection in areas that are not accessible by other methods, or in areas where linear indications are suspected. Liquid penetrant examinations shall be in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 6, or other appropriate codes. Acceptance criteria shall be agreed on by the contracting parties.
- 5.10.10** Helium or similar approved gas-leak testing shall be in accordance with ASME Boiler and Pressure Vessel Code, Section V, Article 10, Appendixes 4 and 5. Acceptance criteria shall be agreed on by the contracting parties.

- 5.10.11** All defects shall be suitably marked to make them readily apparent for repairs. Marks shall not be made in a way that contributes to corrosion of the titanium.

5.11 Repair of Defective Welds

- 5.11.1** Weld repair procedures shall be developed and qualified by the installer, approved by the purchaser, and shall include a method for documenting the repair made, its location, the name of the welder making the repairs, and the inspector's approval of the repaired weld.
- 5.11.2** The installer shall repair all welds found to be defective. Weld defects shall be removed by grinding followed by solvent cleaning, then by rewelding with the qualified filler metal. If patches are welded over defective welds, the patch shall be large enough so that a minimum overlap of 50 mm (2 in) around the perimeter of defective weld is achieved. Flame or arc gouging of defective welds shall not be permitted.
- 5.11.3** Cracks shall be ground out and rewelded. Cracks or other defects shall not be repaired by remelting weld beads or covering with additional weld metal.

References

1. AWS D9.1M/D9.1 (latest revision), "Sheet Metal Welding Code" (Miami, FL: AWS).
2. AWS B2.1 (latest revision), "Specification for Welding Procedure and Performance Qualification" (Miami, FL: AWS).
3. ASME Boiler and Pressure Vessel Code, Section IX (latest revision), "Welding and Brazing Qualifications" (New York, NY: ASME).
4. ASME Boiler and Pressure Vessel Code, Section V, Article 10 (latest revision), "Nondestructive Examination: Leak Testing" (New York, NY: ASME).
5. AWWA D100, Section 11.12 (latest revision), "Welded Carbon Steel Tanks for Water Storage" (Denver, CO: AWWA).
6. ASME Boiler and Pressure Vessel Code, Section V, Article 6 (latest revision), "Nondestructive Examination: Liquid Penetrant Examination" (New York, NY: ASME).
7. ASTM A380 (latest revision), "Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems" (West Conshohocken, PA: ASTM).
8. ASTM A967 (latest revision), "Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts" (West Conshohocken, PA: ASTM).
9. NACE No. 3/SSPC-SP 6 (latest revision), "Commercial Blast Cleaning" (Houston, TX and Pittsburgh, PA: AMPP).
10. NACE No. 2/SSPC-SP 10 (latest revision), "Near-White Metal Blast Cleaning" (Houston, TX and Pittsburgh, PA: AMPP).
11. AWS G2.4/G2.4M (latest revision), "Guide for the Fusion Welding of Titanium and Titanium Alloys" (Miami, FL: AWS).

Appendix A

Weld Reinforcement and Undercut Acceptance Criteria (Mandatory)

A1 Weld Reinforcement^(a)

The ideal fillet weld shall have the profile of an isosceles right triangle. Fillet welds shall be limited to leg sizes, which underbuild the ideal profile by Dimension A (see Figure A1), with reinforcement. The overfilling of the ideal profile shall be limited by Dimension C (see Figure A2).

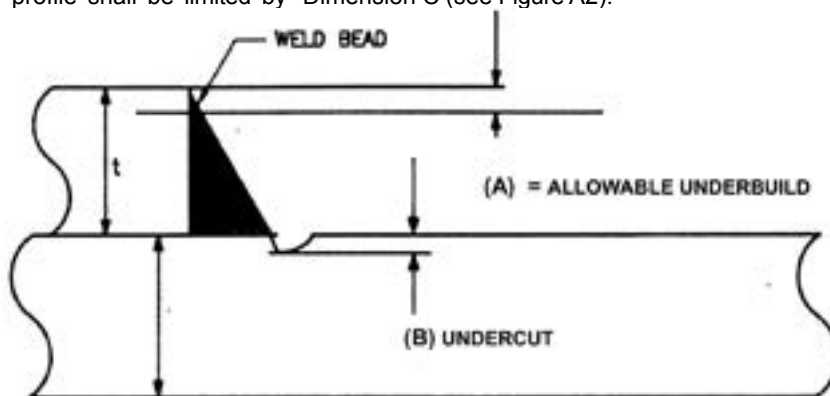


Figure A1: Attachment Weld of Nickel Alloy or Stainless Steel to a Metal Substrate

A2 Weld Undercut

Undercut is defined in this standard as a groove melted into the base metal adjacent to the toe or root of a weld and left unfilled by weld metal (see Figure A2, Dimension D and Figure A1, Dimension B). Reinforcement or undercut of a seal weld must be minimal to avoid the possibility of collection of solid material that may influence corrosion resistance.

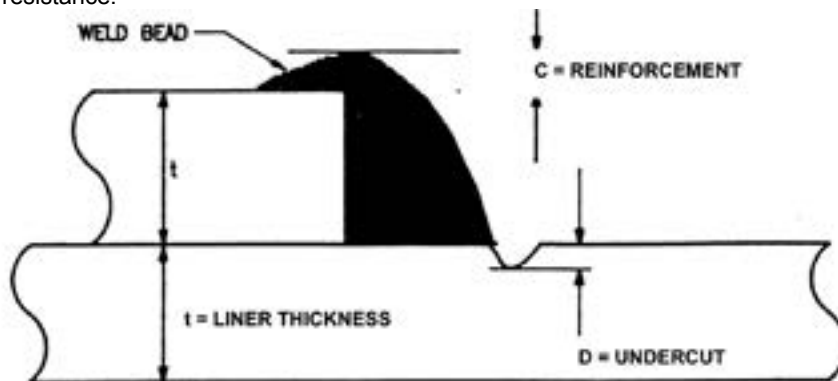


Figure A2: Seal Weld between Corrosion-Resistant Metals

A3 Acceptance Criteria for Dimensions A, B, C, and D in Figures A1 and A2

Table A1 provides the common acceptance criteria used for Dimensions A, B, C, and D in Figures A1 and A2 for U.S. and European installations.

NOTE: Where undercut may be difficult to control because of welding position problems, increased material thickness may be considered to provide full corrosion resistance.

^(a) The term "reinforcement" does not imply any addition of strength in the weld joint.

Table A1
Weld Reinforcement, Underbuild, and Undercut Acceptance Criteria^(A)

Dimension (see Figures A1 and A2)	U.S. Acceptance Criteria	European Acceptance Criteria (fit for purpose)
A	0.4 mm (0.02 in) max	0.4 mm (0.02 in) max
B ^(B)	0.25 t ^(C)	0.25 t
C	4.8 mm (0.19 in) max	1 t max
D	0.25 mm (0.010 in) max	0.1 mm (0.004 in) max

^(A) Seal weld acceptance criteria. Reinforcement or undercut of seal weld must be minimal to avoid the possibility of collection of solid material that may influence corrosion resistance.

^(B) Deep undercut may reduce the structural integrity of the weldment. In the extreme case of exposing the substrate, corrosion of the substrate may occur.

^(C) In accordance with ASME and AWS D9.1M/D9.1

A4 Field Welding

Prior to any field welding on a project, it has often been useful for the installer to develop a set of seal and plug weld preconstruction weld samples. Typically, the samples would be representative of a range of weld profiles including some of minimum acceptable quality as judged by all parties concerned with the project. The samples are retained and available to evaluate acceptability of questionable production welds. The preconstruction weld samples provide a permanent agreed-on quality standard.

Appendix B

Recommended Relevant Welding Variables for Use in Developing Welding Procedures for Nickel Alloys and Stainless Steel (Nonmandatory)

This appendix is considered nonmandatory, although it may contain mandatory language. It is intended only to provide supplementary information or guidance. The user of this standard is not required to follow, but may choose to follow, any or all of the provisions herein.

Table B1
Designations for Alloy Wallpaper Materials^(A)

Alloy Designation	UNS ^(B) Number
1	S31726, S31703
2	N08031, N08367, N08926, S31254, S31266, S32654, S34565
3	N06625
4	N10276
5	N06022
6	N06059
7	N06200
8	N06686

^(A) This list of alloys is not intended to be all-inclusive. As new alloys are introduced, they may be added by the user.

^(B) Unified Numbering System for Metals and Alloys (UNS). UNS numbers are listed in *Metals & Alloys in the Unified Numbering System*, latest edition (Warrendale, PA: SAE International and West Conshohocken, PA: ASTM International).

Table B2
Recommended Relevant Welding Variables

Key: R = Relevant variable; should be included in weld procedure
D = Discretionary variable; may be included as relevant variable in weld procedure
I = Informational variable; may be included in weld procedure for completeness
N/A = Not applicable to process or condition (see SM Appendix B)

					GMAW	
Variable		GTAW	SMAW	Short Arc	Pulsed	Spray
Weld Types	fillet weld	R	R	R	R	N/A
	plug weld	R	R	R	R	N/A
	spot weld	N/A	N/A	N/A	N/A	R
Base metal	alloy combinations	R	R	R	R	R
	thickness	R	R	R	R	R
Filler metal	alloy/grade	R	R	R	R	R
	diameter	D	R	R	R	R
	flux type	N/A	D	N/A	N/A	N/A
Position	flat	R	R	R	R	R
	vertical	D	R	D	D	R
	overhead	D	R	D	D	R
	progression ^(A)	D	R	R	R	N/A
Preheat^(B)		R	R	R	R	R
Interpass^(C)		R	R	R	R	R
PWHT^(D)		R	R	R	R	R
Shield gas	composition	R	N/A	R	R	R
	flow rate	D	N/A	D	D	D
Electrical	power supply type	I	I	D	D	D
	polarity	R	R	R	R	R
	amps	R	R	R	R	R
	volts	D	I	R	R	R
	wire feed speed	N/A ^(E)	N/A	R	R	R
	travel speed ^(F)	I	I	D	D	N/A
	pulse parameters	N/A ^(G)	N/A	N/A	R	N/A
Technique	cleaning	R	R	R	R	R
	antirust paint	R	R	R	R	R
	manual/auto	D	N/A	D	D	N/A

^(A) Uphill/downhill because the D may be confused with D in Key

^(B) Preheat to room temperature as required to avoid condensation.

^(C) Interpass: 90 °C (200 °F) maximum or as recommended by supplier.

^(D) Postweld heat treatment (PWHT): none

^(E) Essential variable if using an automatic welding machine

^(F) Travel speed determines heat input. This information is helpful, especially for seal welds. Heat input is important because it can affect corrosion resistance of many alloys.

^(G) This table does not address pulse-mode GTAW.

Table B3
Alloy Weld Filler Metals^{(A), (B)}

Alloy Designation(C)	1, 2, 3	4, 5	6, 7, 8
SMAW UNS Number (AWS A5.11/A5.11M)	W80276 (ENiCrMo-4) W86022 (ENiCrMo-10) W86026 (ENiCrMo-14) W86059 (ENiCrMo-13) W86112 (ENiCrMo-3)	W80276 (ENiCrMo-4) W86022 (ENiCrMo-10) W86026 (ENiCrMo-14) W86059 (ENiCrMo-13)	W86026 (ENiCrMo-14) W86059 (ENiCrMo-13) W86200 (ENiCrMo-17)
GMAW/GTAW/SAW(D) UNS Number (AWS A5.14/A5.14M)	N06022 (ERNiCrMo-10) N06059 (ERNiCrMo-13) N06625 (ERNiCrMo-3) N06686 (ERNiCrMo-14) N10276 (ERNiCrMo-4)	N06022 (ERNiCrMo-10) N06059 (ERNiCrMo-13) N06686 (ERNiCrMo-14) N10276 (ERNiCrMo-4)	N06059 (ERNiCrMo-13) N06686 (ERNiCrMo-14) N06200 (ERNiCrMo-17)
FCAW UNS Number (AWS A5.34/A5.34M)	W86625 (ENiCrMo-3T) W80276 (ENiCrMo-4T) W86022 (EMoCrMo-10T)	W80276 (ENiCrMo-4T) W86022 (ENiCrMo-10T)	

- (A) To offset the effects of the iron dilution and elemental segregation, the use of overmatching weld filler metals should be considered. Alloy manufacturers should be consulted for specific welding recommendations.
- (B) The manufacturers of some high-nitrogen, superaustenitic stainless chromium-nickel steels recommend that welding consumables without niobium be used to avoid the formation of niobium nitride precipitates. Alloy manufacturers should be consulted for specific welding recommendations.
- (C) Alloy designation numbers refer to those indicated in Table B1. They are not to be confused with the weld bead numbering in the Figures.
- (D) The filler metals shown for SAW should be used with the appropriately qualified submerged arc flux. Because there are no AWS submerged arc fluxes, each user should select and qualify the product of choice.

Appendix C

Recommended Procedures for Use in Conjunction with the Weld Procedure Specifications within this Standard (Nonmandatory)

This appendix is considered nonmandatory, although it may contain mandatory language. It is intended only to provide supplementary information or guidance. The user of this standard is not required to follow, but may choose to follow, any or all of the provisions herein.

- C1** Previous qualification of procedures is not valid. Procedure qualification tests shall be performed under observation of the purchaser's quality-control inspector.

- C2** One specimen from each procedure to be qualified shall be sectioned, polished, and etched to show clearly the fusion zone and the base metal. For the procedure to qualify, the specimen shall show, under visual examination without magnification, complete fusion, complete penetration, and no cracks. Pinholes and nonmetallic inclusions are cause for rejection. **NOTE:** Titanium-to-steel welds shall not be permitted.

- C3** In addition, a tensile test shall be performed on one specimen of alloy to carbon steel. A section 25 mm (1.0 in) wide shall be removed and pulled to failure. The welded lap joint must exhibit 70% of the ultimate calculated strength of the weaker material of the section. **NOTE:** TCL materials are exempt from tensile testing.

Appendix D

Procedures for Use in Conjunction with the Welder Performance Qualifications within this Standard (Mandatory)

- D1** Previous qualification shall not suffice. Welders should qualify under observation of the purchaser's quality-control inspector at the purchaser's discretion.
- D2** Butt-weld qualification shall not suffice for fillet welding. Each joint design shall require retest for welder qualification.
- D3** Unless agreed otherwise by the contracting parties, each welder shall prepare four weld specimens for each weld process used.
- Using 1.6 mm (0.063 in) alloy to 1.6 mm (0.063 in) alloy material, the welder shall fabricate a 15 mm (0.60 in) lap weld in the vertical, horizontal, and overhead positions.
 - Using 1.6 mm (0.063 in) alloy to 6.1 mm (0.25 in) carbon steel material, the welder shall fabricate a lap weld in the vertical, horizontal, and overhead positions.
 - Using 1.6 mm (0.063 in) alloy to 6.1 mm (0.25 in) carbon steel material, the welder shall fabricate two arc spot or plug welds, one in a vertical plane and one in a horizontal (overhead) plane. After inspection, the welder shall cap both plug welds with fillet-welded alloy material. Plug welds are applicable only to stainless steel and nickel alloy lining.
- D4** Each of the four specimens shall be sectioned, polished, and etched to show clearly the fusion zone and the base metal. To qualify, the specimen shall show, under visual examination without magnification, complete fusion, complete penetration, and no cracks. Undercut in excess of that allowed in [Appendix A](#), cold lap, cracks, pinholes, and nonmetallic inclusions are cause for rejection. Excessive melt-through on the 1.6 mm (0.063 in) material shall also be cause for rejection.
- D5** The purchaser shall be given the opportunity to witness all testing. The purchaser shall be given at least two weeks' written notice before the testing is to occur.
- D6** The installer shall bear all costs for qualifying welders, including cost of materials, testing, and requalification.
- D7** During field welding, the purchaser or authorized inspector may require requalification of any welder who has produced an unacceptable weld.
- D8** Each welder shall be assigned a unique certifying mark that shall be used for identifying each weld made by him/her. The contracting parties shall agree on the method by which weld identification is maintained.

Appendix E

Thin-Sheet Wallpaper Lining Welding Processes (Nonmandatory)

This appendix is considered nonmandatory, although it may contain mandatory language. It is intended only to provide supplementary information or guidance. The user of this standard is not required to follow, but may choose to follow, any or all of the provisions herein.

E1 Three welding processes have been widely used in applying nickel alloy and stainless steel sheet linings in FGD. They are GMAW/metal inert gas (MIG) with both short-circuiting and pulsing-arc transfer mode, GTAW/TIG, and SMAW (covered electrodes). Only GTAW/TIG has been used for welding titanium. Advantages and limitations of each process are discussed in this appendix. There are a number of factors influencing selection of the optimum process, such as the shape and extent of surfaces to be lined, the installer's experience with the process, and the skill of the welders available. Often the installer will qualify more than one process and use the one most suited for a particular area.

E2 Acronyms

GMAW	Gas metal arc welding
GTAW	Gas tungsten arc welding
MIG	Metal inert gas
SMAW	Shielded metal arc welding
TIG	Tungsten inert gas

E3 Process Descriptions

E3.1 GMAW/MIG

E3.1.1 In this process, an arc is established between a consumable, bare-wire electrode and the work piece (a range of electrode diameters may be used; 0.89 mm [0.035 in] to 1.1 mm [0.045 in] is typical). The arc and deposited weld metal are protected from the atmosphere by a shielding gas comprised mainly of inert gases, such as argon and helium, with optional small amounts of active gases such as carbon dioxide, oxygen, and hydrogen. Active gases are added to improve wetting and arc action. The two modes most often used are short-circuit transfer and pulsed-arc transfer.

E3.1.2 GMAW is considerably faster than GTAW and SMAW and produces high-quality welds with a minimum dilution from the substrate. GMAW has more welding parameters (e.g., current, wire speed, arc characteristics, and type of shielding gas) than the other processes. Some newer power sources, such as the synergistic pulsing arc, offer control of a number of welding parameters including the pulse rate. The operator may have only one control dial with the other parameters adjusted automatically.

E3.1.3 Advantages include:

- GMAW produces high welding speeds, much faster than those of GTAW or SMAW.
- The operator can control dilution from the substrate with relative ease.
- One-handed operation is helpful when welding is performed in areas of limited accessibility or on scaffolds.
- There is no possibility of slag inclusions.

E3.1.4 Limitations include:

- Weld beads, particularly short arc beads, are prone to be crowned or have high reinforcement unless parameters are carefully controlled.
- A number of welding variables or controls are at the welder's disposal, which tends to make proper adjustment complicated.⁽⁶⁾
- Power sources are more expensive than those required for GTAW and SMAW equipment.
- The number of welders familiar with the sheet-lining process may be limited and extensive training may be needed.

NOTE: Approximately 90% of nickel alloy or stainless steel welding on major projects has been done using the GMAW process to take advantage of high welding speeds. Pulsed gas metal arc welding (GMAW-P) has historically yielded the most consistent results. Improvements in GMAW-P power sources, e.g., synergistic welders, can provide welds with good profile and contour and are capable of storing programmed welding parameters for a number of welding procedures. Conventional short-circuit gas metal arc welding (GMAW-S) has produced variable results, but improved GMAW-S power sources, e.g., waveform control, have allowed more consistent weld quality.

E3.2 GTAW/TIG

E3.2.1 In this process, an arc is established between a nonconsumable tungsten electrode and the work piece. The electrode and the weld bead are protected from the atmosphere by an inert gas shield (usually argon). Filler metal is added, usually by hand feeding.

E3.2.2 This process is the slowest of the three described here. Welder care can minimize dilution from the substrate when making uncapped plug welds. Dilution effects are minimized by proper filler-metal selection, ample addition of filler metal, and proper direction of the arc.

Welds made by GTAW usually display good weld contour, blend well with the lining surfaces, and do not require grinding. Because of the wide range of control possible, GTAW is often used for the repair of welds made by other processes.

E3.2.3 Advantages include:

- GTAW generally produces the highest-quality welds of the three processes described here.
- Weld-bead contour is easy to control and seldom requires touch-up grinding.
- GTAW is a good process for making short repair welds.
- Equipment is less expensive than that required for GMAW.

E3.2.4 Limitations include:

- Slow welding speeds, less than one-third those attained with GMAW.
- When making welds to substrate, the welder may not add sufficient filler metal to compensate for dilution from substrate.
- The welder, not the welding process, controls the dilution.
- Because GTAW is a two-handed operation, it may be difficult in areas of limited accessibility or when personnel are working from a scaffold.

⁽⁶⁾ A practice used to address this problem is to ensure that each welder always uses the same machine, i.e., the welder's name should be on the machine. One option is to "lock in" all but one control to minimize weld-setting errors.

NOTE: GTAW is widely used in making weld repairs. It has been used for seal welding and often for welding the plug weld cap to the lining. GTAW/TIG is typically used for welding titanium.

E3.3 SMAW (coated electrode)

E3.3.1 In this process, an arc is established between a flux-coated electrode and the work piece. The flux protects the molten metal during arc transfer and forms a protective slag on the solidifying weld metal.

E3.3.2 This process is slower than GMAW and requires added time for slag removal and cleanup. Two advantages of the process are its portability for field welding and the fact that it is unaffected by air currents that could preclude use of gas-shielded processes. However, with SMAW there is a risk of entrapped slag. Any slag left on the surface of a weldment requires a thorough postweld cleanup. Electrodes removed from the sealed containers require storage in heated cabinets to prevent moisture absorption by the electrode coating.

E3.3.3 Advantages include:

- Weld quality is not affected by air currents or drafts that could blow shielding gas away from the site of a GMAW or GTAW process.
- High portability is helpful in field use.
- The amount of dilution from the substrate is very consistent and welder technique has minimal influence.

E3.3.4 Limitations include:

- There is a risk of slag inclusions and other weld defects.
- Postweld cleaning is more expensive.
- SMAW produces slow welding speeds, considerably slower than those attained by GMAW.

NOTE: SMAW is used mainly for welds at sites where gas shields cannot be maintained in accordance with required GMAW and/or GTAW procedure. Some prefer SMAW for tack welding. A comparison of GMAW, GTAW, and SMAW for nickel alloys and stainless steels is given in Table E1.

Table E1
Weld Process Comparisons for Nickel Alloys and Stainless Steels

	Welding Speed	Dilution from Substrate	Weld Contour (profile)	Weld Defects^(A)	Out-of-Position Sensitivity	Cost of Power Sources
GMAW	fast	fairly predictable	varies with welding parameters	lack of fusion poor weld contour	sensitive to position	most expensive
GTAW	slowest process	welder technique is a major factor	good to excellent	no particular type	good out of position	more expensive than for SMAW
SMAW	slow	very predictable	usually good	slag inclusion	good out of position	least expensive

^(A)Welds made by any of these processes may have defects such as porosity, cracks, or undercut resulting from poor technique.