BUREAU OF INDIAN STANDARDS

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भारतीय मानक **मसौदा**

रासायनिक प्रक्रियाओं के लिए पात्र और उपकरणों की लाइनिंग – रीति संहिता
भाग 7 संक्षारण एवं उष्मा प्रतिरोधी धातुएँ

(पहला पुनरीक्षण)

Draft *Indian Standard*

Lining of Vessels and Equipment for Chemical Processes — Code of Practice
Part 7 Corrosion and Heat Resistant Metals

(*First Revision*)

ICS 71.120.10

Chemical Engineering Plants and Related Equipment Sectional Committee, MED 17	Last date for receipt of comments is **28 February 2025**

FOREWORD
(*Formal clause would be added later on*)

This standard was first published in 1974. The present revision has been taken up with a view incorporating the modification found necessary as a result of experience gained in the use of this standard. Also, in this revision, the standard has been brought into the latest style and format of Indian Standards, and references of Indian Standards, wherever applicable have been updated.

This standard has been issued in several parts. Corrosion and heat resistant metals lining is covered in this part, the other types of linings are covered in the remaining parts of this standard. The other parts issued in this series are:

Part 1 Rubber Lining
Part 2 Glass Enamel Lining
Part 3 Lead Lining
Part 4 Lining with Sheet Thermoplastics

Part 5 Epoxide Resin Lining
Part 6 Phenolic Resin Lining
Part 8 Precious Metals
Part 9 Titanium
Part 10 Brick and Tile

It is desirable that early consultation and exchange of information should take place between the lining contractor and all parties concerned in the design, manufacture, erection and use of the vessels. Annex A gives the details of information to be exchanged.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (second revision)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

LINING OF VESSELS AND EQUIPMENT FOR CHEMICAL PROCESSES — CODE OF PRACTICE

PART 7 CORROSION AND HEAT RESISTANT METALS

(*First Revision*)

1 SCOPE

1.1 This standard (Part 7) lays down specifications and recommendations on the design of corrosion and heat resistant metal linings, method of application of linings, inspection and testing.

1.2 This standard does not cover deposition of metal by electrolysis, spraying or by explosion.

2 REFERENCES

The standards given below contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of these standards:

IS No.	*Title*
IS 803 : 1976	Code of practice for design, fabrication and erection of vertical mild steel cylindrical welded oil storage tanks (*first revision*)
IS 2825 : 1969	Code for unfired pressure vessels
IS 5206 : 1983	Specification for covered electrodes for manual metal arc welding of stainless steel and other similar high alloy steels (*first revision*)
IS 5856 : 2022/ISO 14343 : 2017	Welding consumables — Wire electrodes, strip electrodes, wires and rods for arc welding of stainless and heat resisting steels — Classification (*third revision*)
IS 5857 : 1970	Specification for nickel and nickel alloy bare solid welding rods and electrodes
IS 6911 : 2017	Stainless steel plate, sheet and strip — Specification (*second revision*)

3 MATERIALS FOR LININGS

3.1 Martensitic/Ferritic Corrosion Resisting Steels

Martensitic/ferritic corrosion resisting steel containing 11.5 percent to 14 percent chromium and with carbon content controlled to a maximum of 0.08 percent is suitable for linings subjected to the less onerous corrosive conditions. The fact that the coefficient of thermal expansion of these steels is very close to that of carbon steels commonly used for vessels requiring linings minimizes the stresses set up between lining and vessel at the points of attachment during operation at high temperatures. These materials have air-hardening properties and are susceptible to cracking in the weld or heat-affected zone. They may be obtained in sheet, strip or plate or as a cladding on carbon, carbon manganese and low alloy steels.

3.2 Austenitic Stainless Steels

Austenitic stainless steels complying with IS 6911 are grades of chromium nickel stainless steels offering good corrosion resistant properties both in the as wrought condition and after welding. It is an advantage to control the carbon content to as low a figure as practicable in the lining materials as some inevitable carbon pick-up, however slight, shall be anticipated from the welding processes used in fixing the lining to the vessel. All of the above materials may be obtained in solid form or as a cladding on carbon, carbon manganese and low alloy steels.

When any of these materials are to be used for linings required to operate at temperatures above 100 °C, consideration shall be given to the possible effect of the difference in coefficient of thermal expansion of these grades of stainless steel compared with carbon, carbon manganese and low alloy steels.

3.3 Nickel

Nickel of 99 percent minimum purity is commonly used in industry and has good resistance to corrosion, particularly by alkalis. This metal, however, shall not be used in contact with highly oxidizing acids or salts. The grade of nickel to be selected is dependent upon the service conditions for which the plant is designed.

3.4 Other Metals

Subject also to demonstration and suitability for the proposed fabrication and service, other weldable corrosion or heat resistant metals based on iron, nickel and/or cobalt may be used.

4 DESIGN OF VESSELS AND EQUIPMENT FOR LINING

4.1 Design Considerations

4.1.1 *General* — In general, it is recommended that vessels to be fitted with a corrosion resistant lining shall be of welded construction from carbon, carbon manganese or low alloy steel plates, using butt-welded joints wherever possible. The inner weld beads shall be ground off flush and smooth in order to ensure that the lining plates may bed down with, good contact against the inner walls of the vessel over the whole area.

Wherever possible, the shape shall be cylindrical with ends either flat, conical or dished and with as large a radius as possible in any corners which occur. Irregular shapes may be lined but will be more difficult and costly.

The vessel shall be fabricated and tested in accordance with recognized standards of good design and practice to suit the operating conditions, with the thickness of the shell and ends being adequate to meet the required strength under operating pressures and temperatures. For guidance on these requirements, reference may be made to IS 803 and IS 2825. Whether the lining is attached to the wall or not it is not generally considered in the calculations to determine the strength of the vessel. In respect of integrally clad plates credit for cladding thickness shall be considered in basing the design calculations. No corrosion allowance need be made in assessing the thickness of the shell. If thermal stresses are likely to be set up by the attachment of the corrosion resistant lining then the necessary allowances shall be made in the design of the vessel. Post weld heat treatment shall be given as specified in IS 2825.

The required thickness of lining will depend upon the information available concerning corrosion under operating conditions. The selection of the correct type of material to meet these conditions is important and it is recommended that welded test plates of the chosen lining material be subjected to searching tests under the worst operating conditions before a final selection is made. It is necessary that the corrosion rate of the lining be known so that the thickness of the lining is made adequate for the intended life of the vessel.

The drawing of the vessel shall give full details of construction, including any holes through the shell that are required for test purposes and the method of lining shall also be shown. These test holes shall be drilled through the shell before the lining is applied. If the sheet lining method is to be used then due attention to access shall be given, and if this is through a manhole then the design of the lining shall cater for this and prefabrication outside the vessel limited to the extent it is necessary. It may be considered an economy in some cases to fully flange one end of the vessel in order to simplify the access for sheet lining.

When the vessel be required to have good heat transfer properties, it is recommended that clad steel or weld overlay be used for construction. If sheet or strip lining is required then means other than jackets shall be used to heat or cool the contents of the vessel. Internal coils of pipes or external heat exchangers are suitable means of providing heat transfer surfaces in such cases.

4.1.2 *Internal Fittings* — Where internal fittings are required, such as support rings, brackets, coil supports, footstep bearings, etc, it is normal to fabricate these from solid corrosion resistant alloy of the same specification as the lining material, Where these are fixed to the vessel wall and are expected to carry some load under operating conditions, it is desirable to fix them in position before lining is commenced, using a suitable welding technique to minimize dilution of the weld by the shell material. The lining may then be arranged to shield this weld and the weld attaching the lining to fitment will then be undiluted corrosion resistant alloy. It is essential that such junctions of fittings to shell wall be fully detailed on a drawing and approved.

Internal fittings may be fitted direct to the lining when the vessel is constructed of clad plate or the lining is by weld overlay, provided special precautions are taken to ensure the integrity and strength of the bond.

4.1.3 *External Fittings* — Special care shall be taken in designing the fittings on a vessel which break through the shell, such as manholes, branches, sight glasses, agitator glands, etc. These may be in solid corrosion resistant material, as in Fig. 1, for simplicity, but this may prove expensive.

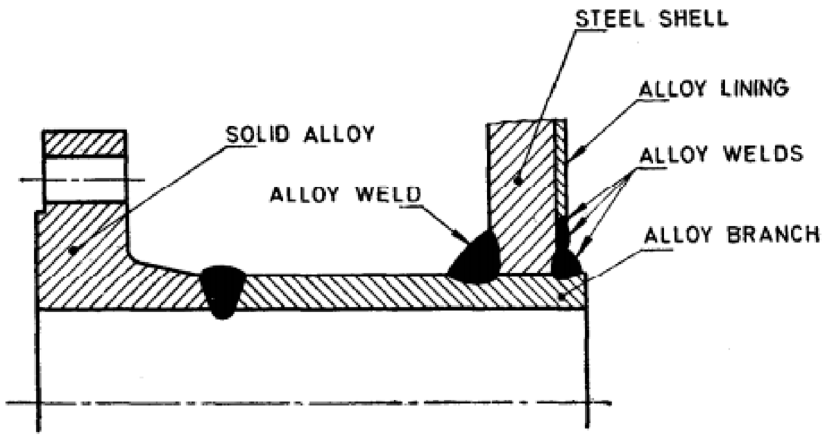


FIG. 1 SOLD ALLOY BRANCH

Carbon steel fittings may be adequate provided good provision is made for a continuous lining of the corrosion resistant material to be welded on all surfaces exposed to the product. Extra care is needed where such linings on the fittings meet the shell lining, and provision for anchoring the latter in the area adjacent to any fittings shall be studied to avoid operational stresses damaging the shell lining.

4.1.4 *Flanged Openings* — The corrosion resistant lining shall be taken on to the sealing surface of the joint face of all flanged openings. Whenever possible, branches, nozzles, manholes, etc, with flanged faces shall be lined before attaching them to the shell so that the joint face may be machined after welding (*see* Fig. 2). Where this is not possible, it is necessary to take precautions so that subsequent welding does not unduly distort the joint face.

With pressure vessels the flanges will be thick enough for the faces to be fitted with a corrosion resistant bar or plate between 6 mm and 12 mm thick inserted within the bolt circle (*see* Fig. 3). Provision shall be made for this in the design of the flanges as this gives a good facility for making a sound undiluted attachment to the lining.

4.2 Materials for Vessels

4.2.1 *Carbon or Carbon Manganese Steels* — Carbon or carbon manganese steels are the most suitable-group of materials from which a vessel shall be constructed if it is to be subsequently fitted with a lining. The quality and thickness of the material chosen shall be such that the subsequent welding of the lining in position will not adversely affect the structure of the vessel.

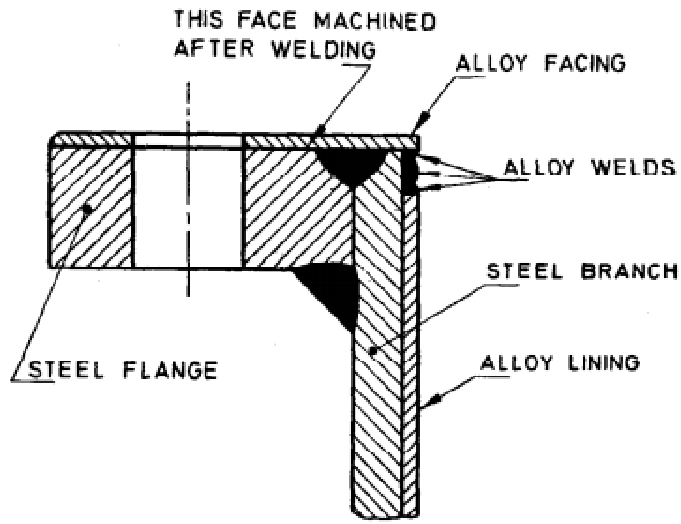


FIG. 2 FLANGED OPENING WITH ALLOY FACING

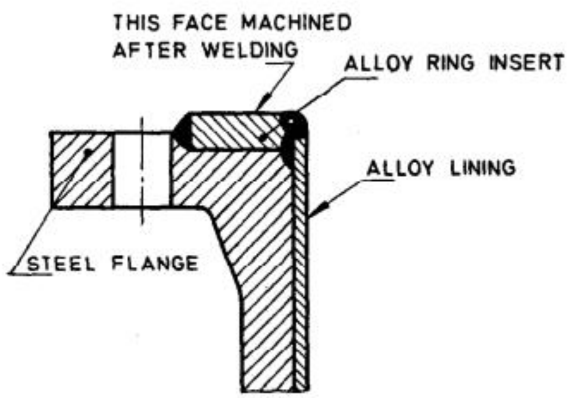


FIG. 3 FLANGED OPENING

The surfaces to be lined shall be smooth and clean and free from scale. Iron grit blasting is recommended as a suitable finish. The vessel shall preferably be of welded construction throughout, with all internal welds ground smooth and flush. Where an existing steel vessel of riveted design is being considered for lining, the riveted joints shall be finally sealed by a cover strip, as shown in Fig. 4.

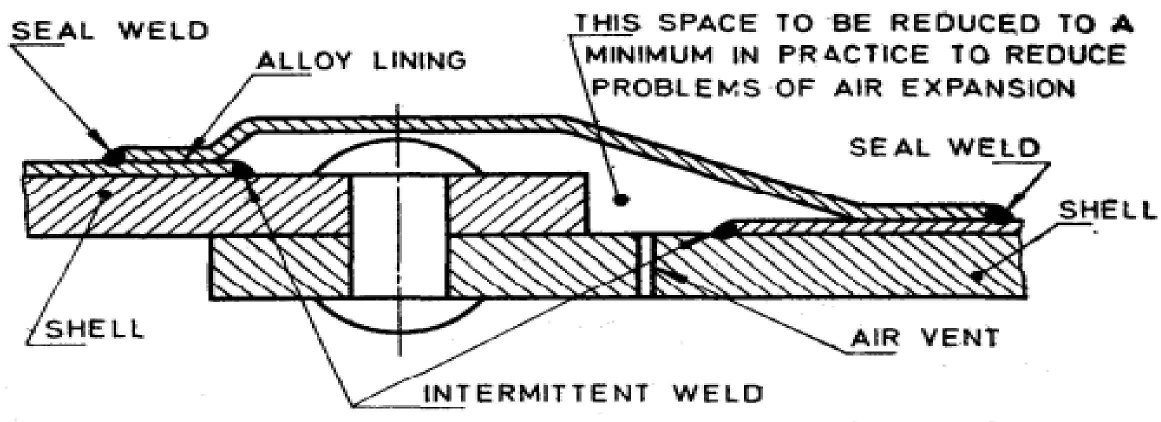


FIG. 4 RIVETED JOINT COVER

Where higher operating temperatures or pressures, or both, are necessary, then low alloy steels may be required.

4.2.2 *Cast Iron* — Where it is necessary for an existing cast iron vessel to be lined, this may be satisfactorily carried out using studs attached to the reverse side of the lining and passing through the vessel wall, as shown in Fig. 5. No attempt shall be made to weld lining materials directly to the surface of ordinary prey cast iron vessels. Backing strips are screwed to the cast iron where any welded joints in the lining occur.

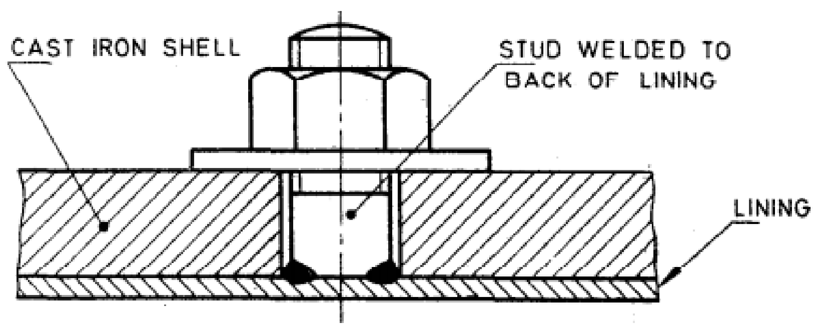


FIG. 5 STUD FIXING METHOD — CAST IRON SHELLS

Another method of construction is one where the lining is riveted to the cast iron vessel by rivets of the same material as the lining. Small sized rivets may be used with considerable benefit.

4.2.3 *Concrete* — Concrete is a suitable material for large vessels, and provision for the fixing of a lining to new vessels shall be included in the design of the vessel. For existing vessels suitable backing strips of steel may be fixed at the points where joints in the lining occur, as shown in Fig. 6. New concrete vessels that are to be lined may have suitable steel backing strips cast in position, as shown in Fig. 7.

In order to avoid corrosion behind the lining, it may be necessary to apply a coating to the vessel, such as bitumen.

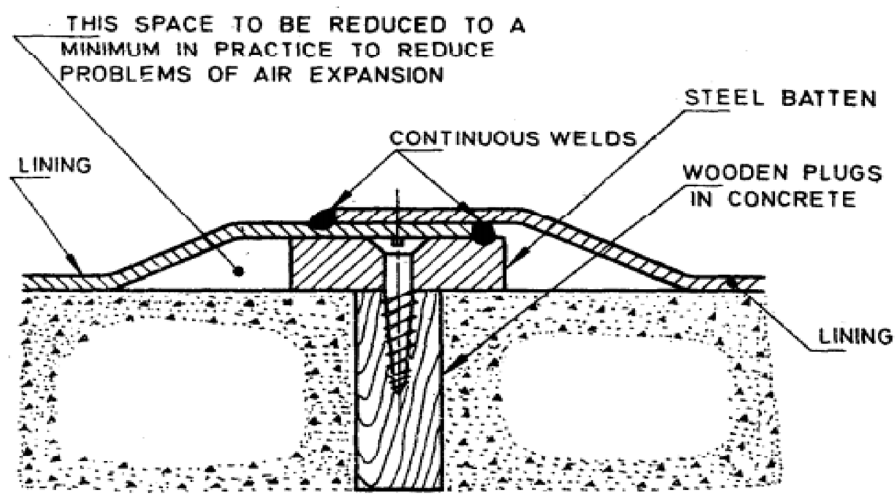
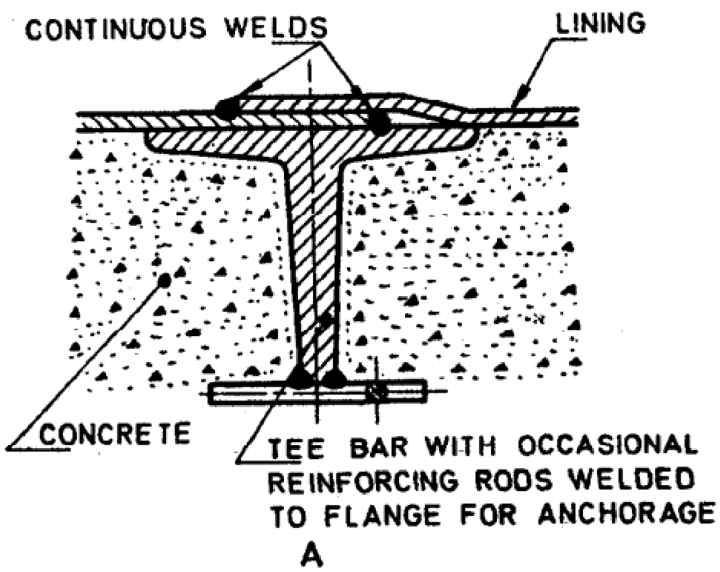


FIG. 6 BATTEN FIXING METHOD — EXISTING CONCRETE VESSELS

4.2.4 *Wood* — New and used vessels of wood are suitable for lining but attention shall be drawn to the danger of shielding corrosion of the surface lining in contact with the wood, if the wood becomes wet. If a used vessel is to be lined it shall be thoroughly cleaned and prepared to ensure against the outer surface of the lining being attached. A number of backing strips shall be screwed or nailed flush with the surface of the vessel to be lined where the joints in the lining occur. The methods of lining the vessels are shown in Fig. 8.



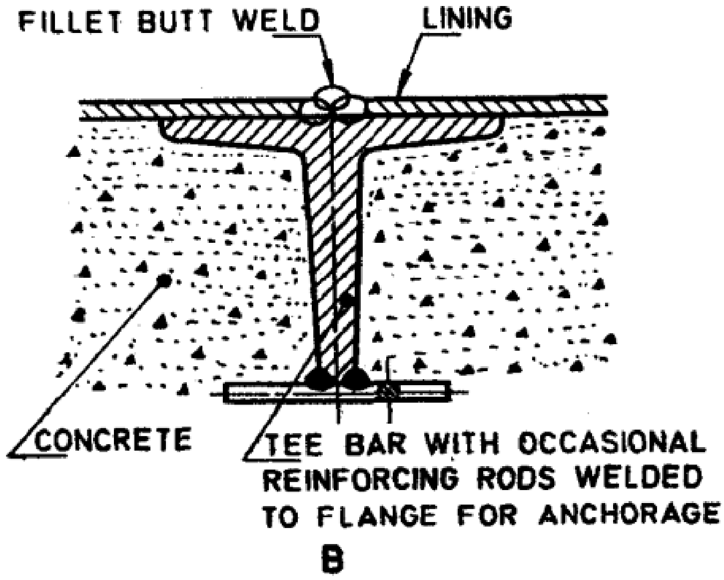
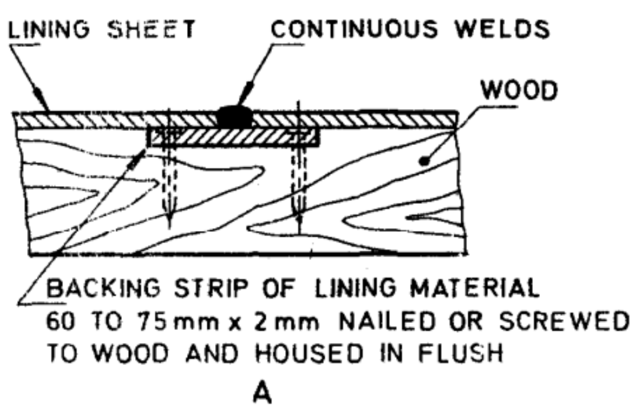


FIG. 7 METHODS OF FIXING LINING — NEW CONCRETE TANKS

4.3 Clad Vessels

A vessel designed to be made from clad material shall have special attention given to ensure that a continuous cladding to the inner surfaces is practicable. Clad plates are available with varying thicknesses of cladding and backing plates.

Because of welding difficulty, it is recommended that the cladding shall not be less than 1 mm. For plates up to 12 mm thick it is suggested that 20 percent cladding fulfils normal requirements and as the total plate thickness increases the percentage of cladding may decrease. On thick plates a cladding of 2.5 mm to 3 mm is usually sufficient to meet corrosion requirements.



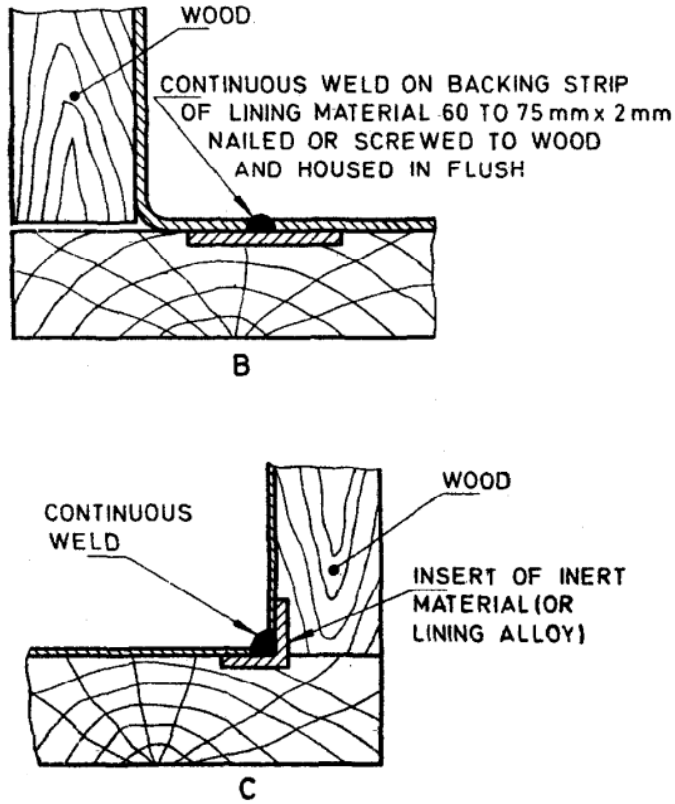


FIG. 8 JOINTS IN LININGS FOR TIMBER VESSELS

Clad plates may be obtained in a variety of sizes and frequently these are greater in size than those obtainable in the solid alloy. The cladding is metallurgic ally bonded to the steel backing plates during manufacture.

Where there is a differential coefficient of expansion between the carbon steel backing plate and the cladding, account shall be taken of the internal stresses which may be produced in the vessel by the temperature variations.

The vessel shall be designed for welded construction throughout and all welds shall be fully detailed on a drawing. In welding clad steels it is important to ensure that the continuity of cladding is preserved and that the corrosion resistance of the weld is not impaired by dilution with the parent metal.

A welded clad vessel may be heat-treated after fabrication, if necessary. Due account shall be given to the effect of this heat treatment which it may have on the backing plates and on the lining materials.

5 DESIGN OF LININGS

5.1 General Factors Affecting Design

The design of lining used will depend upon a number of considerations including:

a) Range of operating temperature;
b) Range of operating pressure;
c) Corrosive media present;
d) Erosion;
e) Accessibility of inner surface for application of lining;
f) Whether lined during original manufacture or after installation;
g) Condition of vessel if already in service; and
h) Cost.

5.2 Integral Cladding

The integral cladding method of lining may be considered only when a vessel is being initially designed for lining. The design considerations for the manufacture of clad vessels are dealt with under **4.3**. Vessels made from clad material using the recommended welding techniques probably offer the best solution to all the relevant design considerations in **5.1**. The bonding of the lining to the shell is good and therefore suitable for vacuum conditions, and this method also gives very good heat transfer properties. A variety of corrosion resistant metals is available for the designer's choice. The hazard of dilution of the weld metal is not great if the approved weld techniques are followed.

Weld preparation on the edges of plates to be butt-welded together is important (*see* Fig. 9) and alignment before welding is vital if sound welds are to be achieved, as shown in Fig. 10.

Four methods of butt-welding plates are in satisfactory use, the first, shown in Fig. 11, being suitable for all ranges of thickness of plate and cladding. The method shown in Fig. 12 is more suited to thick plates and the third and fourth methods, shown in Fig. 13 and Fig. 14, are used when only one ride of the plate is accessible to the welder. Table 1 and Table 2 give recommended alloys for the electrodes used in the welding of clad steels.

Two methods of arranging flanged openings in clad vessels are shown in Fig. 15 and Fig. 16. In both cases provision is made for the sound junction of the flange to the shell plate while at the same time preserving continuity of the clad surface.

5.3 Sheet Lining

The sheet method of lining utilizes sheet material for lining and the sheet is usually applied in the largest pieces that may be handled on the particular application. The sheets are attached to the vessel shell by plug welding through pierced holes (*see* Fig. 17A), or by spot welding as shown in Fig. 17B. When being attached to a finished vessel the sheets shall be held to conform closely to the inner surface contour whilst being fixed and shall be securely held in position during welding.

Table 1 Filler Wires for Welding Martensitic and Austenitic Stainless Steels and Nickel Alloys and for Welding Martensitic and Austenitic Stainless Steels and Nickel Alloys to Mild Steel, also for Welding the Clad Side of Clad Steel – Inert Gas Tungsten Arc and Inert Gas Metal Arc Processes

(*Clause* 5.2)

Sl No.	**Cladding Material**	**Specification for Backing Plates**	**Filler Wire**		**Filler Wire Specification**				**Remarks**
			Root Pass	Subsequent Passes	Root pass TIG to IS 5856/ISO 14343	Subsequent passes TIG to IS 5856/ISO 14343	Root pass MIG to IS 5856/ISO 14343	Subsequent passes MIG to IS 5856/ISO 14343	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	12 % Cr	IS 6911	25/12 CrNi (preferably molybdenum bearing)	25/12 CrNi (preferably molybdenum bearing)	S-BO4 (2.0-3.0 % Mo preferable)	S-BO4 (2.0-3.0 % Mo preferable)	S-BO4 (2.0-3.0 % Mo preferable)	S-BO4 (2.0-3.0 % Mo preferable)	If service conditions demand weld deposit of similar composition to the cladding, a special low carbon 12 percent Cr wire shall be used and a preheat of 200 °C is recommended. A post weld heat treatment of 700 °C - 750 °C is also desirable.
ii)	18/8 CrNi or 18/8 CrNi and Nb stabilized	IS 6911	25/12 CrNi (preferably molybdenum bearing)	18/8 CrNi	S-BO4 (2.0-3.0 % Mo preferable)	S-BO1Nb	S-BO4 (2.0-3.0 % Mo preferable)	S-BO1Nb	—
iii)	18/8/3 CrNiMo	IS 6911	25/12 CrNi (preferably molybdenum bearing)	18/8/3 CrNiMo	S-BO4 (2.0-3.0 % Mo preferable)	S-BO2Mo	S-BO4 (2.0-3.0 % Mo preferable)	S-BO2Mo	—
iv)	25/12 CrNi	—	25/12 CrNi (preferably molybdenum bearing)	25/12 CrNi	S-BO4 (2.0-3.0 % Mo preferable)	S-BO4	S-BO4 (2.0-3.0 % Mo preferable)	S-BO4	—
v)	25/20 CrNi	—	25/20 CrNi (preferably molybdenum bearing)	25/20 CrNi	S-BO4 (2.0-3.0 % Mo preferable)	S-BO5	S-BO4 (2.0-3.0 % Mo preferable)	S-BO5	—
vi)	Nickel	—	Nickel with Ti and Al additions		IS 5857 S-Ni 1	—	IS 5857 S-Ni 2	—	—
vii)	NiCu alloy	—	NiCu alloy Ti and Al additions		IS 5857 S-Ni 2	—	IS 5857 S-Ni 2	—	—

viii)	NiCrFe alloy	—	80/20 NiCr	—	IS 5857 S-Ni 3	—	IS 5857 S-Ni 3	—	Contains 3 percent manganese. Deposits from this wire will age-harden at stress – relieving temperatures of steel.
ix)	—	—	NiCrFe alloy with No, NiCrFe alloy with Ti		IS 5857 S-Ni 4	—	IS 5857 S-Ni 5	—	

Table 2 Flux Coated Electrodes for Joining Martensitic and Austenitic Stainless Steel and Nickel Alloys to Steel, and for Welding the Clad Side of Clad Steel – Manual Metal Arc Process only
(*Clause* 5.2)

Sl No.	**Cladding Material**	**Specification for Backing Plates**	**Electrode Material**		**Electrode Specification**		**Remarks**
			Root Pass	Subsequent Passes	Root Pass	Subsequent Passes	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	12 % Cr	IS 6911	25/12 CrNi (preferably molybdenum bearing)	25/12 CrNi (preferably molybdenum bearing)	IS 5206 S-BO4 (2.0 % - 3.0 % Mo addition preferable)	IS 5206 S-BO4 (2.0 % - 3.0 % Mo addition preferable)	If service conditions demand electrodes of similar composition to the cladding, a special low carbon 12 percent Cr weld rod shall be used and preheat of 200 °C is recommended. A post weld heat treatment at 700 °C – 750 °C is also desirable.
ii)	18/8 CrNi	IS 6911	25/12 CrNi (preferably molybdenum bearing)	18/8 CrNi	IS 5206 S-BO4 (2.0 % - 3.0 % Mo addition preferable)	IS 5206 S-BO1	—
iii)	18/8 CrNiTi or Nb stabilized	IS 6911	25/12 CrNi (preferably molybdenum bearing)	18/8 CrNi (Nb stabilized)	IS 5206 S-BO4 (2.0 % - 3.0 % Mo addition preferable)	IS 5206 S-BO1 Nb	—
iv)	18/8/3 CrNiMo	IS 6911	25/12 CrNi (preferably molybdenum bearing)	18/8/3 CrNiMo	IS 5206 S-BO4 (2.0-3.0% Mo addition preferable)	IS 5206 S-BO3 Mo	—
v)	25/12 CrNi	—	25/12 CrNi (preferably molybdenum bearing)	25/12 CrNi	IS 5206 S-BO4 (2.0 % - 3.0 % Mo addition preferable)	IS 5206 S-BO4	—
vi)	25/20 CrNi	—	25/12 CrNi (preferably molybdenum bearing)	25/20 CrNi	IS 5206 S-BO4 (2.0 % - 3.0 % Mo addition preferable)	IS 5206 S-BO5	—

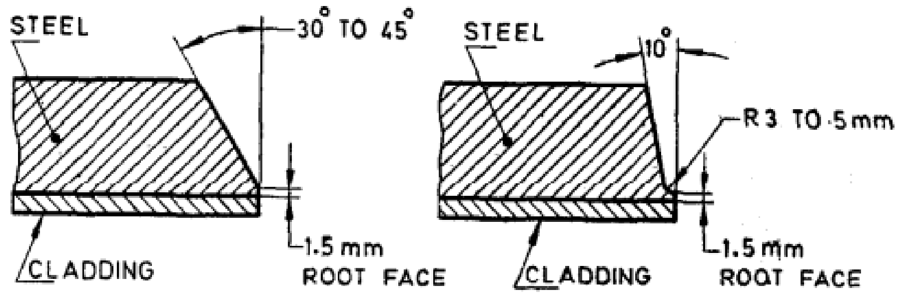


FIG. 9 ACCEPTABLE TYPES OF EDGE PREPARATION OF CLAD PLATES FOR WELDING

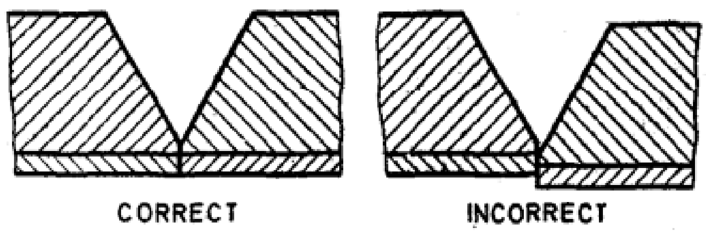


FIG. 10 EDGE ALIGNMENT OF CLAD PLATE FOR WELDING

Sheet lining is not recommended where severe temperature, gradients or frequent cyclic operations occur. For steady temperatures or vacuum working the spacing of plug welds shall not exceed 75 mm between centres. Where vessels operate at normal pressure and room temperature, spacings up to 300 mm may be considered.

Access for any preformed parts shall be considered and this will dictate the size of pieces and the general pattern of lining adopted.

Sheet lining offers a wide choice of materials and thicknesses, enabling most corrosion problems to be met. The risk of dilution of the lining material during its attachment to the shell shall be carefully guarded against and in general it is to be expected that where attachment is made, directly to the shell by welding, spot welding or plug welding, some dilution of the lining will occur. Where this is be tolerated it is first necessary to fix a pattern of backing strips to the shell to coincide with the joints in the lining sheets and then weld the lining to these.

Sheet linings are not the most suitable for vacuum working conditions, and for this duty shall be avoided if possible in favour of other methods. Variations in temperature may also lead to weld fractures where the lining material differs in expansion coefficient from the shell material. Due to the air space present, heat transfer across the lined shell wall is poor.

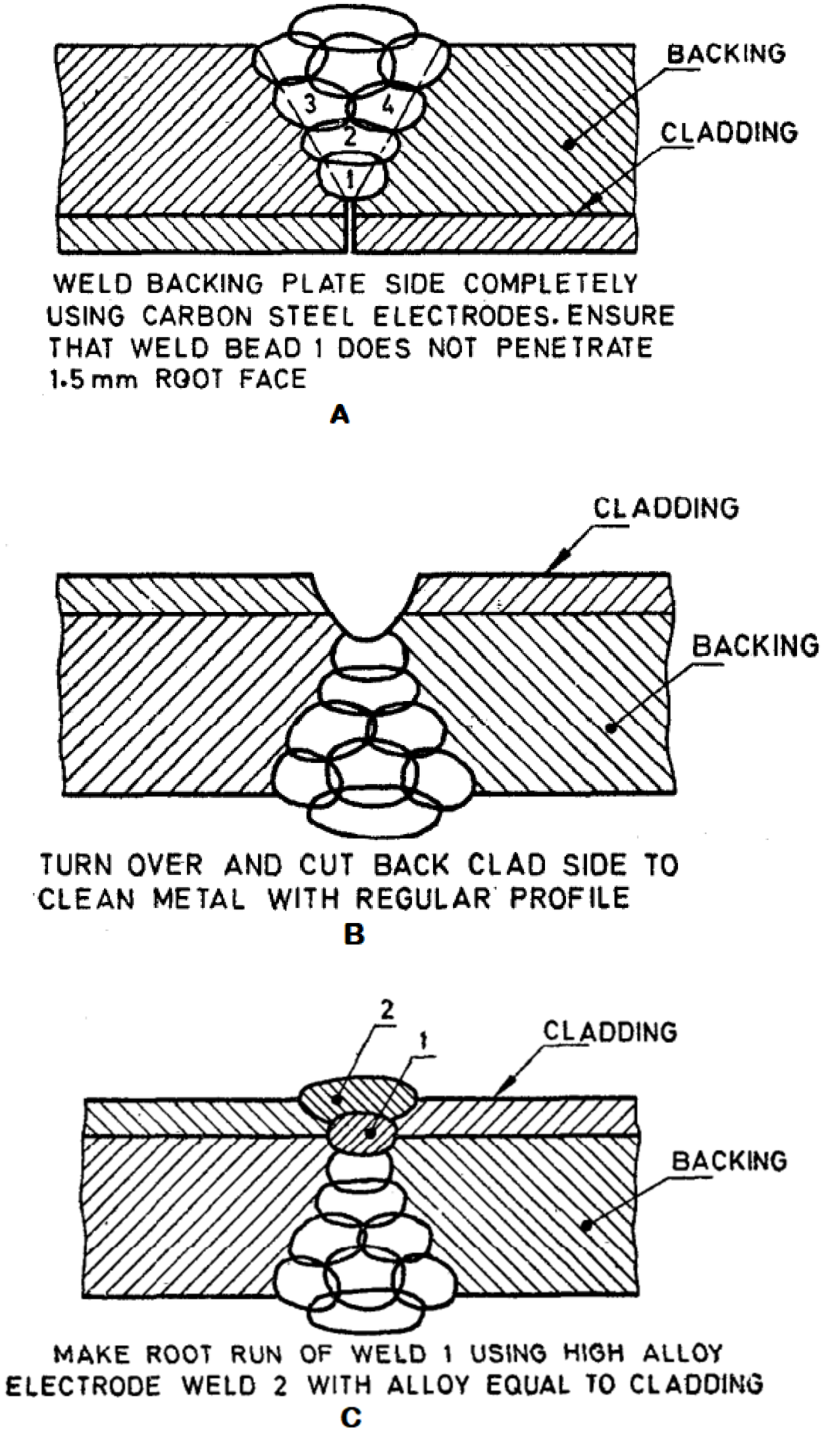


FIG. 11 WELDING SEQUENCE FOR CLAD PLATE

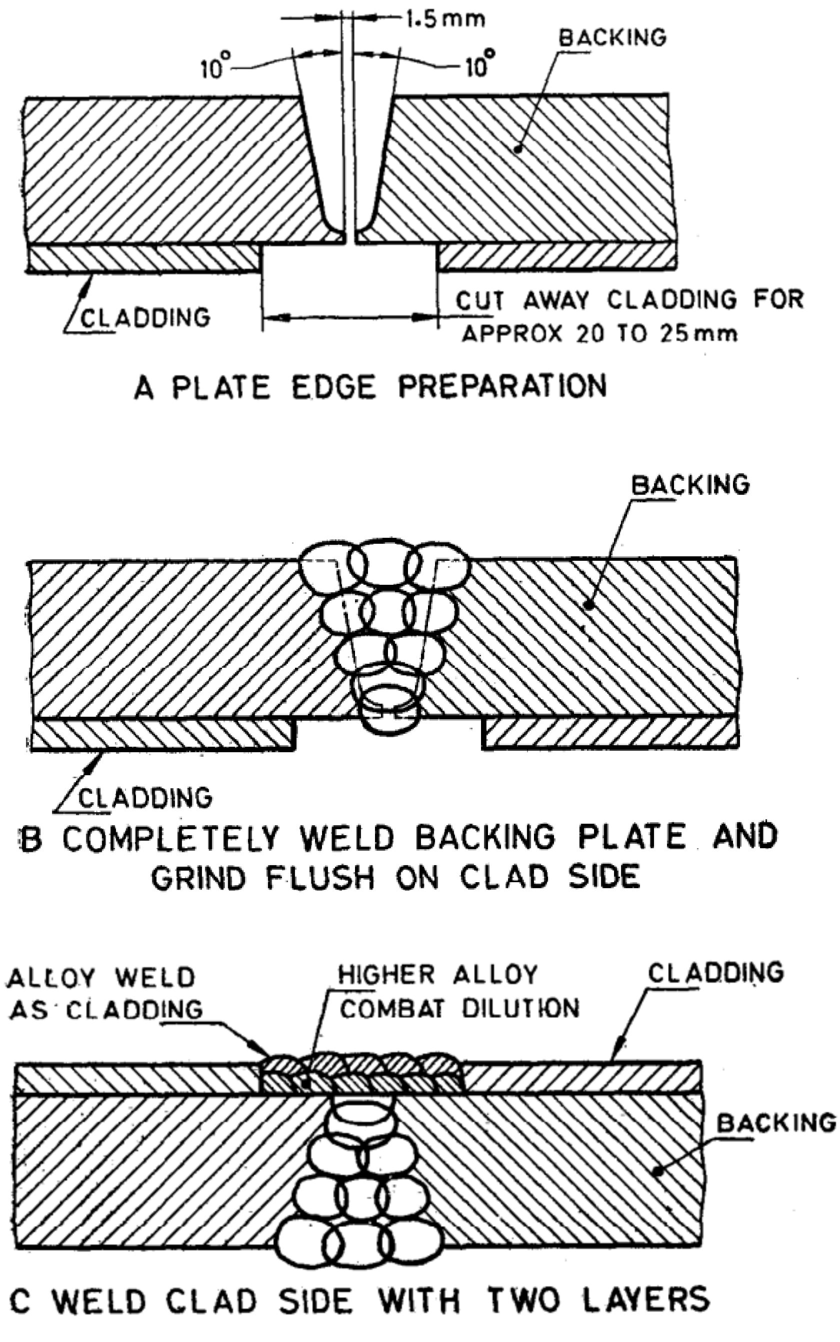
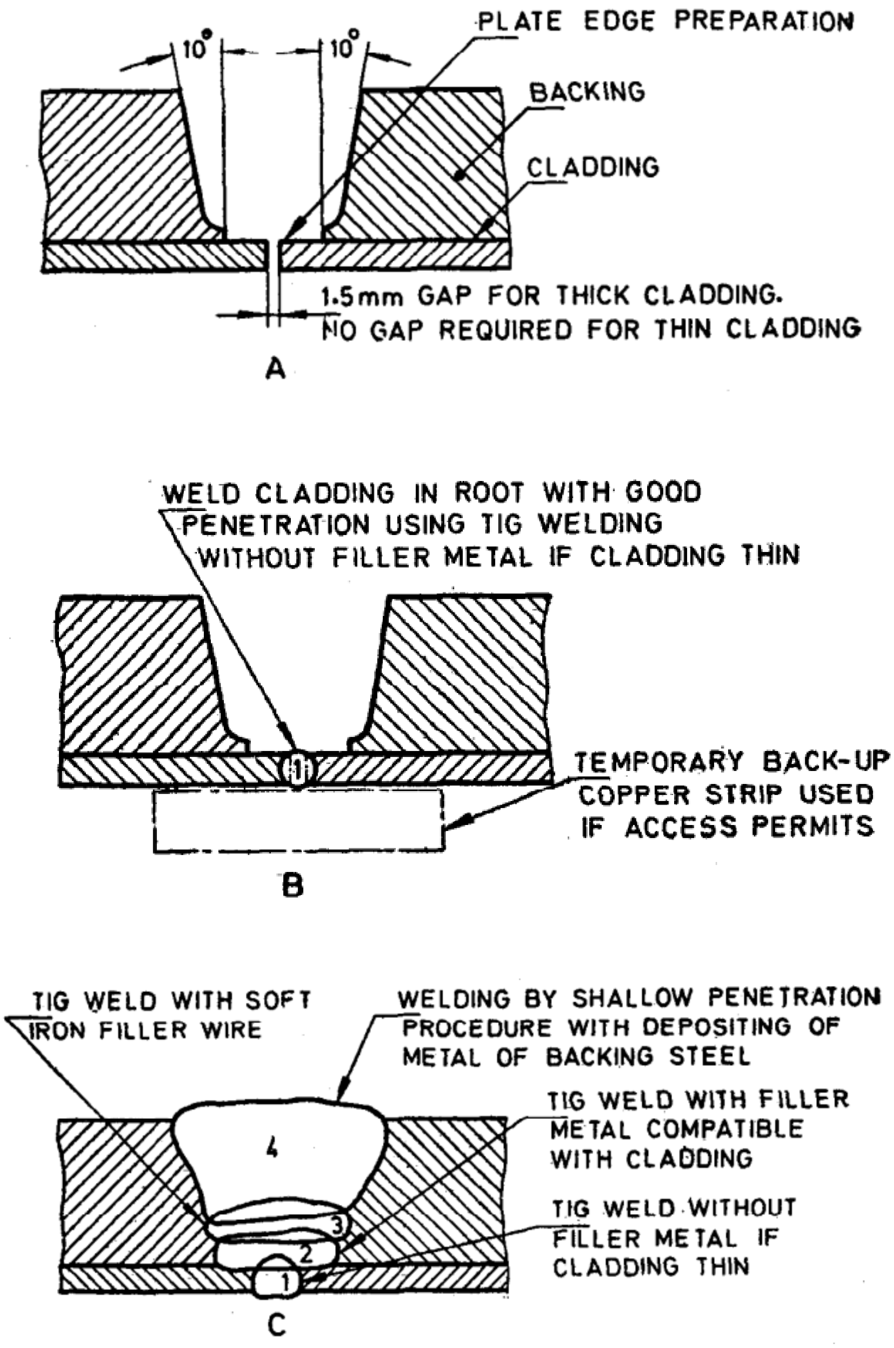


FIG. 12 WELDING SEQUENCE FOR CLAD PLATES — THICK PLATES



NOTE — In some cases it may be desirable to weld completely in alloy electrodes.

FIG. 13 WELDING SEQUENCE FOR CLAD PLATE WITH ACCESS TO BACKING SIDE ONLY

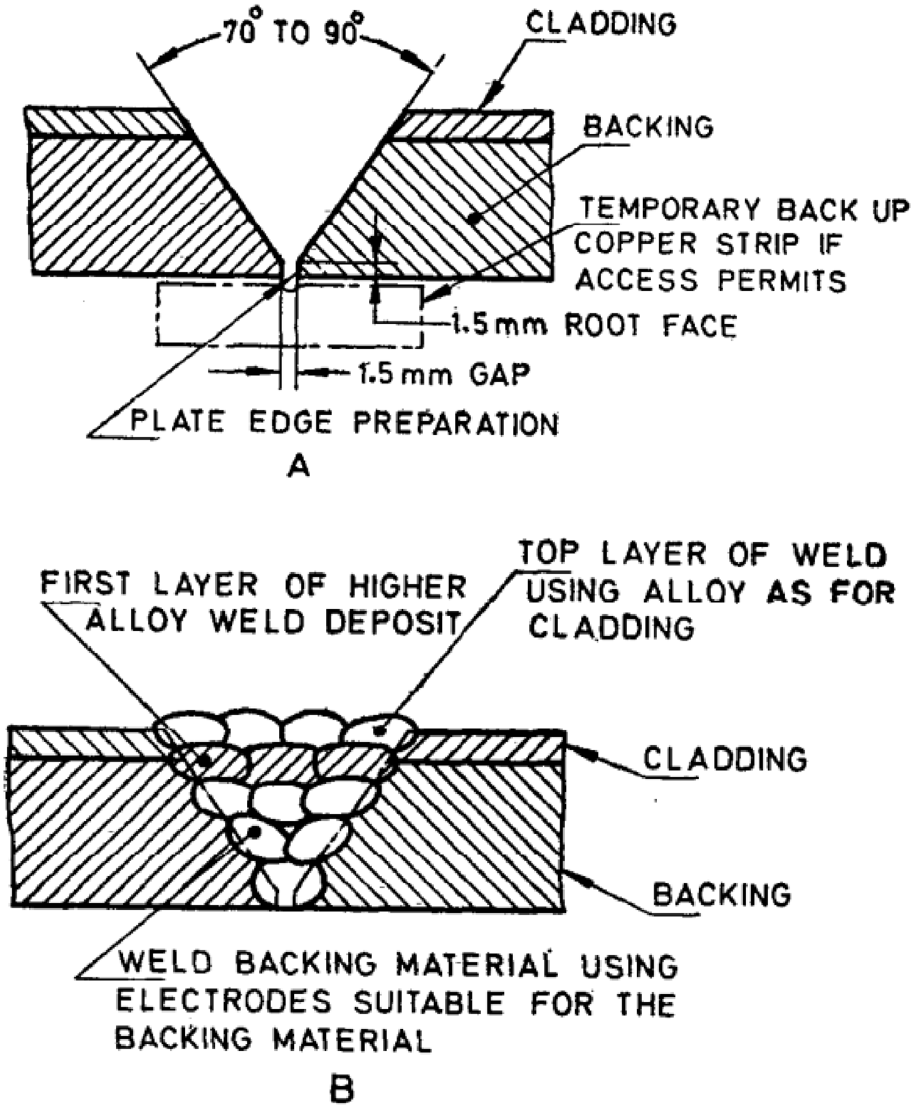


FIG. 14 WELDING SEQUENCE FOR CLAD PLATE WITH ACCESS TO THE CLAD SIDE ONLY

The cost of installing sheet lining is appreciably less than strip lining and is best suited for use on existing vessels with good access, not too severe corrosive conditions and not under vacuum.

5.4 Strip Lining

The strip method employs the use of small strips of lining material cut and formed to be a good fit to the inner surface of the vessel to be lined and welded into position. The entire surface is shielded in this manner and the pattern of strips employed is varied to suit the profile of the vessel. Depending upon the temperature range, also the pressure or vacuum expected, the width of the strips is varied from 150 mm to 5 mm (*see* Table 3). The length of strip will depend upon local conditions (*see* **6.3**). The reduced width for austenitic stainless steels is because of the higher thermal expansion compared with ferritic/martensitic steels and there is a greater susceptibility of the former to buckling. Dished heads and the knuckle radii joining them to the shell wall may be lined by a pattern of pieces as shown in Fig. 18 or Fig. 19. A number of different methods may be employed to weld the strips in position to suit operational requirements and these fall into four main groups: (a) lap or joggle, (b) butt strap, (c) shingle, and (d) fillet butt. These are illustrated in Fig. 20.

Strip lining offers better performance than sheet lining for fluctuating high temperature and pressure conditions. For vacuum conditions the width and thickness of the strip shall be calculated. The hazard of dilution of the weld metal by the shell may largely be eliminated by the correct choice of welding technique. Access need not be more than is normal for any vessel and all parts passes through a-normal 450 mm manhole. Internal fittings may be sealed by the use of strips cut to suit. The surface conditions of used vessels shall be brought to a reasonably smooth condition and any deep pitting welded up to ensure a good bond between lining and shell.

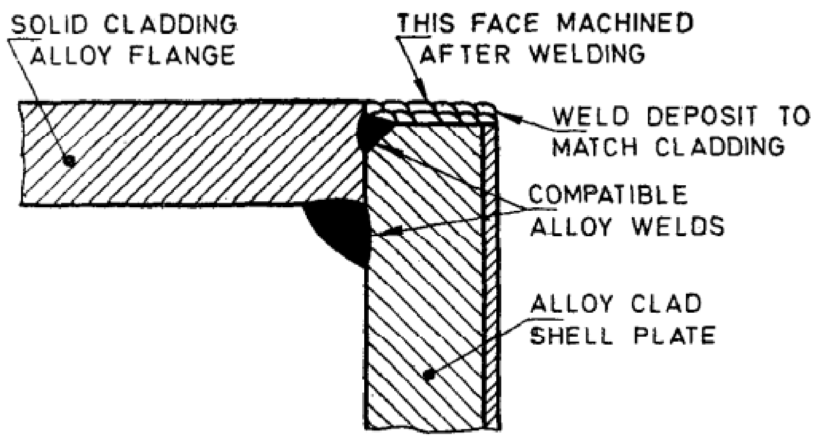


FIG. 15 SOLID FLANGE ON CLAD SHELL

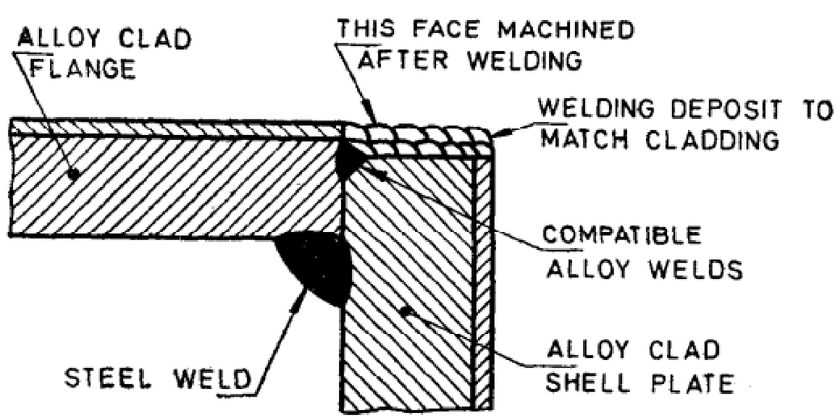


FIG. 16 ALLOY CLAD FLANGE ON CLAD SHELL

Table 3 Maximum Recommended Strip Widths for Varying Temperature Conditions
(*Clause* 5.4)

		Maximum Strip Width

Sl No.	**Maximum Operating Temperature** °C	Ferritic/Martensitic Chromium Steels mm	Austenitic Nickel Chromium Steels mm
(1)	(2)	(3)	(4)
i)	Up to and including 230	150	150
ii)	Over 230 to 400	115 to 130	75 to 100
iii)	Over 400 to 455	100	65 to 75
iv)	Over 455 to 510	90	—
v)	Over 510 to 540	75	—

5.5 Weld Metal Overlay

A layer of corrosion resistant weld metal is deposited on the inner surface of the shell. This is carried out by manipulating the shell and using automatic or semiautomatic arc welding processes. For localized areas around branches and fittings manual arc weld deposits may be used. Some weld metal dilution is unavoidable in the first run and it may be necessary to make a second pass over the surface being clad, giving a very reduced pick-up from the shell material.

However, by using an over alloyed filler material in relation to the cladding analysis desired, a satisfactory single layer cladding is sometimes possible. Preheating is recommended to minimize stresses. This method of lining is useful for thick vessels as an alternative to clad plate. It calls for a fabrication shop with specialist facilities to undertake the work and is more-suitable for cylindrical vessels.

5.6 Thickness of Lining

5.6.1 General *Consideration* — The thickness of the lining material shall be decided by considering the following:

a) Desired life of vessel;
b) Corrosion allowance;
c) Erosion allowance;
d) Complexity of shape of lining;
e) Duty of the vessel, particularly with respect to temperature or pressure cycling and including start-up and shut-down and the possibility of vacuum conditions being encountered;
f) Method of lining;
g) Location where lining is to be carried out; and
h) Cost.

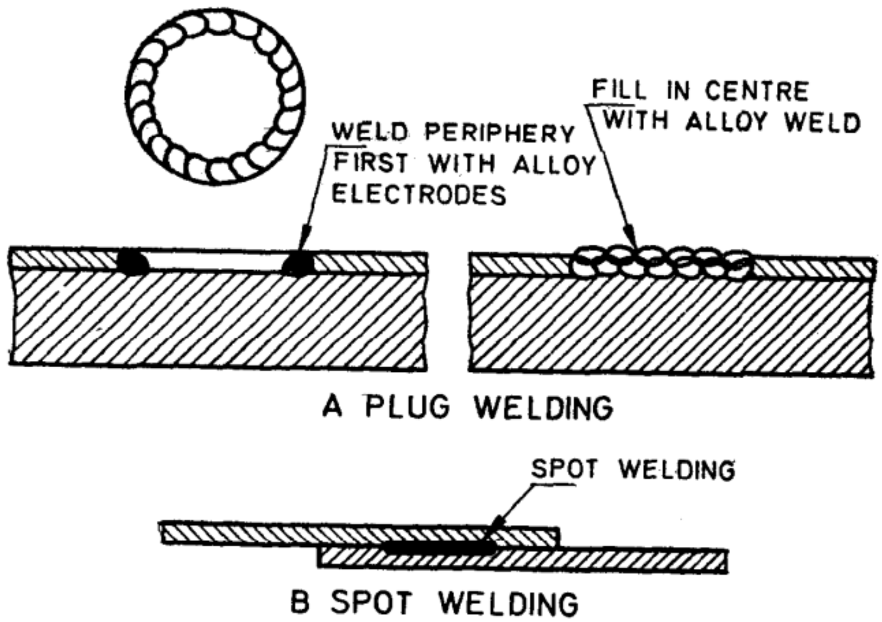


FIG. 17 WELDS FOR FIXING OF LINING SHEETS

It is prudent to calculate for the lining to last the total life of the vessel. Even with the provision of test and inspection holes, any failure in the lining is likely to be detected only after considerable damage is sustained by the outer shell. The correct choice of alloy for the lining is very important.

Where erosion is expected, such as opposite tangential inlet branches, nozzles, etc, it is good practice to fit as thicker panel to act as a wear plate so that the losses by erosion match that by corrosion elsewhere in the vessel.

5.6.2 *Sheet Linings* — Normally sheet linings are 3 mm thick. Sometimes the thickness is increased to 4.5 mm in connection with severe corrosive or erosive conditions. Where the method of fixing is by fusion welding, linings thinner than 1.5 mm are not recommended, as the application becomes very difficult and the increase in cost exceeds the saving in material.

5.6.3 *Strip Lining* — Normally it is adequate for linings to be a maximum of 3 mm thick and a minimum of 1.5 mm. Strip linings are frequently made in 2 mm or 2.6 mm material with good results. These thicknesses enable the strips to be formed to the contour of dishings and corner radii where dishings and cylinders meet. The longer straight strips on the cylindrical portion of vessels may be pushed into position by hand and tack welded into the shell without prior forming being exact.

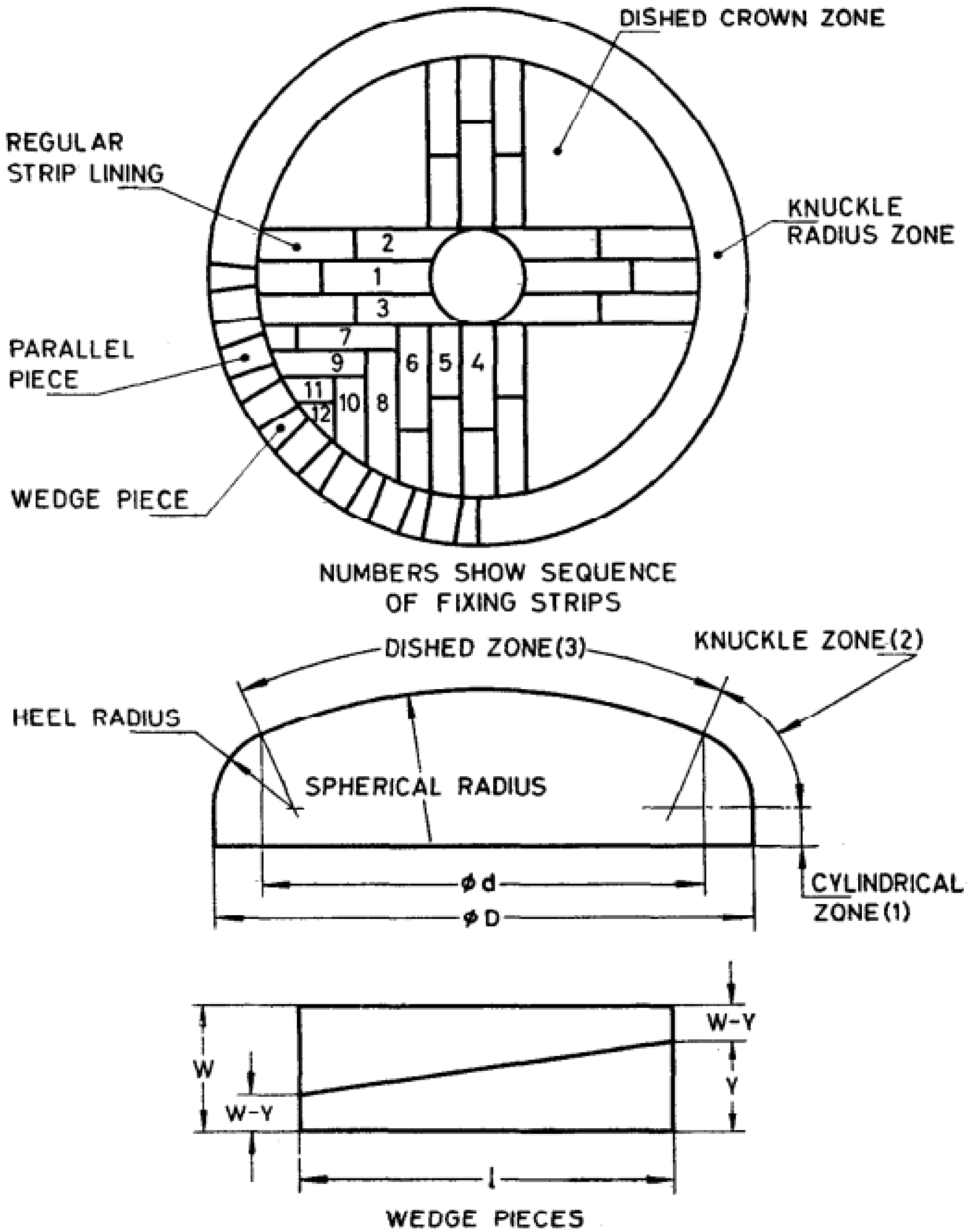


FIG. 18 LAYOUT OF STRIPS FOR LINING DISHED HEADS

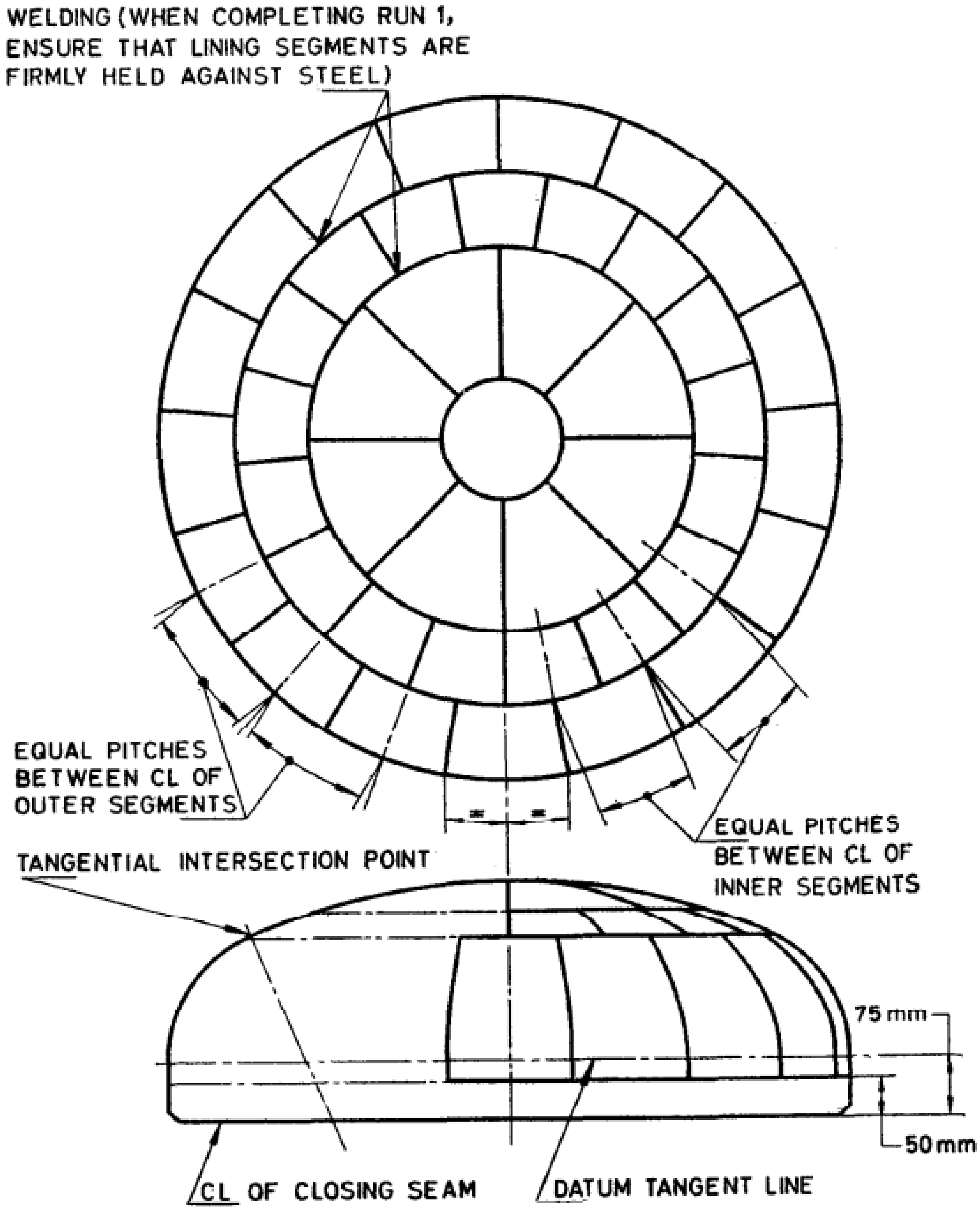


FIG. 19 ALTERNATIVE LAYOUT OF SEGMENTS FOR DISHED HEADS

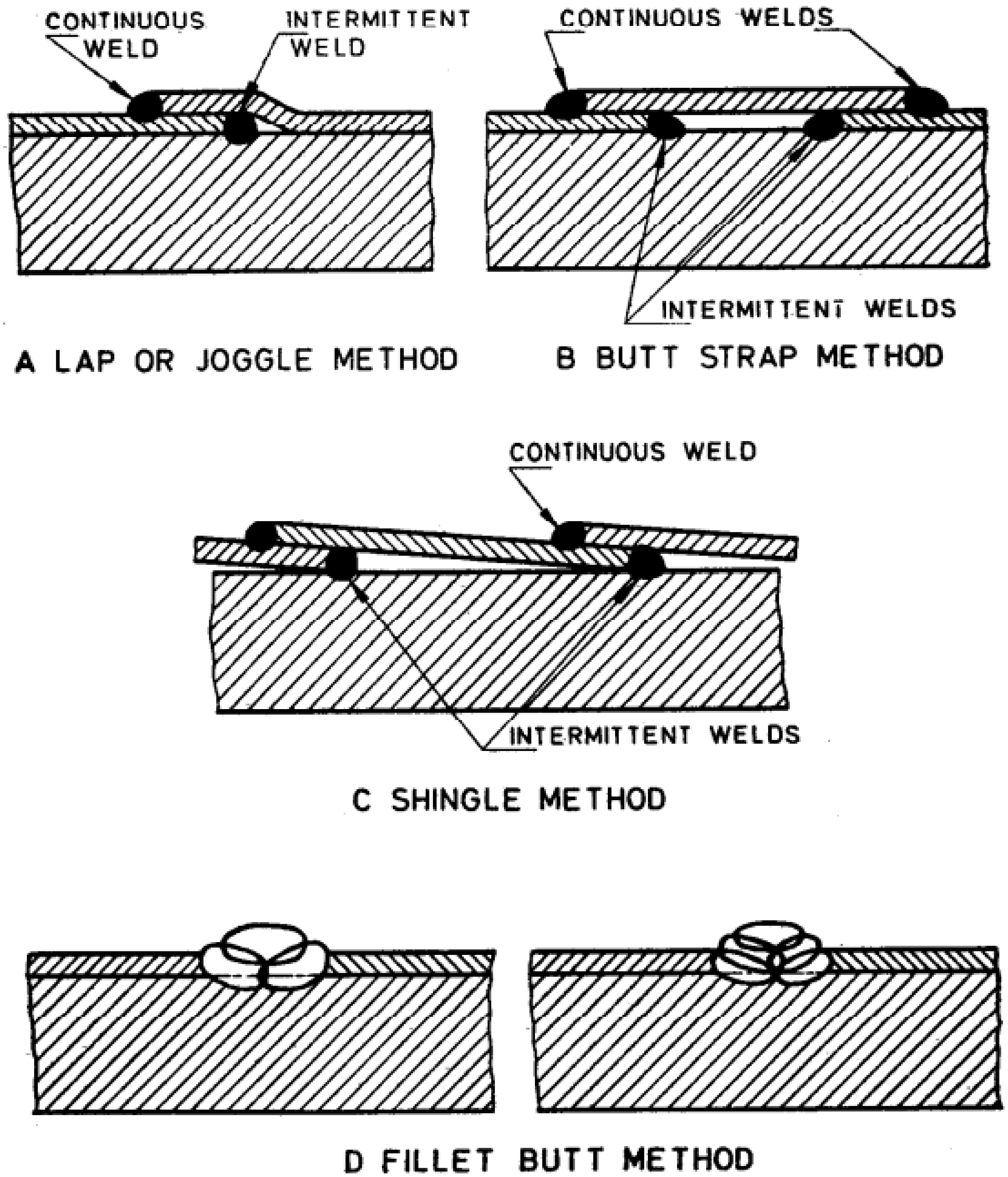


FIG. 20 TYPES OF STRIPS LINING METHODS

It is recommended that strip linings not less than 1.5 mm thick be used for floors and walls of vessels where the welding will be done in the down hand, vertical and horizontal positions. If overhead welding is required, such as for heads in situ, 2 mm is the minimum thickness recommended. Thinner linings may be used but they require a higher degree of welding skill and this, together with the necessity to be precise with the fitting, greatly adds to the labour costs and often will be more costly than heavier linings.

5.6.4 *Integral Cladding* — Integral clad plates for vessels shall have a minimum of 1 mm of cladding if the plate is 5 mm thick. Twenty percent thickness of cladding is usually adequate for the normal range of plate thickness and on thick plates a maximum of 2.5 to 3 mm is generally sufficient.

5.6.5 *Weld Overlay* — The minimum thickness of the corrosion resistant layer applied by this method is 2 mm. For severe service duty this shall be increased to 6 mm. Weld overlays thinner than 2 mm are not recommended in view of the dilution effect from the base metal. To minimize the dilution effects it may be necessary to specify the minimum number of deposited layers.

5.7 Internal Fittings in Lined Vessels

It is recommended that the material to be used for the fittings inside a vessel that is to be lined shall be as resistant as that used for the lining, and wherever possible of the same alloy.

The welding process and tiler material shall be chosen to give the best bond with the shell and the correct corrosion resistant properties.

Great care shall be taken to ensure that the lining is continuous in the vicinity of fittings.

6 METHODS OF LINING

6.1 Preparation of Material

The cutting of alloy material shall be done with great care, and where heat is being used for cutting the material the burnt material shall be removed by mechanical means. Grinding shall be done with an uncontaminated wheel and care exercised that large amounts of heat are not generated.

In fabricating nickel and nickel alloys, precautions shall be taken to prevent pick-up of sulphur.

Before sheet or strip linings or integral clad plates are welded, all surfaces in the proximity of the weld zone shall be cleaned. Oil and grease may be removed by a suitable solvent; light rust by wire brushing; and scale by grinding or grit blasting. The suppliers of materials have their recommended methods for achieving clean conditions and these are generally be used.

Filler metals, such as hare wires or strips, shall be degreased and flux coated electrodes shall be oven-dried to manufacturer’s recommendations.

The surface of the vessel to be lined shall be smooth and free of sudden changes in contour, and any blemishes made good. In the case of metal vessels, the surface to be lined may be rectified by welding and grinding, provided the necessary precautions applicable to the backing material are taken.

In the case of the relining of wood vessels, these shall be free of corrosive media, to avoid shielding corrosion.

6.2 Sheet Lining

6.2.1 *General Considerations* — Sheet linings may be applied to steel, cast iron, concrete and wooden vessels. The layout of panels for the lining shall be first detailed on drawings and then carefully cut out to the exact shape. With used vessels, which may be irregular in shape, it is sometimes preferred to cut the exact shape of each piece as the job proceeds. Where the wall contour is irregular or acutely curved, preforming the panels near the contour is advisable. Where the material is severely cold worked it shall be heat-treated and descaled before fitting. Where the contour is uniformly curved preforming may not be necessary, provided that the panels are properly pressed tightly against the shell wall by suitable struts or jacks.

The size of the lining panels will depend upon access land shall be as large as possible so as to reduce the welding of edges to a minimum.

6.2.2 *Carbon Steel Vessels* — The holes for plug welding the centre of the panels to the vessel are usually punched or drilled, and with panels 3 mm thick and less, these need not be chamfered. For austenitic steel, punching shall be avoided. The diameter of the holes shall be between 12 mm and 25 mm. The plug holes are best welded by first welding the edge of the hole to the shell, forming an unbroken ring of weld. This may be wire brushed with a brush of a material compatible with that of the sheet and inspected before filling in the centre with weld as a separate operation. It is possible to combine the welding of the edge of the plug hole with the filling-in stage and in this case it is beneficial to reduce the hole size.

The panel shall be located in position by jacking or clamping, the central plug hole welded to the shell, and then work continued progressively outwards until all plug holes are tacked. The edge of the panel is then tack-welded to the shell with stitch welds about 12 mm to 25 mm long at not more than 150 mm centres. When the first panel has been fixed the adjacent ones shall be similarly fixed before the edges of the panel are seal-welded to the shell. The gap between each panel shall be between 6 mm and 8 mm according to thickness of the lining, and a three-weld bead technique shall be used, as in Fig. 20D. If desired, panels may be joggled and lapped over the adjacent panel as described in **6.3**.

The lining may also be fixed to the shell by MIG-spot welding (inert gas consumable electrode spot welding). This has the advantage that for thin linings no hole is required, which saves the cost of drilling and demands less care in positioning of the torch. With thicker linings a hole is required, but this will be much smaller (diameter equal to or little greater than the thickness) than that needed for plug welding. TIG-spot welding (inert gas tungsten arc spot welding) may be used, but is less advantageous in that a hole is necessary, with smaller thickness of lining and there is probably more dilution; also the addition of filler wire has to be made manually.

Where no weld dilution whatsoever is permitted, backing strips of the same composition as the lining may be first fixed to the vessel wall to coincide with the pattern of joints in the panels of lining materials. These may be either welded, riveted or screwed in position, care being taken to stagger the fixing to miss any welds in the lining sheets. A small air space is unavoidable with this method, which would be undesirable in applications where good heat transfer qualities are required.

6.2.3 *Cast Iron Vessels* — While attaching linings to cast iron vessels, studs through the vessel wall may be used to fix the lining panels from the outside, and this has the advantage of offering a very smooth and clean finish to the inner surface (*see* Fig. 5). Due to difficulty of location of studs and holes in the shell its use is limited to the more simple applications.

6.2.4 *Concrete and Wooden Vessels* — The technique of fixing backing strips to the vessel wall described in **6.2.2** may be used while fixing linings to concrete or wooden vessels and some types of joints are shown in Fig. 6, Fig. 7 and Fig. 8. Also, in the case of concrete and wooden vessels the backing strips may be satisfactorily fixed in position with a 'nail gun', using pins fixed through the backing strip into the concrete. Care shall be taken to experiment with cartridge strength to ensure that the heads of the fixing pins are flush with the face of the backing strip.

6.3. Strip Lining

Strip lining may be satisfactorily carried out on welded carbon steel vessels. Strips are normally formed to shape to conform to the contour of the vessel. The length of the strips is varied to suit local conditions, for example, if lining is applied in a shop with all normal factory facilities available, strips from 600 mm to 3 000 mm length may be used. However, if work is being undertaken in the field the maximum length shall be reduced to 1 000 mm. The widths of strips vary between 50 mm and 150 mm. The narrower widths are used for linings which operate at high temperatures or experience severe thermal cycle. For strip linings in stainless steels 3 mm thick or less and which are to be operated at elevated temperatures the maximum widths recommended are given in Table 3.

Fig. 20 shows four methods of fixing strips, namely:

a) Lap or joggle;
b) Butt strap;
c) Shingle; and
d) Fillet butt.

The lap or joggle, butt strap and shingle methods for fixing prevent any detrimental effect from weld metal dilution. However, they are much more costly in lining material than the fillet butt method and the covered welds in these lapped methods cannot be inspected in service. With the lap or joggle method a forming operation is required for the joggled edge, with the butt strap method four weld heads are employed for each joint, with the shingle method it is difficult to make a proper fit of the lapping edge and finally, these lapped linings will not withstand high hydrostatic pressure without a tendency to pull away the lapped weld bead.

A three-weld bead technique may be used to minimize dilution from the shell material. A further precaution against dilution may be achieved by the use of higher alloy electrodes than the lining material, for example, 25/12 chromium-nickel electrodes are often used for intermediate and buffer layers while welding stainless steel linings to carbon steel.

It has been found in special cases where a higher alloy is not used, such as pure nickel and nickel alloy liners, that the dilution effect in the weld may be further reduced by using a five-bead technique for the fillet butt joint.

With the fillet butt method the strips are tack-welded to the shell with a gap between 6 mm and 8 mm wide according to the thickness of the lining and the position of the weld, that is, down hand, horizontal or vertical. The overriding consideration in fixing the gap width is to ensure that when two adjacent strips have been welded as shown in Fig. 20D the shell is completely covered. In this way dilution of subsequent runs of weld with shell material is kept to a minimum.

The method of fixing strips in position on flat or cylindrical surfaces is as follows:

The first strip is applied horizontally to the vessel wall, pressed firmly into contact with the wall and tack-welded in position. A number of such strips may be tacked -at a time if so desired once the required spacing has been established. The strips are then welded with one or two weld beads all round according to the method shown in Fig. 20D. The strips are then tested and inspected and any leaks repaired (*see* **7.2.2**). The strips are then thoroughly dried and cleaned and subsequent weld beads added according to whether the three- or five-weld bead technique has been agreed between the customer and the contractor. In manual metal arc welding a slight weaving of the top cover bead may be permitted.

Strip lining mau be carried out satisfactorily on the dished, ellipsoidal, conical and hemispherical heads commonly used in construction of pressure vessels. A suitable method of arranging the lining plates for a dished head is as follows:

As shown in Fig. 18, the surface of the dishing is considered to be in three zones:

a) The cylindrical portion designed for direct attachment to the shell;
b) The knuckle radius; and
c) The dished crown.

The cylindrical zone shall be included in the pattern of strips used to line the wall of the vessel and this shall extend to the tangent line where cylinder and knuckle meet.

The knuckle radius zone is a relatively short radius area and is lined with a series of narrow width strips arranged radially. The length of the strip is arbitrary but shall extend from the tangent line to a point between 50 mm and 75 mm beyond the actual intersection points of the knuckle and the dishing radius. This shall not exceed 300 mm and normally 200 mm to 250 mm suffices and this gives reasonable flexibility of fit-up. These strips shall be a combination of rectangular and wedge-shaped pieces.

The measurements of the wedge-shaped pieces shown in Fig. 18C may be determined for any particular size and shape of dished head by comparing the periphery of the inside diameter of the dished head with that of the diameter of the intersection zones (2) and zone (3). A suitable measurement for Y and W- Y in Fig. 18C may be chosen and a number of such wedge shaped pieces arrived at.

For very large heads the use is recommended of one wedge-shaped piece to two rectangular pieces while with very small heads two wedges to one rectangular gives a better arrangement.

Before strip lining starts the tangent line between the straight portion and the knuckle radius shall be marked on the vessel wall and a circle shall be scribed showing the extent of the knuckle strips on the dished area of the pressing.

In attaching the strips to this knuckle area an effort shall be made to keep the long edges of the strips radial and this is easily checked as work proceeds. Adjustment may be made from time to time either by using a specially cut wedge or by inverting one of the existing wedge pieces.

The dished zone is lined by using a herringbone pattern of layout and a practical sequence for doing this is shown in Fig. 18. The knuckle radius zone having been completed at this stage, the ends of the parallel strips may be cut to produce a satisfactory fit-up for welding to the knuckle strips.

As an alternative to lining the knuckle radius and dished crown with strips shaped as described above, equal segments may be used as shown in Fig. 19.

The segments shall be arranged radially and shall be performed to the correct shape. The width of the segments will be determined by the size and shape of the dished head; for large diameter heads it will be found necessary to increase the number of knuckle and crown radii segment plates.

6.4 Weld Metal Overlay

A layer of corrosion resistant weld metal is deposited on the surface of the plate in contact with the corrosive environment. This may be carried out by any of the manual, semi-automatic or automatic metal arc processes, generally in a down hand position, using round or strip electrodes.

Cylinders and formed heads are best positioned on suitable manipulators. The base metal surface to be layered shall be clean and descaled by either grit blasting or grinding. Preheat may be applied, where the type of base metal and thickness warrants, in order to prevent possible heat affected zone defects.

Due to fusion of the base metal, some dilution of the weld metal occurs in the first run. The effect of this, however, may be reduced by depositing a layer of over-alloyed material. Diffusion of base metal elements into the weld metal is greatly reduced by a second layer and may possibly be eliminated at the surface of a third layer.

Weld metal overlay method of lining is particularly suitable for heavy sections.

7 INSPECTION, TESTING, MAINTENANCE AND REPAIR

7.1 Inspection

7.1.1 Quality control of the material and fabricating procedures for loose lined, overlayed and clad equipment is very important since failure in service may cause irreparable harm. Inspection shall cover the fabrication of the vessel or equipment to be lined, the material to be used, the lining procedure throughout fabrication and the lining after completion.

7.1.2 Quality control procedures shall include the following:

a) The manufacture of the vessel shall be to the appropriate specification and, where applicable, a pressure test shall have been carried out unless special dispensation has been obtained;
b) The internal surface of the vessel shall be thoroughly clean and free from scale or foreign matter, and all surfaces to be lined shall be smooth;
c) All materials used for the lining or cladding of plates shall be to the agreed specification and the cladding shall be inspected to see that it is of uniform thickness and free from faults;
d) The welder shall be tested as detailed in **7.2.1** or, where required, in accordance with the requirements of other authorities;
e) The fit-up lining sheets and strips, the edge preparation and welding gaps shall be in accordance with the approved procedure and the recommendations of this code;
f) Welder's work after sealing runs as have been laid down shall be examined for lack of fusion, porosity, cracks, etc. Special care shall be taken to avoid stray arc striking and spatter on the surface of the corrosion resistant lining;
g) When several welders are working on a vessel each operator shall identify his own work with a symbol (stamping is not permissible) so that inspection relates faulty work to an individual and introduce early steps to effect remedy;
h) Inspection shall ensure that no filling-in runs of weld are laid down on strip lining using the fillet butt technique until all adjoining strips have been thoroughly cleaned down, tested and inspected; and
j) On completion of welding the surface of the weld shall be brushed clean and made free from all welding slag, and examined with dye penetrant for any cracks. Particular attention shall be paid to the inspection of any test holes in the linings that have been filled after testing.

7.2 Welders' Qualification Tests

7.2.1 Qualification tests are necessary for each of the welders employed on the various welding procedures involved in the construction of the vessel.

Where the outer vessel is built to a specification, for example, IS 2825, the welders' qualification tests shall be in accordance with that specification.

Welders' qualification tests for corrosion and heat resistant metal linings or corrosion and heat resistant metal clad material shall take cognizance of the method of construction of the vessel. Test welds shall be carried out under the same conditions and using similar equipment, technique and materials of similar type and thickness as those used in the construction of the vessel or lining. Where positional welding is involved the various positions shall be reproduced in the qualification tests.

For each type of weld detail employed on the construction of the vessel or lining, a simulated test weld shall be undertaken by each welder to be employed on the particular detail. A welder shall be given an opportunity to familiarize himself with somewhat special techniques required before he is subjected to these tests.

7.2.2 Each test weld shall be subjected to:

a) A visual examination, which shall reveal no lack of fusion, undercutting or cracks in the metal or adjacent material;
b) Macro-sectioning and microscopic examination, where appropriate, which shall show that sound root fusion with the shell material is achieved and that the weld is sound and free from porosity;
c) Bend tests, direct, reverse and side, where appropriate;
d) A dye penetrant examination;
e) Radiography and/or ultra-sonic examination, where appropriate; and
f) Ferritic determination of the weld metal and a micro hardness survey of the weld/base metal interface, where appropriate.

7.2.3 Welders' qualification tests may be omitted by agreement, where the welder concerned has passed appropriate tests and has been regularly employed on welds similar to those in question.

7.2.4 During the fabrication it may be necessary to retest welders.

7.3 Testing of Vessels

7.3.1 *General* — This code covers a variety of types of vessels which may be subject in service to a wide range of conditions. The tests described below reflect this variety of circumstances, and it is not necessarily appropriate that all the tests be applied to a particular vessel. The tests are basically of two types, those intended to prove the integrity of the vessel as a whole and those intended to show that the lining is free from leaks. The order in which the tests are to be carried out shall be considered carefully, both from safety aspects and effect of one test on other tests; for example, water trapped in small leaks in a lining following a hydraulic pressure test may prevent the leaks being found in a sensitive leak test.

In vessels operating at temperatures above 100 °C it is essential that water is not trapped between the lining and the shell, and this is most likely to occur during testing operations. Where test holes are drilled through the vessel walls they shall be left as tell-tale holes to show any leak in service. They will then serve as vents to release any vapour pressure behind the sections of lining during operation in which case there is any water or other volatile liquid included as a result of testing or in the event of a leak.

Where the lining itself is drilled these holes shall be efficiently sealed after testing. This may be done by either plug welding or by welding a disc of lining material over the hole. After grinding plug weld, the surface shall be flush with lining surface. It may be convenient to pierce and extrude the holes in the lining plate when they are 2 mm or thinner to enable threads to be cut. This extruded hole may be either hammered flat or ground flush before seal welding after testing (*see* Fig. 21).

7.3.2 *Pressure Test*

7.3.2.1 *General* — Pressure tests serves two purposes, to prove that the shell of the vessel is satisfactory for the intended service, and to prove the integrity of the lining under working conditions. In some cases there are advantages in using separate tests at' different times for these purpose. The shell shall be tested hydraulically to the test pressure laid down in the specification to which it is made, but it may be convenient to carry out this test before work on the lining is complete, or even before it is begun, and to prove the lining by a pneumatic or hydraulic test at lower pressure (at least working pressure) when the vessel is complete. Appropriate precautions shall be taken if a pneumatic test is used, and such a test shall be done only if fabrication operations done after the main pressure test are such that they do not impair the integrity of the shell. The use of a pneumatic test has the advantage that sensitive leak detection techniques may be used subsequently.

7.3.2.2 *Testing of integrally clad vessels* — Integrally clad vessels shall be hydraulically tested to the normal test pressure for the vessel and shall be left standing under test for 24 h to 48 h.

Where parts of the vessel, such as branches, are of a lined construction, consideration shall be given to treating it as a lined vessel.

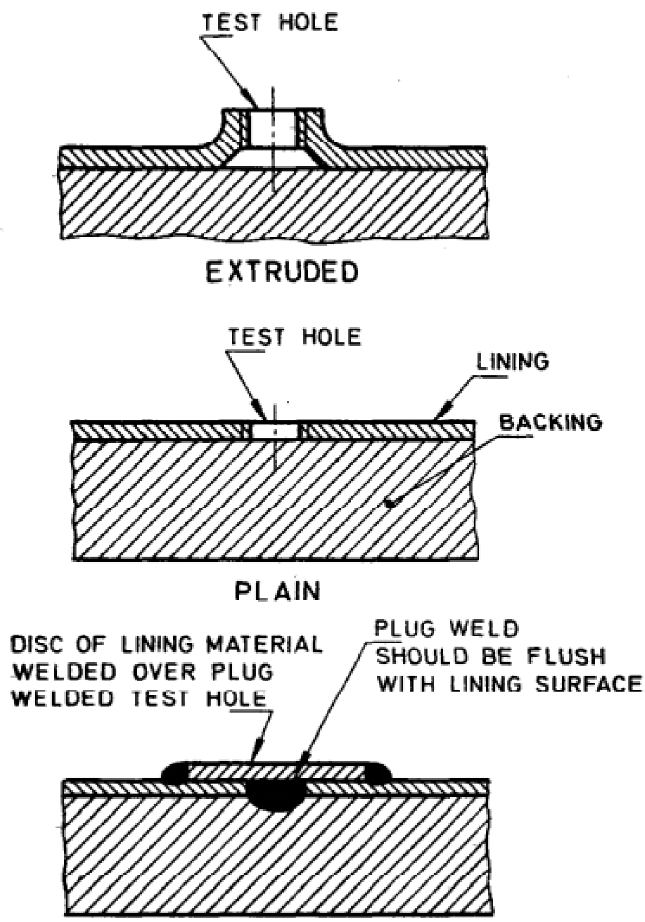


FIG. 21 TESTING HOLES IN LININGS

7.3.2.3 *Testing of loose lined vessels* — The loose lined vessels shall be pressure tested when complete after test for continuity of the lining. Where a prior hydraulic test to the normal test pressure has been done this test may be to a lower pressure, at least the working pressure, and may be a pneumatic test.

After a final hydraulic test the vessel shall be drained and carefully dried, and the welds then checked for seepage after whitewashing the surface.

7.3.3 Tests *for Continuity of the Lining*

7.3.3.1 *Dye penetrant test* — The use of dye penetrants on the sealing welds is recommended when the lining plates have been plug welded after test. Any suspicious areas of dampness showing after hydrostatic whitewash test may be rechecked by dye penetrant examination.

7.3.3.2 *Air test* — The lining shall first be tested by introducing a pneumatic pressure between the shell and lining and the welds swabbed with soap and water. A pressure of about 35 kPa is adequate to detect any leaks and these will show up as a cluster of bubbles. High pressure is not an indication of more stringent testing, as the air from pinholes may jet through the soapy water and produce few or no bubbles and hence not be detected. There is also a danger of lifting and bulging the lining with pressures above 50 kPa.

Air may be introduced by one of the following two methods:

a) Drilled and tapped holes through the vessel; or
b) Drilled and tapped holes through the lining plates.

Another method requires a rubber cup of suitable size and similar in shape to a stethoscope which is attached by a rubber tube to a small vacuum pump. The rim of the cup is moistened with soap solution, glycerin or other viscous liquid so that a seal is formed and the cup moved over the surface of the welded seams. Where the weld is sound the cup will either collapse under suction or draw air through the sealing liquid, and leaks are found where there is no collapse or drawing in of air. This method is particularly suitable for testing or locating leaks in large tanks on site but will be successful only when the weld beads are kept flush with the adjoining metal.

A further alternative is to use a vacuum box fitted with a glass top and sealed to the vessel by a soft rubber gasket. The surface of the vessel is moistened with a soap solution and the box placed over the area to be tested, the presence of a leak being-shown by formation of bubbles visible through the glass top of the vacuum box. It is not necessary to introduce air pressure between shell and lining, although the sensitivity is increased if this is done.

A more sensitive test is obtained by introducing air into the vessel itself and checking for leakage at vent holes in the shell. Leakage is detected by use of soap solutions, ultra-sonic detectors or by connecting manometers or other pressure indicating devices to the vent holes. This technique allows use of higher air pressures than may be safely introduced between the shell and lining, but only shows the approximate location of a leak, which shall be located accurately by, for example, dye-penetrant examination of the inner surface of the vessel or one of the sensitive leak detection methods described in **7.3.3.3**.

7.3.3.3 Sensitive leak detection *techniques* — A number of techniques are used in which the vessel or the space between shell and lining is pressurized with air containing a small amount of an ‘impurity’, the active agent, leaks are detected by devices which are very sensitive to traces of the active agent. The techniques are extremely sensitive, and shall be used only when it is important to ensure that the integrity of the lining is greater than which established by the methods described in **7.3.3.1** and **7.3.3.2**. Because the detection elements are so sensitive, the level of leakage rate that is considered significant shall be determined by experiment, calculation or prior experience and the techniques shall apply only after an air test has been done to eliminate major leaks which would contaminate the air surrounding or inside the vessel and prevent small leaks being detected. The tests are best done by introducing air containing the detection agent into the space between shell and lining, and examining the inner surface of the vessel for leaks.

NOTE — These techniques are special, and few lined vessels will be made for duties where the use of such sensitive methods would be justified.

Greater sensitivity may be obtained by pressurizing the vessel and testing at vent holes in the shell, as higher pressures may be used, but this method does not allow precise location of individual leaks.

Four basic methods are available, differing in the nature of the impurity and method of detection. In each case a sample of air from the region under test is drawn through the sensing element:

a) The detection agent is a halogen or halogen compound, such as dichlorofluoromethane, and the sensing element depends on the increase in positive ion formation which occurs at a heated platinum surface when the halogen content of the surrounding air increases;
b) The detection agent is helium gas, and the sensing clement a mass spectrometer;
c) The detection agent is a radioactive isotope and the sensing element is a scintillation counter or other appropriate device; and
d) The detection agent is hydrogen, helium or argon, and the sensing element depends on changes in thermal conductivity of air caused by de presence of the second gas.

Suitable precautions against the hazards introduced by the presence of the active agents shall be taken.

7.3.4 *Testing of Vessels Subject to Arduous Conditions* **—** Additional tests for vessels which are to be operated under vacuum conditions or subject to thermal and pressure recycling shall be considered.

7.4 Maintenance and Repair

7.4.1 Any lined vessel shall be placed on a schedule for routine inspection for possible failure of the lining, which may be caused by:

a) Corrosion, either general or localized;
b) Erosion by movement of a product in the vicinity of branches;
c) Distortion and ultimate tearing of lining plates due to operational stresses;
d) Cracks; and
e) Bulging of the lining due to moisture trapped behind the lining during fabrication, expansion of gas, forced behind the lining through a pinhole under high pressure, when the high pressure is released, or collapse of a loose lining due to inadvertent exposure to vacuum conditions.

7.4.2 When repair entails only the re-welding of the lining plates where a fracture has occurred this may be done by simply grinding out the faulty weld until the sound shell material is reached and re-welding, using the same technique as for strip lining. If, however, the product produces conditions injurious to welding and some seepage is apparent behind the lining as a result of the fracture, then the lining plates affected shall be stripped off, the shell thoroughly cleaned and fresh lining plates fitted.

Localized corrosion, pitting or eroded areas where the penetration has not come right through the lining may be repaired by building up with weld metal or with further overlaying of more lining plates. In either case the surface shall be thoroughly cleaned and made of a profile that is acceptable to the welder before repair work commences.

When lining plates have become buckled and distorted they shall not be hammered back into position. The affected plates shall be removed, the shell thoroughly cleaned and the area relined. In some instances, where lining failure has allowed liquid to seep behind the plates but has been detected before extensive corrosion has taken place, it is possible to remove the liquid by heating the vessel and lining to a temperature of at least 200 °C. If this device is resorted to, extreme care shall be taken to ensure that all moisture and products of corrosion have been removed before the repair is affected.

7.4.3 If tell-tale holes or holes to prevent build-up of gas pressure have been incorporated in the shell it is important that the holes are kept open and that operating personnel are instructed to report any evidence of a leak immediately.

ANNEX A
(*Foreword*)

EXCHANGE OF INFORMATION

A-1 Early consultation and exchange of information shall take place between all parties concerned in the design, manufacture and use of vessels and equipment which are intended to have a corrosion resistant lining. An accurate detailed drawing, to scale, shall be available to all parties concerned.

A-2 These consultations shall cover the following:

a) Construction of equipment or vessel to be lined, including location of welds, design of branches and fittings, joints and internal supports for any loose equipment to be fitted later;
b) Nature and concentration of media for which the vessel or equipment is to be used;
c) Operating temperature and pressure ranges;
d) Whether vessel will be subjected to vacuum;
e) Other factors influencing stresses on lining, for example, expansion, construction, vibration, erosion, etc;
f) Velocity of contents and abrasive characteristics to be met, especially at points of their entry to the vessel;
g) Means of access of lining materials and installation crew and equipment, lifting facilities, etc;
h) Where existing vessel has been in service on site, details of site conditions that may affect this work being carried out in situ;
j) Safety measures on site;
k) Existing surface finish of the vessel to be lined, that is, pitting or thinning due to corrosion, inclusion of traces of product, etc;
m) Inspection and testing of the lining and vessel, including welders' qualification tests;
n) Whether the vessel is to be internally or externally heated;
p) Media other than working media which will be used, for example, steam or chemical agent for cleaning; and
q) Start up and shut down conditions.