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by Richard E. Avery, Jonathan D. Harrington and William L. Mathay

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By

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The practice of lining carbon steel vessels with stainless steel dates back to the late 1920's, early 1930's, and was used first by the chemical industry. The oil industry followed, and today the technique is used in almost every process industry where corrosion protection of carbon steel vessels is needed.

In spite of some 60 years of use, the technique lacks precise identification. It is known by a variety of names such as sheet lining, strip lining, plug lining and wallpapering. Regardless of the name, however, 60 years of experience gives today's engineers a high level of confidence when they specify sheet lining for corrosion protection.

Lining techniques, procedures, and materials vary depending upon operating conditions. The power industry, for example, uses wallpapering, usually with a minimum 1.57-mm (0.062-inch) thick high nickel alloy, to protect flue gas desulfurization (FGD) equipment. Other industries, such as pulp and paper manufacturing or chemical processing, often use sheet lining with UNS S30403 or S31603 (Type 304L or 316L), or other grades of stainless steel. These materials are the focus of this document.

Capabilities and Limitations

Sheet lining with UNS S30403 or S31603 (Type 304L or 316L) stainless steel has proven to be a very useful and economical technique to protect carbon steel surfaces, and practical applications abound. They include linings for:

- Covering large surface areas where weld overlay would be impractical.
- Applying to local areas experiencing corrosion and/or wear, thus avoiding the need to cover complete surfaces.
- Quick repairs to get plants back on line with minimum loss of production. Of particular interest is the fact that lining can be done by trades employed by most process industry plants.

There are several limitations to sheet lining that should be recognized. They include the following:

- Narrow strip and/or extensive plug welds may be needed to compensate for differences in thermal expansion, over about 316°C (600°F) or if occasional negative pressures are experienced.
- Covering complex surface contours with sheet lining may involve intricately detailed and costly forming.

- Applied linings (as opposed to solid or clad materials) tend to reduce heat transfer across the vessel wall.

PREPARATION FOR LINING

Careful preparation or cleaning of the surfaces to be lined, detailed planning of the steps to follow in applying the lining, and supervised execution are prerequisites to successful lining. This document provides some practical guidelines to each of the three steps.

Cleaning Backing Material

A thorough cleaning of the substrate serves two practical purposes:

- Clean surfaces allow inspection of the carbon steel to determine if repairs are needed.

- Successful welds can only be made on clean, uncontaminated steel.

In most instances, it is easiest to clean all surfaces to be lined. However, when large sheets are used, selective cleaning of only the immediate weld areas is feasible and worthy of consideration, provided a smooth surface is available.

The choice of cleaning method depends upon the condition of the base metal to be lined. Obviously, heavy product buildup requires mechanical removal methods as the initial step, such as chipping, coarse abrasive grinding, or shot blasting. This is followed by a final blast cleaning with clean abrasives, such as silica sand, aluminum oxide, garnet or similar materials. If the abrasive is recycled, care should be exercised to ensure that foreign matter is not redeposited on the surface being cleaned.

Less dense contaminants, such as the low melting metals lead and zinc, chemicals such as caustic or sulfur compounds, and oil or grease, all of which can cause weld defects, should also be removed. Typical less aggressive techniques include the following:

- Grinding with abrasive disks.
- Hydro blasting.
- Grinding with abrasive papers such as flapper wheels.
- Washing with acids or alkalies to neutralize the surface, followed by water rinsing.

Inspection of Areas to be Lined

After cleaning, good practice calls for careful inspection of the substrate with additional cleaning and/or repairs as necessary. There are several important check points. It should be readily apparent to the inspector that the cleaning was adequate. The appearance of white or near-white metal suggests that cleaning was complete. The inspector should look for wall thinning from corrosion or other wastage. Ultrasonic thickness measuring is often used.

Localized thinning is usually restored by a weld-deposit. If the damage area is extensive, it may be more expedient to insert a new plate section. When inserting patches, it is good practice to round the corners of the patch so as to avoid weld starts and stops at sharp corners that could become highly stressed. The inspector should look for any protrusions, such as high weld beads, that could interfere with intimate contact between the liner and backing substrate. These should be removed by grinding.

Protecting Cleaned Surfaces

Depending on atmospheric conditions, the cleaned substrate may start to rust almost immediately, or the surface could remain bright for a number of days. Any number of commercial protective coatings are available that not only prevent rusting but are compatible with welding.

LINING PROCEDURES

Advance planning on any lining project is time well spent. Working drawings of the original equipment should be supplemented by detailed site planning and layout. Major considerations are sheet size and methods of handling, liner thickness, weld joint type, fit-up techniques, welding methods, special situations, and final inspection and cleanup.

Sheet Size and Handling

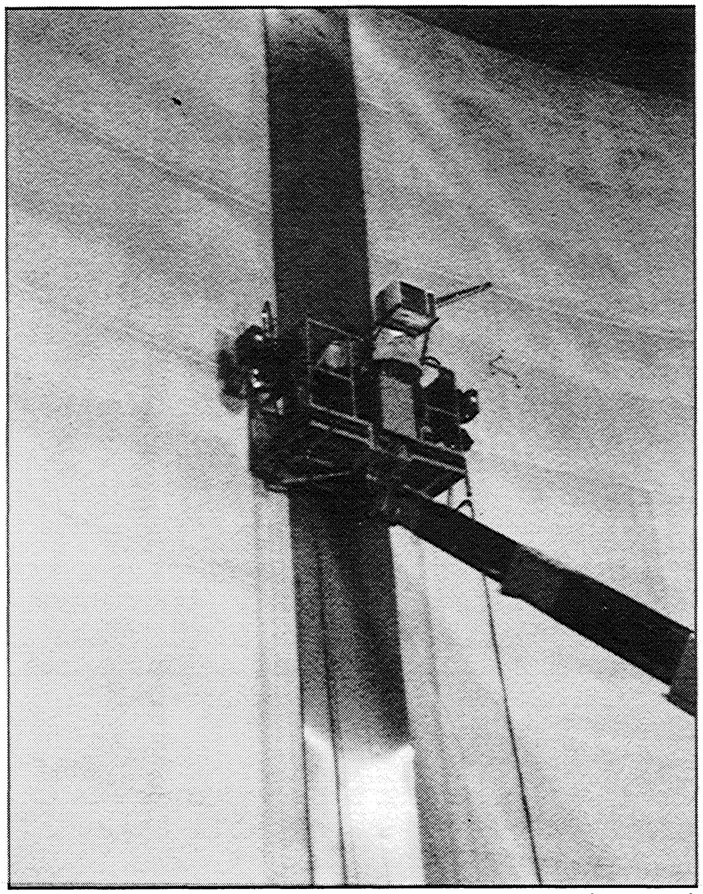
One consideration is to specify the largest practical sheet size, which serves to reduce the amount of seam welding. This tends to minimize total cost. Large sheets are well suited to vessels subject to high static weight such as storage vessels. However, other factors must be considered in selecting the optimum sheet size, namely:

1. **Access opening dimensions**. If all material must be brought in through a small man hole, the width of individual strips is automatically determined.

2. **Geometry of the backing surface**. Flat or simple curved surfaces can accommodate large sheets. More complex geometries such as the knuckles in tank heads, may require extensive forming for good contact between liner and base metal. Narrow strips may require less forming. Typical designs for lining heads are shown in Figure 1.

3. **Operating temperature**. Because of differences in thermal expansion between the stainless steel liner and the carbon steel base, the liner tends to expand and bulge away from the backing substrate as temperature increases. The higher the temperature change, the greater the effect. The effect can be minimized by using narrower strips or plug or spot welds.

4. **Cyclic operation**. Alternate heating and cooling and/or alternating pressure (positive to slight vacuum), which may also cause buckling of the liners, favors the use of narrower strips or plug or spot welds.



UNS S30403 (Type 304L) strip lining in a 43.891m (144-foot) diameter by 24.384m (80-foot) tall steel tank. This shows the installation of the first strip.

Attention should also be given to small details, such as handling methods for moving, shaping, or clamping and bracing the lining material while it is being attached. When handling the stainless steel sheets, workers should avoid the use of carbon steel tools and clamps. If carbon steel press break equipment is used, the stainless steel surfaces should be treated before installation to remove any iron contamination. Normal handling practices are well understood and thoroughly covered in the literature.

Liner Thickness

A liner thickness of 1.57 mm (0.062 inch) is most commonly used and readily available. Sheets thinner than 1.57 mm (0.062 inch) require greater care in welding to avoid "burn backs." Sheets greater than 1.57 mm (0.062 inch) in thickness are more difficult to form and seldom justified except where an allowance may be applied for corrosion and/or erosion. Usually it is better to upgrade to a more corrosion-resistant stainless steel rather than to use a thicker sheet.

Weld Joint Type

The two most common joints for welding stainless steel sheet lining are the three-bead method and the shingle joint or wallpaper technique. Both joint types, shown in Figure 2, have advantages and limitations.

Three-bead method: Each sheet is fillet welded to the steel substrate. A third, covering bead, completes the sequence. These welds are normally made with a higher alloy content filler metal in order to compensate for dilution from the steel substrate. The gap between sheets should be controlled precisely so that three uniform beads will properly fill the gap and give the desired composition in the covering bead. The welding procedure should be developed and controlled to insure the composition of the covering bead is equal to or greater than the composition of the sheet. Since it is difficult to determine whether the composition of the final covering pass has actually reached sheet metal composition at all points, the three bead method of lining tends to be limited to less aggressive alkaline or water environments. The digester and recovery section of pulp mills and municipal waste treatment plants are typical services where the three bead method of lining would perform well. A disadvantage of the three bead method is the need to drill tell tale holes at the low point of each section of sheet since each section is sealed from other sections.

Overlap joint method: In this method each sheet is tack welded to the substrate steel overlapping the adjacent sheet one inch or so. The seal weld is made with a matching or higher alloy content filler metal. Overlapping allows the seal weld to be made between material of the same thickness simplifying the welders problem in making a high quality seal weld. Since the sheets are tack welded to the substrate and not sealed from one another, only one tell tale hole need be drilled at the low point of the vessel. The overlap method tends to be preferred for aggressive environments.

Fit-up and Tack Welding

Lifting sheets into place and holding for tacking calls for ingenuity. Techniques vary according to the area being lined. Wooden "picture frames" are often used for moving sheets into place, after which the sheets are held manually until tacking is complete. Wood braces and devices such as wall board positioners may be helpful, but in no case should carbon steel tooling be used, otherwise free iron could become embedded in the stainless steel liner. In service, iron contamination usually develops rust spots that frequently become initiation sites for pitting corrosion that would not otherwise occur.

Sheets are cut by conventional shearing, sawing, abrasive cutting, or by plasma arc cutting. Subsequent light grinding to bright metal is appropriate to remove all oxides. Carbon arc cutting is not recommended unless the cut area is completely removed.

It is good practice to stagger the sheets, such as in laying bricks, to avoid four corners coming together at one point. In lining vertical walls, starting at the top and working down allows the horizontal welds to be made in the semi-down hand position rather than semi-overhead. See Figure 3.

There are two concerns when tack welding. First a tacking sequence should be selected to prevent sheet lifting. Second, tack welds should be of a shape and size that can be incorporated into the final weld. Tack welds must be free of defects.

One technique to prevent lifting is to start at the midpoint of a sheet, tacking on alternate sides of the initial tack and working out symmetrically. All four edges of the sheet should be checked periodically for lifting. If plug welds are used, start with the center plugs, working outward and tacking the edges last.

Tack welds are normally made with the same welding process used in making the closing seams, that is either gas metal arc (GMAW), gas tungsten arc (GTAW) or shielded metal arc

(SMAW). It is preferable to use a larger number of small short tacks rather than fewer, longer tacks. Tacks 6mm (1/4 inch) long on 8cm (3-inch) centers are typical. The tack welds should be inspected and ground or blended so that they will not interfere with the overlapping sheet and will blend into the seam weld.

Seam Welding

Of the three processes, GMAW is the most common today for liners, but each process has advantages and limitations. It is up to the fabricator to select the one best suited for the particular application and the welding skills available. Some comments regarding process selection follow:

1. **GMAW** (often referred to as Mig) - Both the short circuiting and pulsed arc transfer processes are used in liner work. GMAW is considerably faster than GTAW and SMAW and produces high quality welds. Compared to the other process, GMAW has more welding parameters, e.g. amperage, wire feed, arc characteristics and type of shielding gas. Some newer power sources, such as the synergic pulsed arc, automatically control of a number of welding parameters including the pulse rate. The operator may need only one control dial with the other parameters adjusted automatically.

2. **GTAW** (often called Tig) - This process is the slowest of the three. The welder must take care to minimize dilution from the substrate, which reduces corrosion resistance in the weld metal. Dilution is minimized by proper filler metal selection, ample addition of the filler metal, and by proper direction of the arc. Welds made by GTAW normally have a good weld contour, they blend well with the liner surfaces, and they do not require grinding. Because of the wide control range possible, the process is often used in repair of welds made by other processes.

3. **SMAW** (stick welding) - 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 it is unaffected by air currents that could preclude use of gas shielded processes. Electrodes removed from the sealed containers must be stored in heated cabinets to prevent moisture pickup in the coating.

Typical welding parameters for both the pulsed arc and short circuiting GMAW, GTAW, and SMAW processes are shown in Tables I, II, III, and IV respectively. Regardless of the welding procedure, the weld area should be thoroughly cleaned of all oil, grease, dirt, oxide and other foreign material prior to welding. The only exception is a protective coating, mentioned earlier, that is applied to the backing steel. Chlorinated solvents should never be used because of the possibility of chloride contamination on the under side of the liner.

Plug or Arc Spot Welding

The need for plug or arc spot welding and the spacing required are not easily determined. Before specifying extensive plug welding "just to be safe," the engineer or fabricator should realize that plug welding can be time consuming and, therefore, expensive. Also plug welds require considerable welder skill and are a potential leak path if defective. Other factors that influence the need for plug welds are as follows:

1. **Service temperature variations** -- The wider the temperature range in service, the greater the need for plug welds to prevent bulging of the liner.

2. **Differences in thermal expansion** -- The UNS S30000 series stainless steels are about 50 percent higher in thermal expansion than carbon steel. Therefore, more plugs are needed with the steels than with a lower expansion alloy liner.

3. **Negative pressure excursions** -- Plug or spot welds prevent flutter or vibration.

4. **Sheet width** -- The wider the sheet, the greater the justification for plug welds.

Plug welds are made by using either pre-cut holes or by a GMAW arc spot welding technique where the plug weld fuses completely through the lining and into the backing steel without the need for a pre-cut hole. Pre-cut hole plug welds are much stronger than arc spot welds. About two arc spot welds are required in place of one pre-cut hole weld.

Pre-cut holes, usually 10 to 16mm (3/8 to 5/8 inch) in diameter, may be mechanically punched or drilled. Alternatives to round holes are elongated (rectangular) slots, such as made by a grinding wheel or by plasma cutting. The elongated slots permit horizontal welds when lining vertical surfaces. As cautioned earlier, carbon arc cutting should not be used unless the cut edges can be ground satisfactorily to remove oxides and any carbon pickup. The lining is tack welded to the substrate and welded using any of the processes shown in Tables I through IV.

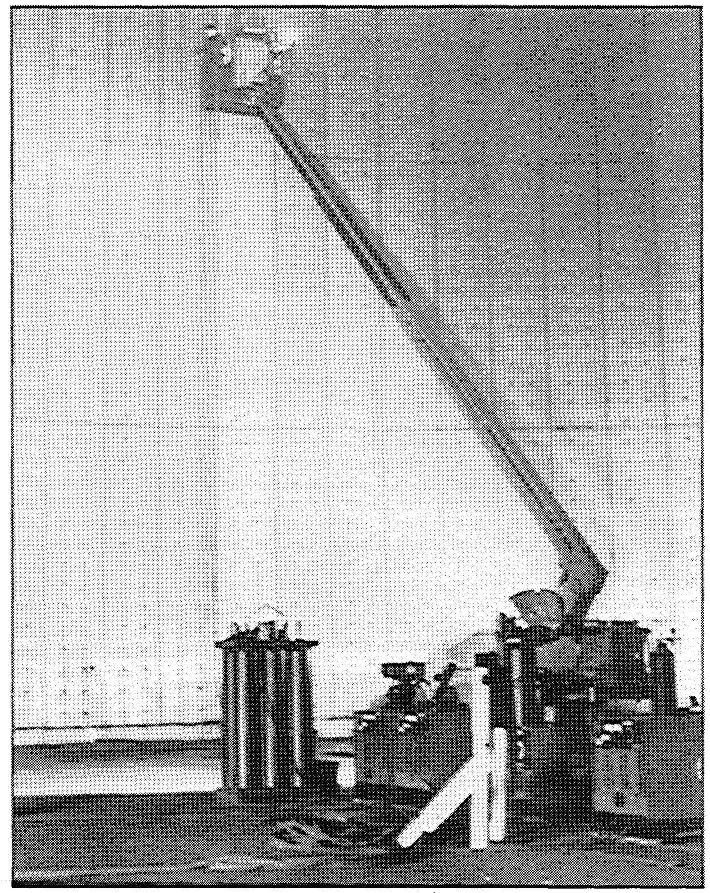
GMAW arc spot welding potentially offers substantial time savings over the use of a pre-cut hole. In this process, a special nozzle is positioned over the liner, and the arc is initiated for a preset time so that the weld fuses through the liner and into the backing steel. Good results have been obtained in all positions when it is possible to maintain good contact between the liner and substrate. The process has been more popular in Europe than in the United States and offers a cost-effective alternative to the use of precut holes.

Lining of Outlets, Corners and Special Structures

The lining principles discussed earlier for large surface areas are also applicable to outlets, corners and special areas. Figure 4 illustrates three typical situations. In lining surfaces with 90 degree corners, such as rectangular cross section duct work, it is preferable to tack the two liners just short of the corner and then cover the corner with a sheet preformed to a 90 degree angle with 8 to 10cm (3- to 4-inch) legs. The legs of the cover sheet are seam welded to the liner sheets.

All structural attachments should be made to the substrate and not to the liner. Structure supports may be lined carbon steel or solid stainless steel. The choice is a matter of economics.

Inspection and Testing



This view of the 43.891m (144-foot) by 24.384m (80-foot) tank shows the strip lining in place.

Since seal welds are single pass welds, they should be carefully inspected for defects that might allow a leak to the backing material. A thorough visual inspection should be made first to find obvious weld defects. However, before making the visual inspection the responsible engineer should establish realistic quality standards, One useful reference for acceptance standards is ANSI/AWS D9.1-84, Specification of Welding of Sheet Metal. A typical visual inspection might cover the following conditions and acceptance levels:

1. Inspection should be made with the aid of a hand magnifying glass.
2. Welds require complete fusion.
3. No weld cracks are allowed.
4. Undercut not to exceed 0.15t where t is the liner thickness.
5. Porosity and inclusions are not to exceed limits such as one visible pore or inclusion no larger than 0.5t in any 25.4mm (one inch), and three visible pores or inclusions no larger than 0.25t in any 25.4mm (one inch).
6. Maximum weld reinforcement to not exceed 2t.
7. Weld spatter and arc strikes to be removed.
8. Heat tint or oxides to be removed.

The vacuum box test is an effective check for leaks in the seam and plug welds. This is a relatively fast test and one that can be conducted without interfering with other fabrication operations. The test uses a box fitted with rubber seals around its open bottom and a plexiglas top cover. The weld to be inspected is coated with a soap type solution and a light vacuum, usually under 69 kPa (10 psi) applied to the box. The formation of bubbles on the soaped weld, indicates the location of a leak.

Dye penetrant and black light provide a quick and effective method of locating defects in liner welds for repair after initial installation and during routine inspections. Once the vessel has been drained, cleaned and prepared for inspection, defects can be located and repaired within a few hours of shut down.

Post Fabrication Cleanup

After inspection and before service, the liner surface must be cleaned of foreign material. The degree of cleaning depends upon the service environment. In environments where pitting corrosion is a possibility, all heat tint and other oxides must be removed. The same good post-fabrication cleanup practices for any stainless steel equipment apply also to linings.

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TABLE I

Welding Procedure Guidelines for GMAW - Pulsed Arc Welding of Stainless Steel Lining

(Seal welds, intermittent filler welds and plug welds)

Substrate Material: Carbon or low alloy steel

Sheet Material: UNS S30403 or S31603 (Type 304 L or 316L) stainless steel

Filler Metal: AWS A5.9, 0.889mm (0.035") diameter

Liner alloy	Liner to Liner	Liner to Steel
UNS S30403 (304L)	ER308L or ER309L	ER309L or ER312L
UNS S31603 (316L)	ER316L or ER309MoL*	ER309MoL* or ER309L

* --If ER309MoL is not available, ER317L may be suitable for liner to steel and liner to liner welds.

Positions: all

Preheat: If needed to prevent moisture condensation.

Shielding Gas: 90% helium, 7 1/2 % argon, 2 1/2% CO_2
99% argon, 1% oxygen (some weld discoloration)

Electrical Characteristics:

Pulsed arc welding parameters vary widely with different power sources and should be developed for the power source to be used.

Techniques:

1. Structural tack welds should be ground flush with the liner.
2. Seal tack welds should be ground and feathered using small grinding wheels or carbide burrs.
3. Seal weld starts and stops should be inspected and ground as needed.
4. Welding is normally forehand except backhand in vertical down.

TABLE II

Welding Procedure Guidelines for GMAW - Short Circuit Welding of Stainless Steel Lining

(Seal welds, intermittent filler welds and plug welds)

Substrate Material: Carbon or low alloy steel

Sheet Material: UNS S30403 or S31603 (Type 304 L or 316L) stainless steel

Filler Metal: AWS A5.9, 0.889mm (0.035") diameter

Liner alloy	Liner to Liner	Liner to Steel
UNS S30403 (304L)	ER308L or ER309L	ER309L or ER312L
UNS S31603 (316L)	ER316L or ER309MoL*	ER309MoL* or ER309L

* --If ER309MoL is not available, ER317L may be suitable for liner to steel and liner to liner welds.

Positions: all

Preheat: If needed to prevent moisture condensation.

Shielding Gas: 90% helium, 7 1/2 % argon, 2 1/2% CO_2

Electrical Characteristics:

Amperage: 70 to 110 amps
Voltage: 16 to 20 volts
Wire feed: 457 to 559cm per minute (180 to 220 ipm)
Travel speed: 25 to 38cm per minute (10 to 15 ipm)

Techniques:

1. Structural tack welds should be ground flush with the liner.
2. Seal tack welds should be ground and feathered using small grinding wheels or carbide burrs.
3. Seal weld starts and stops should be inspected and ground as needed.
4. Welding is normally forehand except backhand in vertical down.

TABLE III
Welding Procedure Guidelines for GTAW - of Stainless Steel Lining
(Seal welds, intermittent filler welds and plug welds)

Substrate Material: Carbon or low alloy steel

Sheet Material: UNS S30403 or S31603 (Type 304 L or 316L) stainless steel

Filler Metal: AWS A5.9, 0.889mm (0.035") diameter

Liner alloy	Liner to Liner	Liner to Steel
UNS S30403 (304L)	ER308L or ER309L	ER309L or ER312L
UNS S31603 (316L)	ER316L or ER309MoL*	ER309MoL* or ER309L

* If ER309MoL is not available, ER317L may be suitable for liner to steel and liner to liner welds.

Positions: all

Preheat: If needed to prevent moisture condensation.

Shielding Gas: 100 % Argon
Use of gas lens attachment to the welding torch provides better gas protection to the weld metal.

Electrical Characteristics:
Tungsten electrode: 1.6 to 2.4mm (1/16 or 3/32 inch)
Amperage: 40 to 60 amps *
Volts: 10 to 13 volts
Travel speed: 10 to 15cm per minute (4 to 6 ipm) *
* Starting guides, may vary with joint conditions.

Techniques:
1. Tack welds, liner to substrate - minimize steel dilution by low current and generous filler metal addition.
2. Plug welds - use two layers to minimize steel dilution.

TABLE IV
Welding Procedure Guidelines for SMAW of Stainless Steel Lining

(Seal welds, intermittent filler welds and plug welds)

Substrate Material: Carbon or low alloy steel

Sheet Material: UNS S30403 or S31603 (Type 304 L or 316L) stainless steel

Filler Metal: AWS A5.9, 0.889mm (0.035") diameter

Liner alloy	Liner to Liner	Liner to Steel
UNS S30403 (304L)	ER308L or ER309L	ER309L
UNS S31603 (316L)	ER316L or ER309Mo	ER309Mo or ER309L

2.4mm (3/32-inch) diameter preferred, 3.2mm (1/8-inch) alternate

Positions: all

Preheat: If needed to prevent moisture condensation.

Electrical Characteristics:

Polarity: DCRP (electrode positive)
Amps: use manufacturer's recommendations
Volts: 22 volts
Travel speed: 40 to 61 cm per minute (16 to 24 ipm) depending on welding conditions

Techniques:

1. SMAW may be preferred in areas of poor accessibility or in field welding where air currents remove the gas shield in GMAW or GTAW.
2. All welding slag must be removed prior to service.

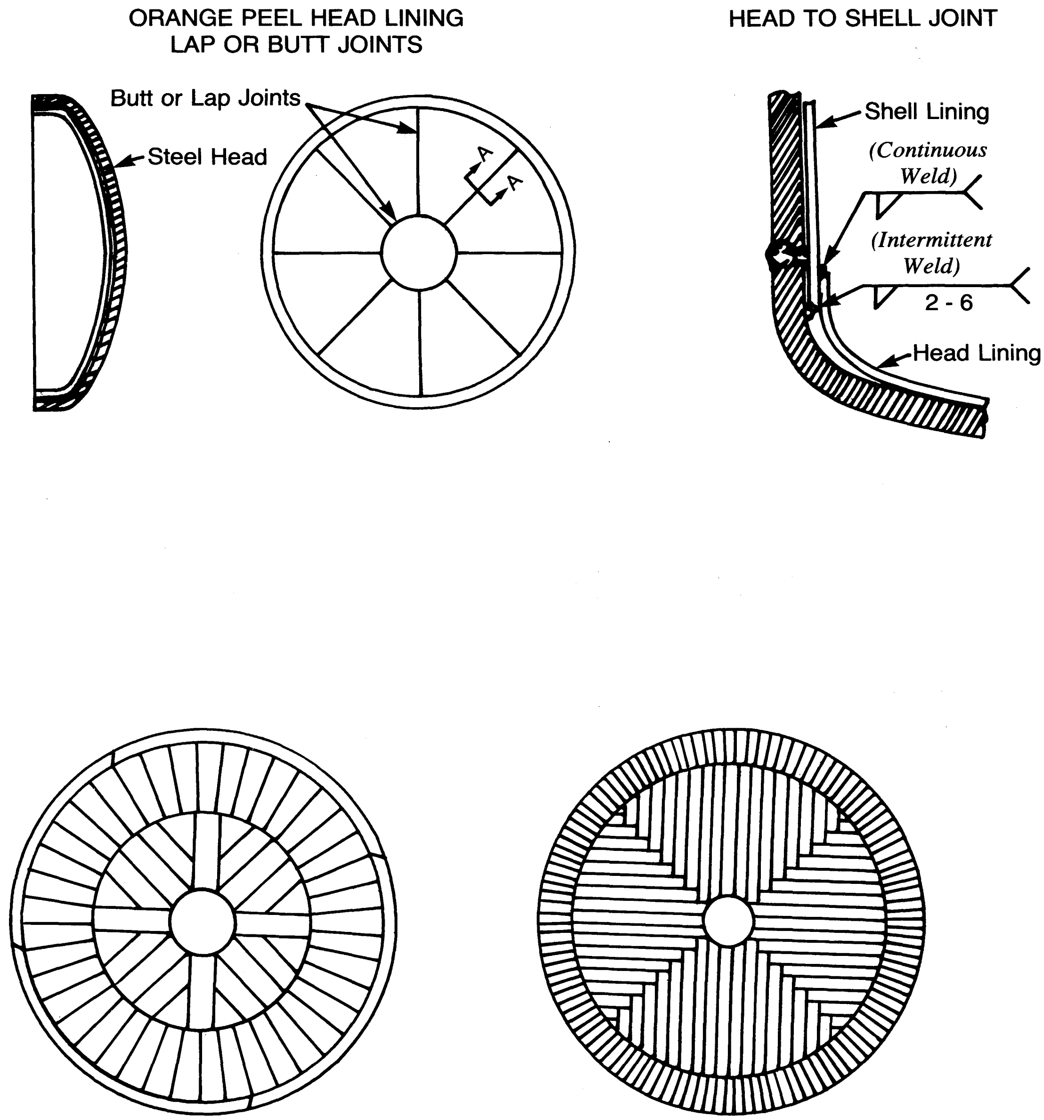
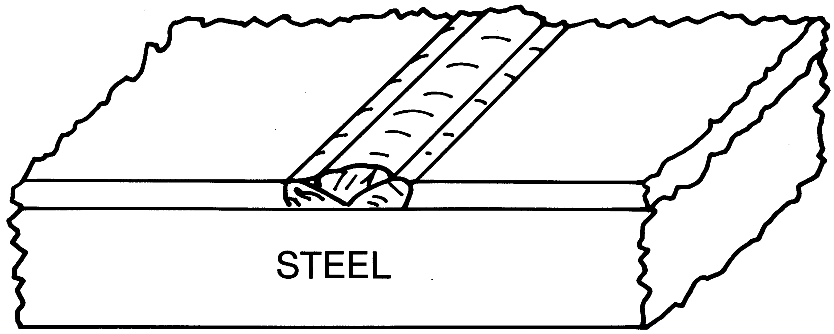
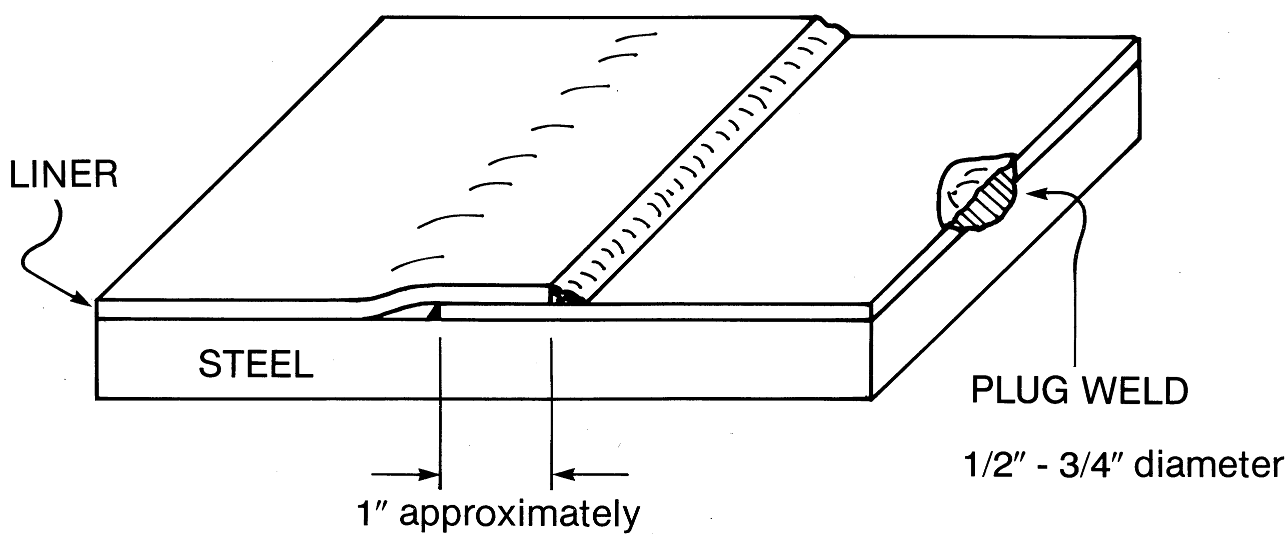


Figure 1

Typical designs for lining heads



THREE-BEAD METHOD



OVERLAP JOINT METHOD

Figure 2

Weld joints for liners

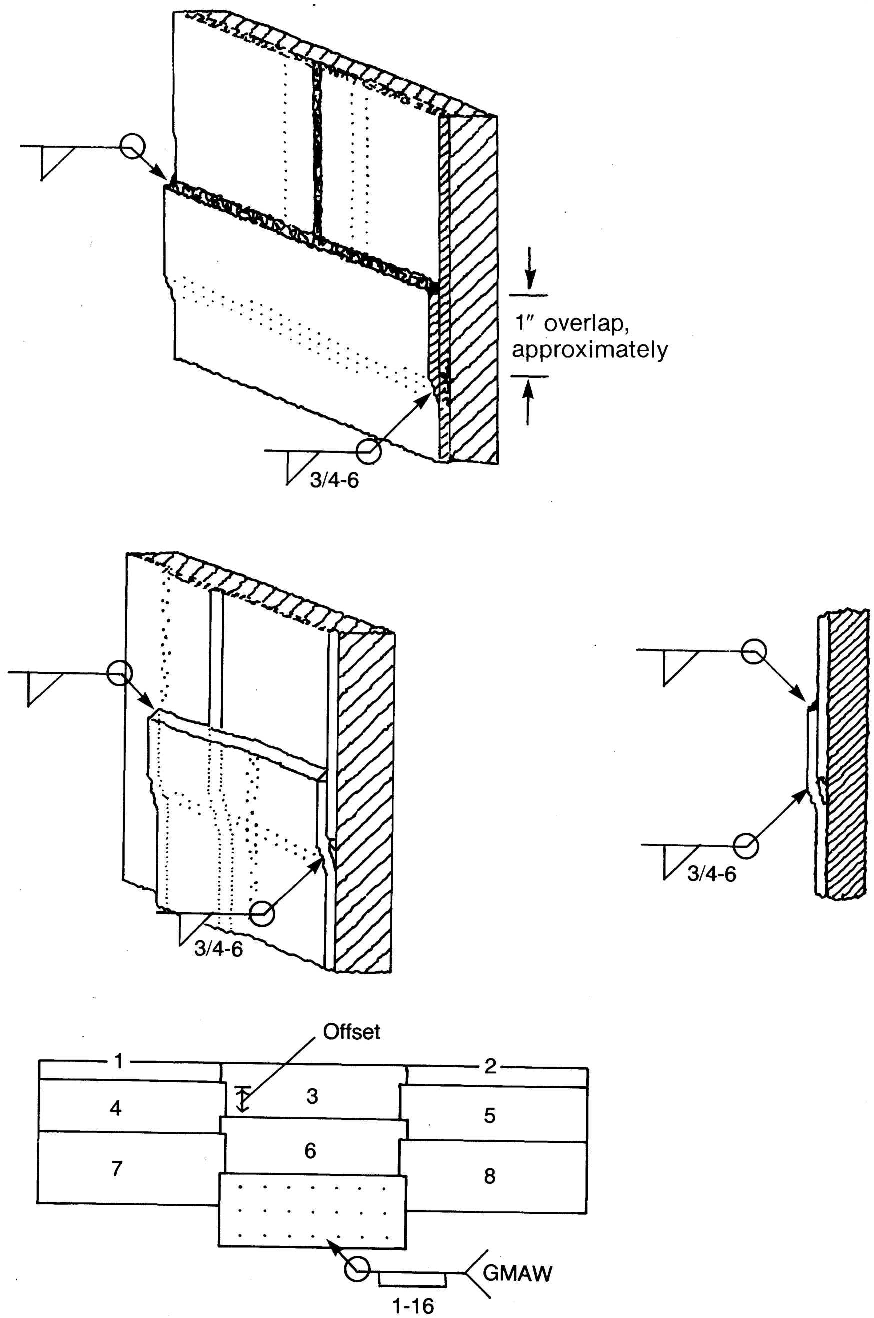


Figure 3
Lining sequence

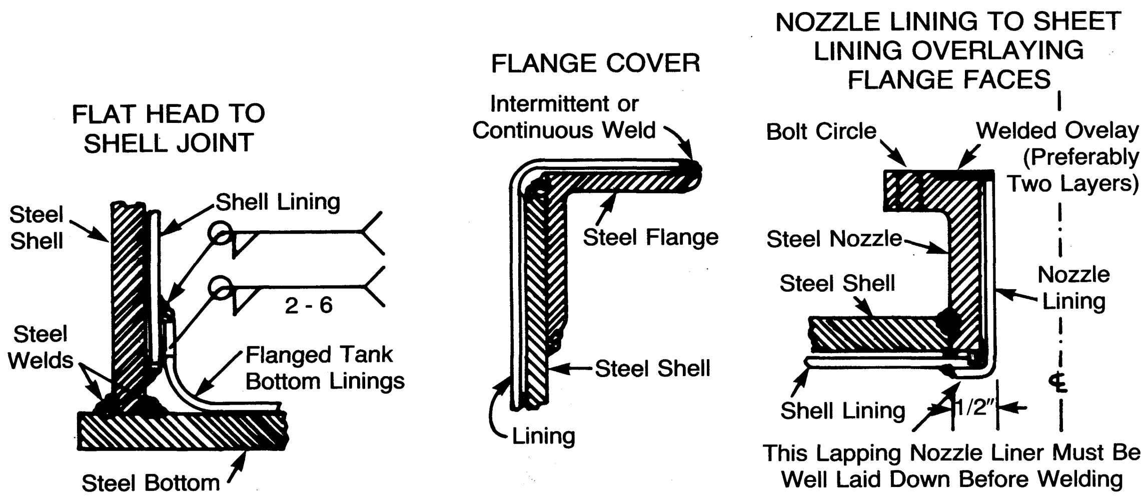


Figure 4

Typical designs for lining nozzles and flanges

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