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BUREAU OF INDIAN STANDARDS

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भारतीय मानक **मसौदा**

रासायनिक प्रक्रियाओं के लिए पात्र और उपकरणों की लाइनिंग – रीति संहिता
भाग 9 टाइटेनियम

(पहला पुनरीक्षण)

Draft *Indian Standard*

LINING OF VESSELS AND EQUIPMENT FOR CHEMICAL PROCESSES — CODE OF PRACTICE
PART 9 TITANIUM

(*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. Titanium 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 7 Corrosion and Heat Resistant Metals
Part 8 Precious Metals
Part 10 Brick and Tile

The selection of the linings of this method is to be based on the information supplied by the user. Therefore, it is necessary that full details are submitted to the contractor to enable him to choose the suitable method. Annex A gives the information to be exchanged between the contractors and users.

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 9 TITANIUM

(*First Revision*)

1 SCOPE

This standard (Part 9) lays down the recommendations on the design of vessels for titanium linings, method of application of linings, and inspection and testing.

2 REFERENCES

The standards listed 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 the standards listed below:

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 2041 : 2024	Steel plates and strips for pressure vessels used at moderate and low temperature — Specification (*fourth revision*)
IS 2825 : 1969	Code for unfired pressure vessels

3 MATERIAL

3.1 Types of Titanium

3.1.1 *Commercially Pure* — For the purpose of this standard, five grades of titanium, designated as Grades 1, 2, 3, 4 and 5 are described. The chemical composition of these grades is given in Table 1. These grades are successively harder and stronger as indicated by the data on the mechanical properties given in Table 2. Grade 3 may be used for chemical plant construction but where the maximum formability is required, the softest grade, that is, Grade 1, is used. Grade 2 may be used for tube.

The various grades of titanium have corrosion resisting properties. In some environments, particularly strongly oxidizing or reducing acids, the corrosion resistance of the heat affected zones is reduced by metallurgical changes associated with iron impurities in the titanium. Under such conditions, the maximum iron content shall be 0.05 percent.

3.1.2 *Clad Plate* — Titanium clad plates are obtained in a variety of sizes; the cladding is metallurgically bonded to the steel backing plates during manufacture. The backing steel which is generally boiler quality plate, shall be manufactured to the requirements of IS 2041.

3.2 Alloys of Titanium

3.2.1 With the particular exception of palladium, alloying elements which are normally used do not improve the corrosion resistance of titanium, and in some instances, the corrosion resistance of titanium alloys is inferior to commercially pure titanium.

3.2.2 *Titanium Alloy TP* 1 — A titanium palladium alloy containing 0.15 percent palladium has improved corrosive resistance in certain reducing acids and in some instances may be used in place of anodically protected commercially pure material. The chemical and mechanical properties of titanium alloy TP 1 are given in Table 1 and Table 2.

3.3 Anodic Protection

Titanium relies on a tenacious and stable oxide film for its corrosion resistance. The protective oxide film is maintained for a wide range of reducing acids by applying the principle of continuous anodic passivation. Titanium is connected to the positive side of low voltage d.c. supply, while negative side being connected to a suitable cathode immersed in the acid solution. The continuous passage of a small current is often sufficient to render titanium resistant to acids by which it would be otherwise attached.

Table 1 Titanium and Titanium Alloy, Chemical Composition

(*Clauses* 3.1.1 *and* 3.2.2)

Sl No.	**Element**	**Composition** Percent					
		Titanium Grade 1	Titanium Grade 2	Titanium Grade 3	Titanium Grade 4	Titanium Grade 5	Titanium Alloy TP 1
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Oxygen	0.50, *Max*	0.50, *Max*	0.50, *Max*	0.50, *Max*	0.50, *Max*	0.50, *Max*
ii)	Carbon	0.10, *Max*	0.10, *Max*	0.10, *Max*	0.10, *Max*	0.10, *Max*	0.10, *Max*
iii)	Nitrogen	0.05, *Max*	0.05, *Max*	0.05, *Max*	0.05, *Max*	0.05, *Max*	0.05, *Max*
iv)	Hydrogen	0.01, *Max*	0.01, *Max*	0.01, *Max*	0.01, *Max*	0.01, *Max*	0.01, *Max*
v)	Iron	0.05, *Max*	0.05, *Max*	0.05, *Max*	0.20, *Max*	0.20, *Max*	0.05, *Max*
vi)	Palladium	—	—	—	—	—	0.15, *Min*
vii)	Titanium	99.0, *Min*	99.0, *Min*	99.0, *Min*	99.0, *Min*	99.0, *Min*	99.0, *Min*

Table 2 Titanium and Titanium Alloy, Mechanical Properties: Annealed Material
(*Clauses* 3.1.1 *and* 3.2.2)

Sl No.	Property	Titanium Grade 1	Titanium Grade 2	Titanium Grade 3	Titanium Grade 4	Titanium Grade 5	Titanium Alloy TP 1
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Tensile strength, MPa	432, *Max*	385 to 540	465 to 620	571 to 726	620 to 775	432, *Max*
ii)	0.1 percent proof-stress (*Min*), MPa	216	275	340	432	465	216
iii)	Elongation (*Min*), percent on $4\sqrt{A}$	27	22	20	15	15	27
iv)	Young modulus (typical), MPa	11×10^4	11×10^4	11×10^4	11×10^4	11×10^4	11×10^4
v)	Fatigue limit (approx.), percent of tensile strength	50	50	50	50	50	50
vi)	Bend radius (180° bend) 1.8 mm or thinner	1t	$1\frac{1}{2}$t	2t	$2\frac{1}{2}$t	$2\frac{1}{2}$t	2t
	NOTE — 1 MPa = 1 N/mm^2 = 10 Bar						

3.4 Removal of Surface Contamination

Traces of iron or other metals as contaminants on titanium surface may lead to corrosion which would not occur on a clean titanium surface and while this corrosion may not in itself be serious it may result in uptake of hydrogen into the metal leading to embrittlement. Appropriate precautions for minimizing contamination during fabrication are described in **6**, but these precautions may rarely be completely effective.

For service in severe conditions all the exposed titanium surfaces shall be cleaned after fabrication is complete. Areas in which iron contamination is present may be detected by one of the tests described in Annex B. Any such contamination shall be removed by abrasion or buffing with iron-free grit or by local treatment with a solution containing 4 percent hydrofluoric acid and not less than 20 percent nitric acid by volume. Alternatively, the complete item may be pickled in the above acid mixture, preferably at a temperature of 30 °C to 50 °C. The cleaning may also be achieved by anodizing which may be done on complete items of equipment.

4 DESIGN OF VESSEL AND EQUIPMENT FOR LINING

4.1 General Design Considerations

4.1.1 The use of titanium as a lining for vessels introduces special difficulties that are not encountered with other lining materials.

Contamination by atmospheric gases, degreasing agents and other metals during the welding leads to embrittlement of the titanium, and may also cause deterioration in corrosion resistance.

Embrittlement of the root side of a weld in titanium made in situ is particularly dangerous as it may not be detected until the weld fails in service. Titanium cannot be welded to other common metals except by explosion techniques. In certain cases special brazing techniques may be used but the bond produced by this method may be seriously weakened by heating.

It is, thus, essential that suitable precautions be taken during the fabrication to avoid these problems and these shall be considered at the design stage as they make it necessary to incorporate unusual features in design or fabrication of the vessel or impose limitations on the positioning of welds.

4.1.2 With an increase in temperature the shell will expand more than the titanium lining, and account shall be, taken of stresses which may be produced.

4.1.3 Steel vessels fitted with a titanium lining shall be of welded construction using butt-welded joints wherever possible. The inner welds shall be ground flush and smooth in order to ensure that the lining may bed down with proper contact against the inner welds of the vessel over the whole area.

4.1.4 The vessels shall be fabricated and tested in accordance with recognized standards of proper design and practice to suit the operating conditions. For guidance reference may be made to IS 2825 and IS 803.

If contamination of welds in the lining made in situ is to be prevented by introducing the supply of inert gas to the underside of the weld by means of holes through the shell, this shall be taken into account in the design of the vessel. Holes for purge or test purposes shall be drilled through the shell before the lining is applied. Whether the lining is attached to the wall or not, it is not generally considered in the calculation to determine the strength of the vessel. No internal corrosion allowance need be made in assessing the thickness of the outer shell. It may be appropriate to incorporate a corrosion allowance on the outer surface of the vessel, for example, where spillage may occur or where the vessel is provided with a heating or cooling jacket. Where thermal stresses are likely to be set up by the attachment of the lining then the necessary allowances shall be made in the design of the vessel.

4.1.5 Integrally clad plates may be formed by any method of cold-forming applicable to steel plates of equivalent thickness, but care shall be taken when forming thick plates to tight curvature that the cladding thickness is not reduced seriously by the tool pressures involved in the forming operation.

Hot-forming above 600 °C is not normally recommended as inter-diffusion of steel and titanium occurs forming a brittle layer which reduces its bond strength. Forming at temperatures up to 600 °C is possible but the time and temperature shall be controlled to avoid damage to the bond. Heating for such forming shall be carried out in a furnace with slightly oxidizing conditions and freedom from direct impingement.

Where pressure or temperature considerations require a thick welded vessel consideration shall be given to a composite construction in which, for example, a relatively thin integrally clad inner shell is supported by plate, strip or wire wound round it. Hemispherical ends will normally be necessary.

Butt welds and shell openings are expensive to produce and are the weakest points in the lining, and consideration shall be given to arranging the dimensions of the vessel to minimize but welds and to grouping two or more inlets or outlets as branches into the cover of a single opening.

4.1.6 For loose linings the shape of the vessel wherever possible shall be cylindrical with ends either flat, conical, dished, and with as large a radius as possible in any corners which occur. Shell openings shall be situated at the end of the vessel arranged with their axes parallel to the axis of the vessel if possible. Irregular shapes and shell openings in other positions may be lined but will be more difficult and costly, where the vessel is to operate at high pressures or temperatures, it may be impracticable to fabricate reliable linings for such features.

Consideration shall be given to grounding two or more inlet or outlet branches in the cover plate or a single shell opening; such branches may be arranged at an angle to the axis of the vessel even when the main shell opening is parallel to that axis. In case of branches in dished ends, lining may be facilitated by arranging for branches to be normal to the plate surface.

As welds in the lining made in situ in the shell present special problems, prefabrication of the lining or parts of it outside the vessel is preferred. If possible, a fully flanged end to the vessel shall be provided in order to simplify the access and to allow the complete lining or sections involving the full dimensions of the vessel to be introduced. Where this is not possible, consideration shall be given to introducing sections of the lining into the vessel or lining sections of the shell before final assembly or to constructing the shell assembling sections of the shell around the complete lining. If this is done the subsequent welds in the shell shall be made in such a way that molten weld metal does not come in contact with the titanium, and it may be necessary to take special precautions to ensure a proper fitting between shell and lining. Although the fabrication by such methods introduces complication in the designing and fabrication of the shell, it is preferable to accept these complications in order to simplify the construction of a reliable lining.

4.2 Internal Fittings

Where internal fittings are required, such as support rings, brackets, coil supports, etc, it is normal to fabricate these from solid titanium. The lining shall be reinforced at the point of attachment of the internal fitting. This may be done by increasing the thickness of the lining, and for additional support the thickened section may be bolted through the steel shell as indicated in Fig. 1.

4.3 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. Suitable methods of lined construction, as illustrated in Fig. 2 and Fig. 3, may be used, but due allowance shall be made for relative movement of the lining. Shell flanges are faced with titanium by turning the facing ring over to meet the lining. The facing ring may be butt-welded to the lining, prior to the insertion of the lining in the outer vessel, or may be fillet-welded to the lining when it is fixed in position, as shown in Fig. 4. The facing ring may be mechanically attached, or silver-brazed to the shell flange as shown in Fig. 4.

The cover plate may be of titanium clad or faced with titanium sheet mechanically attached as for the facing ring shown in Fig. 4.

4.4 Coils for Heating or Cooling Lined Vessels

For loose lined vessels the air space ‘between the lining and the shell exercise a thermal insulating effect, and it is preferable to use internal coils or plate-type heat exchangers of titanium rather than jackets for heating or cooling purposes. It is possible to incorporate the plate-type heat exchangers as part of the lining. Where proper heat transfer properties are required, clad plates shall be used.

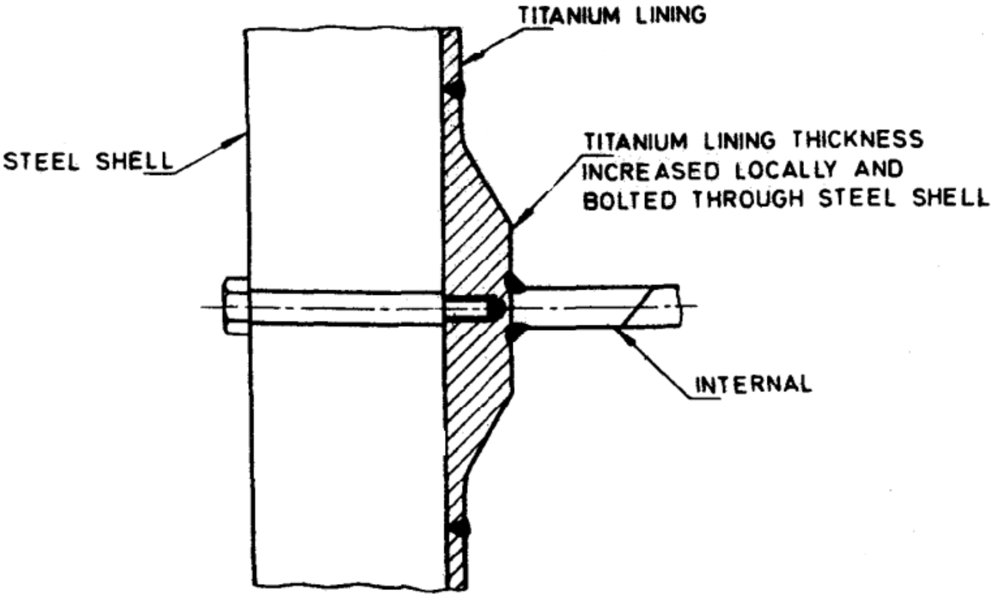


FIG. 1 TYPICAL METHOD FOR ATTACHMENT OF INTERNAL FITTINGS IN LINED VESSELS

4.5 Clad Vessels

A Vessels designed to be made from clad material shall have special attention given to ensure that a continuous cladding to the inner surfaces is practicable.

4.6 Heat Treatment

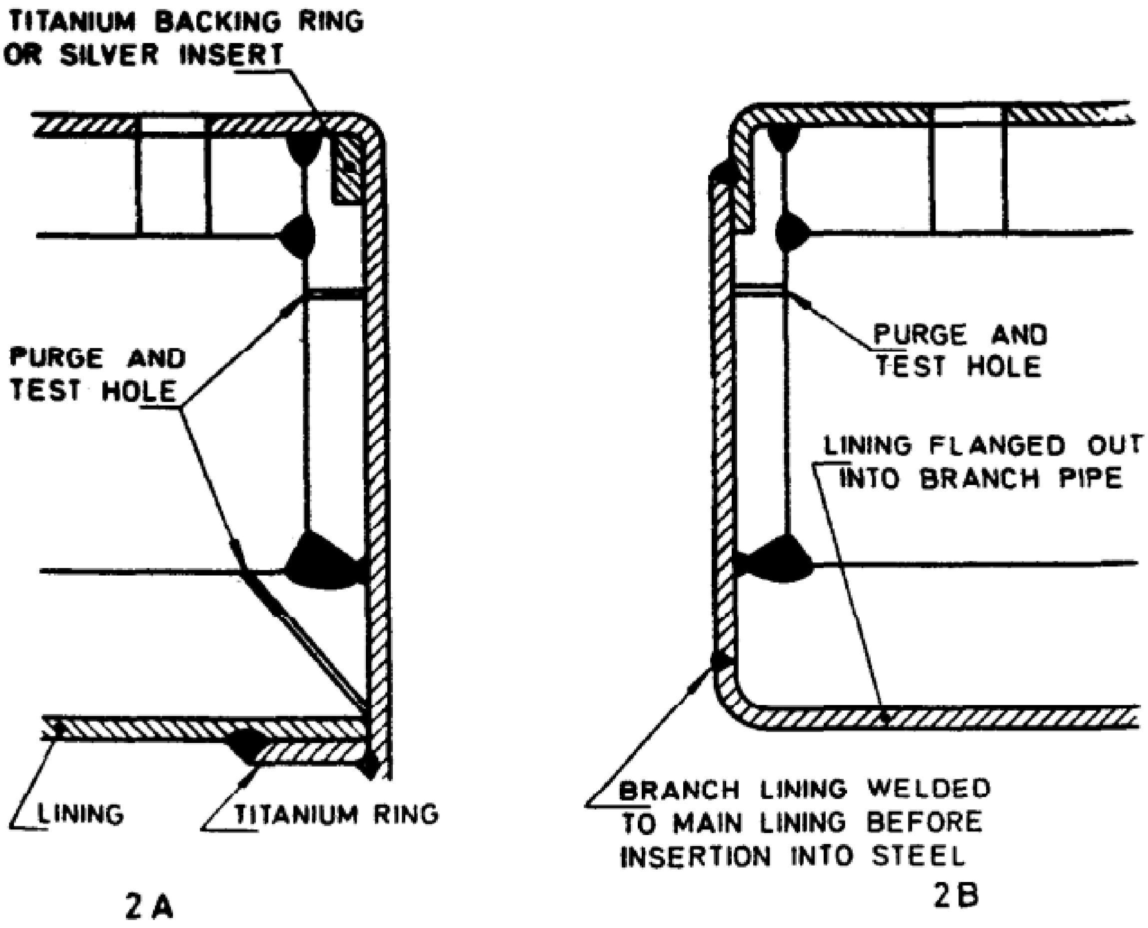
4.6.1 *General Recommendations* — Where post-weld heat treatment of loose lined and clad vessels is necessary, it shall be within a temperature range of 500 °C to 550 °C where normal carbon steel is used. Where alloy steels are employed the temperature range agreed between the fabricator and the purchaser shall take into account the effect of the heat treatment on the oxidation of titanium and, for clad vessels, the strength of the bond between the steel and the titanium.

Under the circumstances, heat treatment shall be carried out in a reducing atmosphere and direct flame impingement on the liming shall be avoided.

4.6.2 *Clad Vessels* — The post-weld heat treatment of clad vessels shall be carried out after fabrication of the steel vessel but before:

a) Introduction of silver or other heat sensitive interlayer;
b) Lining of branches; and
c) Attachment of cover straps to the steel welds.

4.6.3 *Loose Lined Vessels* — The post-weld heat treatment of the outer shell, if required by the specification to which it has been made, shall be carried out prior to the insertion of the lining if this is possible.



NOTES

1 Arrangement shown in 2B may only be used when lining is introduced to shell after attachment of branch lining to main lining.

2 Lining of joint face may alternatively be silver-brazed to flange outside joint ring as shown in Fig. 3.

3 Methods of attaching joint face lining to branch linings are alternatives.

FIG. 2 TYPICAL METHODS OF LINING BRANCHES

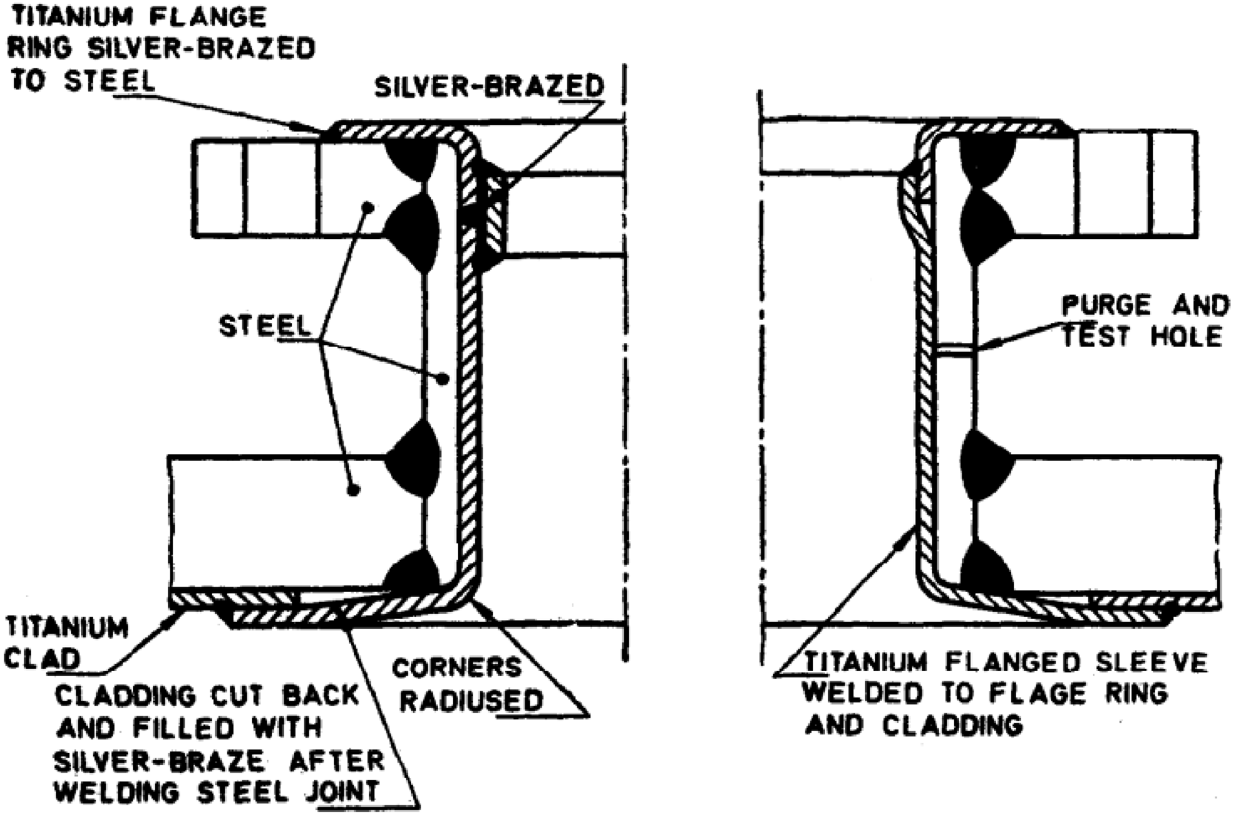


FIG. 3 TYPICAL METHODS OF LINING BRANCHES IN CLAD PLATE CONSTRUCTION

If the heat treatment, has to be carried out with the lining in position due consideration shall be given to the possible effects of differential expansion and the temperature of the heat treatment shall be selected as in **4.6.1**. Joints employing silver shall not be post-weld heat-treated.

5 DESIGN OF LININGS

5.1 General Factors Affecting Design

The design of linings 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.

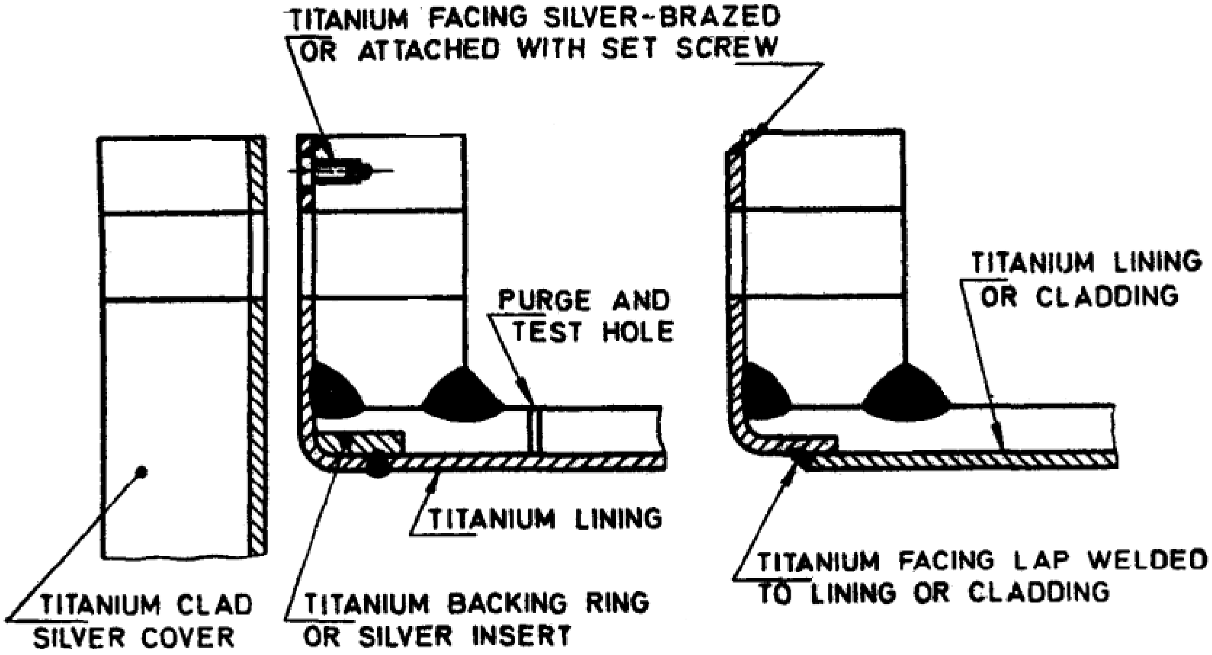


FIG. 4 TYPICAL METHODS OF FACING SHELL FLANGES AND COVERS

5.2 Integral Cladding

5.2.1 This method of lining shall only be considered when a vessel is being initially designed for lining. The design considerations for the manufacture of integrally clad vessels are dealt with in **4**. It is generally considered that it is more economical to use clad plate for a vessel of 13 mm thickness and above, than to use solid titanium. Vessels made from clad material using the recommended welding techniques probably offer the best solutions to all the design considerations in **5.1**.

The bonding of the lining to the shell is proper and therefore suitable for vacuum conditions, and the method also gives very proper heat transfer properties. Because the lining is firmly attached to the shell over almost all the surface, except for cover straps of butt welds or lining of small branches, relative movement of shell and lining on pressure or temperature changes is small and the possibility of dangerous concentration of strain is minimized.

5.2.2 Weld preparation of the edges of plates to be butt-welded together is important and proper alignment before welding is vital to ensure satisfactory completion of the clad side of the joint as shown in Fig. 5 and Fig. 6. Whether any misalignment may be permitted shall be decided by the specification to which the vessel is being built.

5.2.3 Suggested methods of butt-welding clad plate are shown in Fig. 7 and both are suitable for the range of thickness of plate and cladding available.

5.2.4 In designing flanged opening to the shell it is important to consider relative movement of the shell and branch lining caused by differential expansion, elastic distortion due to pressure or localized plastic deformation during pressure test. Where the duty of the vessel is mechanically severe it is essential to ensure flexibility at the intersection of shell and branch, to eliminate sharp changes in section on the shell and to avoid welds in the lining at points of maximum stress. Suitable methods of lining flanged openings in clad vessels are shown in Fig. 3. For duties that are mechanically less severe these precautions are not so necessary, and simpler and less expensive designs may be satisfactory.

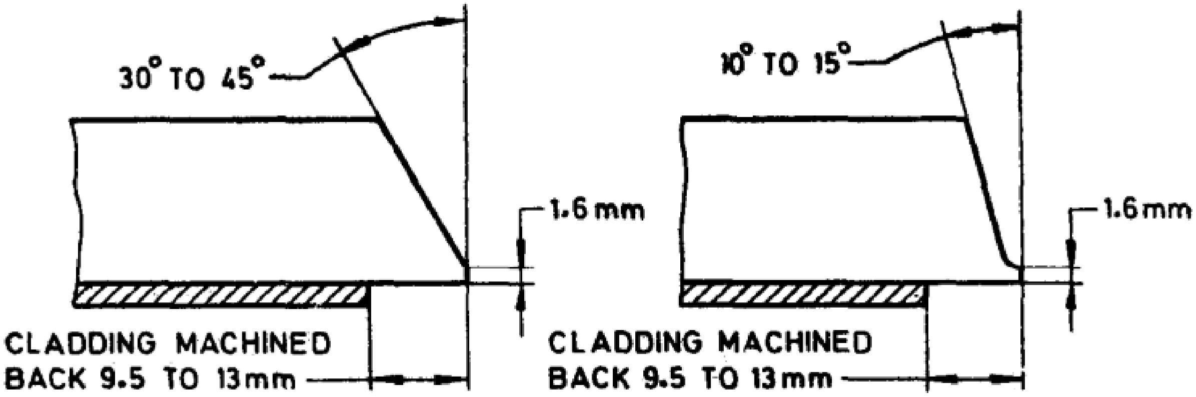


FIG. 5 TYPES OF EDGE PREPARATION OF CLAD PLATE FOR WELDING

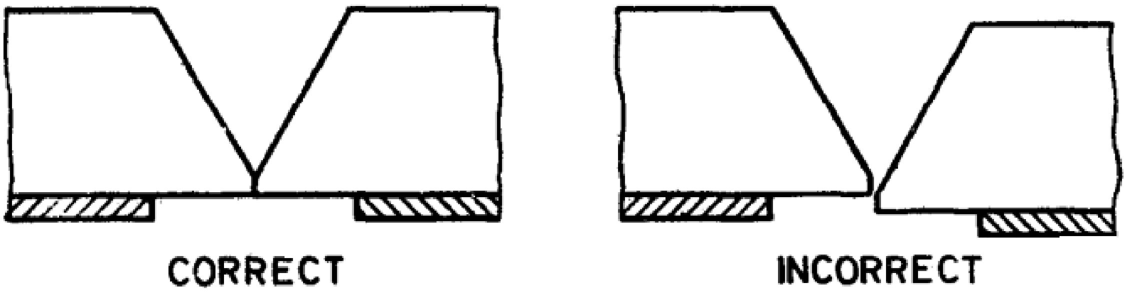
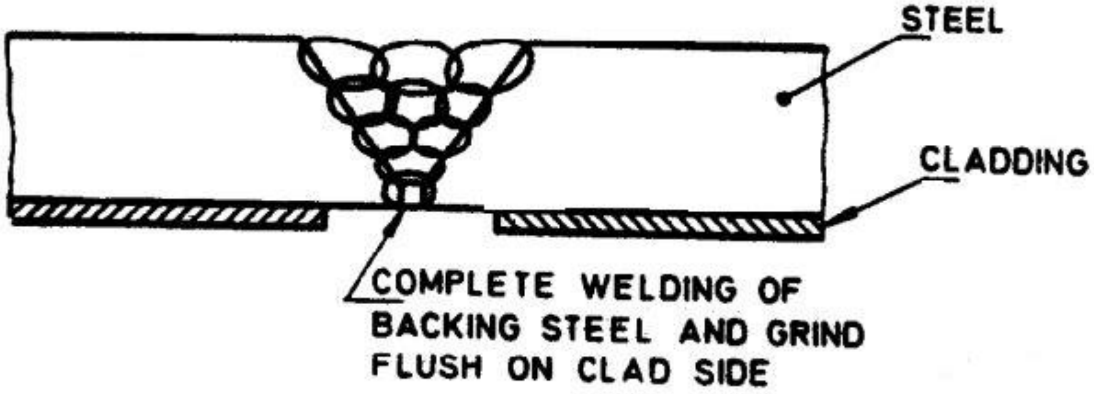


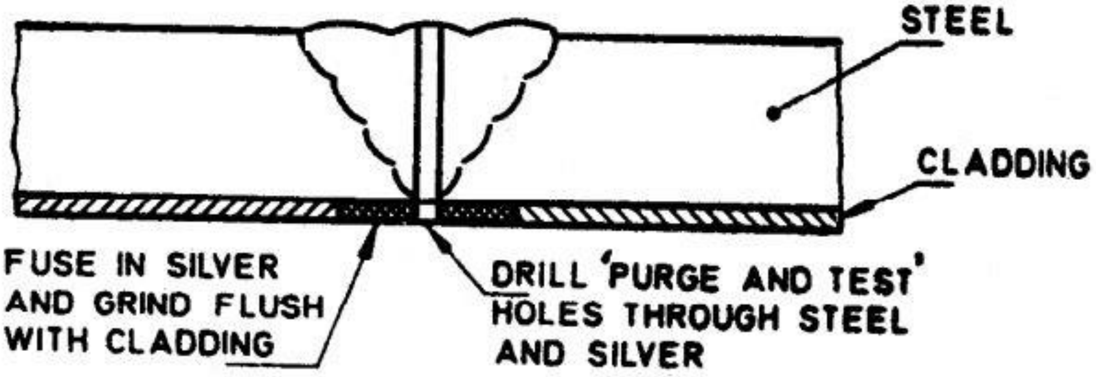
FIG. 6 EDGE ALIGNMENT OF CLAD PLATE FOR WELDING

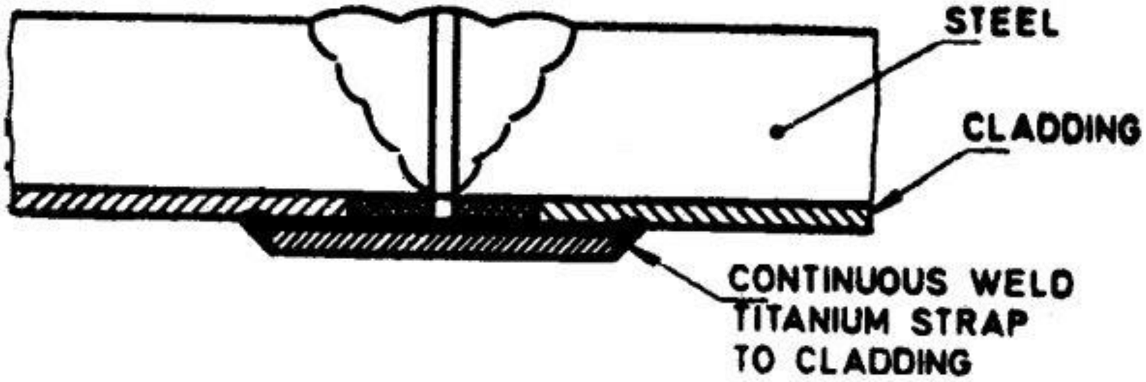
5.3 Loose Linings

5.3.1 Loose linings offers a satisfactory solution to the design conditions in **5.1**, but where the operating conditions are mechanically severe it is usually preferable to use integral cladding. It is possible to secure the linings to the shell at intervals by mechanical means or by localized explosion bonding, and loose linings secured in this way are suitable for vacuum working conditions as long as these conditions are taken into consideration in the design of the lining and the arrangement of the supports. Linings secured in this way are not normally suitable for operating temperatures above 200 °C or where severe temperature gradients or frequent cyclic conditions occur.

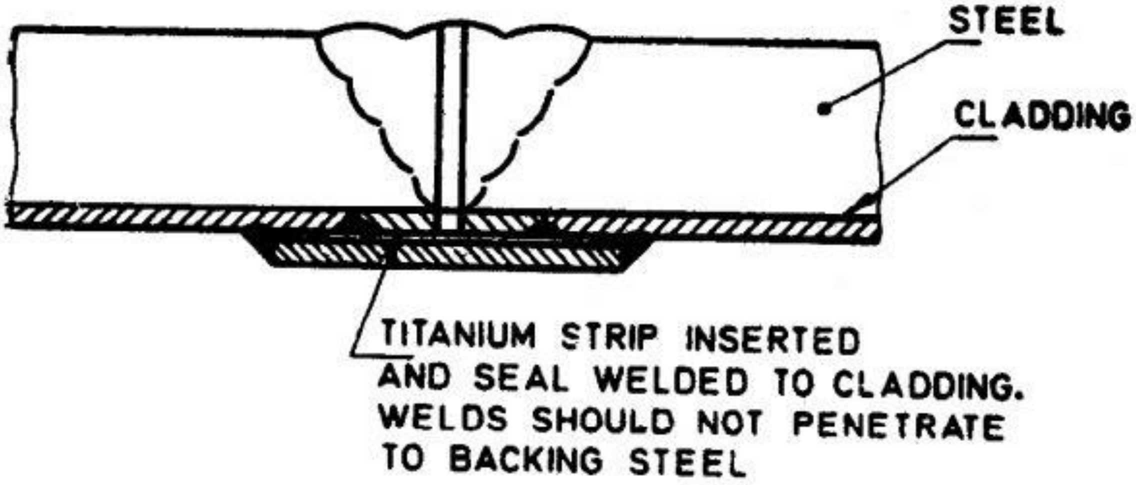
Loose linings may also be secured to the shell at points where internal fittings are to be attached. If the number of such fittings is small and the stresses due to differential expansion or to pressure changes are taken into account such linings may be used in conditions more severe than those mentioned above. For some vessels it may be possible to design the lining so that it will withstand vacuum conditions.







A PREFERRED METHOD



B ALTERNATE METHOD

FIG. 7 METHODS OF BUTT-WELDING CLAD PLATE

5.3.2 Wherever possible the loose lining is made separately from the outer vessel, fabrication of the lining being complete except for those sections of, for example, branch linings which it is necessary to complete after the lining is introduced into the outer vessel.

The lining of the cylindrical portion of branches parallel to the axis of the vessel shall preferably be made as part of the main lining before the lining is inserted. The lining shall be made to fit accurately to the outer vessel, but welds being used wherever possible, and shall be tested for weld soundness before insertion. Where possible the lining shall also be hydraulically or gas leak tested to an appropriate pressure before it is introduced into the shell.

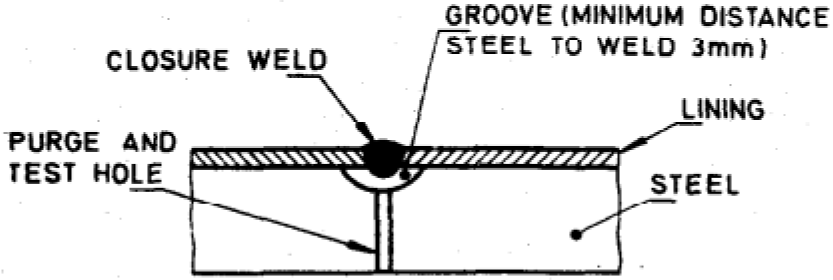
The outer vessel may require machining on the inside surfaces to ensure close fitting with the lining. Where possible, testing of the outer vessel shall take place before insertion of the lining.

After the lining has been inserted it may be expanded to fit tight to the outer shell by hydraulically expanding, wheeling out or explosive forming. Where the lining is to be secured to the outer vessel this shall not be done until after it is expanded into place. A final test of the composite vessel shall be done.

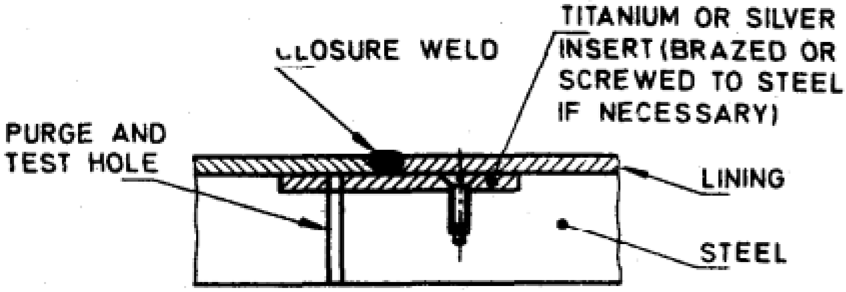
5.3.3 Where it is not possible to introduce the complete prefabricated lining into the outer vessel, sections of the lining shall be prefabricated and tested for weld soundness before insertion, and the outer vessel or sections thereof shall also be completed and tested as far as practicable before the lining or sections of the lining are inserted. It may be necessary to leave part of the lining of shell opening or part of the fabrication of external openings in the shell to be completed after the lining has been introduced.

After the lining or sections of lining have been inserted they may be expanded to fit tight to the outer shell by hydraulically expanding, wheeling out or explosive forming. Where welds are to be made to join sections of the lining these shall be made after the sections have been expanded, and suitable jigs shall be used to hold the lining sections in place while the welds are made. Where the lining is to be secured to the shell by mechanical means or explosive welding these operations shall be completed before the final welds in the lining are made, and in this case jigs will not be required when the final welds are made.

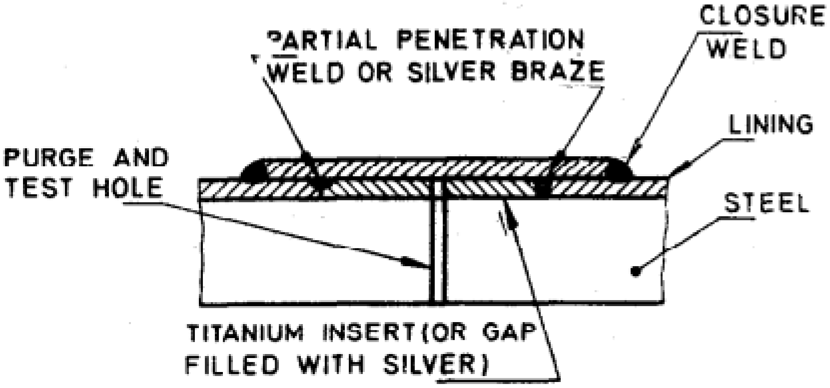
Suitable means of making the final welds are shown in Fig. 8.



A GROOVED METHOD



B INSERT METHOD

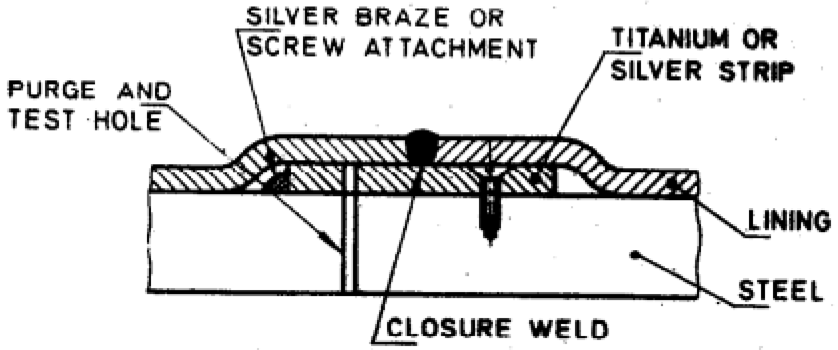


C SUPPORTED COVER STRAP METHOD

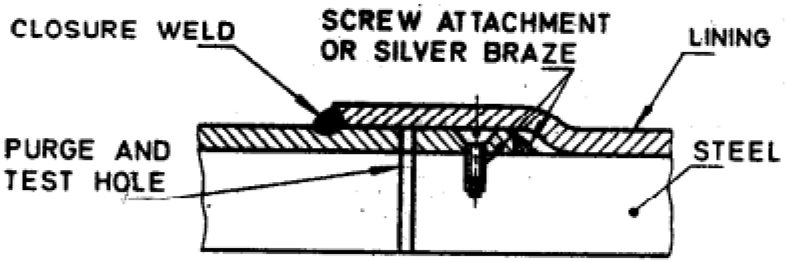
NOTE — Methods B and C are suitable for more severe conditions than A.

8A Types of Lining Joints, Suitable for Mechanically Severe Duties

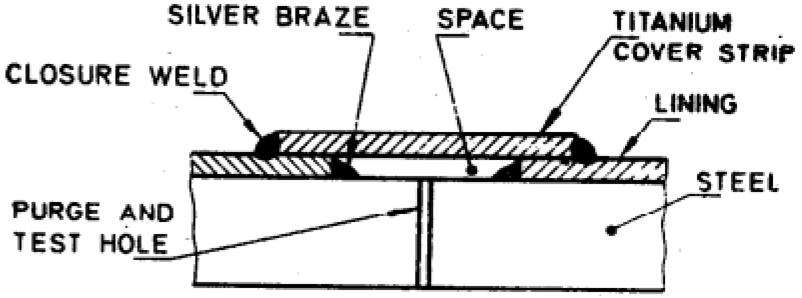
FIG. 8 METHOD OF MAKING FINAL WELD (*Contd.*)



D JOGGLE METHOD



E LAP METHOD



F UNSUPPORTED COVER STRAP METHOD

NOTE — Silver-brazed or screw attachments shown are primarily for location purposes while the joint is being made and not as strength attachments.

8B Types of Lining Joints, Suitable for Less Severe Duties

FIG. 8 METHOD OF MAKING FINAL WELD

Where sections of the shell are to be assembled around a lining, precautions shall be taken to prevent contact of molten weld metal with titanium and to control the rate of heat input to titanium so that it does not reach a temperature at which contamination by atmospheric gases occurs. ‘For but welds this may be achieved by using a steel backing ring and small initial runs of weld metal (*see* Fig. 9). If required, the lining may be expanded to a closer fit in the outer vessel after the steel welds have been made.

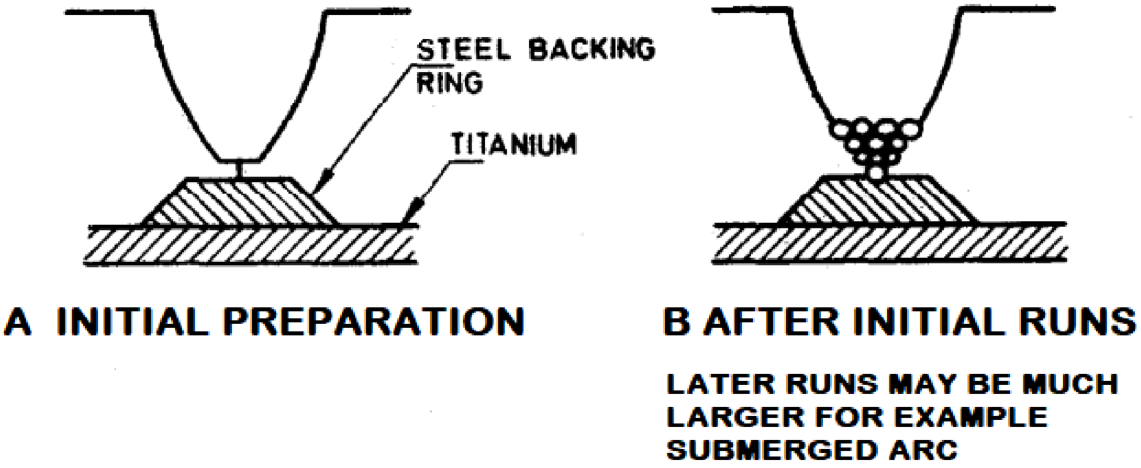


FIG. 9 USE OF STEEL BACKING RING

5.4 Thickness of Linings

5.4.1 *General Conditions*

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; and
g) Cost.

In calculating the thickness of the lining it shall be assumed that the lining shall last for the anticipated life of the vessel. Considerable damage can be sustained by the outer shell when a failure occurs in the lining and the only possible means of detecting such failures is the installation of hypersensitive detection equipment.

Consideration shall be given to introducing ‘sections of increased thickness at points where the lining is likely to be most highly stressed, for example, where the lining is to be secured mechanically to the outer vessel, including branch flanges, or where internal fittings are to be attached to the lining. Consideration shall be given to stresses developed at the junction between different thicknesses of lining material and welds between materials of significantly different thicknesses shall be avoided (*see* Fig. 1).

Where erosion is anticipated, such as opposite tangential inlet branches, a thicker panel shall be fitted to act as wear plate. Whilst consideration shall be given to the stresses that may occur at the junction between sections of linings of different thicknesses it may be possible in this case to allow welds of different thicknesses.

5.4.2 *Integral Cladding*

The thicknesses of the cladding range from l.5 mm to 10 mm but shall be a minimum of 2 mm where attachments are to be welded directly on to the cladding. The lining thickness at shell openings or in cover straps of but welds shall be a minimum of 3 mm.

5.4.3 *Loose Linings*

Thicknesses generally used for loose linings range from 0.75 mm to 5 mm but thicker linings may be appropriate for large vessels under mechanically severe duties. For most purposes lining thicknesses of 1.5 mm to 4 mm are preferred, thicker linings being necessary only for large pressure vessels for service above 100 °C.

Because the lining, or parts of it, are fabricated separately it shall be of sufficient thickness to be self-supporting, so that very thin linings shall be used only for small vessels or where individual sections of the linings are small. The choice of lining thickness shall be made after consideration of the following points;

a) It is easier to make proper welds, either outside the shell or in situ, if very thin sections are avoided. Hence very thin linings are not suitable if the lining is to be expanded into position or may encounter strains in service due to pressure or temperature changes, particularly in large vessels. Defects that would be unimportant in welds in thicker linings may cause early failure of welds in thin linings, and repairs to welds in thin linings are not easy.

b) The force needed to expand a thin lining against the outer vessel is less than that for a thicker lining.

c) It is inevitable that some sections of the lining will not be in contact with the outer vessel, due to irregularities in the surface of vessel or lining or to the problem of ensuring a close fit at branch openings, or other difficult features. A thick lining is more able to bridge such features than a thin one and is thus less likely to give trouble in service.

6 METHOD OF LINING

6.1 Preparation of Materials

6.1.1 *General*

Before welding, the surfaces of titanium and steel in the vicinity of the weld zone shall be cleaned to remove oil, grease, visible oxide and scale.

6.1.2 *Titanium*

The surfaces of titanium and any filler material shall be degreased with a solvent, such as industrial methylated spirits, acetone or any commercial solvent that leaves no residue.

> NOTE—Methanol (methyl alcohol) should not be used because of the dangers of stress corrosion cracking.

6.1.2.1 The oxide film may be removed by machining, wire brushing or abrasive cleaning.

The underlying oxygen enriched layer may be removed by acid pickling. The pickling solution shall contain 4 percent hydrofluoric acid and not less than 20 percent nitric acid by volume and may be used at a temperature range of 30 °C to 50 °C. This minimum concentration of nitric acid ensures that the solution remains oxidizing and prevents hydrogen pick-up.

Titanium shall be immersed for the time necessary to produce a clean and bright surface. After pickling, all traces of acid shall be removed by washing in clean water and the surface thoroughly dried before welding.

6.1.3 *Steel*

The surface of the vessel to be lined shall be smooth and free from sudden changes in contour and any blemishes made proper. Where necessary the surface may be rectified by welding and grinding.

6.2 Integral Cladding

For butt-welding clad plate the cladding is stripped back from the butting edges, and the steel weld made following normal steel welding procedures. The internal surface of the weld is ground flush and the gap in the cladding is filled flush with a suitable inlay, such as silver. Holes are drilled in the shell at intervals along the weld seams to facilitate inert gas purging to the underside of the covering strips during welding, and to provide a means for testing the tightness of the joints. A covering strip of titanium of sufficient width to overlap the filled gap is continuously welded to the cladding. Suitable methods of butt-welding clad plate are shown in Fig. 7A and Fig. 7B.

6.3 Loose Linings

6.3.1 The loose lining or sections of the lining are made separately from the outer vessel and shall be tested as far as practicable before installation. Where the material has been severely cold-worked it shall be heat-treated at 450 °C to 550 °C and, if necessary, descaled before fitting. This precaution is particularly important for linings of shell openings to minimize the residual stresses in regions where other stresses are likely to be high.

6.3.2 Considerable care is necessary to ensure that the lining is a proper fit in the outer vessel. Suitable jigs shall be used, and it may be preferable to cut sections of the lining to their final shape or dimensions as the job proceeds.

Similarly, where part or the whole of the outer vessel is to be constructed after the lining is completed, it shall be made to suit the actual dimensions of the lining.

6.3.3 Where possible welds in the lining shall be made under conditions allowing free access to both sides of the weld. But welds shall be used where possible. Where fusion welds in the lining are to be made in situ in the outer shell it is essential to ensure an adequate inert gas purge to the back surface of the weld and that all traces of oil, grease, water or other contaminants are removed from the vicinity of the weld. Precautions shall also be taken to prevent contact of the weld pool with the outer shell. Some methods of achieving this, for example, by the use of backing strips of titanium (or silver or vanadium) or by machining a groove in the outer shell behind the line of the weld, are shown in Fig. 8:

6.3.4 Where the closure weld on the outer vessel has to be made after installing the titanium lining, care shall be taken to avoid contamination of titanium. This may be done by the use of an integral backing bar to separate the weld in the outer shell from the titanium (*see* Fig. 9), and by an inert gas purge applied between the lining and outer vessel.

6.4 Fusion Welding

6.4.1 Titanium is fusion welded by the inert gas (usually argon) shielded are process, and the welding of titanium sheet in the thickness likely to be required for lining vessels is straightforward provided due consideration is given to the characteristics of the material.

When heated in air, even to temperatures appreciably below its melting point, titanium readily absorbs oxygen, nitrogen and hydrogen. The presence of any of these elements, even in small quantities, will embrittle the material. Once embrittled, titanium cannot be treated in any practicable way to restore its normal properties. Molten titanium is highly reactive with most materials, therefore, it is necessary to clean the weld area free from dust, oil and other foreign matter immediately before welding and avoid contact with any material during welding.

6.4.2 As long as protection against contamination is achieved the characteristics of titanium make the detailed welding procedure less critical than with most other metals welded by inert gas shielded arc methods. The weld pool has little tendency to fall or burn through so that down hand welds may be made without backing bars and there is no difficulty in positional welding. For sections up to 2 mm, square edge preparations are satisfactory and a root gap of up to 2 mm may be used with advantage if filler metal is added. For thicker sections a ‘Vee’ or ‘J’ preparation is usually necessary, but considerable variation in root face, root gap or in the form of ‘Vee’ or ‘J’ is possible. The detailed weld preparation shall therefore be chosen form experience or from appropriate procedure tests.

6.4.3 Contamination with steel and most other common metals greatly reduces the ductility of titanium due to the formation of brittle intermetallic compounds and excessive hardening. In consequence, titanium cannot be welded directly to steel, except by explosion welding. However, metals, such as silver and vanadium may be used as an interlayer between the steel and titanium to produce satisfactory attachment joints. It is recommended that where such joints are used they shall be fully covered by titanium straps, continuously -welded to the lining of cladding as indicated, for example, in Fig. 3, 4, 7 and 8.

6.4.4 Precautions are required to ensure that there is complete gas coverage with a uniform non-turbulent flow over all areas of heated metal including the rear surface of the weld. This normally requires the use of elongated shrouds fitted to the standard torch nozzle, and the use of appropriate shrouding to the back surface of the weld. The need for these additional shrouds particularly that attached to the torch nozzle, may impose limitations on the positioning of welds. For small assembles it may be preferable to carry out the welding in a chamber purged by inert gas.

6.4.5 Manual TIG welding produces excellent joints provided that speeds are limited to 75 mm/min to 100 mm/min to avoid turbulence in the shielding gas and to avoid the need for large unwieldy shrouds. The torch shall be held as upright as possible to ensure effective distribution of inert gas over the weld metal and weaving shall be avoided. While using added weld metal, the filler wire shall be kept within the gas shield and fed into the pool continuously, a dabbing technique shall not be used.

Simple shrouds for attachment to the nozzle of a TIG torch are readily fabricated from sheet metal, and it is common practice to use a variety of forms of shroud, shaped to accommodate the geometry in the vicinity of the weld. Additional protection may be obtained, if necessary, by the use of baffles, made from metal or plastics, held in place by clamps or adhesive tape. This method is effective in providing protection to the back surface of the weld. Backing bars incorporating a shallow channel for the inert gas flow may also be used. Separate supplies may be required to the different parts of the shrouding; screening and other precautions to avoid draughts are highly desirable.

6.4.6 Details of welding conditions for various lining thicknesses are given in Table 3, and typical mechanical properties of welds arc given in Table 4.

6.4.7 Other welding processes, including some ‘automatic features, are also used to allow faster welding speeds. These techniques tend to require larger shields than the manual TIG technique, and are thus less flexible and best suited to long welds in regions of low curvature.

6.4.8 While arranging weld sequences it is good practice to ensure that no section of any weld is melted more than twice, since the possibility of weld contamination increases with each pass. Surface contamination from one pass will be dissolved in the weld pool on a subsequent pass, and unless the weld is kept clean and thoroughly protected for each pass, the final result may be a brittle weld.

6.5 Spot Welding

6.5.1 Titanium is readily resistance spot welded and has thermal and electrical conductivities and high temperature strength similar to corrosion-resisting steels. The welding techniques which have been developed for corrosion-resisting steels, may be applied to a similar thickness of titanium.

6.5.2 No shielding gas is necessary as the close proximity of the adjacent surface, at the weld zone, together with the very short duration of the welding cycle, makes special shielding unnecessary.

Table 3 Welding Conditions for Titanium Sheet
(*Clause* 6.4.6)

Sl No.	**Type of Weld**	**Sheet Thickness** mm	**Filler Rod Diameter** mm	**Sheet Edge Preparation**	**Type of Reinforcement**	**Welding Current** (d.c.) A	**Number of Runs**	**Gas Flow**	
								Torch m^3/h	Backing m^3/h
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	Butt	0.711	—	Square edge	U$^{1)}$	20	1	0.70-0.85	0.05-0.11
ii)		0.914	1.625	Square edge	F$^{2)}$	35	1	0.70-0.85	0.05-0.11
iii)		1.219	—	Square edge	U	50	1	0.70-0.85	0.05-0.11
iv)		1.219	1.625	Square edge	F	60	1	0.70-0.85	0.05-0.11
v)		1.574	—	Square edge	U	60	1	0.70-0.85	0.05-0.11
vi)		1.574	1.625	Square edge	F	65	1	0.70-0.85	0.05-0.11
vii)		2.108	—	Square edge	U	80	1	0.70-0.85	0.05-0.11
viii)		2.108	2.032	Square edge	F	85	1	0.70-0.85	0.05-0.11
ix)		3.175	2.032	90° included angle 1.5 mm root face or U-preparation 0.8 mm root face	First run U Second run F	50-80 120	2	0.70-0.85	0.05-0.11
x)	Fillet	1.219	1.674	—	F	40	1	0.56-0.85	0.05-0.11
xi)		1.651	2.159	—	F	40	1	0.56-0.85	0.05-0.11
xii)		3.937	2.159 to 2.641	—	F	70-90	1	0.56-0.85	0.05-0.11
xiii)	Corner	1.168	—	—	U	40	1	0.56-0.85	0.05-0.11
xiv)	Lap	1.219	1.574	—	F	50	1	0.56-0.85	0.05-0.11
	$^{1)}$ Unfilled. $^{2)}$ Filled.								

6.5.3 It is possible to spot weld titanium to steel using an interlayer of silver or Vanadium foil. It is recommended. However, that tests on simulated joints shall be made before proceeding with a particular design to evaluate weld quality and strength of the joint.

Table 4 Typical Mechanical Properties of Argon-Arc Welds in Titanium
(*Clause* 6.4.6)

Sl No.	**Material**	**Tensile Strength** MPa	**Elongation Percent on 50 mm**	**Bend Radius**	**Hardness (HV 10)**			
					Sheet	Heat-Affected Zone	Weld	Increment Weld Hear-Affected Zone
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Titanium	345	35 *p*	$\frac{1}{2}$-1 t	154	148	163	15
ii)	Titanium	345	19 *w/p* -29 *w/p*	1-1$\frac{1}{2}$ t	182	193	201	8

w = Fractured in the weld metal; and
p = Fractured in parent material.

NOTE — 1 MPa = 10^6 N/m^2 = 10 bar.

6.6 Precautions against Iron Contamination

6.6.1 *General*

Contamination by small traces of iron and certain other metals during fabrication can lead to trouble in service in severe conditions in two ways. The contaminant may diffuse into the titanium in the vicinity of welds, or on items that are heated above 400 °C, and so lead to the deterioration in corrosion resistance (*see* **3.1.2**) while surface contamination can lead to reduced corrosion resistance or embrittlement by hydrogen (*see* **3.4**). Special precautions are thus necessary for items intended for service in severe conditions.

The object of these precautions is to ensure that dangerous contamination is not present in the final equipment. Two basic types of precautions are possible, namely:

a) Avoidance of contamination at all stages in the fabrication process; and
b) Removal of contamination before any operation involving heating of items or the complete assembly above 400 °C, after fabrication is complete.

In practice the most effective approach is to use a combination of both precautions, in combination with tests to confirm that surfaces are free of iron, such as those described in Annex B.

6.6.2 Methods of Avoiding Contaminations The most important cause of contamination is contact with a second metal or with other materials that have been in such contact, loose particles, such as airborne dust are less troublesome as they are readily removed in the degreasing operations (*see* **6.1.2**) or similar processes.

6.6.2.1 Tools shall be reserved for use with titanium or, where this is impracticable, scrupulously, cleaned or protected, so that direct contact (particularly sliding or rubbing) between the tool and titanium is minimised.

6.6.2.2 Iron, carbon or low alloy steel tools, particularly wire brushes, shall not be used if they can be avoided.

6.6.2.3 Work on titanium shall be carried out in an area reserved, at least temporarily, for the purpose, and this area shall be cleaned to remove metal dust before use. If fabrication of carbon or low alloy steel is carried out in the same building, it is desirable that the area reserved for work on titanium is separated from the rest of the building by, for example, plastic sheeting.

6.6.2.4 Titanium items shall be covered when work is not being done in them, for example, by the use of plastic bags or sheeting.

6.6.2.5 All personnel engaged on work on titanium shall be provided with special footwear, reserved for the purpose, with soles of rubber or other soft material, and their overalls shall be kept clean.

6.6.3 *Methods of Removing Contamination*

The following methods are recommended:

a) Abrasive blasting with iron-free grit, for example, alumina or silica;
b) Buffing with a fabric wheel using an iron-free abrasive;
c) Abrasive cleaning with an iron-free abrasive cloth; and
d) Pickling in aqueous solution containing 4 percent hydrofluoric acid and not less than 20 percent nitric acid by volume at 30 °C to 50 °C followed by rinsing in potable water.

All regions in the vicinity of welds, including the filler material, if appropriate, shall be cleaned by one or other of these methods immediately before the final degreasing before welding, any surface to be heated above 400 °C shall also be cleaned. This cleaning may be omitted if the surfaces have been shown to be free of contamination, by one of the tests in Annex B, or on any surface that will not come into contact with a corrosive medium.

7 INSPECTION, TESTING, MAINTENANCE AND REPAIR

7.1 Inspection

7.1.1 Quality control of the material and fabricating procedures of both loose lined 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 titanium 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) All welders shall be approved to the procedures as detailed in **7.2** or where required in accordance with the requirements of other authorities;
e) The fit-up of sections of the lining shall be proper. The weld preparation shall be correct for the welding procedure being used;
f) After each run the weld shall be visually examined for contamination as indicated by the weld colour, lack of fusion, cracks, etc. The quality of the work may be compared with the welders qualifying test plates;
g) The colour of a titanium weld is an indication of the effectiveness of the gas shielding used and is an indirect measure of the degree of weld contamination. A bright silver metallic lustre usually indicates proper shielding. Other colours that may be encountered are listed in order of increasing level of contamination:

   Light straw, Dark straw, Light blue, Dark blue, Grey blue, Grey, White (loose deposit)

   Weld colours of light and dark are acceptable whereas the grey blue and grey or the appearance of a loose powdery substance indicates unacceptable contamination. Since contamination is only indirectly indicated by weld colour it is important that a welding procedure previously qualified by destructive testing is followed; and
h) On completion of the weld the minimum non-destructive test shall be a dye-penetrant test and shall be made on all welds.

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 titanium linings or titanium clad materials 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 the somewhat special technique required before he is subjected to these tests. Where employed, mechanical fixing or brazing shall be included in the simulated test.

7.2.2 Each test weld shall be subjected to:

a) A visual examination, which shall show no lack of fusion or undercutting or unacceptable discoloration of the titanium;
b) Macro-sectioning and microscopic examination where appropriate, which shall show that sound root fusion 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) A hardness survey.

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.

7.3 Testing of Vessels

7.3.1 *General*

This code covers a variety of types of vessels which may be subjected 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 done shall be considered carefully, both from safety aspects and because some tests can interfere with others, for example, water trapped in small perforations 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 or purge 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 shall there be any water or other volatile liquid included as a result of test or in the event of a leak.

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 purposes. 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 a lower pressure (at least the 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*

The clad vessel shall be hydraulically tested and this shall be carried out when the fabrication of the steel vessel is complete but before the lining of branches and the attachment of cover straps to the shell welds. The branch linings and cover straps shall be tested by a halogen, helium or radio-active test, the test gas being introduced between the shell and the cover straps by way of holes drilled in the vessel wall. A prior air test at low pressure is recommended before the leak procedure detailed above. A second pressure test (to at least working pressure) shall be carried out, when the vessel is complete.

7.3.2.3 *Testing of loose-lined vessels*

The loose-lined vessel 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 maybe a pneumatic test.

7.3.3 *Tests for Continuity of the Lining*

7.3.3.1 *Dye-penetrant test*

Welds in the lining or in a clad vessel shall be examined by a dye-penetrant technique, and any cracks or porosity repaired before further testing. The dye-penetrant test may be omitted if a sensitive leak detection test, such as described in **7.3.3.3**, is to be applied.

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 above 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 two methods, either

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, glycerine, 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 will only be successful 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, and the presence of a leak is 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 may be 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 which may be safely introduced between the shell and lining, but it 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 which are 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, or 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. 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 dichlorodifluoromethane, 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 element 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 the 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.

7.3.5 *Tests for Contamination*

The tests described in Annex B shall be used to ensure that the precautions employed to avoid or remove surface metallic contamination are effective. Iron is the most likely contaminant, as well as the most dangerous, and the use of the precautions described in **6.6**, combined with these tests, provide an effective precaution against contamination by iron and other metals.

Tests for iron contamination are required on surfaces in the vicinity of welds immediately before welding; on surfaces to be heated above 400 °C; and on the complete assembly. The number of such tests shall be chosen by agreement between the fabricator and the customer after consideration of the circumstances.

If precautions against contamination are fully employed it will only be necessary to carry out spot checks as a quality control procedure, but more extensive testing for iron contamination may be required if the precaution against contamination cannot be fully employed.

Other tests for iron contamination, or variations in the composition of the reagents than those described in Annex B may be used after agreement between the fabricator, and the customer.

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, both general and 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:

    1) Moisture trapped behind the lining during fabrication;
    2) Expansion of gas, forced behind the lining through a pinhole under high pressure, when the high pressure is released; and
    3) A collapse of a loose lining due to inadvertent exposure to vacuum conditions.

7.4.2 Before any repair to a lining is carried out the original lining in the defective area shall be removed and the exposed shell surfaces thoroughly cleaned and made proper, if necessary, extreme care shall be taken to ensure that all moisture and products of corrosion have been removed before the repair is affected.

Where damage to the steel shell has occurred care shall be taken to ensure that any repair procedure is compatible with the subsequent lining technique and safe operation of the vessel.

Purge holes shall be drilled in the vessel wall and a supply of inert gas supplied to the underside of any welded joints made to effect the repair.

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 leak immediately.

ANNEX A

(*Foreword*)

EXCHANGE OF INFORMATION

A-1 Early consultation and exchange of information shall take place between the lining contractor and all parties concerned in the design, manufacture, erection and use of the vessels and equipment to be lined. Complete and accurate scale drawings shall be made available to all parties concerned.

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) Service temperature and pressure ranges;
d) Whether vessel will be subjected to vacuum;
e) Other factors influencing stresses on linings, for example, expansion, contraction, vibration, and erosion;
f) Velocity of contents and any abrasive characteristics to be met, especially at points of their entry to the vessel;
g) Means of access for lining materials and installation crew and equipment, lifting facilities, etc;
h) Details of site conditions, where existing vessel, has been in service on site 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.

ANNEX B

(*Clauses* 3.4, 6.6.1, 6.6.3 *and* 7.3.5)

TEST FOR IRON CONTAMINATION

B-1 TESTS

The following tests for iron contamination are recommended.

B-1.1 Ferroxyl Test

The test solution is made up by dissolving 7 g of potassium ferricyanide and 4.5 ml of nitric acid (65 percent concentration) in 214 ml of distilled water. (The solution deteriorates in a few days, becoming cloudy, and shall therefore be used shortly after it is made up.) The test may be done in two ways.

NOTE — Demineralized water may be used in place of distilled water in any of the reagents described.

B-1.1.1 Soak a filter paper in the solution and apply this to the surface under examination ensuring proper contact over the whole surface. The presence of iron is revealed by a blue coloration almost immediately after application of the paper in those areas which contain iron contamination.

B-1.1.2 Swab or spray the surface to be tested using the solution. Iron contamination is again disclosed by blue coloration. It may be helpful to increase the viscosity of the solution by the addition of iron-free gelatin or similar agent, and this will be permitted as long as it is demonstrated that the presence of the gelatine or similar agent does not interfere with the sensitivity of the test.

B-1.2 Phenanthroline Test

The reagent, which is used for calorimetric determination of iron in titanium and other alloys, is made up as follows:

a) Dissolve 272 g of hydrated sodium acetate ($CH_3COO\ Na\ 3H_2O$) in about 500 ml of hot distilled water add 240 ml glacial acetic acid and dilute to 1 l with distilled water;
b) Dissolve 3.5 g of hydroxylamine hydrochloride ($HO.NH_2.HCl$) in 350 ml of distilled water;
c) Dissolve 2.5 g of 1:10 phenanthroline monohydrate in about 200 ml of hot distilled water and dilute to 300 ml; and
d) Mix solutions (a), (b) and (c) together to make 1 650 ml. The mixed solution is reasonably stable, and provided that it is kept in a stoppered bottle, it has a shelf life of 2 to 3 months.

NOTE — Demineralized water may be used in place of distilled water in any of the reagents described.

The procedure is the same as for the ferroxyl test, that is, a filter paper soaked in the solution is laid over the surface to be tested, again ensuring proper contact between paper and metal surface. Iron contamination is shown by an orange-red coloration in the contaminated region.

B-1.3 Because the phenanthroline solution is more stable it is more convenient than the ferroxyl test where only a limited amount of testing is to be done. Both reagents react to some extent with iron bearing dust, including rust, so that it is recommended that the surfaces to be tested are swabbed with an approved solvent (*see* **6.1.2**) before the test. After the test the reagent shall be removed from the titanium surface by washing with potable water, followed by rinsing in an approved solvent (*see* **6.1.2**).