ENGINEERING STANDARD

FOR

LININGS

CONTENTS :

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APPENDICES:

1. SCOPE

1.1 This Engineering Standard covers the minimum requirements for the lining which will be used in equipment (e.g. vessel, storage tank and pipeline).

1.2 It is intended for use in refineries, petrochemical plants, oil and gas plant and, where applicable, in exploration, production and new ventures.

1.3 The Standard covers 30 nonmetallic lining system which are classified in following main groups (see Table 6):

a) Thermoplastic material
b) Thermosetting material
c) Rubbers
d) Mineral and bitumen material.

1.4 The lining applies to equipment fabricated in metal or concrete and both bonded and loose lining. For the choice of lining option is open to the specifier regarding the provisions of Section 8.

1.5 Requirements for design and fabrication of the equipment and the state of preparation necessary for the surfaces to be lined are specified in this Standard.

1.6 Guidance on metallic lining (cladding) of pressure vessels and pipelines are included in Appendices of A and B, while the Appendix C includes hardness comparison chart for plastics and rubbers. The test procedure for effect of lining materials on drinking water quality is given in Appendix D.

1.7 Application of lining shall be in accordance with IPS-C-TP-352.

2. REFERENCES

Throughout this Standard the following standards and codes are referred to. The editions of these standards and codes that are in effect at the time of publication of this Standard shall, to the extent specified herein, form a part of this Standard. The applicability of changes in standards and codes that occur after the date of this Standard shall be mutually agreed upon by the Company and the Vendor/Consultant:

API (AMERICAN PETROLEUM INSTITUTE)

API-RP-1631	"Interior Lining of Underground Storage Tanks"
API-PR-10E	"Recommended Practice for Application of Cement Lining to Steel Tubular Goods, Handling Installation and Joining"

ASME (AMERICAN SOCIETY OF MECHANICAL ENGINEERING)

ASME-SA-263	"Corrosion-Resisting Chromium Steel Clad Plate, Sheet, and Strip"
ASME-SA-264	"Stainless Chromium-Nickel Steel Clad Plate, Sheet, and Strip"
ASME-SA-265	"Nickel-Base Alloy Clad Steel Plate"
ASME-SA-578	"Straight Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Application"

ASTM (AMERICAN SOCIETY FOR TESTING AND MATERIALS)

ASTM-A-106	"Specification for Seamless Carbon Steel Pipe for High-Temperature Service"
ASTM-A-185	"Specification for Steel Welded Wire, Fabric, Plain, for Concrete Reinforcement"

ASTM-A-240	"Specification for Stainless and Heat-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet and Strip for Fusion-Welded Unfired Pressure Vessel"
ASTM-A-262	"Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steel"
ASTM-A-283	"Specification for Low and Intermediate Tensile Strength Carbon Steel Plates"
ASTM-A-285	"Specification for Pressure Vessel Plates Carbon Steel, Low and Intermediate-Tensile Strength"
ASTM-A-314	"Specification for Stainless and Heat-Resisting Steel Billets and Bars for Forging"
ASTM-A-424	"Specification for Steel Sheet for Porcelain Enameling"
ASTM-A-497	"Specification for Welded Deformed Steel Wire Fabric for Concrete Reinforcement"
ASTM-A-516	"Specification for Pressure Vessel Plates, Carbon Steel, for Moderate and Lower-Temperature Service"
ASTM-A-575	"Specification for Steel Bars, Carbon, Merchant Quality"
ASTM-B-432	"Copper and Copper Alloy Clad Steel Plate"
ASTM-C-27	"Classification of Fire Clay and High-Alumina Refractory Brick"
ASTM-C-33	"Specification for Concrete Aggregates"
ASTM-C-35	"Specification for Inorganic Aggregate for use in Gypsum Plaster"
ASTM-C-150	"Specification for Portland Cement"
ASTM-C-155	"Classification of Insulating Fire Brick"
ASTM-C-494	"Specification for Chemical Admixture for Concrete"
ASTM-C-581	"Code of Practice for Determining Chemical Resistance of Thermosetting Resin Used in Glass Fiber Reinforced Structure"
ASTM-C-616	"Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete"
ASTM-C-618	"Specification for Flyash and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Portland Cement Concrete"
ASTM-C-660	"Production and Preparation of Gray-Iron Casting for Porcelain Enameling"
ASTM-D-531	"Test Method for Rubber Property"
ASTM-D-543	"Test Method for Resistance of Plastics to Chemical Reagents"
ASTM-D-785	"Test Method for Rockwell Hardness of Plastic and Electrical Insulting Material"
ASTM-D-1415	"Test Method for Rubber Property-International Hardness"
ASTM-D-2240	"Test Method for Rubber Property-Durometer Hardness"
ASTM-G-28	"Method for Detecting Susceptibility to Intergranular Attack in Wrought Nickel-Rich, Chromium-Bearing Alloys"
ASTM-G-48	"Test Method for Pitting and Crevice Corrosion Resistance of Stainless Steel and Related Alloys by The Use of Ferric Chloride Solution"

AWWA (AMERICAN WATER WORKS ASSOCIATION)

AWWA-210-84	"Liquid Epoxy Coating Systems for Interior and Exterior of Steel Water Pipelines"

BSI (BRITISH STANDARDS INSTITUTION)

BS 470	"Specification for Inspection, Access and Entry Opening for Pressure Vessels"
BS 490: Part 10	"Testing for Physical Properties of Rubber and Plastics"
BS 2035	"Specification for Cast Iron Flanged Pipes and Flanged Fitting"
BS 3416	"Specification for Bitumen-Based Coatings for Cold Application, Suitable for Use in Contact with Potable Water"
BS 6374	"Lining of Equipment with Polymeric Materials for The Process Industries"
Part 1:	"Specification for Lining with Sheet Applied Thermoplastics"
Part 2:	"Specification for Lining with Non-Sheet Applied Thermoplastics"
Part 3:	"Specification for Lining with Stoved Thermosetting Resins"
Part 4:	"Specification for Lining with Cold Curing Thermosetting Resins"
Part 5:	"Specification for Lining with Rubbers"
BS 8007	"Code of Practice for Design of Concrete Structures for Retaining Aqueous Liquids"
BS 8110	"Structural Use of Concrete"

DIN (DEUTSCHES INSTITUTE FÜR NORMUNG)

DIN-53456	"Testing of Plastics"
DIN-53505	"Testing of Rubber, Elastomer and Plastic, Shore Hardness Testing A & D"
DIN-53519	"Testing of Elastomers, Determination of Indentation Hardness of Soft Rubber"

IPS (IRANIAN PETROLEUM STANDARDS)

IPS-C-TP-101	"Surface Preparation"
IPS-C-TP-352	"Lining"
IPS-E-TP-742	"Corrosion Consideration During Fabrication and Installation"
IPS-E-TP-760	"Corrosion Consideration in Design"

NACE (NATIONAL ASSOCIATION OF CORROSION ENGINEERS)

NACE-6H160	"Glass Lining and Vitreous Enamels"
NACE-6K157	"Acid Proof Vessel Construction with Membrane and Brick Lining"

SIS (SWEDISH STANDARD)

SIS 05 59 00	"Rust Levels of Steel Structure and Quality Levels for Preparation of Steel Surface for Rust Protecting Paints"

SSPC (STEEL STRUCTURE PAINTING COUNCIL)

SSPC-SP-8	"Pickling"

3. DEFINITIONS AND ABBREVIATIONS

3.1 Definitions

Applicator

Is the party which applies the chemical resistant linings specified by the Company.

Blister

A gas or liquid filled cavity within the lining material or between the lining and substrate.

Ceramic

Articles with a glazed or unglazed body of crystalline or partly crystalline structure or of glass, produced from essentially inorganic, non-metallic substances and formed either from a molten mass solidified on cooling, or simultaneously or subsequently matured by the action of the heat, ASTM-C-242.

Chemical Resistant Resin Mortar

An intimate mixture of liquid resinous material, selected filler material, and setting agent forming a trowelable mortar that hardens by chemical reaction, ASTM-C-904.

Cladding

A composite metal containing two or more layers that have been bonded together corralling coextention, welding diffusion, bonding, heavy chemical deposition or heavy electro plating.

Contractor

The party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility.

The Company may undertake all or part of the duties of the Contractor.

Company

The party which initiates the project and ultimately pays for its design and construction. The Company will generally specify the technical requirements. The principal may also include an agent or consultant authorized to act for and on behalf of the Company.

Designer

Person or party responsible for all or part of design and engineering of project.

Dew Point

The temperature at which moisture will condense.

Fabricator

The party which manufactures components to perform the duties specified by the Company. It is generally considered to be synonymous with the term manufacturer.

Hydraulic Cement

Cement that sets and hardens by chemical interaction with water and capable of doing so under water.

Inspector

The inspector or engineer employed by the Purchaser and acting as the purchaser’s representative, the inspector’s or engineer’s respective assistants properly authorized and limited to the particular duties assigned to them, or the Purchaser acting as the inspector.

Glass

Inorganic fusion product that has cooled to a rigid condition without crystallizing.

Laitance

A milky white deposit on new concrete.

Lining

Any sheet or layer of material attached directly to the inside face of form work to improve or after quality and surface texture.

Lump

In porcelain enamels, a rounded projection in the enamel surface, usually a defect.

Orange Peel

A surface condition characterized by an irregular waviness of the porcelain enamel resembling an orange skin in texture, sometimes considered a defect.

Pinhole

A small defect in the lining that would permit corrosion of the substrate under the conditions for which the lining is designed.

Note:

The word ’pinhole’ is synonymous with ’holiday’ and ’pore’.

Plastic

A material that contains as an essential ingredient a high polymer and which at some stage in its processing into finished products can be shaped by flow.

Porcelain

Glazed or unglazed vitreous ceramic whiteware matured like ceramic and glazed together in the same firing operation.

Powder Organic Coating

A product containing pigments, resins and other additives which is applied in the form of a powder on to a metallic substrate and is fused to form a coherent continuous finish.

Quartz/Silica

Glass made either by flame hydrolysis of silicon tetrachloride or by melting silica, usually in the form of granular quartz, i.e. fused silica, ASTM-C-162.

Refractories

Non-metallic materials with chemical and physical properties applicable for structures and system components exposed to environments above 538°C (1000°F), ASTM-C-71.

Resin

A solid, semisolid, or pseudo solid organic material that has an indefinite and often high relative molecular mass, exhibits a tendency to flow when subjected to stress, usually has a softening or melting range and, usually fractures conchoidally. In a broad sense, the term is used to designate any polymer that is a basic material for plastics.

Rubber

A material capable of quickly and forcibly recovering from all deformations. It can be modified to be essentially insoluble, but it can swell in boiling solvents, e.g. benzene, methyl ethyl ketone and ethanol/toluene azeotrope. Rubber in its modified state, free of diluents, stretched at 18 to 29°C and held for 1 minute before release, retracts within 1 minute to less than 1.5 or 2 times its original length, ASTM-D-1566.

Sagging

1) A defect characterized by a wavy line or lines appearing on those surfaces of porcelain enamel that have been fired in a vertical position.

2) A defect characterized by irreversible downward bending in an article insufficiently supported during the firing cycle.

Stone Ware

Vitreous or semi-vitreous ceramics of fine texture made primarily from non-refractory fire clay, ASTM-C-242.

Surface Profile

Surface profile is a measurement of the roughness of the surface which results from abrasive blast cleaning. The height of the profile produced on the surface is measured from the bottoms of the lowest valleys to the tops of the highest peaks.

Tearing

A defect in the surface of porcelain enamel, characterized by short breaks or cracks which have been healed.

Thermoplastic Material

A plastic that repeatedly will soften by heating and harden by cooling within a temperature range characteristic for the plastic. In the softened state it can be shaped by flow into articles, e.g. by molding/extrusion, ASTM-D-883.

Thermosetting Material

A plastic being substantially infusible and insoluble after curing by heat or other means, ASTM-D-883.

3.2 Abbreviations

BR	Polybutadiene Rubber
CSM	Chlorosulfonated Polyethylene (Chlorinated Rubber)
CR	Chloroprene Rubber
E C TFE	Ethylene-Chlorotrifluoro-Ethylene
E PDM	Ethylene-Propylene Diene Monomer
EPR	Ethylene-propylene Rubber
EVA	Ethylene Vinyl Acetate
FEP	Fluorinated Ethylene Propylene Copolymer
FKM	Fluorinated Rubber (Polymethylene Type)
IIR	Butyl Rubber
IR	Synthctic Polyisoprene
NBR	Nitril Rubber
NR	Natural Rubber (Poly isoprene)
PA	Polyamide
PE	Polyethylene
PF	Phenol-Formaldehyde
PFA	Perfluoroalkoxy
PP	Polypropylene
PTFE	Polytetra Fluoro Ethylene
PU	Polyurethane
PVC	Polyvinyl Chloride
PVDF	Polyvinylidene Fluoride
SBR	Styrene butadiene Rubber
XNBR	Carboxylated Nitril Rubber

4. UNITS

This Standard is based on International System of Units (SI), except where otherwise specified.

5. PURPOSE OF LINING

Preventation of corrosion by lining may be desirable for several reasons:

5.1 To extend the life of equipment.

5.2 To prevent shutdowns.

5.3 To prevent accidents resulting from corrosion failures.

5.4 To avoid product contamination.

6. THE NEED FOR STANDARD

6.1 The potential life of a protective system is unlikely to be realized, unless:

a) The correct choice of system is made;

b) the materials used in the system can be supplied when required and with the properties attributed to them when making the choice;

c) the materials are applied in conditions and with standards of workmanship described in the IPS-C-TP-352;

d) the handling, transportation and storage (over which the main contractor has minimal control) of all materials and lined components results in no damage to the integrity of the materials or coating that can not be completely restored;

e) the erection procedures cause no damage to the lining that can not be completely restored;

f) such restoration of damaged areas results in a protection at least as good as that of the undamaged areas.

Notes:

1) If the lining is applied after the equipment has been installed, due consideration should be given to proper surface preparation and quality control after application.

2) If the lining is applied before the equipment is installed, due consideration shall be given to lining of field joints.

6.2 There are many variable factors (both natural and otherwise) which can influence the fulfillment of all these conditions for success, and it follows that no two projects can be exactly similar, this is one reason why a "standard" specification shall always be included in a set of contract documents.

7. LINING DESIGN

7.1 Exchange of Design Data

Early consultation shall be arranged between all parties concerned with the application of this Engineering Standard, to establish the following information which shall be fully documented.

7.1.1 Information to be supplied by the Purchaser

The Purchaser shall state either 7.1.1.1 or 7.1.1.2:

7.1.1.1 Precise details of the lining requirements;

7.1.1.2 The service conditions for which the lining required so that the lining contractor can make recommendations.

In case of 7.1.1.2 the Purchaser shall provide the relevant information detailed in following:

a) Design and fabrication details of the equipment to be lined and provision of drawings (see Clause 7.3).
b) Details of gasket materials.
c) Details of the contents of the vessels or equipment, including trace materials (see Section 8).
d) The design temperature (see Section 8).
e) The design pressure.
f) The details of any solids to be handled (see Section 8).
g) Any specific mechanical properties required of the lining including suitability for machining (see Section 8).
h) The methods of heating and/or cooling.
i) Cleaning methods, for example, water washing, solvent washing, boiling out or steaming (see IPS-C-TP-352).
j) Where the lining work will be done.
k) Site conditions which may affect the work, for example, availability of services.
l) Preparation of surface (see IPS-C-TP-101).
m) Application of lining (see IPS-C-TP-352).

7.1.2 Information to be supplied by the Designer of lining

The contractor shall provide the relevant information detailed in following:

a) Any special requirements for materials and system used in surface preparation.

b) The type and specification of material to be used for lining (see Section 8).

c) The minimum thickness of the lining and where applicable the maximum thickness (see Section 8).

d) The provision of test plates.

e) When the lining is to be applied outside the applicator's works and the primers and/or adhesive as applied contain solvents, the types of solvents are to be stated, together with their flash points and threshold limit values.

f) Specified sheet or rubber lining.

g) The minimum and maximum allowable temperature and allowable humidity which are required for the correct application of the lining.

h) The minimum temperature required during the vulcanization of the lining in case of rubber lining and the vulcanization schedule, where applicable.

i) Inspection techniques/procedures to be employed, acceptance levels and stages of inspection.

j) Handling, transport, storage and installation procedure .

k) Any special information needed or recognized with regard to inorganic linings.

7.2 Compliance

7.2.1 Fabricator

The fabricator of metal equipment to be lined shall comply with the following:

7.2.1.1 Design and fabrication details of the equipment to be lined and provision of drawings (see Clause 7.3)

7.2.1.2 Responsibility for inspection and testing of:

- The equipment as fabricated.
- The equipment after preparation of welds and edges in the case of metals, surfaces and edges in the case of concrete.

7.2.1.3 Handling, transport, storage and installation procedure.

7.2.2 Applicator (contractor)

The applicator shall comply with IPS-C-TP-352.

7.2.2.1 Selectioned lining (see Section 8).

7.2.2.2 Method of lining.

7.2.2.3 Responsibility for inspection and testing of:

- The equipment after blast cleaning.
- The lining material.
- Lining after fitting.
- After welding of the lining.

7.2.2.4 Method of continuity test for lined equipment .

7.2.2.5 Rectification of faults in fully cured linings.

7.2.2.6 Handling, transport, storage and installation procedure.

7.3 Design, Fabrication and Surface Finish of Equipment to be Lined (see also IPS-E-TP-760)

7.3.1 General

The basic design, fabrication and testing for mechanical reliability of the equipment to be lined shall be carried out to the appropriate IPS Standards and shall comply with Clauses 7.3.2 and 7.3.3 or 7.3.4 and 7.3.5 before the lining operation commences.

Note:

Linings will affect heat transfer and tolerances required for joints; both features need to be considered at the design stage of the equipment.

7.3.2 Design of metal equipment to be lined with organic materials (Thermoplastics, thermosets and rubber as well as bitumen and coal-tar) (see also IPS-E-TP-760)

7.3.2.1 Equipment to be lined shall be sufficiently rigid that there is no possibility of deformation which would result in damage to the lining during transportation, installation and operation. When stiffeners are required, they shall normally be applied to the unlined side of the equipment.

Note:

In the case of hard rubber and ebonite linings this requirement is of particular importance.

7.3.2.2 The arrangements for the lifting of equipment shall be determined at the design stage.

7.3.2.3 The design of all equipment shall allow for access during the preparation of the surface and application of the lining and for venting of fumes evolved during the operation.

In completely enclosed vessels there shall be at least one manhole that after lining complies with BS 470 and one additional branch of not less than 77 mm bore to permit adequate circulation of air.

Note:

It is recommended that, where practicable, the minimum diameter of a manhole should be 600 mm.

7.3.2.4 Riveted constructions shall not be used.

7.3.2.5 Bolted joints shall be permitted only if they can be dismantled for lining.

7.3.2.6 When calculating clearances, allowance shall be made for the thickness of the lining.

7.3.2.7 Surfaces to be lined shall be of a smooth contour.

7.3.2.8 Discontinuities, crevices and sharp projections shall be avoided.

7.3.2.9 Fittings which have to be installed after the completion of the lining process shall be designed to be lined or fabricated from materials that will not be affected by the process conditions.

7.3.2.10 Normally all connections to lined parts of equipment shall be flanged. If for any reason screwed connections are required, then these parts shall be fabricated in corrosion-resistant materials.

7.3.2.11 All nozzles and outlets shall be as short as possible, straight and flanged. Flange faces shall have a plain surface to allow the lining to continue over the face.

7.3.2.12 Branches and outlets, except for plain ended pipes, shall be as short as possible and flanged so that the lining may be taken over the flange face to prevent the ingress of process fluid between the lining and the substrate. Acceptable flange systems are shown in Fig. 1. Plain-ended pipes shall be designed so that the lining may be turned over the end and the outside of the pipe. Where pads are required they shall be designed as shown in Fig. 1(d). Drilled and tapped holes in pads for studs shall not penetrate the shell of the equipment.

7.3.2.13 Heating coils, immersion heaters and sparger pipes shall be installed after the completion of the lining process and shall be located so that no part is closer than 100 mm from a lined surface. In the case of nozzles through which heating coals, etc., enter equipment, a smaller clearance is permitted provided that the temperature of the pipe through the nozzle does not exceed 80°C. In no case shall this clearance be less than 25 mm. Fluids introduced through sparger pipes or dip pipes shall not impinge directly on to the lining. External heating of equipment shall not be permitted without full consultation with the applicator of the lining.

7.3.2.14 The design of equipment shall be such that there is easy hand access to areas where thermoplastic sheets need to be welded.

7.3.2.15 The design of pipework shall be such as to allow ready access to welds and bends for weld and surface preparation and permit the fitting of extruded liners (see Fig. 1).

Note:

Pipe systems made from straight lengths with separate 'standard' (1.5 D) bends and tees meet this requirement. Bends shall not be greater than 90°.

Where pipe systems include 'non-standard' fittings their suitability for lining shall be established. Suitable arrangements are illustrated in Fig. 9.

The maximum dimensions of pipes and fittings which can be rubber lined shall be determined during the exchange of data (see Clause 7.1.1.2a). Typical maximum lengths of straight pipe which can be rubber lined are detailed in Table 1.

TABLE 1 - MAXIMUM LENGTH BETWEEN FLANGES

NOMINAL PIPE SIZE mm	MAXIMUM LENGTH BETWEEN FLANGES mm
25	2000
32	2500
40	3000
50	3500
65	4000
80 to 600	6000

Cast iron pipework and fittings manufactured to BS 2035 are of suitable dimensions and shall be permitted for lining.

Pipes less than 25 mm diameter shall not be rubber lined.

Pipes less than 450 mm diameter shall be of seamless construction only. Screwed fittings shall not be rubber lined.

Depending on the fabrication method, where flat face or raised face flanges are used they shall be welded square to the pipe or fitting according to normal manufacturing tolerances.

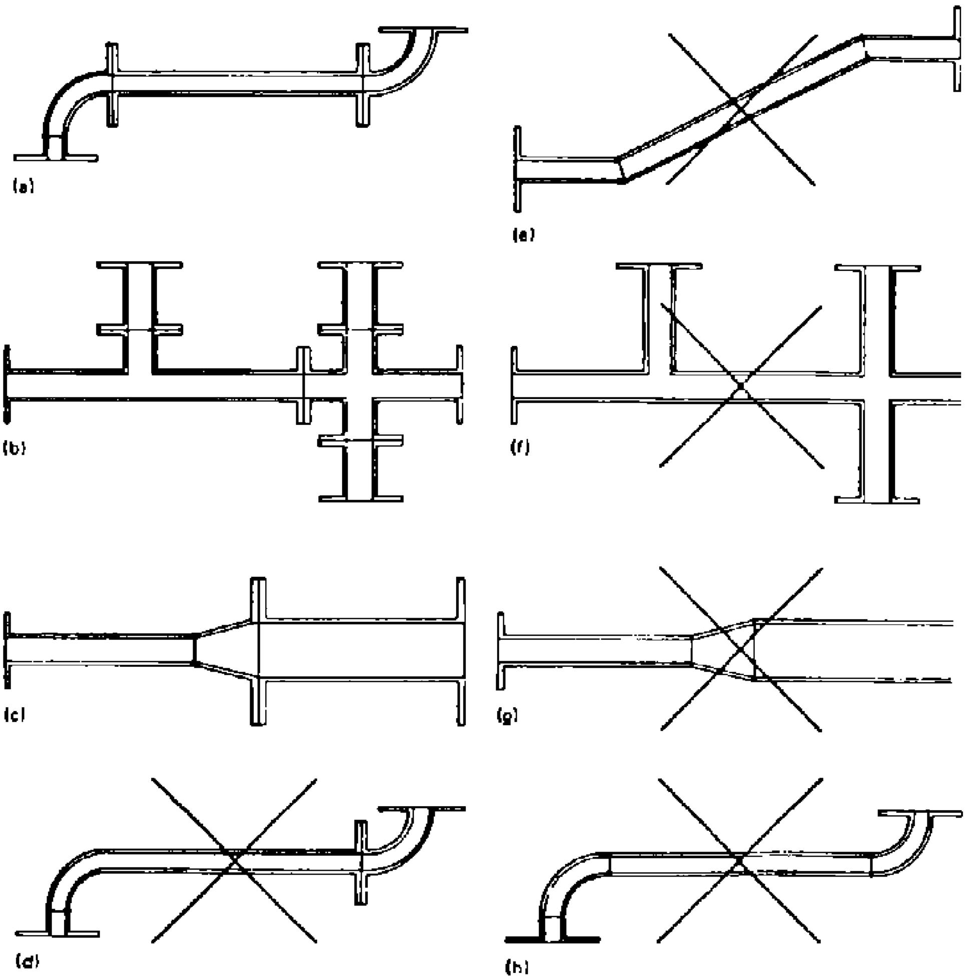
Flanges which are attached to a pipe by fillet welding (for example slip-on flanges)shall be suitably vented to allow any air trapped between fillet welds to escape to atmosphere during lining and vulcanizing.

Note:

This may be accomplished by using a vent hole in the flange, providing this meets piping design standard requirements.

For pipe spools with a length > 400 mm: venting is achieved by two vent holes of 3 mm ±0.5 mm diameter drilled in the pipe wall, perpendicular to each other, at a distance of 150 mm from each flange. Hence four holes per pipe spool. For pipe spool with a length ≤ 400 mm, one vent hole of minimum 3 mm ±0.5 mm diameter at each flange is acceptable. Hence two holes per pipe spool. Spiral grooves at the inside of the pipe, venting through a perforated metallic back-up gasket (a locking collar).

7.3.2.16 The metallic equipment to be lined shall be capable of withstanding heating up to a processing temperature (or drying) of polymer, for example 450°C in PTFE lining.



PIPEWORK DETAILS
Fig. 1

Note:

The details shown in (a), (b) and (c) are permissible; those shown in (d), (e), (f), (g) and (h) are not permissible.

7.3.2.17 Unless otherwise specified surface treatment of metal components to be lined shall be as in Table 2.

TABLE 2 - FABRICATION REQUIREMENTS FOR THE PART

COMPONENT PART	FABRICATION REQUIREMENTS
Outside Corners	Round to minimum radius of (3 mm) (1/8 in)
Sharp Inside Corners	Fill to smooth radius with uncured rubber fillet strip over primed surface
Welds	Welds shall be continuous. Grind to a smooth and uniform surface
Porous Areas Cavities and Pockets	Fill in with weld metal

7.3.2.18 No welding is permitted on interior or exterior surfaces of equipment during or after application of lining. Hydrostatic tests on equipment shall be performed prior to application of lining.

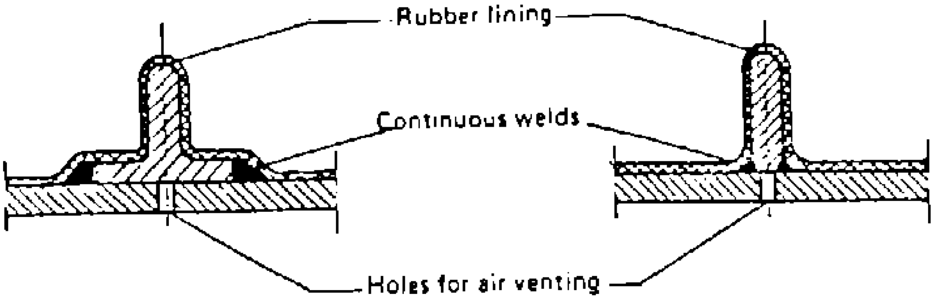
7.3.2.19 The design of equipment shall allow for adequate access and venting.

7.3.2.20 All branches shall be flanged and the lining shall be taken over the flange face to prevent ingress of the process liquid behind the lining.

7.3.2.21 Sharp changes of contor in the surface to be lined shall be avoided. Such changes shall be finished by means of grinding with mortar to a suitable radius, such that the internal radius of the lining is not less than 3 mm. Air vent holes to prevent air trapped in welded joints may sometimes be necessary (see Fig. 2).

7.3.2.22 If necessary, connections for stairs, supports, etc., shall be made before the rubber lining is applied, since welding is not allowed on lined equipment and piping. Heating elements shall be situated at a distance not less than 100 mm from the rubber lining to avoid overheating.

7.3.2.23 Impingement of steam on the rubber surface shall be avoided when using steam injection heating. When the equipment is subject to approval by authorities, the lining shall be carried out after hydrotesting.



AIR VENT HOLES
Fig. 2

Note:

Air vent holes to be drilled at regular distances. Diameter of holes depends on dimensions of vessel, but is generally 5 mm.

7.3.2.24 Pipes less than 600 mm diameter shall not be lined with thermoset materials such as epoxy.

7.3.2.25 The pipe less than 686 mm (27 in) diameter shall be joined in a manner that eliminates the need for entering the pipe to complete or repair the coal-tar or bitumen lining at the joints. Pipe that is 686 mm (27 in) or larger in diameter may be joined by any suitable method, including welding.

7.3.2.26 The types of pipes to which this Standard is applicable include both welded and seamless pipes of non-alloy steel used for the conveyance of fluids. The types of fittings are mainly bends, tees, reducers and collars.

7.3.3 Design of metal equipment to be lined with inorganic materials (glass, ceramic, brick, cement-mortar and refractory)

In addition to the provisions of Clause 7.3.2 the following consideration shall also be carried out:

7.3.3.1 Design of metal equipment to be glass lined

7.3.3.1.1 Because glass is very strong in compression, but weak in tension, the glass is formulated so that it has less thermal expansion than the base metal to which it is applied. Therefore, during the cooling, very high compressive stresses are set up in the glass coating. Sharp edges will not glass well due to the surface tension of the glass, but even edges that are ground with a radius are not suitable if the radius is not generous enough. Glass will tend to shear off of radii that are too sharp. This requirement for curved surfaces and rounded edges results in the necessity for using swaged openings, Vanston flanges, and flanges on covers and clamp-top vessels.

7.3.3.1.2 Jacket aprons and sealers must be so designed that no undue stresses are introduced into the liner shell during welding of the jacket. Excessive heat applied to the liner shell will cause the steel to expand and thus crack the glass by tension stress.

7.3.3.1.3 The heating (firing) procedure used in glassing steel must be carefully controlled and for this reason the design of the equipment must be such that there are no sudden changes in metal thicknesses, such as in very heavy flanges, etc.

7.3.3.1.4 The base metal must be thick enough to withstand the operating pressures and also to support the vessel from sagging during firing at the elevated temperatures encountered in glassing. The unit must be so designed that any stress, or combinations of stresses occurring during the actual operation of the vessel does not exceed the yield point of the base metal.

7.3.3.1.5 Sharp edges on castings shall be avoided, because neither the wet nor dry-process coatings will adequately cover sharp edges. Inside and outside corners should be rounded to uniform thickness and generous radii provided for fillets and outside corners.

7.3.3.1.6 Special styling techniques shall be used for designing appendages, internal passages, and lug-fastening faces so as not to emplace a mass of metal near an otherwise uniform enameling surface. These design considerations shall include a thorough review of the available mold-making techniques in conjunction with the pattern designer.

7.3.3.2 Design of metal equipment to be ceramic lined

7.3.3.2.1 All areas of high stress that will result in movement of the steel structure, such as oil conning or vibration, shall be externally supported.

7.3.3.2.2 Anchorage is required to secure the lining to the shell and to distribute shrinkage cracking evenly over the whole area.

7.3.3.2.3 Anchors, such as v-type or long horn studs, shall be installed on the proper center lines in a diamond or staged pattern with the lines randomly oriented.

7.3.3.2.4 For lining up to 50 mm thickness, anchorage may be provided by mild steel welded wire fabric. Anchorage shall be used in both single and dual layer systems.

7.3.3.3 Design of metal equipment to be brick lined

7.3.3.3.1 It is important to have smooth, continuous steel surfaces, where membrane lining are used.

7.3.3.3.2 Grades of steel generally used fall within the requirements of ASTM specification A-283 or A-285.

7.3.3.3.3 Tanks of cylindrical design are used frequently in preference to rectangular shape for reasons of economy, pressure rating and stability of the brick linings.

7.3.3.3.4 Thickness of steel in shell plates for cylindrical vessels shall be as follows: [(Except that 0.6 mm (¼ inch) minimum thickness is recommended for tanks over 1.25 m (4 feet) in diameter).]

7.3.3.3.5 When the temperature differential between brick lining and steel shell is negligible or when expansion joints are provided in the brick lining, it is suggested steel tanks be designed in accordance with the usual rules for accommodating forces imposed by the internal pressure, the weight of the vessel, lining and contents and by wind, shock, or other loads that may occur. If operating pressure is to be 1 bar (15 psig) or less, consideration shall be given to designing the vessel to permit hydrostatic testing at twice the operating pressure. If vessels are to operate at pressure above 1 bar, it is suggested they be designed to meet requirements of the ASME Code.

7.3.3.3.6 When a temperature differential between the brick lining and steel shell will exist and expansion joints are not provided in the brick lining, it is suggested the thickness of steel shall be determined by the following equation:

$$t_s = \frac{t_b E_b}{S_s}^{2} \; a_b £T_a \quad a_s £T_s \; \frac{S_s}{E_s}^{3} + \frac{PD}{2S_s}$$

(When the term in parenthesis is negative it indicates the steel tank will expand more than the brick lining or that the stress in the steel shell caused by expansion of the brick lining is less than the maximum allowable S_s. The thickness of the shell then shall be determined from the internal pressure.)

Where:

t_s	is thickness of shell-inches.
t_b	is thickness of brick lining-inches.
E_s	is modulus of elasticity for steel-psi (use 30×10^6 psi).
E_b	is modulus of elasticity in compression for brick lining-psi (may vary from 2×10^6 to 7×10^6 psi).
S_s	is allowable stress for shell-psi (use 13,750 psi).
S_b	is allowable compressive stress for brick lining-psi (may vary from 4000 to 10,000 psi).
a_s	is coefficient of expansion for steel inches per inch per degree F; 6×10^{-6}.
a_b	is coefficient of expansion for brick inches per inch per degree F; 3×10^{-6} to 6×10^{-6}.
ΔT_s	is average temperature rise of steel-F.
ΔT_b	is average temperature rise of brick-F.
p	is maximum allowable internal pressure, psi.
D	is inside diameter of shell-inches.

When the thickness of the shell has been established, compression stress in the brick shall be determined by the following equation:

$$S_b = E_b \frac{bT_b \quad T_b}{\frac{t_b E_b}{t_s E_s} + 1}$$

Should the compressive stress of the brick exceed a safe value, expansion joints may be provided, the thickness of the brick lining may be increased, or stronger brick used. A reduction in the thickness of the steel also will reduce the stress in the brick.

Flat bottom thickness shall be 0.9 mm (3/8 inch) minimum or sufficient to limit the deflection to 1 m/10 m (1/32 inch/ft.) of the span. Consideration should be given to warpage of flat bottoms which may result from welding. This can be reduced by increasing thickness.

Shells and heads must be made stiff enough to avoid deformations that will seriously crack the brick lining and allow it to disintegrate or fall (see 7.3.3.3.2).

Joints in all surfaces that are to be covered by a membrane lining shall be made by butt welding. Lap and riveted joints shall not be used. Welds at inside and outside corners shall be finished so that they may be ground to 0.45 mm (3/16 inch) minimum radius. Vessels shall be hydrostatically tested and repaired as may be necessary, before any lining work is started.

7.3.3.3.7 Prevention of deformation

7.3.3.3.7.1 Since the brick lining can not sustain even very small deformations without cracking, the shell must be very rigid.

Rigidity can be obtained by the following design measures:

a) The design shall ensure ample wall thickness.

b) High-strength steels with a tensile strength exceeding 500 N/mm² shall not be used.

c) The maximum deflection due to wind load shall not exceed $\frac{H}{500}$

d) Full account shall be taken of the mass of the brick lining, including packing bed, contents, etc. This can be estimated as follows.

e) Equipment with diameters up to 3000 mm, operating at pressure up to 3 bars and temperatures up to 100°C shall be designed for an additional stress of 25-30 N/mm².

f) Equipment with diameters greater than 3000 mm, operating at pressures up to 10 bars and temperatures up to 200°C shall be designed for an additional stress of 30-50 N/mm².

g) For operating conditions above 10 bars and 200°C it is recommended that each application shall be considered separately.

7.3.3.3.7.2 The following additional measures, aimed at avoiding stress concentrations, will reduce the likelihood of (local) deformations occurring:

h) Use cylindrical vessels.

i) Use vertical vessels supported on skirts with the same diameter as that of the vessel shell. Legs are not recommended.

j) If horizontal vessels are unavoidable, use extra wide saddles or longitudinal supports of ample rigidity.

k) Avoid flat heads and use hemispherical heads or other types of head with very generous knuckle radii.

l) Atmospheric storage vessels with flat bottoms can be brick-lined. The temperature decrease over the brick lining shall be kept small, since a cooler bottom causes lifting of the brick lining. Welding the bottom plates to the supports can prevent buckling of the steel bottom.

m) Avoid sudden changes in wall thickness. Where a change in wall thickness occurs, the internal surface shall be flushed (see Fig. 3).

n) Avoid external stiffening rings or bars attached to the vessel, and avoid internals connected directly to the shell.

o) Connections for stairs, supports, etc., shall be made before the brick lining is applied, since welding afterwards will damage the chemical-resistant brick lining.

p) Minimize the number of nozzles, manholes, etc., by combining as many of these as possible into one manhole cover. Nozzles shall not protrude into the inside of the vessel, but shall be welded either in the corner or on to the bulged-out vessel wall (see Fig. 4). Belled-out nozzle openings should be used whenever possible for vessels operating at higher pressures.

7.3.3.3.8 Surface condition

When the vessel to be brick-lined is to have an impervious membrane, which is generally the case, the requirements for the internal surface condition of the shell shall be of those ruling for the application of the membrane (see Table 3). Air inclusions can be prevented as follows:

a) Avoid designs with head curved to the inside (see Fig. 5).

b) Provide for correct weld design.

c) Preferably in the cylindrical part of the vessel (see Fig. 6).

d) If not possible, then the corner may be made with a profile giving a weld in the cylindrical part and in the bottom; an extra leg may be included to guide rain water, etc., (see Fig. 7).

e) Butt-weld cone-shaped ends or bottoms, the welds can be made in the corner provided it is finished smoothly (see Fig. 8).

f) If corner welds can not be avoided, air-escape holes are to be applied.

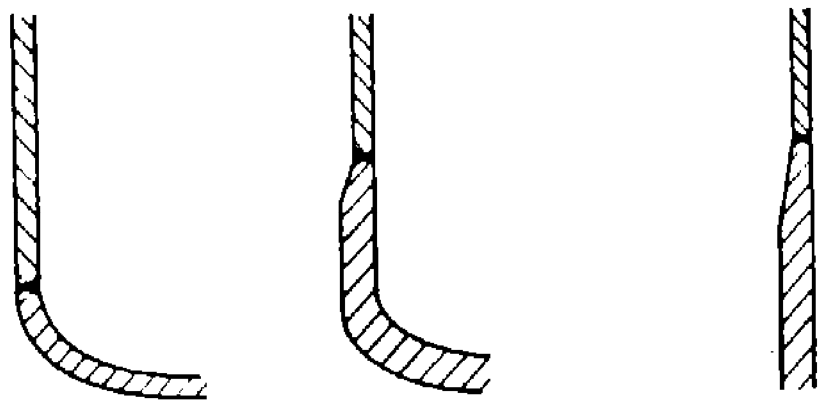
g) V-welds made from the inside are preferred.

h) Sharp edges, weld spatters, etc., shall be removed.

i) Welds shall be in-line and be finished smoothly.

j) Internal changes shall be rounded with a radius of at least 3 mm, but preferably 5 mm.

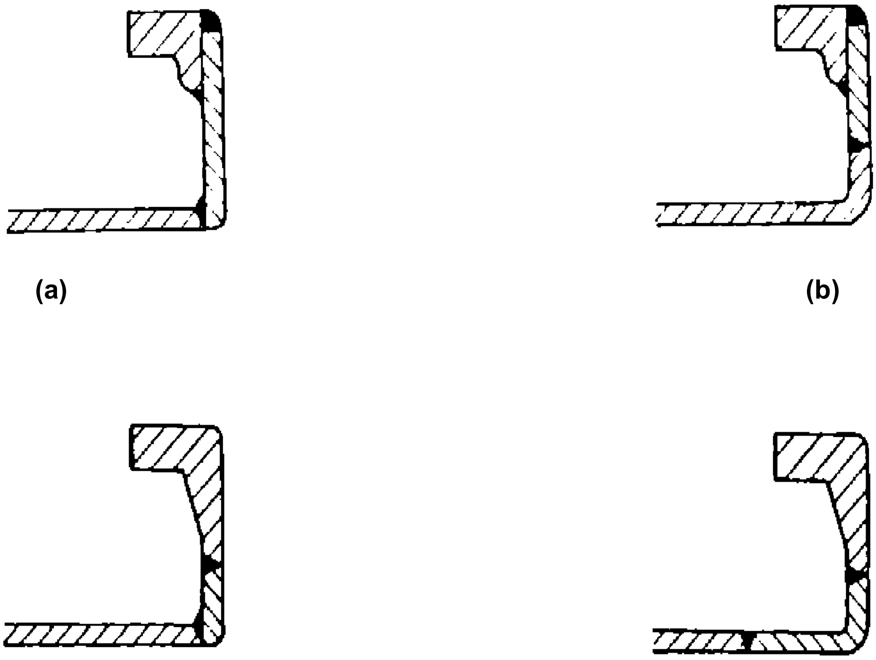
k) Riveted constructions are not acceptable.



RECOMMENDED SHAPES FOR CYLINDRICAL SEAMS
Fig. 3

Note:

All welds shall be finished smoothly.



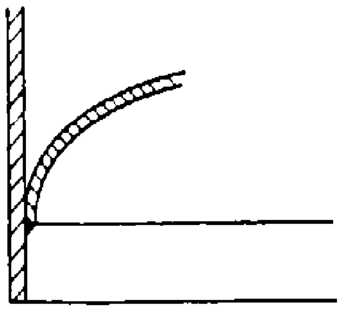
(a) (b)

(c) (d)

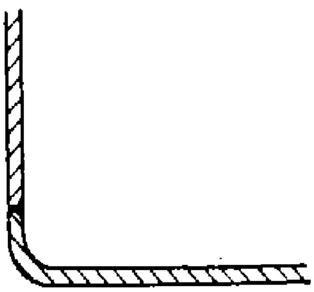
NOZZLE CONSTRUCTIONS
Fig. 4

Note:

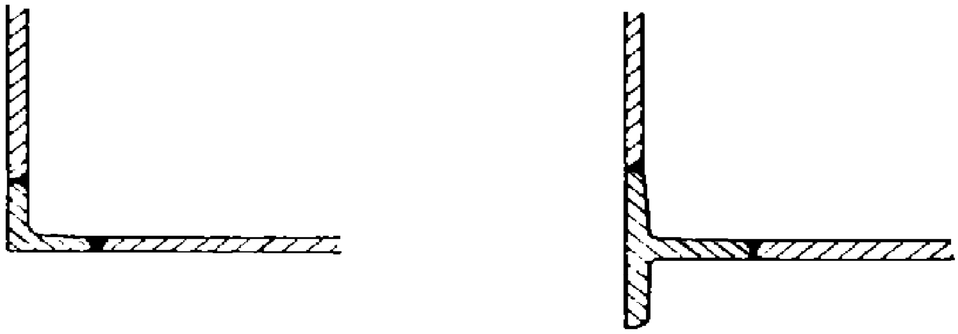
The flange facing shall be adapted for receiving a membrane.



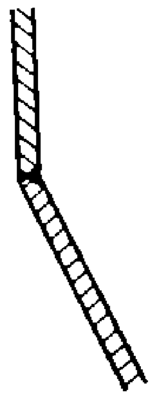
A NOT-ALLOWED FORM OF A CURVED HEAD
Fig. 5



RECOMMENDED JOINT IN A FLAT BOTTOM
Fig. 6



RECOMMENDED CONSTRUCTION FOR FLAT BOTTOMS IN TANKS
Fig. 7



RECOMMENDED JOINT IN A CONE-SHAPED END
Fig. 8

7.3.3.4 Design of metal equipment to be cement-mortar lined

The steel pipes to be lined shall have:

a) No holes in the wall, e.g. branches.
b) Limit of bending not exceeding 3 mm per 3 m of length.
c) Maximum out-of-roundness (difference between minimum and maximum dimensions) not exceeding 1.6 mm or 1% of the nominal outside diameter whichever is the greater.

7.3.3.5 Design of metal equipment to be refractory lined

7.3.3.5.1 Wall and floor refractories for heaters shall be of sufficient thickness to insure and exterior cold face temperature not to exceed 82°C with a 8 km/h wind velocity and a 40°C ambient temperature. Arch refractory thickness shall be in accordance with good design practice and resulting casing temperature shall be noted on the data sheets.

Portions of stacks and ducting which are adjacent to instrumentation or equipment which requires frequent attention shall be insulated with a minimum of 138 mm (1-½") of insulating concrete.

7.3.3.5.2 Anchoring and Reinforcement

Linings 75 mm thick or less

- The anchoring of this type of lining shall consist of cleats, or 5 mm dia. V-shaped studs. The cleats may be made from 5 mm thick carbon steel or 2 mm stainless steel plate. For the selection of the materials for both types of anchor (see Table 3). For other lining thicknesses, the height and the pitch of the cleats or studs shall be adapted.

Linings over 75 mm thick

- Anchoring of these linings shall be by 5 mm diameter V-shaped studs welded to a crimped wall.
- For the material of the studs see Table 3.

Lining of floors

- Anchoring of lining to furnace floors is not necessary, except for protruding.

Welding of cleats and studs

- Cleats and studs shall be welded to the walls by means of the electric are welding process with welding electrodes appropriate for the metals concerned.

- Welding surfaces must be dry and clean. Cleats and studs shall be welded along the whole circumference of their base, and be checked by hammer testing after welding, and be rewelded if necessary.

TABLE 3 - THE MATERIAL OF THE ANCHORS

LOCATION	PART	CONCRETE SURFACE TEMPERATURE °C	V-SHAPED STUDS AND CLEATS [2)]
Radiant section	Floors	—	Not applicable
	Walls	Max. 600 Above 600	Carbon steel 18/8 Cr-Ni
	Roof, incl. flue gas branches	Max. 870 Above 870	18/8 Cr-Ni 25/20 Cr-Ni
"Hot" flue ducts and plenum chamber [1)]	—	Max. 870 Above 870	18/8 Cr-Ni 25/20 Cr-Ni
Convection section	Unshielded walls and roof	Max. 870 Above 870	18/8 Cr-Ni 25/20 Cr-Ni
	Shielded walls incl. bottom part	—	Carbon steel
"Cold" flue ducts	—	—	Carbon steel

1) The floor of the plenum chamber needs no reinfrocing

2) Carbon steel: **Plate - ASTM A 283 Gr max. 0.23%** / **Bar - ASTm A 575 Gr 1020** } **Bessemer steel not allowed**

Stainless steel: **18/8 Cr-Ni:** **Plate - ASTM A 240; type 304 L, 321 or 347**
Bar - ASTM A 314; type 304 L, 321 or 347
25/20 Cr-Ni: **Plate - ASTM A 240;type 310 S**
Bar - ASTM A 314;type 310 S

7.3.4 Design of concrete equipment to be lined with polymeric materials (see also IPS-E-TP-760)

7.3.4.1 Whilst it is not possible to eliminate shrinkage cracks in concrete, the design shall be such that structural cracking is eliminated. Particular attention shall be paid to avoiding cracking due to thermal stresses.

In the case of loose liners, equipment shall be designed to BS 8110. In the case of bonded liners, equipment shall be designed to BS 8007.

Note:

The ability of the lining to accommodate cracking of the concrete will determine the detail of design. Equipment designed and constructed to class A of BS 8007, is liable to develop cracks up to 0.1 mm wide. Equipment designed and constructed to Class B of BS 8007 is liable to develop cracks up to 0.2 mm wide.

The concrete in the case of Class A of BS 8007 shall have a minimum compressive strength of 30 N/mm² and in that of Class B of BS 8007 25 N/mm².

7.3.4.2 If necessary extra reinforcements shall be used and construction joints treated so as to promote a bond between adjacent areas of concrete. Expansion joints create special problems in lining and shall not be used without consultation between the Purchaser and the applicator of the lining.

7.3.4.3 Pipes and fittings shall be designed with puddle flanges and cast into the concrete. Where possible pipes and fittings shall either be of the same material as the liner so that the weld may be made between the liner and the fitting or designed so that the lining may be carried through the fitting. If this is not possible the fitting shall be designed so that a mechanical joint can be made between the fitting and the lining. In the latter case the fitting shall be of a corrosion-resistant material.

7.3.4.4 The arrangements for the lifting of equipment shall be determined at the design stage.

7.3.4.5 The design of all equipment shall allow for access during the preparation of the surface and application of the lining and for venting of fumes evolved during the operation.

In completely enclosed vessels there shall be at least one manhole conforming to BS 470 and one additional branch of not less than 75 mm bore to permit adequate circulation of air.

7.3.4.6 All corners shall be designed to be formed with a 45° fillet with a minimum leg length of 20 mm.

7.3.4.7 All equipment to be placed below ground level or subject to external water pressure shall be provided with a waterproof barrier on the outside of the equipment.

7.3.4.8 All equipment shall be designed with a minimum of 20 mm of concrete over reinforcement.

7.3.5 Design of concrete equipment to be lined with inorganic materials

In addition to the provisions of 7.3.4 the following consideration shall also be carried out:

7.3.5.1 Design of concrete equipment to be glass lined

7.3.5.1.1 Slopes of the surfaces shall be a minimum of 3.2 mm to a maximum of 6.4 mm per linear 30 cm (foot) and shall have attained a minimum compressive strength of 21 MPa (3000 psi).

7.3.5.1.2 The anchoring system that is used shall be placed at the specified centerline distance in a diamond shape pattern with a random orientation of anchor lines. The anchoring system shall consist of V-type or longhorn studs.

7.3.5.2 Design of concrete equipment to be brick lined

7.3.5.2.1 Special attention shall be given to form work for concrete equipment since bulging, sagging, etc., in the equipment may cause the lining to fail prematurely. Care shall be taken to insure the inside forms of vessels are adequate to prevent bowing in toward the center.

7.3.5.2.2 It is better to have bowing out rather than in. In large rectangular vessels it is often recommended to bow and batter the inside walls to place the chemical resistant masonry lining in compression upon thermal expansion. All concrete tanks, regardless of shape, shall be reinforced with steel. Where practical, the vessel shall be poured monolithically to avoid "dry joints" which are potentially weak.

7.3.5.2.3 In addition to good engineering design details, it is desirable to have a smooth interior surface when a flexible membrane type lining is to be applied. A wood float finish generally is desirable. Bolt holes, honeycombed surfaces, etc. shall be filled with a stiff Portland cement mortar. Rough projections or high spots shall be removed by chipping or use of abrasive stone.

7.3.6 Fabrication of metal equipment to be lined with organic materials

7.3.6.1 All metal-to-metal joints shall be made by welding. Welds shall be homogeneous and free of pores. Welds shall be ground smooth and flush with the parent metal on the side to be covered. Wherever possible they shall be made from the side to be lined. Where this is not possible the root shall be chipped out and a sealing run shall be applied. Internal corner and tee joints shall be welded with full penetration. Welds shall be ground smooth and concave to the required radius. Welds shall be examined according to applicable design codes.

7.3.6.2 All welds shall be continuous on surfaces to be lined. Only butt joints shall be permitted on surfaces to be lined. Stitch welding, spot welding and other non-continuous welding processes shall not be used.

7.3.6.3 Weld surfaces shall be smooth. Some welding procedures provide surfaces of adequate smoothness but, in other cases surfaces shall be ground wholly or partly to removed weld ripples. The grinding process shall be done so that the remaining weld does not have sharp edges.

7.3.6.4 Welding procedures shall be chosen to avoid porosity on the side of the weld to be lined.

Note:

It is preferable that capping runs are applied to the lining side in order to minimize this effect.

All welds shall be free from the following surface defects:

- **a)** Undercutting;
- **b)** cracks;
- **c)** porosity;
- **d)** any other type of surface cavity;
- **e)** lack of fusion.

Weld defects that are exposed either on initial inspection or after blast cleaning shall be repaired.

Repairs shall be by grinding or by welding (with or without subsequent grinding) provided that the requirements for equipment design and fabrication are met.

7.3.6.5 Weld profile details shall be generally in accordance with Figs. 9 to 13.

Note:

Incorrect details are also illustrated.

7.3.6.6 Filler materials, such as resin, putties, fillers and low melting point solders and brazes, shall not be used.

7.3.6.7 Before the equipment is passed for lining, all attachments to be made by welding, for example lagging cleats and lifting lugs, shall be complete.

7.3.6.8 All drilling shall be completed before the equipment is passed for lining.

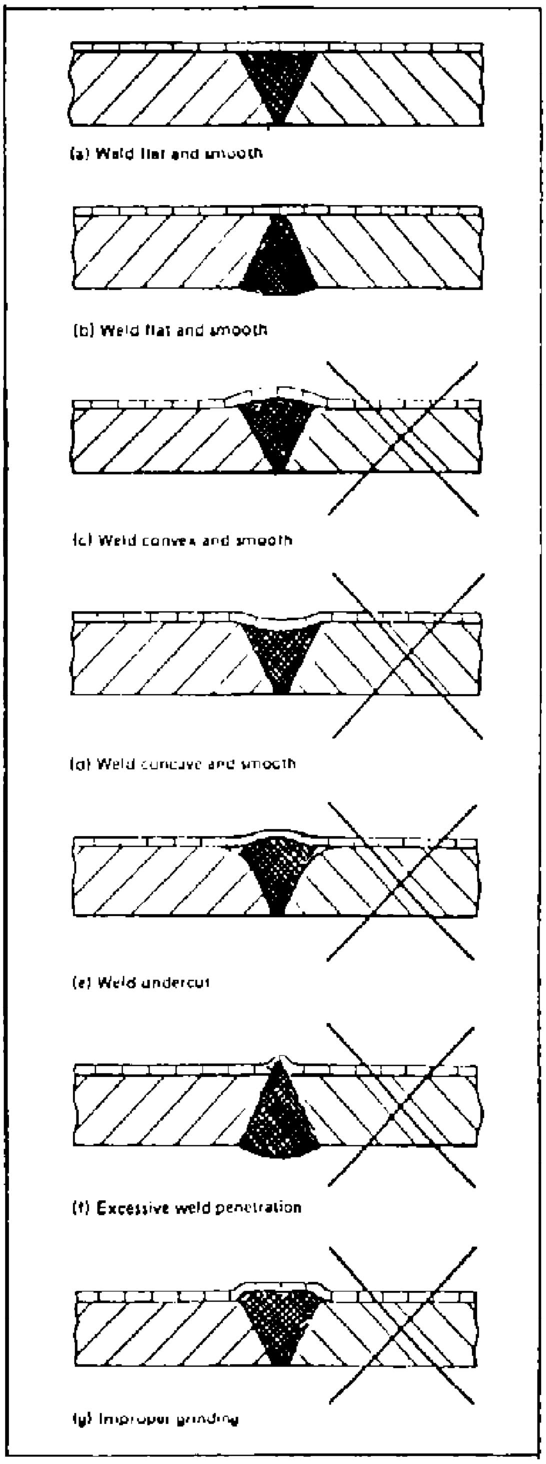
7.3.6.9 When the lining is to be thermo-formed at corners, those corners shall be finished to a radius of not less than 5 mm. When the lining is to be welded at corners, those corners shall be finished to a radius of a nominal 1.5 mm.

7.3.6.10 All slag, anti-spatter compounds or similar materials shall be removed.

All weld spatter shall be removed by chipping and/or grinding.

7.3.6.11 Surface defects such as scores, pitting and rolling defects, shall be removed by grinding, or where necessary repaired by welding provided that the requirements of design and construction are met.

7.3.6.12 Rotating parts shall be balanced before and after lining.

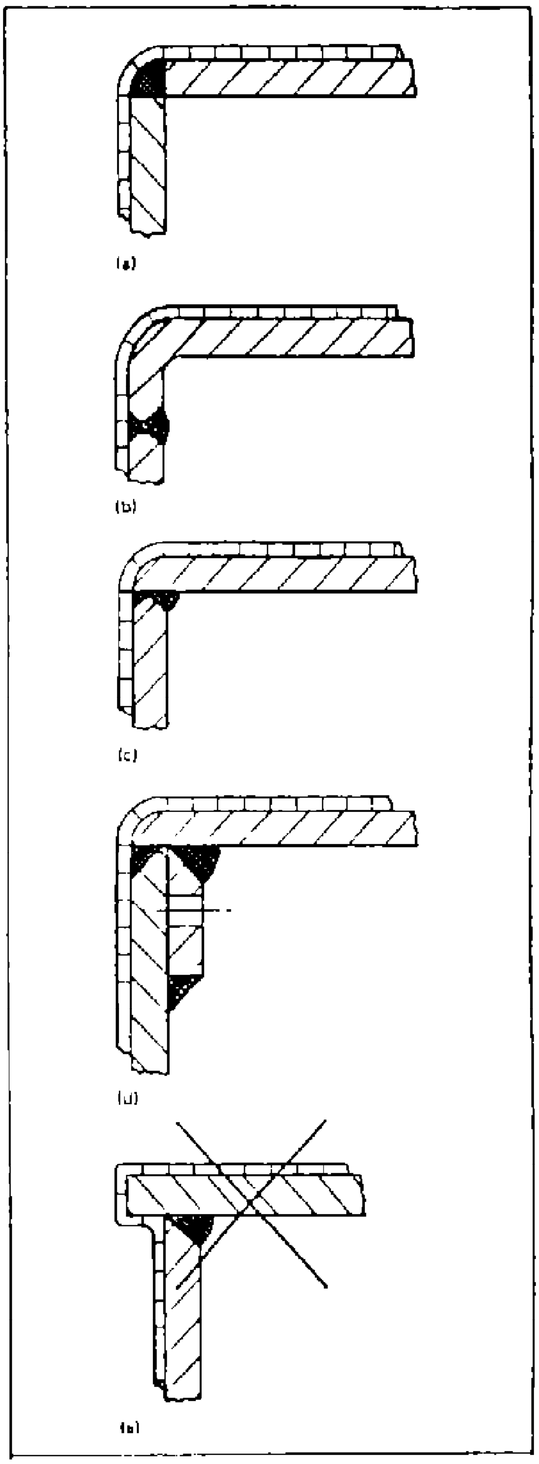


WELD PROFILE DETAILS: BUTT WELDS

Fig. 9

Note:

The details shown in (a) and (b) are permissible; those shown in (c), (d), (e), (f) and (g) are not permissible.

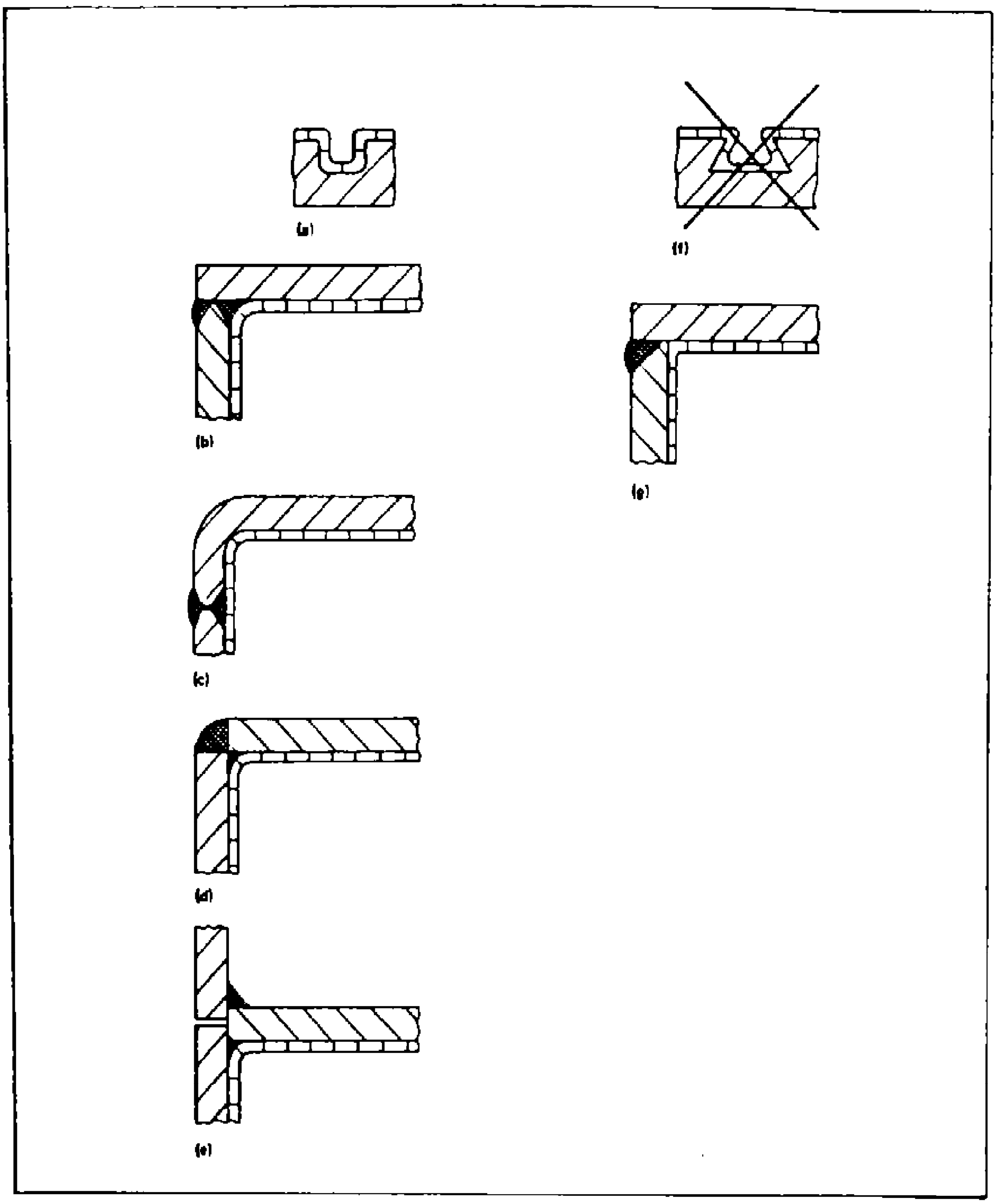


WELD PROFILE DETAILS: EXTERNAL CORNERS AND EDGES

Fig. 10

Note:

The details shown in (a), (b), (c) and (d) are permissible; that shown in (e) is not permissible.

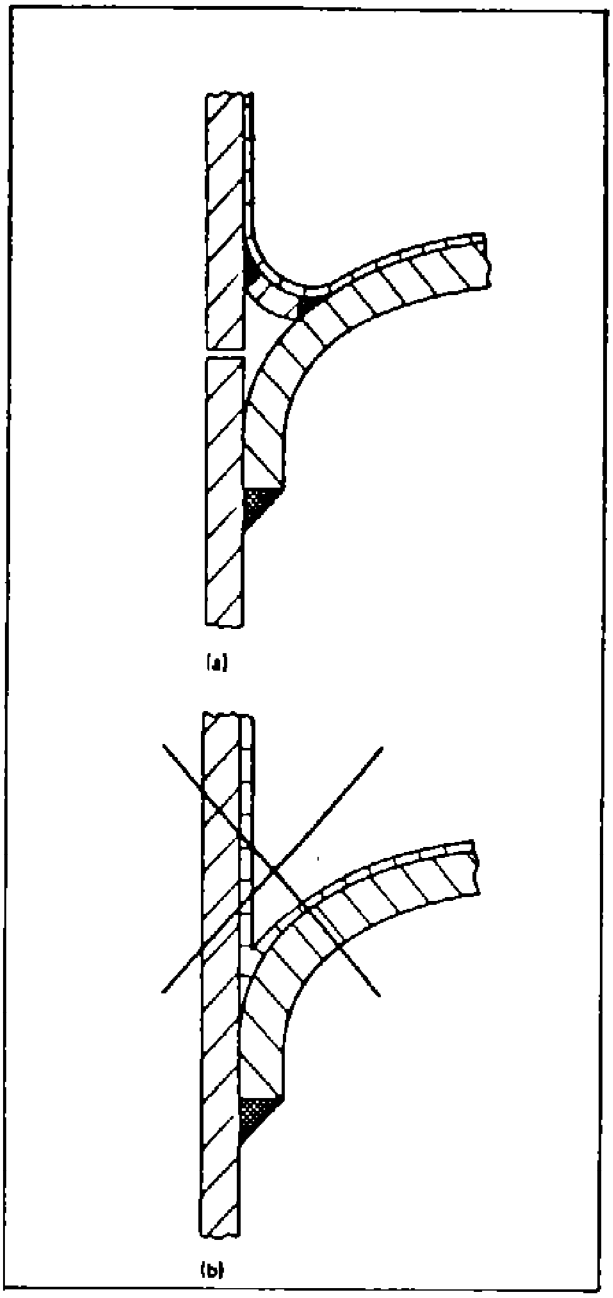


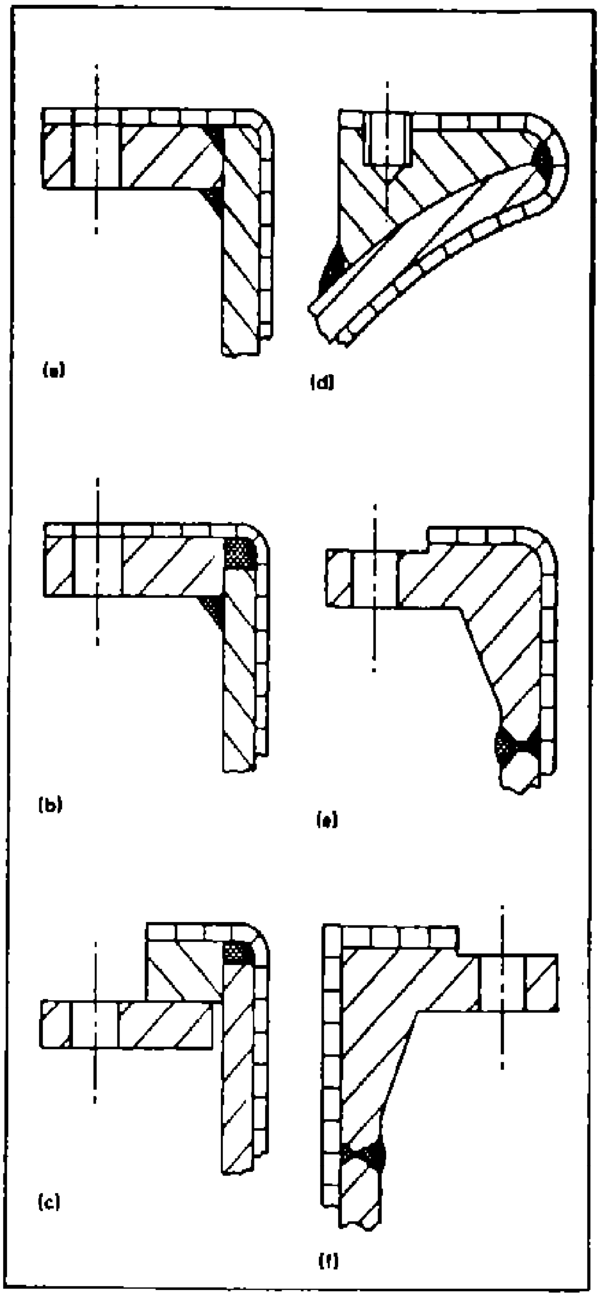
WELD PROFILE DETAILS: INTERNAL CORNERS AND EDGES
Fig. 11

Notes:

1) The details shown in (a), (b), (c), (d), (e) and (g) are permissible; that shown in (f) is not permissible.

2) The detail shown in (g) is to be used only when the lining is bonded and is to be welded at the internal corner.





**WELD PROFILE DETAILS:
CONCAVE HEADS
Fig. 12**

Note:

The detail shown in (a) is permissible; that shown in (b) is not permissible.

**WELD PROFILE DETAILS:
FLANGES
Fig. 13**

Note:

The detail shown in (f) is to be used only when the lining is bonded and it is welded at the external corner.

7.3.7 Fabrication of metal equipment to be inorganic lined

In addition to the provisions of 7.3.6 the following consideration shall also be carried out:

7.3.7.1 Pipe connections to glass lined equipment shall be made only after the vessel has been leveled and securely fastened to a foundation. To avoid stress failures in glassed pipe, the pipe must be adequately supported by means of pipe hangers and allowance must be made for expansion of the lines if surface temperature is appreciably above room temperature.

7.3.7.2 Enough pipe hangers must be provided so that the weight of the pipe and its contents are carried by the hangers rather than on the nozzles of the vessel.

7.3.7.3 The welds shall be made as specified in Table 4.

7.3.8 Fabrication of concrete equipment to be lined with organic materials

7.3.8.1 All concrete equipment shall be constructed in accordance with the requirements of BS 8007 or BS 8110.

7.3.8.2 Proper curing of the concrete shall be ensured by the use of curing membranes wherever necessary. If shuttering is removed under 7 days a curing membrane shall be applied.

Concrete equipment shall be allowed to cure for 28 days before the work of lining proceeds.

7.3.8.3 Equipment which is slip formed shall be bagged as the concrete leaves the formwork before the curing membrane is applied.

Note:

This process will reduce the amount of laitence.

7.3.8.4 All concretes which have been not cast against shutters or slip formed shall be float finished.

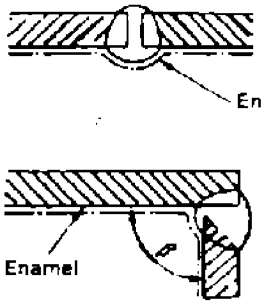
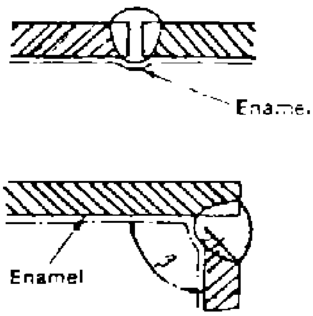
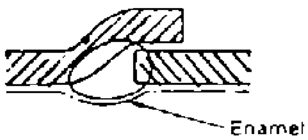
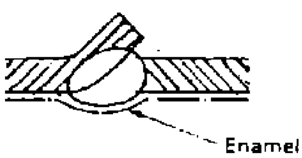
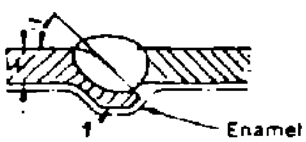
Note:

In the case of equipment to be fitted with loose linings a steel float or a wooden float may be used. In the case of equipment where the lining is to be bonded a wooden float finish shall be used.

7.3.8.5 Any steps in the concrete due to misalignment of shutters or surplus material formed because of gaps at joints in shutters shall be dressed off and ground smooth.

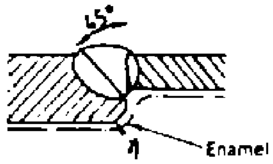
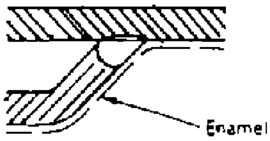
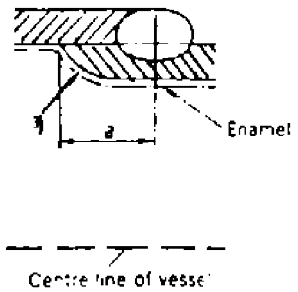
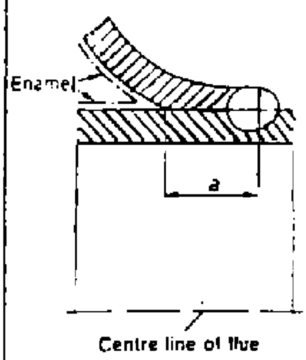
7.3.8.6 All holes left after removal of ties to secure and align formers shall be filled. Any surface defects such that the aggregate is exposed shall be filled. The material used for filling shall be a sand/cement grout with a high cement content or a sand/cement water miscible epoxy resin grout or an epoxy resin mortar.

TABLE 4 - WELD TYPES OF GLASS LINED EQUIPMENT

	Type	Comments
1		Welding on both sides also permissible Angle β on the enamel side may range from 30 to 360°. Resulting edges on the enamel side shall be rounded
2		Angle β on the enamel side may range from 30 to 330°. Resulting edges on the enamel side shall be rounded
3		-
4		-
5		-
6		Roll in under $\alpha = 45° \pm 5°$ ——— 1) Round off edge to $r \approx \frac{s}{2}$, with r at least 2 mm, or chamfer at less than 45° to $\frac{s}{2}$

(to be continued)

TABLE 4 (continued)

	Type	Comments
7		2) Round off edge to r = 2 mm or chamfer accordingly at less than 45°
8		-
9	Gapless form closure of the overlap 	The maximum overlap length, a, shall be 10 mm. 3) Rounded to r ≥ 2 mm.
10		The maximum overlap length, a, shall be 10 mm.

Toes shall be finished without notches on the enamel side

Types 1 to 9 welds shall be made before enamelling. Type 10 welds shall be made after enamelling

8. SELECTION OF LINING MATERIAL

8.1 Selection of the type, and the thickness of lining to be used shall be based on the duty for which it is intended (see Table 6).

8.2 For the final selection of lining system which to be used and the method of application, which shall be made in conjunction with the materials specialist and the lining contractor, the following details shall be considered. The designer who select the lining, with regard to this Engineering Standard, shall verify that such a lining will withstand existing chemical and physical conditions and meet all requirements of this Engineering Standard. Full details of lining shall be submitted to the Company for approval.

8.3 Process Information to be Established

8.3.1 Full analysis of the contents equipment including constituents present in small and trace quantities, and details of cleaning operations.

8.3.2 Temperature of material to be handled:

- Normal operating temperature
- Maximum and minimum
- Cycle of temperature variation

8.3.3 Degree of vacuum or pressure:

- Normal operating pressure
- Maximum and minimum pressures
- Cycle of pressure variation

8.3.4 Cycle of operations:

Whether batch or continuous process.

8.3.5 Abrasion and erosion:

Details of amount, particle size and physical characteristics of the suspended matter together with rates of flow.

8.3.6 Mechanical damage:

Any difficulties expected in the handling and final siting of the equipment or any vibration of equipment and the possibility of mechanical damage.

8.3.7 Immersion conditions:

Constant or intermittent immersion of the lining, and partially or completely filled operation.

8.3.8 Special conditions:

For example, extremes of weather likely to be encountered during the handling, transport and storage of the equipment.

8.4 Material Characteristics to be Considered

8.4.1 Chemical resistance of the lining (see Table 6 and relevant table in each individual section)

8.4.1.1 Unless documented previous experience demonstrates that a lining will be suitable for a particular duty, appropriate testing shall be carried out. When testing is required service conditions shall be reproduce accurately, (see ASTM C-581, ASTM D-543, ASTM D-531).

Where it is not possible to place samples in process streams, service condition shall be simulated. Where it is known that a lining has to withstand an environment where heat transfer is made through the lining, the heat transfer condition shall be maintained during the test.

Substances including dissolved gasses present in a process stream in trace quantities only shall be added to the test liquors.

8.4.1.2 When selecting the lining effect of materials on water shall be considered (see Appendix D).

8.4.2 Physical and mechanical characteristics of lining (see Table 8)

8.4.2.1 Available form of material.

8.4.2.2 Abrasion and erosion aspects.

8.4.2.3 Shape and weld ability (see Table 8).

8.4.2.4 Vacuum or pressure resistance.

8.4.2.5 Thermal expansion of the lining material.

8.4.2.6 Creep characteristics of the lining material.

8.4.2.7 Liability of the lining material to stress crack in the particular environment.

8.4.2.8 Whether or not the lining is to be bonded to the substrate and the temperature limit of the adhesive system when used.

8.4.2.9 Effect of vacuum on loose linings.

8.4.3 Other characteristics

8.4.3.1 Maintainability of the lining.

8.4.3.2 Availability of lining material.

8.4.3.3 Handling of lining material.

8.4.3.4 Compatibility of lining with the substrate material: Efficiently compatible lining material with the substrate; concrete and metal parts (see Table 5).

8.4.3.5 Thickness of lining; The thickness of finished lining depends upon the material selected and the duties for which it is intended (see Table 9).

8.4.4 Complexity and shape of equipment to be lined

8.4.4.1 The size, configuration and complexity of shape of substrate has an important bearing on the suitability of the particular lining material.

8.4.4.2 Some of the lining materials are backed with rubber, glass fiber or other fiber to enable the lining to be bonded to the substrate. There may be limitations on shaping, such as double curvature.

8.4.5 Method of application (see Table 8)

8.4.5.1 The required surface preparation (see Table 5).

8.4.5.2 The process and equipments shall be used for application and installation.

8.4.5.3 Field or shop application.

8.4.5.4 Curing condition.

8.4.6 Economics of lining

The costs associated with the use of lining which shall be considered in selection of lining are mainly as follows:

8.4.6.1 Cost of lining material(s).

8.4.6.2 Cost of application.

8.4.6.3 Cost of maintenance.

8.4.6.4 Extra cost for installation and transportation due to possibility of mechanical damage.

8.4.6.5 Personnel safety equipment.

8.4.6.6 In cases where major shutdowns can be avoided through the use of a certain lining, the economic advantages of such lining will be clear. Other cases will require detailed economic evaluations.

TABLE 5 - TYPE OF THE SURFACE PREPARATION AND SUBSTRATE TO BE LINED

No.	LINING MATERIAL	SHAPE	SURFACE PREPARATION IS REQUIRED	TYPE OF SUBSTRATE	
				METAL	CONCRETE
	A- Thermoplastic				
1	PE	Sheet	Sa 2½	×	×
2	PE	Non-sheet	Sa 2½	×	—
3	PP	Sheet	Sa 2½	×	×
4	PP	Non-sheet	Sa 2½	×	—
5	PVC	Sheet	Sa 2½	×	×
6	PVC	Non-sheet	Sa 2½	×	—
7	PVDF	Sheet	Sa 2½	×	×
8	PVDF	Non-sheet	Sa 2½	×	—
9	FEP	Sheet	Sa 2½	×	×
10	FEP	Non-sheet	Sa 2½	×	—
11	PTFE	Sheet	Sa 2½	×	×
12	PTFE	Non-sheet	Sa 2½	×	—
13	PFA	Sheet	Sa 2½	×	×
14	PFA	Non-sheet	Sa 2½	×	—
15	E-CTFE	Sheet	Sa 2½	×	×
16	E-CTFE	Non-sheet	Sa 2½	×	—
17	Nylon (Polyamid)	Non-sheet	Sa 2½	×	—
18	EVA	Non-sheet	Sa 2½	×	—
19	Fusion-bonded epoxy	Non-sheet	Sa 2½	×	—
	B-Thermosetting				
20	Phenol-formaldehyde	All shapes	Sa 2½		
21	Epoxy-phenolic	Non-sheet	Sa 2½	×	—
22	Epoxy	All shapes	Sa 2½	×	—
23	Polyesters	All shapes	Sa 2½	×	×
24	Furanes	All shapes	Sa 2½	×	×
25	Polyurethanes	All shapes	Sa 2½	×	×
26	Polychloroprene	Liquid	Sa 2½	×	×
	C-Rubbers			×	×
27	NR	Sheet	Sa 2½		
28	IR	Sheet	Sa 2½	×	×
29	IIR	Sheet	Sa 2½	×	×
30	NBR	Sheet	Sa 2½	×	×
31	CSM	Sheet	Sa 2½	×	×
32	FKM	Sheet	Sa 2½	×	×
33	CR	Sheet	Sa 2½	×	×
34	Hard&Ebonite rubber	Sheet	Sa 2½	×	×
	D-Glass, ceramic				
35	Glass	—	Sa 2½		
36	Porcelain	—	Sa 2½		
37	Ceramic	—	Sa 2½	×	—
	E-Bricks			×	—
38	Acid-resistant brick&Tile	Fabricated	Sa 2	×	×
39	Porcelain tiles (unglazed)	Fabricated	Sa 2		
40	Carbon bricks	Fabricated	Sa 2	×	×
41	Graphit bricks	Fabricated	Sa 2	×	—
42	Silicon carbide bricks	Fabricated	Sa 2	×	
	F-Cements			×	—
43	Silicate base cement	—	Sa 2	×	—
44	Phenol formaldehyde cement	—	Sa 2		
45	Furane resin cement	—	Sa 2	×	×
46	Reinforced epoxy cement	—	Sa 2	×	×
47	Phenolic furfuraldehyde cement	—	Sa 2	×	×
48	Sulfur cement	—	Sa 2	×	×
49	Polyester based cement	—	Sa 2	×	×
	G-Bitumen and coaltar			×	×
50	Cold applied bitumen	Liquid	Sa 2	×	×
51	Hot applied bitumen	Solid	Sa 2		
52	Cold applied coal tar	Liquid to paste	Sa 2	×	×
53	Hot applied coal tar	Solid	Sa 2	×	×
				×	×
				×	—

× **Means the lining material can be used.**

— **Means the lining material shall not be used.**

TABLE 6 - CHEMICAL RESISTANCE OF LININGS FOR SERVICE IN VARIOUS CHEMICAL ENVIRONMENTS

		INORGANIC ACIDS											ORGA		
CHEMICAL CLASSIFICATION		CHLOROSULFONIC	HYDROCHLORIC	HYDROFLUORIC	HYDROGEN SULFIDE	NITRIC	NITROUS	PERCHLORIC	PHOSPHORIC	PHOSPHOROUS	SULFURIC	SULFURIC FUMING	ACETIC	ADIPIC	BENZENE SULFONIC
1. THERMOPLASTIC MATERIAL															
POLYETHYLENE	PE	-	L	L	-	L	-	-	R	-	L	-	L	-	L
POLYPROPYLENE	PP	-	L	L	L	L	-	L	R	-	L	-	L	-	R
POLYVINYL CHLORIDE	PVC	L	L	L	L	L	-	L	R	-	L	-	L	L	L
ETHYLENE-CHLOROTRIFLUORO-ETHYLENE	ECTFE	L	L	L	-	L	-	-	R	-	L	-	L	-	L
POLYTETRA FLUORO ETHYLENE	PTFE	L	L	L	-	L	-	-	L	-	L	-	L	-	-
POLYVINYLIDENE FLUORIDE	PVDF	-	L	R	L	L	L	L	R	-	R	-	L	-	L
PERFLUOROALKOXY	PFA	R	L	L	-	L	-	-	L	-	L	L	L	-	-
FLUORINATED ETHYLENE PROPYLENE COPOLYMER	FEP	L	L	L	-	L	-	-	L	-	L	-	L	-	-
POLYAMIDES	PA	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2. THERMOSETTING MATERIAL															
PHENOL-FORMALDEHYDE	PF	L	L	-	L	-	-	-	L	L	L	-	L	-	L
EPOXY-PHENOLIC		-	L	-	-	-	-	-	-	L	L	-	-	-	-
POLYESTER		-	L	L	L	L	L	L	R	-	R	-	R	-	L
EPOXY		-	L	-	L	L	L	L	R	-	L	-	L	L	-
POLYURETHANE	PU	-	L	L	R	L	-	-	L	-	L	-	L	-	R
POLYCHLOROPRENE		-	R	L	L	-	-	L	L	-	L	-	R	L	-
FURANE		-	R	L	L	-	-	L	L	L	L	L	L	-	R
3. RUBBERS															
NATURAL OR SYNTHETIC POLYISOPRENE	IR&NR	-	-	-	L	-	-	-	R	-	L	-	R	L	-
BUTYL RUBBER	IIR	-	R	L	L	L	-	R	R	-	L	-	R	L	-
NITRIL & CARBOXYLATED NITR	NBR	-	L	L	L	-	-	L	R	-	-	-	-	-	-
CHLORINATED RUBBER (CHLOROSULFORATED POLYETHYLENE)	CSM	-	L	R	R	L	R	-	L	-	L	-	L	-	[illegible]
HARD & EBONITE		-	R	R	-	-	-	L	R	-	-	-	-	-	-
FLUORINATED RUBBER (FLUORO RUBBER OF POLYMETHYLENE TYPE)	FKM	-	L	L	L	L	-	-	R	-	R	L	R	L	[illegible]
CHLOROPRENE RUBBER	CR	-	L	L	L	-	-	L	R	-	-	-	-	-	-
4. MINERAL & BITUMEN MATERIAL															
GLASS / PORCELAIN		R	L	-	R	R	-	R	R	-	R	R	R	-	R
CERAMIC (STONEWARE)		-	L	-	-	L	-	-	L	-	L	-	-	-	-
BRICK AND TILE		-	-	-	-	-	-	-	-	-	-	-	-	-	-
CEMENT - MORTAR		-	R	-	R	R	-	R	R	-	-	-	R	-	R
CEMENT / RESIN FURAN, PHENOLI, EPOXY, POLYESTER, SULFUR, ASPHALT		-	R	R	R	L	-	R	R	-	L	-	L	-	R
COAL TAR		-	L	-	R	L	-	-	L	-	L	-	L	-	-
BITUMEN		-	L	-	L	-	-	-	L	-	-	-	-	-	-

* Commercially available under the registered trade mark "Hypalon"

** Ebonites are rubbers with a hardness value of atleast 60° type D shore and can be produced from NR, synthetic isoprene rubber (IR), SBR, NBR or blends thereof.

*** Commercially available under the registred trade mark "Viton"

(to be continued)

TABLE 6 (continued)

CHEMICAL CLASSIFICATION		ALKALIS: ALUMINUM HYDROXIDE	AMMONIUM HYDROXIDE	CALCIUM HYDROXIDE	POTASSIUM HYDROXIDE	SODIUM HYDROXIDE		LIQUIDS/GAS: AMMONIA	BROMINE	CARBON DIOXIDE	CHLORINE	HYDROGEN PEROXIDE	NITROGEN	NITROUS OXIDES	[illegible]
1. THERMOPLASTIC MATERIAL															
POLYETHYLENE	PE	-	R	L	L	R		L	-	L	-	L	-	-	
POLYPROPYLENE	PP	L	L	L	R	L		L	-	-	-	L	-	L	
POLYVINYL CHLORIDE	PVC	L	L	L	L	R		L	L	L	R	L	-	L	
ETHYLENE-CHLOROTRIFLUORO-ETHYLENE	ECTFE	L	L		L	L		-	L	-	-	L	-	-	
POLYTETRA FLUORO ETHYLENE	PTFE	L	L	L	L	L		-	L	-	-	R	L	-	
POLYVINYLIDENE FLUORIDE	PVDF	L	L	L	L	L		-	R	-	-	L	-	R	-
PERFLUOROALKOXY	PFA	-	L	-	-	L		-	L	-	-	L	-	-	-
FLUORINATED ETHYLENE PROPYLENE COPOLYMER	FEP	L	L	L	L	L		-	L	-	-	R	L	-	-
POLYAMIDES	PA	-	L	-	L	L		-	-	-	-	-	-	L	-
2. THERMOSETING MATERIAL															
PHENOL-FORMALDEHYDE	PF	-	-	-	-	-		-	L	L	-	-	-	-	-
EPOXY-PHENOLIC		-	R	-	-	R		L	-	R	L	-	-	-	-
POLYESTER		-	L	L	L	L		L	L	R	R	L	-	-	I
EPOXY		L	L	R	R	L		L	-	R	L	-	-	-	-
POLYURETHANE	PU	-	L	L	L	L		L	-	-	L	L	-	-	-
POLYCHLOROPRENE		-	L	-	L	R		L		-	-	L	-	-	L
FURANE		L	L	L	L	L		R	L	R	-	-	-	-	-
3. RUBBERS															
NATURAL OR SYNTHETIC POLYISOPRENE	IR & NR	-	-	-	R	R		-	-	-	-		-	-	-
BUTYL RUBBER	IIR	-	R	R	R	R		R	R	R	L	L	R	L	R
NITRYL & CARBOXYLATED NITRIL	NBR	-	R	R	R	R		R	-	R	-		R	-	R
CHLORINATED RUBBER (CHLOROSULFORATED POLYETHYLENE)	CSM	R	R	-	R	R		-	-	L	L	L	-	-	-
HARD & EBONITE **		-	R	R	R	R		R		R	L	L	R	-	-
FLUORINATED RUBBER (FLUORO RUBBER OF POLYMETHYLENE TYPE)	FKM	-	-	L	-	L		-	L	-	-	L	-	L	R
CHLOROPRENE RUBBER	CR	-	R	R	R	R		R	L	R	-	L	R	-	R
4. MINERAL & BITUMEN MATERIAL															
GLASS / PORCELAIN		-	R	-	-	L		-	L	-	-	L	-	L	-
CERAMIC (STONEWARE)		-	L	-	-	L		-	-	-	R	-	-	-	-
BRICK AND TILE		-	-	-	-	-		-	-	-	R	-	-	-	-
CEMENT MORTAR		-	-	-	-	-		-	L	-	R	-	-	-	-
CEMENT / RESIN FURAN, PHENOLI, EPOXY, POLYESTER, SULFUR, ASPHALT		-	L	L	L	L		-	-	-	-	L	-	-	-
COAL TAR		L	-	R	-	L		L	-	R	-	-	-	-	-
BITUMEN		-	L	L	L	L			-	-	L	-	-	-	-

(to be continued)

TABLE 6 (continued)

		SALTS													
CHEMICAL CLASSIFICATION		ALUMINUM ACETATE	ALUMINUM AMMONIUM SULFATE	ALUMINUM CHLORIDE	ALUMINUM POTASIUM SULFATE	ALUMINUM SODIUM SULFATE	ALUMINUM SULFATE	AMMONIUM ACETATE		AMMONIUM CARBONATE	AMMONIUM CHLORIDE	AMMONIUM FLUORIDE	AMMONIUM NITRATE	AMMONIUM PHOSPHATE	AMMONIUM SULFATE
1. THERMOPLASTIC MATERIAL															
POLYETHYLENE	PE	.	.	R	-	.	R	-		-	R	-	-	.	L
POLYPROPYLENE	PP	-	R	L	L	-	L	L		L	R	L	R	R	L
POLYVINYL CHLORIDE	PVC	-	.	L	-	.	L	L		L	L	L	L	L	L
ETHYLENE-CHLOROTRIFLUORO-ETHYLENE	ECTFE	.	-	-	.	-	-	-		-	-	-	-	-	-
POLYTETRA FLUORO ETHYLENE	PTFE	L	L	L	-	-	.	-		-	R	.	-	L	L
POLYVINYLIDENE FLUORIDE	PVDF	-	R	L	L	.	-	-		L	L	L	L	L	L
PERFLUOROALKOXY	PFA	.	-	-	.	.	-	-		-	-	-	.	.	-
FLUORINATED ETHYLENE PROPYLENE COPOLYMER	FEP	L	L	L	-	-	.	.		-	R	.	-	L	L
POLYAMIDES	PA	.	.	L	-	-	L	.		L	L	.	-	-	-
2. THERMOSETTING MATERIAL															
PHENOL-FORMALDEHYDE	PF	-	-	L	-	-	.	-		-	L	-		L	-
EPOXY-PHENOLIC		-	.	.	-	-	.	.		.	.	.	.	-	-
POLYESTER		-	-	R	R	-	R	L		L	R	L	R	-	R
EPOXY		.	.	L	L	.	.	.		L	L	L	L	L	L
POLYURETHANE	PU	.	-	.	.	-	-	-		.	R	-	R	.	R
POLYCHLOROPRENE		-	.	R	R	-	R	R		R	R	L	R	R	R
FURANE		.	-	R	R	.	R	-		L	L	L	L	L	R
3. RUBBERS															
NATURAL OR SYNTHETIC POLYISOPRENE	IR & NR	.	-	L	R	-	L	R		R	R	L	R	R	R
BUTYL	IIR	R	R	L	L	R	R	R		R	R	L	R	R	R
NITRYL CARBOXYLATED NITRIL	NBR	R	R	R	R	R	R	R		R	R	R	R	R	R
CHLORINATED RUBBER (CHLOROSULFORATED POLYETHYLENE)	CSM	-	.	.	-	-	.	.		-	-	.	.	-	R
HARD & EBONITE**		R	R	R	R	R	R	R		R	R	R	R	R	R
FLUORINATED RUBBER (FLUORO RUBBER OF POLYMETHYLENE TYPE)	FKM	.	-	L	R	.	R	R		R	R	L	R	R	R
CHLOROPRENE	CR	R	R	R	R	R	R	R		R	R	R	R	R	R
4. MINERAL & BITUMEN MATERIAL															
GLASS / PORCELAIN		.	.	L	L	.	R	-		-	L	.	R	R	R
CERAMIC (STONEWARE)		.	-	.	-	-	.	.		-	-	.	.	.	-
BRICK AND TILE		.	-	-	-	.	-	-		.	.	.	-	-	.
CEMENT-MORTAR		-	-	.	.	-	-	-		.	R	-	R	L	R
CEMENT / RESIN FURAN, PHENOLI, EPOXY, POLYESTER, SULFUR, ASPHALT		.	.	-	-	-	-	-		-	R	.	R	-	R
COAL TAR		-	-	.	-	-	.	.		L	L	L	L	L	L
BITUMEN		.	.	L	L	.	L	.		-	L	.	L	.	L

(to be continued)

TABLE 6 (continued)

CHEMICAL CLASSIFICATION		SALTS													
		FLUORIDE SALTS	FERROUS CHLORIDE	FERROUS SULFATE	LEAD ACETATE	MAGNESIUM CHLORIDE	MERCURIC CHLORIDE	MERCURIC CYANIDE	MERCUROUS NITARTE	NICKEL ACETATE	NICKEL CHLORIDE	NICKEL SULFATE	PHOSPHORUS CHLORIDE	POTASSIUM CHROMATE	POTASSIUM [illegible]
1. THERMOPLASTIC MATERIAL															
POLYETHYLENE	PE	-	R	R	-	R	-	-	-	-	-	-	L-	-	-
POLYPROPYLENE	PP	-	R	R	R	R	L	L	R	-	R	R		L	L
POLYVINYL CHLORIDE	PVC	-	L	L	L	L	L	L	L	L	L	L	-	L	L
ETHYLENE-CHLOROTRIFLUORO-ETHYLENE	ECTFE	-	-	-	-	-	-	-	-	-	-	-	R	-	-
POLYTETRA FLUORO ETHYLENE	PTFE	-	-	L	L	R	-	-	-	-	L	L	L	L	L
POLYVINYLIDENE FLUORIDE	PVDF	-	L	L	L	L	L	L	L	-	-	L	L	L	L
PERFLUOROALKOXY	PFA		-	-	-	-		-	-	-	-	-	-	-	-
FLUORINATED ETHYLENE PROPYLENE COPOLYMER	FEP	-	-	L	L	R	-	-	-	-	L	L	L	L	L
POLYAMIDES	PA	-	-	-	-	L	-	-	-	-	-	L	-	-	L
2. THERMOSETTING MATERIAL															
PHENOL-FORMALDEHYDE	PF	-	-	-	L	L	-	-	-	-	-	-	L	L	-
EPOXY-PHENOLIC		-	R	-	-	-	-	-	-	-	-	-	-	-	-
POLYESTER		L	R	L	R	R	R	-	-	-	R	L	-	R	R
EPOXY		-	L	L	L	R	L	-	-	-	L	L	-	R	R
POLYURETHANE	PU	-	-	-	-	-	-	-	-	-	-	-	-	-	-
POLYCHLOROPRENE		-	-	-	L	L	-	-	-	-	-	R	-	L	R
FURANE		-	-	-	-	R	L	-	-	-	R	R	L	L	L
3. RUBBERS															
NATURAL OR SYNTHETIC POLYISOPRENE	IR & NR	-	-	-	L	L	-	-	-	-	-	R	L	-	R
BUTYL RUBBER	IIR	R	R	R	R	L	L	R	L	R	R	R	L	R	R
NITRYL & CARBOXYLATED NITRIL	NBR	R	R	R	-	R	R	R	-	R	R	R	-	R	R
CHLORINATED RUBBER (CHLOROSULFORATED POLYETHYLENE)	CSM	-	R	R	-	R	R	R	R	R	R	R	-	R	R
HARD & EBONITE		R	R	R		R	R	R	-	R	R	R	-	R	R
FLUORINATED RUBBER (FLUORO RUBBER OF POLYMETHYLENE TYPE)	FKM	-	-	R	R	R	L					R	L	L	R
CHLOROPRENE	CR	R	L	R	-	R	R	R	-	R	R	R	-	R	R
4. MINERAL & BITUMEN MATERIAL															
GLASS / PORCELAIN		-	-	R	-	-R	L	-	-	-	-	-	-	R	R
CERAMIC (STONEWARE)		-	-	-	-	-	-	-	-	-	-	-	-	-	-
BRICK AND TILE		-	-	-	-	-	-	-	-	-	-	-	-	-	-
CEMENT-MORTAR		-	-	-	-	R	-	-	-	-	R	R	-	-	L
CEMENT / RESIN FURAN, PHENOLI, EPOXY, POLYESTER, SULFUR, ASPHALT		-	R	R	-	R	-	-	-	-	R	R	-	-	R
COAL TAR		-	-	-	-	-	-	-	-	-	-	-	-	-	-
BITUMEN		-	L	L	L	L	-	-	-	-	L	L	-	-	L

(to be continued)

TABLE 6 (continued)

	SALTS						ALIPHATIC HYDROCARBONS						Al
CHEMICAL CLASSIFICATION	SODIUM SILICATE	SODIUM SULFATE	SODIUM SULFIDE	SODIUM THIOSULFATE	STANNIC CHLORIDE	SULFUR CHLORIDE	BUTADIENE	BUTANE	BUTYLENE	HEPTANE	HEXANE	PROPANE	BENZENE
1. THERMOPLASTIC MATERIAL													
POLYETHYLENE PE	-	R	-	-	R	-	-	-	-	-	R	R	-
POLYPROPYLENE PP	L	R	L	-	L	-	-	L	-	L	L	-	-
POLYVINYL CHLORIDE PVC	-	L	L	L	L	-	-	L	L	L	-	L	-
ETHYLENE-CHLOROTRIFLUORO-ETHYLENE ECTFE	-	-	-	-	-	-	-	-	-	-	L	L	-
POLYTETRA FLUORO ETHYLENE PTFE	L	L	L	-	L	L	-	-	-	L	L	L	-
POLYVINYLIDENE FLUORIDE PVDF	L	L	L	L	-	L	R	-	R	R	R	R	L
PERFLUOROALKOXY PFA	-	-	-	-	-	-	-	-	-	-	-	-	-
FLUORINATED ETHYLENE PROPYLENE COPOLYMER FEP	L	L	L	-	L	L	-	-	-	L	L	L	-
POLYAMIDES PA	L	-	L	L	-	-	-	-	-	L	L	-	L
2. THERMOSETTING MATERIAL													
PHENOL-FORMALDEHYDE PF	-	L	-	L	L	-	L	-	-	L	-	-	L
EPOXY-PHENOLIC	-	-	-	-	-	-	R	-	-	R	R	-	R
POLYESTER	R	L	L	-	R	-	-	-	-	L	L	-	R
EPOXY	R	R	R	L	R	-	L	L	-	L	L	L	-
POLYURETHANE PU	-	-	R	-	-	-	L	-	-	L	L	-	R
POLYCHLOROPRENE	R	L	-	L	R	-	L	L	L	L	L	L	L
FURANE	-	L	L	-	R	-	-	-	-	L	-	-	-
3. RUBBERS													
NATURAL OR SYNTHETIC POLYISOPRENE IR & NR	L	R	L	L	R	-	-	-	-	-	-	-	-
BUTYL RUBBER IIR	L	L	R	L	R	-	-	L	L	-		L	-
NITRYL & CARBOXYLATED NITRIL NBR	R	R	R	R	R	-	-	-	-	L	L	-	L
CHLORINATED RUBBER CSM (CHLOROSULFORATED POLYETHYLENE)	R	R	R	R	R	-	-	R	-	-	R	R	-
HARD & EBONITE	R	R	R	R	R	-	-	L	-	L	L	-	-
FLUORINATED RUBBER FKM (FLUORO RUBBER OF POLYMETHYLENE TYPE)	L	R	L	R	R	-	L	L	L	L	L	L	-
CHLOROPRENE CR	R	R	R	L	L	-	-	-	-	L	L	-	-
4. MINERAL & BITUMEN MATERIAL													
GLASS / PORCELAIN	L	R	-	-	R	R	-	-	-	-	-	-	R
CERAMIC (STONEWARE)	-	-	-	-	-	-	-	-	-	-	-	-	-
BRICK AND TILE	-	-	-	-	-	-	-	-	-	-	-	-	-
CEMENT-MORTAR	R	R	-	-	R		-	-	-	-	-	-	R
CEMENT / RESIN FURAN, PHENOLI, EPOXY, POLYESTER, SULFUR, ASPHALT	-	R	L	R	R	-	-	-	-	-	-	-	L
COAL TAR	R	R	R	R	-	-	L		L	L	L	-	-
BITUMEN	-	L	-	L	-	-	-	-	-	-	-	-	-

(to be continued)

TABLE 6 (continued)

CHEMICAL CLASSIFICATION		ALCOHOLS / HYDROCARBONS									ETHERS		A…	
		CYCLOHEXANOL	ETHYL	ETHYLENE GLYCOL	FURFURYL	GLYCEROL	ISOPROPYL	LAURYL	METHYL	PROPYL	ETHERS		ACETALDEHYDE	ACETONE
1. THERMOPLASTIC MATERIAL														
POLYETHYLENE	PE	-	R	L	-	L	R	-	L	R	L		L	-
POLYPROPYLENE	PP	L	L	L	-	L	L	-	L	L	-		L	L
POLYVINYL CHLORIDE	PVC	-	L	L	-	L	-	-	L	L	L		-	-
ETHYLENE-CHLOROTRIFLUORO-ETHYLENE	ECTFE	-	L	L	-	L	-	-	L	-	-		-	L
POLYTETRA FLUORO ETHYLENE	PTFE	L	-	L	L	L	L	L	L	L	L		L	L
POLYVINYLIDENE FLUORIDE	PVDF	L	L	L	-	L	-	-	L	L	-		-	-
PERFLUOROALKOXY	PFA	-	-	-	-	-	-	-	-	-	-		-	-
FLUORINATED ETHYLENE PROPYLENE COPOLYMER	FEP	L	-	L	L	L	L	L	L	L	L		L	L
POLYAMIDES	PA	-	-	-	-	L	L	-	-	-	-		-	-
2. THERMOSETTING MATERIAL														
PHENOL-FORMALDEHYDE	PF	-	L	L	-	L	L	-	L	-	-		-	L
EPOXY-PHENOLIC		-	R	-	-	-	-	-	-	R	R		L	L
POLYESTER		-	R	R	L	R	L	L	L	-	L		-	L
POXY		-	L	L	-	L	L	-	L	-	L		L	L
POLYURETHANE	PU	-	L	R	-	R	-	-	L	-	R		-	L
POLYCHLOROPRENE		-	L	L	L	R	R	-	L	L	-		L	L
FURANE		-	L	L	L	L	-	-	L	-	-		L	L
3. RUBBERS														
NATURAL OR SYNTHETIC POLYISOPRENE	IR & NR	-	R	L	L	R	L	-	L	-	-		-	-
BUTYL RUBBER	IIR	L	L	R	L	R	L	-	L	L	-		L	L
NITRYL & CARBOXYLATED NITRIL	NBR	L	R	R	-	R	-	-	R	-	-		-	-
CHLORINATED RUBBER (CHLOROSULFORATED POLYETHYLENE)	CSM	-	R	R	-	-	R	-	R	-	-		-	-
HARD & EBONITE		L	R	R	-	R	-	-	R	-	-		L	L
FLUORINATED RUBBER (FLUORO RUBBER OF POLYMETHYLENE TYPE)	FKM	L	R	L	-	L	L	-		L	-		L	L
CHLOROPRENE	CR	L	R	R	-	R	-	-	R	-	-		-	L
4. MINERAL & BITUMEN MATERIAL														
GLASS/PORCELAIN		-	-	R	-	R	-	-	R	-	-		L	-
CERAMIC (STONEWARE)		-	-	-	-	-	-	-	-	-	-		-	-
BRICK AND TILE		-	-	-	-	-	-	-	-	-	-		-	-
CEMENT-MORTAR		-	R	-	-	-	-	-	R	-	-		L	R
CEMENT / RESIN FURAN, PHENOLI, EPOXY, POLYESTER, SULFUR, ASPHALT		-	R	R	-	R	-	-	R	L	-		-	L
COAL TAR		-	L	-	-	-	L	L	L	L	-		-	-
BITUMEN		-	L	L	-	L	-	-	L	-	-		-	-

(to be continued)

TABLE 6 (continued)

		ESTERS / HYDROCARBONS							AMINE				HALO		
		AMYLACETATE	BUTYACETATE	DIOCTYL PHTHALATE	ETHYL ACETATE	METHY SALICYLATE	SODIUM BENZOATE	VINY ACETATE	ANILINE	DIMETHYL AMINE	TRIETHYL AMINE	UREA	ALLYL CHLORIDE	AMYL CHLORIDE	CARBON TETRACHLORIDE
CHEMICAL CLASSIFICATION															
1. THERMOPLASTIC MATERIAL															
POLYETHYLENE	PE	-	-	-	-	-	L	-	L	-	-	R	-	-	-
POLYPROPYLENE	PP	-	-	-	-	-	L	-	L	-	-	L	-	-	-
POLYVINYL CHLORIDE	PVC	-	-	-	-	L	L	-	-	-	L	L	-	-	-
ETHYLENE-CHLOROTRIFLUORO-ETHYLENE	ECTFE	-	R	-	R	-	-	-	L	L	-	-	-	-	L
POLYTETRA FLUORO ETHYLENE	PTFE	L	L	L	L	-	-	L	L	-	L	L	L	L	L
POLYVINYLIDENE FLUORIDE	PVDF	L	L	-	L	-	L	R	L	-	L	L	L	R	L
PERFLUOROALKOXY	PFA	-	L	-	-	-	-	-	R	-	-	-	-	-	L
FLUORINATED ETHYLENE PROPYLENE COPOLYMER	FEP	L	L	L	L	-	-	L	L	-	L	L	L	L	L
POLYAMIDES	PA	L	L	L	L	-	L	-	-	-	-	L	-	-	L
2. THERMOSETTING MATERIAL															
PHENOL-FORMALDEHYDE	PF	-	L	L	L	-	-	R	L	L	L	-	L	-	L
EPOXY-PHENOLIC		L	L	L	L	-	L	L	L	L	L	L	-	-	R
POLYESTER		L	L	L	R	-	L	-	-	-	-	L	-	-	R
EPOXY		L	L	-	L	-	-	L	L	-	L	L	L	-	-
POLYURETHANE	PU	-	-	-	R	-	-	-	-	-	-	-	-	-	L
POLYCHLOROPRENE		-	-	-	-	L	-	L	-	L	-	L	-	-	-
FURANE		L	L	-	L	-	-	-	L	-	-	L	-	-	L
3. RUBBERS															
NATURAL OR SYNTHETIC POLYISOPRENE	IR & NR	L	L		-	-	L	L	-	L	-	L	-	-	-
BUTYL RUBBER	IIR	L	L	L	L	-	L	L	L	L	L	L	-	-	-
NITRYL & CARBOXYLATED NITRIL	NBR	-	-	-	-	-	R	-	-	R	L	L	-	-	-
CHLORINATED RUBBER (CHLOROSULFORATED POLYETHYLENE)	CSM	-	-	-	-	-	-	-	-	-	-	R	-	-	-
HARD & EBONITE		-	-	L	L	-	R	-	L	R	L	L	-	-	-
FLUORINATED RUBBER (FLUORO RUBBER OF POLYMETHYLENE TYPE)	FKM	-	-	-	-	-	L	L	L	R	-	L	-	-	-
CHLOROPRENE	CR	L	-	-	-	-	R	-	L	R	L	L	-	-	-
4. MINERAL & BITUMEN MATERIAL															
GLASS / PORCELAIN		-	L	-	L	-	-	-	R	R	-	-	-	-	R
CERAMIC (STONEWARE)		-	-	-	-	-	-	-	-	-	-	-	-	-	L
BRICK AND TILE		L	L	-	L	-	-	-	-	-	-	L	-	-	R
CEMENT-MORTAR		L	L	-	R	-	-	-	-	L	-	-	-	-	L
CEMENT / RESIN FURAN, PHENOLI, EPOXY, POLYESTER, SULFUR, ASPHALT		-	-	-	L	-	-	-	-	-	-	-	-	-	L
COAL TAR		-	-	-	-	-	-	-	-	-	-	-	-	-	-
BITUMEN		-	-	-	-	-	-	-	-	-	-	L	-	-	-

(to be continued)

TABLE 6 (continued)

CHEMICAL CLASSIFICATION		PETROLEUM FRACTIONS: BITUMEN (ASPHALT)	CRUDE	DIESEL FUEL	FUEL OIL	GASOLINE	JET FUEL	KEROSENE	LUBRICATING OIL	MINERAL OIL	NAPHTA	NAPHTHALENE	NATURAL GAS	PARAFFIN
1. THERMOPLASTIC MATERIAL														
POLYETHYLENE	PE	L	-	-	-	-	-	-	-	-	-	-	-	-
POLYPROPYLENE	PP	L	-	L	L	-	-	L	-	L	L	R	L	L
POLYVINYL CHLORIDE	PVC	-	L	-	-	-	-	L	L	L	L	-	L	L
ETHYLENE-CHLOROTRIFLUORO-ETHYLENE	ECTFE	-	-	-	-	-	-	-	-	-	-	-	-	-
POLYTETRA FLUORO ETHYLENE	PTFE	L	L	L	L	L	L	L	L	L	L	L	L	L
POLYVINYLIDENE FLUORIDE	PVDF	-	R	R	R	R	L	R	R	R	R	R	R	-
PERFLUOROALKOXY	PFA	-	-	-	-	-	-	-	-	R	R	-	-	-
FLUORINATED ETHYLENE PROPYLENE COPOLYMER	FEP	L	L	L	L	L	L	L	L	L	L	L	L	L
POLYAMIDES	PA	-	-	L	L	L	-	-	-	L	-	L	-	L
2. THERMOSETTING MATERIAL														
PHENOL-FORMALDEHYDE	PF	-	-	-	L	L	-	-	-	L	-	L	-	L
EPOXY-PHENOLIC		-	-	-	-	-	-	-	-	R	-	-	-	-
POLYESTER		-	L	L	L	R	-	-	-	R	L	L	-	-
EPOXY		-	L	L	-	L	L	L	-	R	L	L	L	-
POLYURATHANE	PU	-	-	-	-	R	R	-	-	-	-	-	-	-
POLYCHLOROPRENE		-	L	L	L	L	-	L	L	L	-	-	-	L
FURANE		-	-	-	-	L	-	-	-	R	-	L	-	L
3 RUBBERS														
NATURAL OR SYNTHETIC POLYISOPRENE	IR & NR	-	-	-	-		-	-	-	-	-	-	-	-
BUTYL RUBBER	IIR	-	-	-	-		-	-	-	-	-	-	-	-
NITRYL & CARBOXYLATED NITRIL	NBR	L	L	-	-	L	-	R	R	R	L	L	L	-
CHLORINATED RUBBER (CHLOROSULFORATED POLYETHYLENE)	CSM	-	-	L	L		-	-	-	R	-	-	-	-
HARD & EBONITE		-	L	-	-		-	-	L	L	-	-	L	-
FLUORINATED RUBBER (FLUORO RUBBER OF POLYMETHYLENE TYPE)	FKM	-	L	-	L	L	-	-	L	L	-	L	-	L
CHLOROPRENE	CR	-	L	-	-	L	-	L	L	R	-	-	-	-
4. MINERAL & BITUMEN MATERIAL														
GLASS / PORCELAIN		-	R	-	R	-	-	-	-	-	-	-	-	-
CERAMIC (STONEWARE)		-	-	-	-	-	-	-	-	-	-	-	-	-
BRICK AND TILE		-	-	-	-	-	-	-	-	-	-	-	-	-
CEMENT-MORTAR		-	-	-	-	-	-	-	-	-	-	-	-	-
CEMENT / RESIN FURAN, PHENOLI, EPOXY, POLYESTER, SULFUR, ASPHALT		-	-	-	-	R	-	-	-	R	-	-	-	-
COAL TAR		-	-	-	-	-	-	-	-	L	-	-	-	-
BITUMEN		-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 7 - WORKING TEMPERATURE FOR LINING

	LINING MATERIAL	Max. WORKING TEMP. °C		LINING MATERIAL	Max. WORKING TEMP. °C
1	Polyethylene - PE	60-65	20	Butyl rubber (11R)	120
2	Poly propylene - PP	90-100	21	Nitril rubber (NBR)	110
3	Poly vinyl chloride PVC	60-90	22	Chloro sulfonated poly ethylene. (CSM)	100
4	E. CTEF	120-140	23	Hard & Ebonite	90
5	PTFE	160-200	24	Fluorinated rubber (FKM)	200
6	PVDF	90-110	25	Chloroprene rubber (CR)	90
7	PFA	160	26	Glass and porcelain	200-260
8	FEP	120	27	Ceramic	200
9	Polyamide	80	28	Brick and tiles	65-200
10	Fusion bonded epoxy	80	29	Silicate base cement	900
11	EVA	—	30	Phenolic furfuraldehyde cement	180
12	Phenol formldehyde	80-150	31	Furan resin cement	220
13	Epoxy phenolic	90-150	32	Reinforced epoxy cement	90
14	Poly chloprene (liquid)	100	33	Phenol formaldehyde cement	180
15	Furan	140	34	Sulfur cement	90
16	Polyester	70-130	35	Polyester based cement	120
17	Polyurethane	140	36	Coal tar	32
18	Liquid epoxy lining	90-140	37	Bitumen	32
19	Natural or synthetic Polyisoprene	100			

TABLE 8 - PHYSICAL AND MECHANICAL CHARACTERISTICS OF LININGS

TABLE 8.1 - SPECIFICATION OF SHEET THERMOPLASTICS LINING

	SHEET THERMO-PLASTICS	SHAPE ABILITY	WELD ABILITY	AVAILABLE FORM	TYPE OF APPLICATION	REMARK
1	PVC	G	G	UPVC sheet PVC sheet	Bond or loose	Unplasticized polyvinyl chloride (UPVC) softens and loses strength as the temperature increases (more than 85°C).
2	PE	B	G	LDPE sheet HDPE sheet	Normally loose	Susceptible to environmental stress cracking in polar organic.
3	PP	G	G	sheets with glass or synthetic fiber or rubber backing	Bond or loose	The backing material can impose limitation on the thermal forming process (shopping). Glass fiber backed is not readily formed into complex shapes.
4	E. CTFE	B	G	sheet with a glass fiber backing	Bond or loose	The backing material impose limitation on the thermoforming process (shopping)
5	PVDF	G	G	sheets with glass or synthetic fiber or rubber backingBond or loose	Bond or loose	The backing material can impose limitation on the thermal process.
6	FEP	G	G	sheet with or without glass fiber backing	Bond or loose	- When FEP is bonded to a substrate the maximum service temperature will be determined by the adhesive used. - In the case of glass backed material the complexity of the formed shape may be limited.
7	PFA	G	G	sheet with or without glass and carbon fiber backing	Bond or loose	—
8	PTFE	No	G up to 4 mm thickness	Sheet with or without glass fiber backing	usually loose	The process is very difficult and required special techniques and equipment.

"G" means: Good,
"B" means: Bad.

TABLE 8.2 - SPECIFICATION OF NON-SHEET THRMOPLASTICS LINING

	NON-SHEET THERMOPLASTIC	AVAILABLE FORM	TYPE OF APPLICATION	REMARK
1	PVC	Powder (UPVC) plastisol (PVC)	- Dip - Spray - Fluized bed	Some solvents e.g. aromatic hydrocarbons, will extract the plasticizer and after evaporation of the solvent the lining will be hard and liable to develop cracks.
2	PE	Powder	- Spray - Fluized bed	All three grades of PE (low, medium and high density) have susceptibility for environmental stress. Cracking in polar organic liquids.
3	PP	Powder	- Spray - Fluized bed	Polypropylene lined pipe and fitting are suitable for conveying corrosive liquid and gases in operating pressures up to 10 bar.
4	E.CTFE	Powder	- Spray - Fluized bed	Similar as characteristic noted for PP
5	PVDF	- Dispersion - Powder	- Dip - Spray - Fluized bed	Similar as characteristic noted for PP
6	FEP	- Dispersion	- Dip - Spray	Similar as characteristic noted for PP
7	PFA	Powder	- Spray - Fluized bed	Similar as characteristic noted for PP
8	PTFE	- Dispersion	- Dip - Spray	PTFE lining are resistant to most chemicals but because of the presence of pinholes, are not used for corrosion protection.
9	EVA	Powder	- Spray - Fluized bed	EVA has excellent weather resistance. It may be applied to a variety of metals including zinc, without use of primer and adhesion to the substrate is excellent.
10	Nylon	Powder	- Spray - Fluized bed	The grades of nylon are available for power coating are Nylon 11 and 12.
11	Fusion bonded epoxy	Powder	- Spray - Fluized bed	Fusion-bonded epoxy coatings are suitable for the interior and exterior of steel pipe lines installed under ground or under water (see API-RP-5L7 and AWWA 213-85).

TABLE 8.3 - SPECIFICATION OF THERMOSETS PLASTICS LINING

THERMOSETTING RESIN	CURING	AVAILABLE FORM	TYPE OF APPLICATION	REMARK
Phenol - formaldehyde	Stoved	Liquid	Spray	This lining have good resistance to erosion. For lining application several coats are necessary in order to achieve the specified thickness. When defects are discovered, the lining shall be cleaned and abraded to wherever resin is to be applied.
Epoxy-phenolic	Stoved	Liquid	Spray	Similar as characteristic is noted for phenol-formaldehyde.
Polyester	Cold curing	Liquid	Spray brushing trawling	The different types of polyester used for lining include isophthalic, terephthalic, orthophtalic bisphenol, vinyl ester and HET acid. Polyester is used with or without reinforced material.
Epoxy	Cold curing	Liquid	Spray	Typical grades of epoxy are used for lining: Amine cured solvent containing, poly amide cured solvent containing, high solid epoxy, solvent-free epoxy, coal tar epoxy.
Furane	Cold curing	Liquid	Brush, roller, trowel, spray	This resin shall be used with reinforcing fillers.The final coat is un-reinforced resin.
Polyurethane	Cold curing backed	Liquid	Spray	The typical grades of polyurethane are used for lining: Backed, airdry and coal tar polyurethane. All polyurethane systems are sensitive to moisture.
Polychloro prene	Cold curing	Liquid elastomer	Spray	Several coats are necessary in order to achieve the specified thickness. At 15°C the cure time of lining is approximately 7 days. This lining have good resistance to abrasion and water up to 100°C.

TABLE 8.4 - SPECIFICATION OF RUBBER LINING

RUBBER	HARDNESS (SHORE DUROMETER) ASTM D2240	FORM ABILITY	CURING	REMARK
NR or IR	50° - Type A	1-Unvulcanized sheet	1-Using an autoclave for vulcaization of lined equipment	Lining compounds based on NR, IR and SBR have less abrasion resistance than other types of rubber linings.
SBR	50° - Type A			
CR	60° - Type A			Polychoroprenes give lining compounds with greater resistance to heat, ozone, sunlight than above rubbers.
11R	60° - Type A			This lining have very good resistance to heat and have low permeability to gases.
NBR & XNBR	80° - Type A	2- Pre-vulca-nized sheet	2- The adhesiveis used for bonding is cold curing	These linings have excellent resistance to swelling by mineral oils and fuels. Polymers of high acrylonitrile to butadiene ratio have the best resistance and also have lower gas permeability. Higher butadiene ratio have better low temperature properties. XNBR is normally used for its outstanding abrasion resistance.
CSM	80° - Type A			CSM has excellent resistance to heat and ozone.
HARD RUBBER & EBONITE	80° - Type D			These lining have a higher resistance to chemicals than soft rubbers based on the same polymer types. This resistance again generally increases with decrease in unsaturation of vulcanized polymer.
FKM	80° - Type A			These materials have excellent resistance to oil and fuels.
BR	—			Polybutadiene rubber is normally used in combination with polyiso- prene or carboxylated nitrile rubber to produce linings with superior abrasion resistance compared to the individual rubbers and to improve the lower temperature properties of nitrile rubber.
EPR & EPDM	—			These lining have very good resistance to ozone.

TABLE 8.5 - SPECIFICATION OF BITUMEN AND COAL-TAR LINING

LINING MATERIAL	FORM AVAILABLE	TYPE OF APPLICATION	WORKING TEMP. °C	REMARK
Cold applied bitumen	Solvent base liquid	1- Brushing 2- Spraying	4 - 32	Solvent base bitumen lining are suitable for protection of ferrous metals, galvanized surfaces and concrete and brick. Emulsion base bitumen shall not be used for the protection of steel. This lining are neither intended to withstand hot conditions, nor to resist contamina- tion with mineral oils or paint solvents.
Hot applied bitumen	Solid (molten for use)	1- Spraying 2- Mapping 3- Trowelling (For floor) 4- Trough method (For pipe) 1)	4 - 32	The bitumen in this lining used in molten state. For lining of metallic or concrete surface, one or more coats of primer shall be used prior to hot applied lining. This lining have high resistance to moisture and good adhesion to steel.
Cold applied coal tar	Thin liquid to heavy paste	1- Spraying 2- Brushing 3- Dipping	4 - 32	This lining is not recommended for atmospheric exposure and sunlight. Coal tar linings are suitable for water and sewage lines and equipment. This lining have excellent adhesion to ferrous metals, slightly etched galvanized iron and steel, concrete and brick. It is not recommended where a high degree of resistance to abrasion is required.
Hot applied coal tar	Solid (molten for use)	1- Brushing 2- Spraying 3- Trough method (For pipe) 1) 4- Feed-line method (For pipe) 2) 5- Mapping	4 - 32	Hot applied coal tar lining shall be used only on metal surfaces and usually are applied over a coal for primer.This lining provides for protection of buried steel water pipelines and structures that are immersed in water.

1) In through method the pipe shall be rotated and molten enamel shall be introduced into pipe by a pouring through extend-ing the full length of the pipe.

2) In retracting-weir or feed-line method, pipe shall be rotated and molten enamel shall be supplied to the weir or feed-line from a reservoir through supply pipes.

TABLE 8.6 - SPECIFICATION OF CERAMIC LINING

LINING MATERIAL	TYPES	TYPE OF APPLICATION	REMARK
Silicate base	1- Alkali-alumina borosilicate 2- Barium, Crown 3- Water-soluble Silicate	1- Spraying 2- Dipping 3- Brushing (soluble type) 4- Packed cementation 5- Trowelling (soluble type)	Lining with silicate base ceramic, with or without added refractories, have the greatest industrial usage of all ceramics. These lining use for turbines, exhaust man folds, heat ex- changer and combustion chamber. Soluble silicate use for lining Aluminum, copper, steel, stainless steel, super alloys and magnesium.
Oxides base	Without reinforcement	1- Flame spraying (up to 6 mm)	Thermal shock resistance of flame sprayed lining decrease with increasing thickness.
	Without reinforcement	2- Trowelling (up to 25 mm)	Mineral bonding material and expanded-metal reinforcements used for ceramic lining with trowelling.
Carbides base	—	1- Flame spray 2- Air spray 3- Packed cementation	Principal use of carbides base ceramic lining is for wear and seal application, in which the high hardness of carbides is an advantage. This lining is used for jet engine seals, compressor and turbine blades, and plug gages.
Silicide base	—	1- Cementation	This lining used for the protection of refractory metals against oxidation. Silicide lining generally embrittle the metals (ferrousand non ferrous) to which they are applied, but shall not be used for repair lined metals.
Phosphate-bonded	With or without reinforcement	1- Air spraying 2- Trowelling	These materials are formed by the chemical reaction of phosphoric acid and a metal oxide. Phosphate-bonded lining are used for the protection of metals against heat during high temperature service.

TABLE 8.7 - SPECIFICATION OF BRICKS, TILES AND GLASS LINING

LINING MATERIAL	TYPES	TYPE OF APPLICATION	REMARK
Glass	1- High silica glass 2- Boro silicate glass	1- Slushing (1) 2- Spraying 3- Hot-dusting (2)	Glass lining are used for protection of carbon steel, high tensile steel, cast iron, stainless steel in equipment in against many corrosive environments in temperature up to 260°C.
Brick and tiles	1- Acid resistant brick 2- Porcelain, tile 3- Carbon brick 4- Graphite brick	Installation of three layer of membrane, brickand cement	Chemical-resistant brick lining is a multilayer system supported by a shell, consist of an impervious membrane to prevent the corrosive medium reaching the shell and layer of chemical-resistant brick laid in chemical-resistant cement. This lining is used for protection of steel and concrete vessels and columns.
Porcelain lining	1- Alkali resistant 2- Acid resistant 3- Hot water resistant 4- Regular-blue-black enamels	1- Slushing (1) 2- Spraying 3- Hot-dusting (2)	Porcelain enamels are used for sheet steel, cast iron, or aluminum parts to improve appearance and to protect the metal surface against chemicals and hot water. Porcelain enamels have specific electrical properties and thermal shock capability and are used to lining chemical reactors and heat exchangers.

1) Slushing and spraying are the wet-process. Slushing consists of two method of dipping and pouring.

2) Hot dusting consists of shifting glass dust onto a preheated metal surface.

TABLE 8.8 - SPECIFICATION OF CEMENT MORTAR AND REFRACTORY LINING

LINING MATERIAL	TYPES	TYPE OF APPLICATION	REMARK
Chemical resistance cements mortar	1- Silicate cements 2- Resinous cements	1- Centrifugally spinning (For pipe) 2- Line traweling 3- Shotcrete 4- Hand Troweling	Silicate cements linings are resistant against acids, gases, chlorine solution, and some of salts and solvents. Resinous cement consist of furane-cement, phenolic cement, polyester-cements, epoxy-cements and sulfur cement have more resistance to chemicals than silicate cement.
Refractory cement	—	1- Shotcrete (gunning) 2- Casting	Refractory cement linings are used for insulating of furnaces, boilers, flue ducts and steel stocks. This lining applied to equipment fabricated in metals.
Refractory brick	—	Installation of brick lining	Brick refractories are used for insulating of reformer furnaces and where refractory cement linings are unsuitable this lining normally used in conjunction with refractory cement lining.

TABLE 9 - LININGS THICKNESSES

LINING MATERIAL	THICKNESS mm		THICKNESS mm
Polyethylene (PE)	0.4-2	Rubbers: For pipe-Min. For vessel-Min.	3 5
Polypropylene (PP)	0.2-0.75	Thermosets: Reinforcement Un-reinforcement	0.6-5 0.2-0.4
Plastisized PVC	0.6-10.0	Glass	0.3-2
Unplastisized PVC	0.25-0.75	Ceramic: Reinforcement Un-reinforcement	2-50 0.01-6
Ethylene-chlorotrifluo-roethylene (E-CTFE)	0.2-0.75	Brick	50-80
Poly-tetra-fluoro ethylene (PTFE)	0.015-0.05	Chemical resistance cement	4-13
Poly vinylidene fluoride (PVDF)	0.075-0.8	Refractory cement	40-200
Per fluoro alkoxy (PFA)	0.05-0.3	Cold applied coal tar	0.1-2.7
Fluorinated ethylene propylencopolymer (FEP)	0.025-0.17	Hot applied coal tar	1.6-3.2
Polyamid (Nylon)	0.25-0.75	Cold applied bitumen	1.6-3.5
Fusion banded epoxy	0.25-0.75	Hot applied bitumen	3-6.5
Ethylene vinyl acetate (EVA)	0.35-1.25	—	

9. THERMOPLASTIC RESIN LINING

9.1 General

9.1.1 Thermoplastic materials are available in two types:

Sheet applied and non-sheet applied thermoplastics. Non-sheet applied polymers in forms of dispersion, powder and granule shall not be used for lining of concrete and shall only be used for metallic surfaces. Sheet applied thermoplastics polymers are suitable for lining of concrete and metallic surfaces.

9.1.2 Sheet applied polymers can be used in bonded or loose forms.

9.1.3 When the lining is to be bonded to the substrate the type of adhesive, the maximum service temperature and the conditions required for application and curing shall be conferred by the Company.

The minimum bond strength between the lining and the substrate shall be 3.5 N/mm² in direct shear and 5 N/mm² width in peel at a test temperature of 20°C when tested in accordance with BS 490: Part 10.4.

The adhesive shall be capable of maintaining a bond at the design temperature and after cycling between ambient and maximum surface temperatures, the applicator shall provide the Company with evidence of the suitability of the adhesive.

9.1.4 When a lining is bonded to the substrate it may be the choice of adhesive which is the limiting factor. A typical maximum service temperature for bonded lining is 100°C.

Except when stated otherwise the maximum service temperature quoted is for linings which are not bonded to the substrate. The limits suggested in Table 6 are what might be considered the upper temperature limit for the stability of the material but are quoted as safe working temperatures for the materials used as linings.

The limits may be varied depending upon the process environment and the design of the equipment.

9.1.5 Selection for type of lining to be used shall be based on the duty for which it is intended. The characteristics of sheet and non-sheet thermoplastic material for lining are given in Tables 7 and 8.

9.1.6 Unless previous experience demonstrates that a lining will be suitable for a particular duty, appropriate testing shall be carried out (see ASTM D 543 and ASTM C 581).

9.1.7 Only virgin polymer shall be used for the production of the liner; a maximum of 0.2% wt of additives is permitted. A large amount of additives is allowed if electrically conductive properties are required. Additives or coloring agent shall be finely homogenized.

9.1.8 Unless specified otherwise by the Purchaser the specification and quality of lining materials selected shall be approved by the Purchaser before application.

9.1.9 As the lining shall be inspected visually for defects, selection of the bonding liner shall be avoided where the shape of equipment does not allow for visual inspection during installation (i.e. in case of welded joint pipeline with ID smaller than 610 mm).

9.2 Thickness

9.2.1 The thickness of the finished thermoplastic lining will depend upon the material selected and the duties for which it is intended. The maximum thickness as well as the minimum thickness shall be specified by the designer. If necessary the material shall be capable of being thermo-formed and welded to give joints which are pinhole free.

9.2.2 The thickness of linings based on non-sheet applied material varies considerably with the particular plastic selected (see Table 10).When the thickness of the lining is less than 400 μm it is difficult to obtain linings which are pinhole free. Furthermore, even if linings as applied are free from imperfections, consideration has to be given to the possibility of damage in operation. If the corrosion rate is low then the thickness of the lining is not a critical factor. If the corrosion rate is high and is due to simple solution of the material, then it is not to use thin linings because of the risk of severe corrosion through a pinhole.

9.2.3 If sheet pipes are to lined with thermoplastic materials the thickness of the thermoplastic liner shall be in accordance with Table 11.

9.3 Application of Thermoplastic Linings

Application of thermoplastic linings, requirements and inspection of the works shall be in accordance with IPS-C-TP-352.

TABLE 10 - THE THICKNESS OF FINISHED THERMOPLASTIC LINING

NON-SHEET THERMOPLASTIC	THICKNESS (mm)
PVC	UPVC: 0.25-0.75 PVC: 0.6 to 10
PE	0.4 to 2 *
PP	0.2 to 0.75 *
E.CTFE	0.2 to 0.75 *
PVDF	0.075 to 0.8 *
FEP	0.025 to 0.17 *
PFA	0.05 to 0.3 *
PTFE	0.015 to 0.05
EVA	0.35 to 1.25
Nylon	0.25 to 0.75 *
Fusion bonded epoxy	0.25 to 0.75

*** Exact thickness to be defined according to duty.**

TABLE 11 - DIMENSIONS OF LINERS AND FLARES

NORMAL PIPE SIZE		MINIMUM LINER THICKNESS mm						MINIMUM FLARE DIAMETER, mm
Inch	mm	PP	PDVF	FEP	PTFE	PTFE *	PFA	
1	25	3.2	3.8	1.9	1.5	3.0	1.9	47.6
1½	40	3.8	4.0	1.9	1.6	3.9	1.9	68.3
2	50	4.3	4.3	1.9	1.7	3.9	2.0	87.3
3	80	4.4	4.4	2.3	2.4	4.0	2.2	117.5
4	100	5.2	5.2	2.4	2.7	4.5	2.4	150.8
6	150	5.5	5.5	3.3	3.7	5.0	3.3	201.0
8	200	5.5	5.5	3.3	4.0	5.0	—	255.6
10	250	6.3	—	3.5	5.0	6.5	—	311.2
12	300	6.3	—	3.5	5.3	8.1	—	365.1
14	350	7.2	—	3.5	6.0	—	—	423.5
16	400	7.2	—	3.5	6.3	—	—	470.0
18	450	—	—	—	7.5	—	—	—

*** Special thickness for vacuum or heavy duty service (chlorine, bromine, etc.) only applicable when specified in purchase order.**

10. THERMOSETTING RESIN LINING

10.1 General

10.1.1 Thermosetting resins used for the lining are divided into two groups: Cold curing thermosetting resin and stoved thermosetting resin (see Table 8.3). Cold curing resins are suitable for lining concrete and metallic surfaces, but stoved resin shall not be used for lining of concrete and only be used for metallic surfaces.

10.1.2 The stoved thermosetting resin linings are used for protection against corrosive environments, prevention to contamination of products and provision of surfaces that do not foul easily or that can be cleaned easily.

10.1.3 The minimum pipe diameter for liquid epoxy lining shall be 610 mm (24") to permit inspection and repair of the internal lining by entering the pipe.

10.1.4 The actual stoving temperature are specified by the lining supplier. Normally in the range from 150°C to 200°C depends on stoving time.

10.1.5 All of cold curing resin linings are poor thermal conductor and therefore reduce heat transfer. Most of these linings offer good resistance to erosion by suspended particles and to build-up of deposits (see Tables 12 and 13).

10.1.6 Cold curing thermoset resins may be used on metallic structures with or without reinforcement regarding the lining thickness required (see 10.2).

10.1.7 Some lining materials are not acceptable due to incompatibility with petroleum products or product additives. Acceptable thermosetting material shall be tested in accordance with ASTM-D-543 and ASTM- C-581.

10.1.8 For lining of under ground storage tanks with thermosetting materials see API-RP-1631.

10.1.9 For lining of water pipelines with liquid epoxy systems see AWWA-C-210-84.

10.1.10 Unless previous experience demonstrates that a lining will be suitable for a particular duty, appropriate testing shall be carried out. (see ASTM-D-543 and ASTM-C-581).

10.1.11 Selection of thermosetting lining, its type and thickness for a special service shall be based on the provisions of Section 8 and this Section. Resistance of various types of thermoset epoxy and polyurethane lining in chemical environments are shown in Tables 12 and 13.

10.1.12 Selection of type of lining to be used shall be based on duty for which it is intended (see Tables 12 and 13) as well as the shape of equipment.

10.2 Thickness

10.2.1 The dry film thickness of the finished lining will depend upon the type of material selected and the duties for which it is intended. The designer shall specify the thickness of the finished lining (see IPS-C-TP-352).

10.2.2 The dry film thickness of the finished thermosetting resin lining without use of reinforced material (thin layer) shall not thicker than 400 µm, as there is a tendency for the material to crack when thicker, and shall not normally be thinner than 200 µm in order to minimize the incidence of pinholes.

10.2.3 The thickness of finished thermosetting resin lining with using of inert fillers and/or reinforcing agent (thick layer) such as mica. Glass flake. glass fiber and carbon black are from 600 µm up to 5 mm.

10.2.4 In case of thick layer cold curing thermosetting resins, typically the liner is 2.5 to 3.5 mm thick and averages 20-25% glass fiber and 75-80% resin. For good long-term lining performance the temperature shall be limited to 60°C.

10.3 Application of Thermosetting Resin Lining (see also IPS-C-TP-352 Lining)

10.3.1 Description

10.3.1.1 In the case of metal equipment the lining process shall start as soon as possible after surface preparation is complete and before any visible rusting occurs. Unless maintained in a dehumidified atmosphere application of the lining shall commence within 4 h. If signs of rusting occur then the surface shall be prepared again to the required standard.

10.3.1.2 In the case of concrete equipment lining shall not proceed until at least 28 days after the concrete was cast and when the free water content is down to the level specified.

10.3.1.3 Where necessary surfaces shall be primed in order to promote a bond with the lining material. Once a primer has been applied the equipment shall be kept clean and the lining process shall start as soon as possible with references to manufacturer recommendation.

Notes:

1) The primer shall be pigmented to facilitate uniform application and to assist in establishing full coverage of the surface to be lined.

2) In the case of steel equipment with large surface areas, holding primers may be used to hold the blast cleaned surface, provided that the holding primer is compatible with the lining material and does not interfere with the adhesion of lining.

10.3.2 Stoved thermosetting resins

10.3.2.1 Several coats are necessary in order to achieve the thickness stipulated and each coat shall be allowed to air dry before application of the next coat. Any intermediate stoving shall be at a lower temperature than the final stoving temperature such that cure does not proceed beyond the stage that impairs intercoat adhesion.

All external angles and edges shall be ’strip coated’ by applying a thin coat before the rest of the surface is coated.

10.3.2.2 Before the final stoving takes place the lining shall be tested for continuity. If the continuity of the lined equipment meets the quality stated in IPS-C-TP-352, final stoving can proceed; if not, further coats shall be applied locally or over the whole surface until the specified standard is reached. When extra coats are applied, the final thickness shall not exceed the specified limit.

Note:

This procedure is necessary because once these materials have been cured at the final stoving temperature, it is not possible to obtain the same level of intercoat adhesion.

10.3.3 Thick layer cold curing thermosetting resins

10.3.3.1 The lining process shall be appropriate to the grade of material selected for the lining.

10.3.3.2 Cold curing thermosetting lining are applied by following methods:

- Hand laid-up mat linings
- Spray-up chopped lining
- Flake glass lining
- Troweled mortar lining

10.3.3.3 Hand laid-up mat lining consist of two to three layers of glass fiber mat laid up over a blasted primed substrate and finish off with a coat of resin (see 10.2.3). Typically, the liner is 2.5 to 3.5 mm thick and averages 20-25% glass fiber and 75-80% resin (see 10.2.4).

10.3.3.3.1 For good lining long-term lining performance, the temperature shall be limited to 60°C.

10.3.3.4 Flake glass lining

The advent of flake glass lining extended the service range to 71-82°C. It also produced a higher quality (and premium price) lining system. The glass flakes, blended with a suitable resin system selected for the service conditions. Flake glass lining shall be applied in three coats (according to manufacturer recommendation). A formulation of 0.75 to 1 mm thickness of lining used in gas and vapor service and 1.5 to 2 mm system used in severe corrosive conditions for gas, vapor and submerged areas. This last is the system that can be used in lining of large vessels and tank and flue gas desulfurization system.

Flake glass lining can not be used for structural repairs. Edges and sharp corners shall be radiused and the flake glass lining covered with a mat lining.

10.3.3.5 Troweled mortar lining

The filled resin lining stabilized with a light roving can be used in lining of sumps, trenches, concrete tanks, and vessels.

The troweled mortar lining, although providing much better abrasion resistance than a flake glass lining, does not possess the heat resistance to excursions.

Silica-filled epoxy liners can be used in lining of concrete trenches and sumps.

TABLE 12 - RESISTANCE OF VARIOUS TYPES OF THERMOSET EPOXY LININGS IN CHEMICAL ENVIRONMENTS

CORROSIVE		EPOXY AMINE CURED COATING	EPOXY ESTER COATING (NOT RECOMMENDED FOR IMMERSION)	COAL TAR EPOXY
Acids:				
Sulfuric,10%		R	LR	R
	50%	LR	NR	R
	78%	NR	NR	—
Hydrochloric,	10%	R	LR	LR
	20%	LR	LR	—
	35%	NR	NR	—
Nitric,	10%	NR	NR	—
	20% +	NR	NR	—
Phosphoric,	10%	R	R	R
	85%	NR	LR	LR
Acetic, Glacial		NR	NR	—
Fatty acids		NR	R	R
Boric acid		—	—	R
Water:				
Tap		R	R	R
Distilled		R	R	LR
Sea		R	R	R
Alkalies:				
Sodium Hydroxide,	20%	R	NR	R
	70%	R	NR	LR
Ammonium Hydroxide,	10%	LR	LR	—
Aluminum Hydroxide		—	—	R
Potassium hydroxide		—	—	R
Oxidizing Agents		NR	NR	
Fats and Oils:				
Mineral		R	R	—
Animal		R	R	—
Vegetable		R	R	—
Gases:				
Chlorine (wet)		LR	LR	LR
Ammonia		LR	R	—
Carbon Dioxide		R	R	R
Aldehydes		LR	LR	—
Amines		LR	LR	—
Solvents:				
Alcohol Ethyl and Above		R	LR	—
Aliphatic Hydrocarbons		R	R	—
Aromatic Hydrocarbons		R	R	LR
Ketones		LR	NR	—
Ethers		LR	NR	—
Esters		LR	NR	—
Chlorinated Hydrocarbons (General)		LR	NR	—
Carbon Tetrachloride		R	LR	—
Diethyl Ether		R	NR	—
Salts:				
Sodium Chloride		R	R	R
Sodium Phosphate		R	R	R
Copper Sulfate		R	R	—
Ferric Chloride		R	R	R
Wetting Agents (Ionic and Non-ionic)		R	R	—
Miscellaneous:				
Hydrogen Proxide, 30%		NR	NR	—
Sodium Hypochloride		NR	NR	—
Chromic Acid		NR	NR	—
Perchloric Acid		NR	NR	—

Code: R = Recommended; NR = Not Recommended; LR = Limited Recommendation.

TABLE 13 - RESISTANCE OF VARIOUS TYPES OF POLYURETHANE LININGS IN CHEMICAL ENVIRONMENTS (AT AMBIENT TEMPERATURE)

CHEMICALS		AIR DRY POLYURETHANE	BAKED POLYURETHANE	COAL TAR POLYURETHANE
Acids, Mineral:				
Hydrochloric,	10%	LR	LR	LR
Hydrochloric,	37%	LR	LR	—
Sulfuric,	10%	LR	LR	LR
Sulfuric,	70%	NR	LR	—
Nitric,	10%	LR	LR	—
Nitric,	70%	NR	NR	—
Phosphoric,	10%	R	R	LR
Phosphoric,	85%	LR	LR	—
Chromic,	10%	LR	R	—
Chromic,	50%	NR	LR	—
Hydrofluoric,	48%	LR	LR	—
Hypochlorous		LR	NR	—
Acids, Organic:				
Acetic,	10%	LR	R	—
Glacial Acetic		NR	NR	—
Anhydride Acetic		R	R	—
Formic		NR	LR	—
Lactic		R	R	R
Cresylic		NR	NR	—
Oleic		R	R	—
Oxalic		R	R	—
Maleic		R	R	R
Stearic		R	R	—
Benzene sulfonic		R	R	—
Fatty acids		R	R	R
2-ethyl butyric acid		R	R	—
Citric acid		—	—	R
Boric acid		—	—	R
Acid Salts:				
Aluminum sulfate		R	R	—
Ammonium chloride, nitrate, sulfate		R	R	R
Calcium chloride, nitrate, sulfate		R R	R	—
Zinc chloride, nitrate, sulfate		R	R	—
Ferric chloride		—	—	R
Magnesium chloride		—	—	R
Alkalis:				
Aluminum hydroxide		—	—	R
Ammonium hydroxide dilute		LR	R	—
Ammonium hydroxide:				
conc.		LR	R	—
Calcium hydroxide		LR	R	—
Potassium hydroxide		LR	R	LR
Sodium hydroxide,	15%	LR	LR	LR
Sodium hydroxide,	50%	LR	LR	LR
Alkaline Salts:				
Sodium bicarbonate		R	R	R
Sodium carbonate		R	R	—
Sodium sulfide		R	R	—
Sodium sulfite		R	R	R
Trisodium phosphate		R	R	R
Sodium nitrate		R	R	—
Oxidizing Agents:				
Sodium hypochlorite		NR	NR	—
Potassium-permanganate		NR	NR	—
Sodium chlorate		LR	LR	—
Hydrogen peroxide		LR	LR	—
Gasses:				
Chlorine, dry		LR	R	—
Chlorine, wet		LR	R	—
Ammonia		LR	R	—
Hydrogen sulfide		R	R	—
Carbon dioxide		—	—	R

(to be continued)

TABLE 13 (continued)

CHEMICALS	AIR DRY POLYURETHANE	BAKED POLYURETHANE	COAL TAR POLYURETHANE
Solvents:			
Ethyl acetate	NR	R	—
Butyl acetate	NR	R	—
Acetone	NR	RL	NR
Methyl ethyl ketone	NR	R	—
Methyl isobutyl ketone	NR	R	—
Cyclohexanone	NR	RL	—
Isophorone	NR	R	—
Methyl alcohol	NR	R	—
Ethyl alcohol	NR	R	—
Fatty alcohols	R	R	—
Glycols	R	R	R
Trichloroethylene	NR	R	LR
Perchlorethylene	LR	R	LR
Carbon tetrachloride	LR	R	LR
Methylene chloride	NR	LR	—
Ethylene dibromide	LR	LR	—
Toluene	R	R	LR
Benzene	R	R	—
Aromatic hydrocarbons	R	R	—
Ethyl ether	R	R	—
Aliphatic hydrocarbons	R	R	—
Gasoline	R	R	—
Jet fuel	R	R	—
Orthodichlorobenzene	R	R	—
Carbon disulfide	R	R	—
Dimethyl formamide	NR	NR	—
Turpentine	R	R	—
Xylene	—	—	LR
Other:			
Cutting oils	R	R	—
Vegetable oils	R	R	—
Lubricating oils	R	R	—
Diester lubricants	R	R	—
Stryrene monomer	R	R	—
Glycerin	R	R	—
Pyridine	NR	—	—
Detergents	R	R	—
Formaldehyde, 37%	R	R	
Distilled water	R	R	LR
Tap water	R	R	R
Salt water	R	R	LR
Condensate water	R	R	—
Fruit juices	R	R	—
Milk products	R	R	—
Phenol in alcohol	NR	LR	—
Sewage waste	R	R	—
Hydrazine	LR	—	—
Glyoxal	R	R	—
Anionic wetting agents	R	R	—
Acetonitrile	LR	R	—
Butyraldehyde	R	R	—
Monoethanolamine	LR	LR	—

Code: R = Recommended; NR = Not Recommended; LR = Limited Recommendation.

11. RUBBER LINING

11.1 General

11.1.1 The storage of corrosive or abrasive, or both, solutions or suspensions requires that the metal surface of storage tank, large pipes, or holding vessels be lined with a material that resist such action. Vulcanized rubber that is securely adhered to the tank or other metal and concrete surface imparts such resistance (see Table 8.4).

11.1.2 Rubbers are elastomeric polymers having reactive sides along their molecular chain enabling cross-linking with each other. The cross-linking process is called vulcanization. This process is induced either by heat or vulcanization agents or by a combination of both.

11.1.3 The physical and chemical properties of vulcanized rubbers vary widely according to the type of rubber used and the amount and type of filler and vulcanization agent present in the compound. Some rubbers are available both as hard rubber (ebonites) and as soft rubber. For one rubber, chemical resistance increases and abrasion resistance decreases with increasing hardness.

11.1.4 Rubber lining are generally designed for vulcanization at elevated temperature but similar rubber lining containing accelerated system capable of promoting vulcanization at ambient temperature are also available. Certain rubber lining can be applied in the form of prevulcanized sheets.

11.1.5 The minimum thickness of rubber lining shall be 4.5 mm in vessels and 3 mm in piping. Rubber shall be calendared to contain at least 4 plys for each 3 mm of thickness.

11.1.6 The adhesive system used for bonding the rubber sheet to the substrate shall depend upon the type of rubber and the method of vulcanization, and may consist of one or more individual layers. It shall be the responsibility of the applicator to select an adhesive system which will provide an adequate bond between rubber and substrate.

Notes:

1) In case where there is a likelihood of severe chemical reaction, abrasion or mechanical damage, the thickness may be increased to 6 mm or greater. When the rubber is used as a membrane under chemical-resistant brick lining, the thickness shall not be less than 5 mm. Up to these thicknesses linings are applied as one single layer except in the case of a composite build-up, i.e. soft rubber base with an ebonite top layer. Thicknesses greater than 6 mm are normally applied in two or more layers.

2) The applicator shall provide the Company with evidence of the suitability of the adhesive.

11.1.7 The application of rubber lining shall be carried out by experienced contractors.

11.1.8 Properly applied rubber lining will resist vacuum in the order of 130 m bar absolute. Shop-vulcanized rubber linings have in general a better resistance to vacuum than in-situ vulcanized ones.

11.1.9 Rubber lined equipment shall not be stored in extreme temperature conditions, such as below 0°C or above 49°C. Avoid sudden changes in temperature.

11.1.10 Rubber-lined equipment may be protected for extended periods of time by storing the tank partially filled with a diluted solution. When recommended by the rubber lining manufacturer, a 5% sulfuric acid, 5% sodium carbonate solution, or a weak salt solution make ideal storage media to help keep the lining flexible, to minimize expansion and contraction, and to keep the air (ozone) from prematurely deteriorating the lining surface. Do not permit the liquid contained within to freeze.

11.1.11 It is recommended that all rubber lined plant and equipment shall be thoroughly inspected at the end of the first year of service. If its condition is satisfactory then the inspection period can be longer than one year, but one year inspection period is preferred.

11.1.12 The temperature range capability of a particular rubber or compound lining will vary depending upon the chemical environment to which it is exposed and the composition of the rubber compound, but in no case shall exceed the maximum temperatures indicated in Table 6.

11.1.13 The designer shall specify the hardness of the lining material. The hardness shall conform to the value specified on the requisition within a tolerance of ±5°, a minimum of three readings per square meter shall be taken.

11.2 Design Aspects for Rubber Linings

11.2.1 Material selection

For the final selection of the type of rubber lining to be used and the method of application, which shall be made in conjunction with the materials specialist and the lining contractor, the following details shall be considered (see also Section 8).

11.2.1.1 Products to be handled

A full analysis shall be made of the products to be handled, including components present in trace quantities. It is imperative to state the latter as they may have a deleterious effect on the life span of the lining.

For certain services it may be important to determine whether contamination or discoloration of the material by the liner can occur.

11.2.1.2 Temperature

The temperature of the products to be handled:

- Normal operating temperature;
- maximum and minimum temperatures;
- cycle of temperature variation.

11.2.1.3 The degree of vacuum or pressure

- Normal operating pressure;
- maximum and minimum pressures;
- cycle of pressure variation.

11.2.1.4 The cycle of operations

Continuous or batch process.

11.2.1.5 Abrasion and erosion

Details of the amount, particle size and physical characteristics of suspended matter, together with flow rates.

11.2.1.6 Immersion conditions

Constant or intermittent immersion of the lining, and partially or completely filled operation.

The contractor shall be prepared to supply the specification, including a reference number for the approved rubber compound, and samples of the vulcanized rubber sheet for test and reference purposes.

11.3 Thickness of Rubber

11.3.1 Generally, the thickness of the lining should be a minimum of 3 mm. In cases where there is likelihood of severe chemical reaction, abrasion or mechanical damage, the thickness may be increased to 6 mm or greater.

When the rubber is used as a membrane under chemical-resistant brick lining, the thickness should not be less than 5 mm. Up to these thicknesses linings are applied as one single layer except in the case of a composite build-up, i.e. soft rubber base with an ebonite top layer. Generally minimum thickness shall be 4.5 mm for vessels and 3 mm for piping.

11.3.2 The thickness of the lining applied on a metallic substrate shall be determined with a suitable thickness meter and shall conform to the specified thickness within a tolerance of ±10%. A minimum of 3 measurements per square meter shall be made. The thickness of the rubber lining applied on concrete or any other non-magnetic surface shall be determined destructively.

11.4 Hardness of Rubber

11.4.1 The hardness of a rubber is a property indicative of its chemical resistance and mechanical strength. In general for one rubber composition the chemical resistance increase and the mechanical properties (e.g. abrasion resistance) decreases with increasing hardness (see Table 8.4).

11.4.2 The hardness is determined by measuring the penetration of a specified indentor under a certain load. Various types of indentores and loads are used. In general, it is common to express hardness in Durometer A or Durometer D readings in accordance with ASTM D 2240.

11.4.3 A chart giving an approximate comparison of hardness values as measured with different instruments is given in Appendix C.

11.4.4 Typical values for the different rubbers used for lining purposes are:

Hard NR	rubber	60°	Type	D	shore	durometer
Soft NR	rubber	50°	Type	A	shore	durometer
SBR	rubber	50°	Type	A	shore	durometer
CR	rubber	60°	Type	A	shore	durometer
IIR	rubber	60°	Type	A	shore	durometer
NBR	rubber	80°	Type	A	shore	durometer
CSM	rubber	80°	Type	A	shore	durometer
FKM	rubber	80°	Type	A	shore	durometer
Ebonites		80°	Type	D	shore	durometer

11.5 Application of Rubber Liners

Application of rubber liners, requirements and inspection of the works shall be in accordance with IPS-C-TP-352.

12. GLASS AND PORCELAIN LINING

12.1 Glass Lining (Vitreous Enameling)

12.1.1 General

12.1.1.1 Glass lining are used for protection of ferrous metals equipment such as reactors, storage tanks, pipes and valves in against corrosive environments.

12.1.1.2 Their resistance to strong alkalis is dependent on temperature (see Table 14). At room temperature practically any alkaline concentration may be safety handled. At the boiling point, concentration having a pH value between 10 to 12 will cause glass etching, and for this reason are not recommended.

12.1.1.3 The glass lining shall only be used for metals (ferrous metals aluminum).

12.1.1.4 Carbon steel (ASTM-A-285-Grade A and B), high-tensile steel, cast iron, stainless steel (Type 430) can be glassed successfully. Items made of cast steel do not glass well.

12.1.1.5 There are two types of glasses which have the high universal corrosion resistance required by the chemical industry:

a) High silica glass, while being the most acid resistant glass, is very difficult to apply to steel.
b) Borosilicate glass, is the type used in coating most vessels and equipment for severe chemical service.

12.1.1.6 Borosilicate glasses are combination of metal oxides, which shall be dry mixed and fused at 1370°C and then shall be chilled suddenly. Glass in this quenched condition is known as "frit". The glass frit is prepared for use in production in two forms: "slip and dust". In spraying and slushing method of application glass lining slip form of glass frit and in hot-dusting method dust form of glass frit shall be used.

12.1.1.7 For more information on production of glass for glass lining see NACE Publication 6 H 160.

TABLE 14 - CORROSION RESISTANCE OF GLASSED STEEL TO ALKALINE MEDIA

ALKALI	CONCENTRATION PERCENT	TEMPERATURE, °C	LIQUID PHASE CORROSION RATE, μm PER YEAR
NaOH	1	21 65 100	25 125 1600
	5	21 65 100	25 250 4025
	10	21 65 100	25 250 4375
	20	21 65 100	25 550 5100
Na_3PO_4	1	21 65 100	25 175 1000
	5	21 65 100	25 225 2350
	10	21 65 100	25 150 2350
	20	21 65 100	25 175 1975
Na_2CO_3	1	21 65 100	25 100 450
	5	21 65 100	25 100 725
	10	21 65 100	25 100 100
	20	21 65 100	25 125 1325

12.1.2 Glass lining thickness

12.1.2.1 The thickness of glass lining shall be selected based on duty for which it is intended and with reference to the following general types of glassed steel substrate. The types are:

a) High voltage tested glass lining or alkali-borosilicate (Thickness of 1 to 2 mm) for very severe corrosive service.

b) Low voltage tested glass lining (Thickness 0.3 to 1.25 mm) for mild corrosive service.

c) Visual tested glass lining (0.38 to 0.63 mm), shall not be used for corrosive environment but is used in handling stored materials.

12.1.2.2 The upper and lower limits of thickness for water heaters shall be 0.15 and 0.4 mm where local increases in thickness are technically unavoidable, they shall be of limited extent. The lining thickness shall nowhere be greater than 1 mm.

12.1.3 Application of glass lining

Application of glass lining shall be in accordance with IPS-C-TP-352.

12.2 Porcelain lining

12.2.1 Porcelain enamels are glassy inorganic coating that are applied primarily to fabricated sheet steel, cast iron, or aluminum parts to improve appearance and to protect the metal surface. For standard specification of steel sheet for porcelain lining see ASTM-A-424-80.

12.2.2 Alkali resistant, acid resistant, hot water resistant and regular blue-black enamels are four types of porcelain enamel materials that are used to protect the metal surface in corrosive environments.

12.2.3 In porcelain enamels for application to most metals silica, alumina and the oxides of boron, sodium, magnesium, calcium and potassium are the basic ingredients.

The raw material fused at a temperature above 420°C and then chilled to produce frits. The porcelain frit is prepared in two forms of slip and dust.

12.2.4 The optimum thickness of porcelain enamel depends on the substrate metal and the service requirements of the part (see Table 15).

TABLE 15 - THE FIRED PORCELAIN ENAMEL THICKNESS

TYPE OF METALS	THICKNESS mm
Aluminum	0.065 - 0.125
Sheet steel	0.1 - 0.225
Cast iron	1 - 1.78

12.2.5 Normally, porcelain enamels are selected for products or components where there is a need for one or more of the special service requirements that porcelain enamel can provide, such as chemical resistance, corrosion, protection, weather resistance, specific mechanical or electrical properties, and thermal shock capability. Porcelain enamels are used for lining of chemical reactors, heat exchangers, induction heating coils, jet engine components and transformer cases. In selection of porcelain lining the provisions of section 8 shall be considered.

12.2.6 Preparation prior to porcelain enamelling and lining application are the same as glass lining (see IPS-C-TP 352). The porcelain enamels shall be fired in 1010°C.

12.2.7 The hard surfaces of enamel coatings have low coefficients of friction and are highly resistant to abrasion, rating 3½ to 6 on Moh's scale (see Note) of mineral hardness. Being smooth and impervious to absorption, they minimize product adhesion and clean readily. Porcelain enamels are essentially glassy and are electrically non-conductors with dielectric strength in the range from 100 to 450 volts per 0.025 mm depending upon composition.

Note:

Mohs' scale: A scale of hardness for minerals in which 1 represents the hardness of talc; 2, gypsum; 3, calcite; 4, fluorite; 5, apatite; 6, orthoclase; 7, vitreous pure silica; 8, quartz; 9, topaz; 10, garnet; 11, fused zirconium oxide; 12, fused alumina; 13, silicon carbide; 14, boron carbide; and 15, diamond.

13. CERAMIC LINING

13.1 General

13.1.1 Ceramic coating and lining, by strict definition, are "super porcelains" based on silicates and oxides. However, by extension, high-temperature coating based on carbides, silicides, borides, nitrides, cermets and some other inorganic materials also have come to be referred to as ceramic coatings and linings (see 13.2).

13.1.2 Ceramic coatings and linings are applied to metals, concrete and brick surfaces to protect them against oxidation, corrosion and erosion at room and at elevated temperatures. Special coatings and linings have been developed for specific uses, such as wear, chemical resistance, and prevention of hydrogen diffusion. Some of the application in which ceramic coated metals are employed are furnace components, heat treating equipment, chemical-processing equipments and heat exchangers.

13.1.3 Ceramic lining can be applied in two systems; single layer and dual layer system over metallic, concrete, and brick substrate.

13.1.3.1 Single-layer lining consist of a layer of castable or gunitable ceramic with or without an anchoring system.

13.1.3.2 Single layer of ceramic lining shall be used only on metallic surfaces for specific uses such as wear, chemical resistance, and electrical resistance in heat treating equipment and chemical processing equipment.

13.1.3.3 Dual lining consist of a layer of membrane, protected by a surface layer of erosion resistant castable ceramic. The surface layer may be supported by either Y or V-studs or retained in hex mesh supported by 50 mm, square washers and studs (see Fig. 14).

13.1.3.4 Dual system is used for lining of both steel and concrete equipments. Membrane choices include asphaltics, resins and synthetic elastomers (see Clause 14.2.2).

13.1.3.5 Dual system of ceramic lining shall be used for storage of sodium chlorate ($NaClO_3$), hot HCl acid, titanium dioxide (TiO_2) slurry, ethylbenzene, aluminum chloride and benzene.

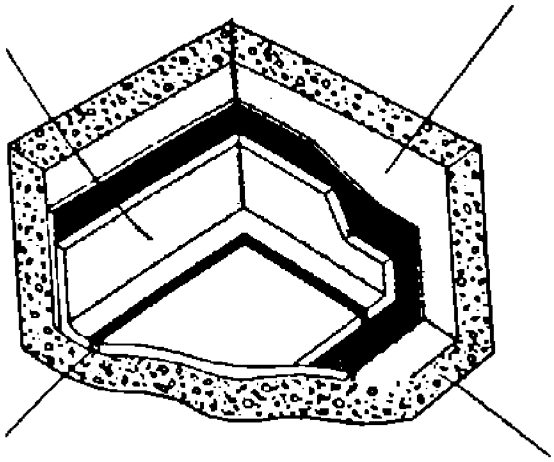


Fig. 14

Schematic of a chemical-resistant dual-lining system that provides double protection to the substrate in the form of a flexible membrane and a rigid surface layer. The flexible corrosion-resistant membrane is applied in direct contact with steel or concrete substrates. It is then covered by the monolithic ceramic lining, which provides protection over a broad pH range as well as against high temperatures.

13.2 Ceramic Lining Thickness

13.2.1 The thickness of ceramic linings are depended on types of material and methods of lining.

13.2.2 Silicate linings are applied by spray, brushing and dipping at the usual thickness of 0.02 - 0.12 mm, and with reinforcement up to 25 mm thickness.

13.2.3 Oxides linings are applied at the usual thickness of 0.04 to 6 mm, and with reinforcement up to 25 mm thickness.

13.2.4 Carbides linings are applied at the usual thickness of 0.04 to 0.3 mm.

13.2.5 Silicides linings are applied in thicknesses of 0.0.1 to 0.1 mm.

13.2.6 Phosphate-bonded linings are applied with reinforcement up to 50 mm thickness.

13.2.7 Cermets linings are applied in thicknesses of 0.02 to 0.7 mm.

13.3 Application of Ceramic Lining

Application of ceramic lining shall be in accordance with IPS-C-TP-352.

14. CHEMICAL-RESISTANT BRICK AND TILE LINING

14.1 General

14.1.1 A chemical-resistant brick lining is used for the internal protection of steel and concrete types of process vessels, columns, tanks, trenches, etc.

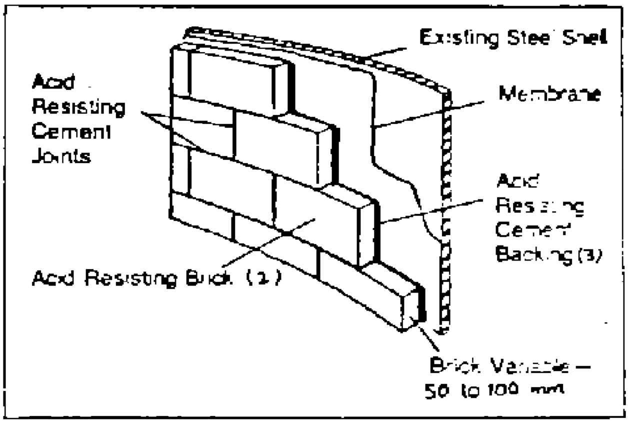
It is a multilayer system supported by a shell to provide rigidity and strength and, generally, consists of:

1) An impervious membrane to prevent the corrosive medium reaching the shell; and,
2) one or more layers of chemical-resistant brick and tile, laid in a chemical-resistant cement;
3) see Clause 14-2 and Fig. 15.

For more information about acid proof vessel with membrane and brick lining see NACE publication 6 K 157.

14.1.2 Brick-lined equipment should be installed such that a complete inspection of the outer surface is always possible. Flat bottom steel vessels shall therefore be supported on beams so that an inspection of the bottom can be made.

14.1.3 Chemical-resistant lining shall be regularly inspected for defects. The main defects are spalling of the bricks or tiles, erosion effects, cracks in the lining and degradation of chemical-resistant lining materials.



CHEMICAL - RESISTANCE BRICK AND TILE LINING
Fig. 15

14.1.4 When a defect is detected, repairs shall be carried immediately in order to prevent serious attack to the concrete or steel substrate.

14.1.5 The brick lining shall be carefully treated and protected against damage by traffic loads, impact and impermissible local chemical and thermal attack (steam, leaking flanges, etc.).

14.2 Type of Brick Lining

14.2.1 Chemical-resistant brick lining is a multilayer system consist of following layers:

- Impervious membrane (14.2.2)
- Chemical-resistant cement (14.2.3)
- Layer of brick or tile (14.2.4)

14.2.2 Impervious membrane

14.2.2.1 It is almost always desirable to use a continuous and impervious membrane lining between the vessel shell and the chemical-resistant brick. This will protect the vessel shell from chemical attack by the solution which permeates the brick lining through pores or cracks. Materials which employed for this purpose are sheet elastomers and plastics and also coatings that vary in thickness and chemical resistance properties (see Table 17).

14.2.2.2 It is desirable to provide brickwork sufficiently thick to hold membrane temperatures to about 65°C maximum.

14.2.2.3 When there is no suitable impervious membrane available, even for moderate corrosion and temperature conditions behind the brick lining, a brick lining shall only be selected when there is convincing evidence that a crack-free lining can be applied and maintained e.g. by pre-stressing the brick lining (see Note).

Note:

The heating and pressing of brick lined equipment before the cement is fully cured, known as pre-stressing. In this case joint cement will cure in the expanded condition and will not contract on cooling down.

14.2.2.4 For compatibility of some membranes with substrate material see Table 16.

TABLE 16 - COMPATIBILITY OF MEMBRANE WITH SUBSTRATE MATERIAL

SURFACE TO BE LINED	MEMBRANE					
	Hard & Soft rubber	Poly-isobutylene	Reinforced epoxy	Poly-urethane	Lead (Sheet and Melted)	Asphaltic Bitumen
Concrete	—	×	×	×		×
Steel	×	×	×	—	×	—

× = Can be used,
— = Shall not be used.

TABLE 17 - MEMBRANES FOR USE WITH BRICK LININGS

CORRODENT	Soft Natural Rubber 24°C	Soft Natural Rubber 65°C	Neoprene 24°C	Neoprene 65°C	Plasticized Polyvinyl Chloride 24°C	Plasticized Polyvinyl Chloride 65°C	Asphaltics 24°C	Asphaltics 65°C	Lead 24°C	Lead 65°C
ACIDS—										
Acetic, 10%	F	P	F	P	F	P	P	P	P	P
Acetic, glacial	P	P	P	P	P	P	P	P	F	P
Benzene sulfonic 10%	E	E	G	F	E	E	E	E	G	F
Benzoic, sat'd.	E	E	E	E	E	E	E	E	P	P
Boric, sat'd	E	E	E	E	E	E	E	E	G	G
Butyric 100%	F	P	F	P	P	P	P	P	P	P
Chloroacetic 10%	P	P	F	P	F	P	P	P	P	P
Chromic, 5%	P	P	P	P	E	F	G	F	E	E
Chromic, 10%	P	P	P	P	G	F	G	F	E	E
Citric 10%	E	E	E	E	E	E	E	E	E	E
Fatty Acids (C6 and up) 100%	P	P	F	P	G	F	P	P	G	G
Fluosilicic, 40%	E	E	G	G	E	E	P	P		
Formic, 90%	G	F	G	F	F	P	F	P	F	P
Hydrobromic, 48%	G	F	F	P	E	F	E	G	P	P
Hydrochloric, 37%	E	G	F	P	E	F	E	E	P	P
Hydrocyanic, 25%	G	G	E	E	E	E	E	E	G	F
Hydrofluoric, 40%	G	F	G	F	E	P	F	F	F	P
Hypochlorous, 10%	E	G	P	P	E	P	P	P	P	P
Lactic 25%	E	E	E	E	E	E	E	E	P	P
Maleic 25%	G	G	G	F	G	F	G	F	P	P
Nitric 5%	P	P	F	P	E	E	G	G	P	P
Nitric, 10%	P	P	F	P	E	E	G	G	P	P
Nitric, 20%	P	P	F	P	E	F	G	F	P	P
Oleic, 100%	F	P	F	P	E	F	F	P	P	P
Oxalic 20%	G	G	G	G	E	F	E	E	P	P
Perchloric 10%	G	F	G	F	E	P				
Phosphoric 85%	E	E	E	E	E	E	E	E	E	G
Picric 10%	F	P	F	P	P	P	P	P	G	G
Stearic 100%	F	P	F	F	E	F	F	P	G	F
Sulfuric 50%	E	E	E	E	E	E	E	E	E	E
Sulfuric 70%	F	P	F	P	E	P	F	P	E	E
Sulfuric, 93%	P	P	P	P	P	P	P	P	G	P
Oleum (110% Sulfuric)	P	P	P	P	P	P	P	P	P	P
ALKALIES—										
Ammonium hydroxide 28%	G	G	G	G	E	F	G	F	G	F
Calcium hydroxide, sat'd.	E	E	G	G	E	F	G	F	G	F
Potassium hydroxide 25%	E	E	E	E	E	G	G	F	G	F
Sodium hydroxide, 25%	E	E	E	E	E	G	G	F	G	F
ACID SALTS—										
Alum 10%	E	E	E	E	E	E	E	E	E	E
Ammonium chloride, nitrate, sulfate	E	E	E	E	E	E	E	E	G	F
Copper chloride, nitrate sulfate	E	E	E	E	E	E	E	E	E	E
Ferric chloride, nitrate sulfate 10%	E	E	E	E	E	E	E	E	F	P
Nickel chloride, sulfate 10%	E	E	E	E	E	E	E	E	E	G
Stannic chloride, 100%	E	E	G	F	E	E	E	E	G	F
Zinc chloride, nitrate, sulfate, 10%	E	E	E	E	E	E	E	E	G	F
ALKALINE SALTS—										
Barium sulfide	E	E	E	E	E	E	F	P	E	F
Sodium bicarbonate, 10%	E	E	E	E	E	E	E	E	E	E
Sodium carbonate, 10%	E	E	E	E	E	E	G	F	E	E
Sodium sulfide	E	E	E	E	E	E	F	F	G	G
Trisodium phosphate 10%	E	E	E	E	E	E	P	P	P	P
NEUTRAL SALTS—										
Calcium chloride, nitrate, 10%	E	E	E	E	E	E	E	E	G	F
Magnesium chloride, nitrate, sulfate, 10%	E	E	E	E	E	E	E	E	G	F
Potassium chloride, nitrate, sulfate, 10%	E	E	E	E	E	E	E	E	G	F
Sodium chloride, nitrate, sulfate, 10%	E	E	E	E	E	E	E	E	G	G
GASES—										
Chlorine, dry	G	F	P	P	E	F	E	E	E	E
Chlorine, wet	P	P	P	P	E	F	E	F	G	G
Hydrogen sulfide	G	F	E	E	E	E	E	E	E	G
Sulfur dioxide, dry	G	F	E	E	E	E	E	E	E	G
Sulfur dioxide, wet	E	E	E	E	E	G	E	E	E	G
ORGANIC MATERIALS—										
Acetone 100%	G	F	G	F	P	P	P	P	E	E
Alcohol, methyl, ethyl 95%	E	E	E	E	E	F	E	E	E	E
Aniline	F	P	F	P	P	P	P	P	E	E
Benzene	P	P	P	P	P	P	P	P	E	E
Carbon tetrachloride	P	P	P	P	P	P	P	P	G	G
Chloroform	P	P	P	P	P	P	P	P	G	G
Ethyl acetate	P	P	P	P	P	P	P	P	E	E
Ethylene dichloride	P	P	P	P	P	P	P	P	E	E
Formaldehyde, 37%	P	P	G	P	G	E	F	F	P	P
Phenol 5%					P	P	P	P	E	G
Trichloroethylene	P	P	P	P	P	P	P	P	G	G
BLEACH SOLUTIONS—										
Chloride dioxide acid solutions	P	P	P	P	E	E	P	P	F	P
Chlorine dioxide neutral solutions	P	P	P	P	E	E	P	P	P	P
Chlorine dioxide alkaline to pH 11	P	P	P	P	E	E	P	P	P	P
Sodium hypochlorite acid neutral or alkaline to pH 11 (8% sol.)	P	P	P	P	E	P	P	P	P	P
Sodium hypochlorite above pH 11, (8% sol.)	P	P	P	P	E	P	P	P	P	P

Resistance to corrosives at two temperature levels at surface of membrane behind brick Legend:

- E excellent.
- G good, occasionally used.
- F fair, for limited service only.
- P poor, not recommended.

14.2.3 Chemical-resistant cement layer

14.2.3.1 Description

Silicate-based cements or synthetic resin-based cements are used to cement the bricks (see Table 17). The chemical resistance of these cement is not as universal as that of the bricks, so that careful selection with respect to chemical resistance is required (see Table 18).

Sometimes it will also be necessary to consider the erosion resistance of the cement. Hydraulic cements shall not be used for chemical-resistant brick lining for process equipment. Some chemical-resistant cements can also be used as membrane (see Table 19).

14.2.3.2 Silicate-based cements

Silicate-based cement are two component systems. They consist of a sodium or potassium silicate solution mixed with inert fillers e.g. quartz flour.

Silicate-based cements do not have much resistance to erosion especially in hot water, steam, and alkali service where washing out of the cement from the joints may occur. The use of resin-based cements for these condition has to be considered.

Silicate-based cements shall not be used as a membrane (see Table 19) and also they do not adhere to rubber membrane.

14.2.3.3 Phenol-furfuraldehyde cement

These cements consist of phenol-formaldehyde resin and furane derivates with an inert filler. The cements are supplied as two components, a syrup (the resin solution) and an inert powder (containing also a part of the reactive agent), which shall be mixed thoroughly and immediately before use.

In cases where resistance to hydrofluoric acid is required, graphite is used as a filler instead of sand or barytes. They are erosion-resistance and free of pores when properly applied.

When it is used as a membrane, before applying the cement directly on to steel or concrete the surface must be coated by a suitable primer.

14.2.3.4 Furane cements

They are supplied as two components, a powder and a syrup, which gives a cement of excellent adhesive qualities when mixed correctly. The syrup cures to hard solid resin with the addition of suitable catalysts.

Furane-cement have a good chemical resistance (see Table 18). If a filler such as graphite is added, resistance to hydrofluoric acid is obtained.

Furane-cements are erosion resistant and free of pores, when properly applied.

14.2.3.5 Polyester cements

Cements based on (unsaturated) polyester resin are supplied in two or more components. The components (liquid resin, catalyst, accelerator, filler, etc.) are mixed immediately before use. The addition of inert fillers, such as graphite, to the cement extends its resistance even to hydrofluoric acid and its resistance to alkalis becomes greater (see Table 18). They posses good erosion resistance.

14.2.3.6 Epoxy-cements

Cements based on epoxy resin are supplied in two or more components (liquid resin, cold curing agent, filler or fiber-glass reinforcement, etc.). Curing starts immediately after mixing. Epoxy cements have the very good adhesion to metallic and concrete substrate. In metallic process equipment they can be used as a membrane, if necessary, with glass-fiber reinforcement. When applied on a concrete substrate, no prior treatment, other than proper surface cleaning is necessary (see IPS-C-TP-101).

If a filler such as graphite is added, resistance of hydrofluoric acid is obtained. Epoxy-cements with glass-fiber reinforcement can be used for marine steel structures specially for splash zone (see NACE Standards)

14.2.3.7 Phenolic cements (phenol-formaldehyde cements)

Phenolic cements is prepared by combining the liquid phenolic formaldehyde resin suitably modified with an acid containing filler like carbon or silica. The mixing ratio is about two to one powder-to-liquid for the carbon filled and 2½ to one for the silica-filled cements. The chemical resistance of phenolic cement is shown in Table 18.

14.2.3.8 Sulfur cements

Plasticized sulfur cements essentially are mixture of sulfur and inert fillers with minor amount of plastisizer. Sulfur cements are applied as hot melt materials. The major advantages of sulfur cements over the resin cements are lower cost. They can be used with silica or carbon fillers.

TABLE 18 - RESISTANCE OF RESIN-CEMENTS IN CHEMICAL ENVIRONMENT

CORROSION MEDIA	RESISTANCE OF RESINS - CEMENT					Silicate
	Furan	Phenolic	Polyester	Epoxy	Sulfur	Cement
Acids:						
Acetic, dilute	R	R	LR	R	R	R
Acetic, glacial	R	LR	NR	NR	LR	R
Chromic	NR	LR	LR	NR	R	R
Citric	R	R	—	R	R	R
Fatty acids	R	R	R	R	LR	R
Hydrochloric	R	R	R	R	R	R
Hydrofluoric	R	R	LR	R	R	NR
	(with carbon	(with carbon		(carbon		
Hypochlorous	filler)	filler)	R	filled)	NR	R
Nitric	LR	LR	—	NR	—	R
Nitric, 2%	NR	—	LR	NR	R	R
Nitric, over 2%	—	—	NR	—	—	R
Nitric, over 5%	—	—	—	—	LR	R
Nitric, under 5%	—	NR	—	—	R	R
Phosphoric	—	LR	R	—	R	R
Sulfuric, 50%	R	R	R	R	R	R
Sulfuric, 80%	R	R	NR	R	LR	R
Sulfuric, concentrated	LR	LR	NR	NR	NR	
	NR	NR		NR		
Alkalis:						
Ammonium hydroxide			NR		NR	NR
Calcium hydroxide	R	NR	NR	R	NR	NR
Sodium hydroxide, 1%	R	LR	NR	R	NR	NR
	R	NR		R		
				(carbon filled preferred)		

(to be continued)

TABLE 18 (continued)

Sodium hydroxide, 10%	LR*	NR	NR	R"	NR	NR
Sodium hydroxide, 25%	LR*	NR	NR	R"	NR	NR
Gases:						
Chlorine	NR	LR	LR	NR	NR	R
Bromine	NR	NR	LR	NR	—	—
Sulfur Dioxide	R	R	R	R	R	R
Hydrogen sulfide	R	R	R	R	R	R
Oils:						
Animal	R	R	R	R	—	—
Vegetable	R	R	R	R	—	—
Mineral	R	R	R	R	—	—
Oxidizing Agents:						
Hydrogen peroxide	—	—	R	LR	—	—
Hydrogen peroxide, 3%	R	LR	—	—	—	—
Bleach	LR	—	—	NR	—	—
Acid bleach	—	LR	R	—	—	—
Alkaline bleach	—	NR	LR	—	—	—
Perchloric acid,10%	R**	R**	R**	R**	R	R
Concentrated oxidizing agents, all types	NR	NR	NR	NR	NR	NR
Chlorine solutions	LR	LR	R	NR	NR	R
Chlorine dioxide solutions	NR	NR	R	NR	NR	R
Salts:						
Alum	R	R	R	R	R	R
Copper sulfate	R	R	R	R	LR	R
Ferric salts	R	R	R	R	R	R
Magnesium sulfate	R	R	R	R	R	R
Potassium permanganate	R	R	R	R	—	—
Silver nitrate	R	R	R	R	—	—
Sodium bisulfite	R	R	R	R	—	—
Sodium carbonate	R	LR	LR	R	LR	NR
Sodium chloride	R	R	R	R	R	R
Sodium hypochlorite	LR	NR	LR	NR	NR	NR
Sodium nitrate	R	R	R	R	R	R
Sodium sulfate	R	R	R	R	R	R
Sodium sulfite	R	R	R	R	LR	NR
Solvents:						
Alcohols	R	R	R	R	R	R
Glycols and glycerin	R	R	R	R	—	—
Acetone	R	R	NR	LR	NR	R
Aniline	NR	NR	NR	LR	NR	R
Methylene chloride	NR	NR	NR	LR	—	—
Carbon tetrachloride	R	R	LR	LR	NR	R
Chloroform	R	R	LR	LR	NR	R
Ethyl acetate	R	R	NR	R	NR	R
Gasoline	R	R	R	R	—	—

*** For caustic alkali service, carbon filled mortars should be used. In the lower range of temperatures, chemical resistance is usually quite satisfactory but at high temperatures mortars of different brands vary in caustic alkali resistance and simulated field test should be made.**

**** Handling of perchloric acid in organic materials is hazardous. Dangers of explosion will ordinarily be basis for rejection of resin mortars.**

Code: R = Recommended; NR = Not Recommended; LR = Limited Recommendation.

TABLE 19 - PURPOSE OF CHEMICAL RESISTANT CEMENT IN BRICK LINING

PURPOSE	CHEMICAL RESISTANT CEMENT						
	SILICATE BASE CEMENT	PHENOLIC FURFUR-ALDEHYDE CEMENT	FURAN CEMENT	REINFORCED EPOXY CEMENT	PHENOL FORM-ALDEHYDE CEMENT	SULFUR CEMENT	POLYESTER CEMENT
Joint	×	×	×	×	×	×	×
Membrane	—	×	—	×	×	—	—

× = Can be used,
— = Shall not be used.

14.2.4 Brick and tile layer

14.2.4.1 There are several types of chemical resistant brick and tiles, can be used for lining of steel and concrete equipments (see Table 8.1).

14.2.4.2 Most brick and tile materials have good resistance to organic chemicals, so that the resistance to inorganic chemicals often determines the final selection.

14.2.4.3 Porous bricks offer low resistance to penetration of liquids and/or gases. They have high thermal conductivity and good thermal shock resistance. Porosity needs to be considered, particularly in the case of crystallizing liquids where there is a potential danger of volume change destroying the brick.

Dense bricks resist penetration of liquids. Thermal conductivity is low, so high thermal gradients can occur in the brick and temperature shock(s) will lead to thermal spalling.

14.2.4.4 Erosion resistance of the bricks and tiles also need to be considered at times.

14.2.4.5 The bricks and tiles shall have a roughened surface and shall not be glazed, which will ensure good adhesion to the cement.

14.2.4.6 Arched bricks are required when the width of the side joint at the back of the standard brick would be greater than 1.5 times the joint width at the front of the standard brick.

14.2.4.7 Console bricks are sometimes used in the inner course of bricks to support internals.

14.2.4.8 Temperature drop through the brick in a lined steel tank depends on the temperature gradient between the atmosphere and the process temperature and the total thickness of the brick lining. This is subject to calculation. A rule of thumb allowance of (3.2°C per 10 mm) 8.5°C per 25 mm of thickness of fire clay or shale type bricks and (2.2°C per 10 mm) 5.5°C per 25 mm of thickness carbon brick has been found adequate for design purposes for process temperatures up to about 200°C. Temperature drop through the brick in a lined concrete tank will be somewhat less due to the insulting effect of the concrete shell. In almost all instances total thickness of brick used shall be sufficient to limit temperature at the membrane lining interface to 65°C maximum. In some services even lower temperatures may be desirable.

14.3 Thickness of the brick lining

14.3.1 The thickness of the brick lining is determined by the number of layers of bricks, by the dimensions of the brick and by the lay of the brick within the layer. When the brick lining functions as a heat barrier, the minimum thickness is determined either by the maximum permissible membrane temperature, (see Table 20) or by the steel wall temperature (maximum 100°C), or by the maximum temperature gradient of the brick.

14.3.2 Too thin a lining may crack open and tear away, because of high stresses due to internal pressure and thermal gradient, even when cements with swelling properties are used.

14.3.3 Too thick a lining may result in spalling and crushing of the weaker adjacent layer, because of high thermal and tensile stresses.

14.3.4 In general, a lining will comprise two layers of bricks staggered, the layers over-lapping both horizontally and vertically.

This arrangement is suitable for severe corrosive conditions, although for 90°C hydrochloric acid service good results have been obtained with one layer of bricks laid radially. At higher temperatures this may cause spalling.

TABLE 20 - THICKNESS AND MAXIMUM TEMPERATURE WORKING OF BRICK LINING MATERIAL

LAYERS	THICKNESS OF LINING mm	max. TEMP. °C
Carbon steel vessel wall	10	100
Hard natural rubber (80°C shore D)	5	80
Soft natural rubber (65°C shore A)	5	80
Butyl rubber	5	110
Polyisobutylene	3	70
Glass-fiber reinforced epoxy	4	130
Lead	6	70
Silicate-based cement	5-10	900
Synthetic-resin-based cement	5-10	180
Acid-resistant brick (normally applied)	65	65
Carbon brick (unimpregnated)	40	200
Porcelain tile	40	65

15. REFRACTORY LINING

15.1 Refractory bricks and shapes lining

15.1.1 General

Application of brick refractories shall be for refractory lining of floors and burner areas of boilers furnaces and where refractory concrete lining alone are unsuitable. Refractory brick lining are normally used in conjunction with refractory concrete lining (see Clause 15.2).

15.1.2 Materials

15.1.2.1 Refractory brick and tile classification shall be as follows:

a) High alumina fire brick containing more than 50% wt alumina (see ASTM C 27).
b) Insulating fire brick containing 50% wt alumina or less (see ASTM C 155).

15.1.2.2 Bricks shall have their flat surfaces true to within the following limits:

a) Concavity: Not more than 3 mm in 30 cm and prorata.
b) Convexity: Not more than 1.5 mm in 30 cm and prorata.

15.1.3 Dimension

The dimensions of brick shall be specified by the Purchaser. The bricks shall not depart from the stated dimension by more than 2%.

15.1.4 Application

Application of refractory brick lining shall be in accordance with chemical resistance brick lining (see IPS-C-TP-352).

15.2 Refractory Concrete Lining

15.2.1 General

15.2.1.1 Refractory concrete lining are used for lining of radiant and convection Sections of furnace, waste heat boilers, flue ducts and steel stacks.

15.2.1.2 Refractory materials shall not be applied in freezing or excessively hot weather unless precautions are taken to maintain refractory, steel and mixing equipment at as close to an ambient temperature of 15°C as possible during mixing, application, and for a minimum of 24 hours thereafter. No admixture of any kind, nor live steam shall be used for this purpose.

15.2.1.3 Vessel is to be lined in erected position in the field.

15.2.1.4 Only personnel who are thoroughly familiar and experienced in application of refractory shall be employed in application of lining. Skilled tradesmen such as brick layers and nozzle operators shall have at least one year’s previous experience of such work on jobs of a similar nature.

15.2.2 Types of refractory concrete and usage

15.2.2.1 Refractory concrete lining material consists of a mixture of calcium aluminate cement and light-weight aggregates. It shall be supplied by the manufacturer as a dry mix. After the addition of water, it shall be suitable for application by gunning or casting in the same way as ordinary concrete.

15.2.2.2 Two type of refractory concrete materials are used for lining of heating equipment.

15.2.2.2.1 Light-weight (LW) concrete

Lw concrete shall be a mixture of calcium aluminate cement with aggregates e.g. perlite, vermiculite, blast-furnace slag, clay, diatomite, fly ash, shale or slate. Lw refractory concrete shall be used as a lining material for radiant Sections and convection sections of furnaces and waste heat boilers-except as stated otherwise by the Company and also for "hot" flue ducts, e.g. ducts between radiant section and convection Sections of furnaces/waste heat boilers.

15.2.2.2.2 Medium-weight (MW) concrete

Mw refractory concrete shall be a mixture of calcium aluminate cement with aggregates e.g. blast-furnace slag, clay, diatomite, fly ash, shale or slate.

It shall be used as a lining material for furnace header boxes and "cold" flue ducts, e.g. for ducts from convection Sections of waste heat boilers to the stack, for steel stacks and for convection Sections of furnaces and waste heat boilers where shot cleaning will be applied.

15.2.2.3 The water to be added to the dry mix shall be clean, cool and potable. During cold weather the water temperature shall not be less than 5°C.

15.2.2.3.1 Refractory concrete for lining of steel walls shall be applied with use of anchors. Anchoring of lining to furnace floors is not necessary, except for protruding parts.

15.2.3 Thickness of lining

15.2.3.1 Refractory cement lining should preferably be not thicker than 200 mm nor thinner than 40 mm.

15.2.3.2 Minimum thickness of castable refractories in convection Section of fired heaters shall be 75 mm (3"). The tolerance of lining thickness shall be ±5 mm.

15.2.4 Application of lining

Refractory concrete lining is applied by gunning or casting methods. The application methods, requirements and inspection of works shall be in accordance with IPS-C-TP-352.

16. CEMENT-MORTAR LINING

16.1 General

16.1.1 Cement-mortar lining is mainly used for lining of steel, ductile-iron and cast-iron pipe and tubing for shielding the steel from chemical corrosive attack encountered in the handling of water and oil field brines and the like. It is intended for lining of new and old pipes and fittings.

16.1.2 Cement-mortar-lined and cement-mortar-coated steel pipe combines the physical strength of steel with the protective qualities of cement mortar. The lining, applied centrifugally, creates a smooth, dense finish that protects the pipe from tuberculation and provides a measure of corrosion protection. The smooth interior surface provides a high flow coefficient, which is maintained for a long period of time. In addition, the cementmortar coating results in a tough, durable, and rugged coating that forms an alkaline environment where oxidation or corrosion of the steel is inhibited.

16.1.3 The user is cautioned that soft, aggressive waters, as well as prolonged contact with heavily chlorinated water, may be injurious to cement-mortar linings. When this environment is anticipated, further studies may be necessary to determine the suitability of this type of lining.

16.2 Materials

16.2.1 Cement meeting the requirements of ASTM-C-150 Type I or II (Portland cement) is required for the lining pipes and fittings carrying water but cement conferring to ASTM-C-150 Type III (high sulfate resistant (HRS) similar to API-RP 10E with zero tricalcium aluminate (C3A) should be used for lining oil field pipe and tubing. This cement is suitable for exposure to corrosive waters, regardless of the soluble sulfate concentration.

16.2.2 When API Class C (API specification 10) cement with zero C3A is unavailable, other cements as follow may be used, but only upon specific approval by the Company.

16.2.2.1 Moderate sulfate resistant (MSR) cements (having less than 8 percent C3A) may be used when the corrosive fluid contains less than 1000 ppm soluble sulfates. These may be either API Class B (MSR) or Class C (MSR) cement.

16.2.2.2 High sulfate resistant (HSR) cements (having less than 3 percent C3A) shall always be used when the corrosive water contains 1000 ppm or higher soluble sulfates. These may be either API Class B (HSR) or Class C (HSR) cement.

16.2.3 The Purchaser of cement lined pipe may be require the applicator to furnish a written statement of the chemical composition of the cement for the Purchaser's approval. Similarly, the applicator may require the cement manufacturer to furnish a written statement of the chemical composition of the cement for the approval by the applicator or by the Purchaser of the cement lined pipe. The method for determining the C3A content of the cement selected should be by mutual agreement among the cement manufacturer, the applicator and the Purchaser of the cement lined pipe.

16.2.4 The cement used for cement lining pipe and filling shall be uniform and free of lumps.

16.2.5 Sand should be at least 95 percent quartz (silicon dioxide) and should not lose more than 0.5 percent on ignition.

16.2.6 The sand should meet ASTM-C-33 and conform to screen analysis as Table 21.

TABLE 21 - SCREEN ANALYSIS OF SAND USED FOR CEMENT - MORTAR LINING

OPENING mm (US SERIES)	PERCENT RETAINED ON EACH SIEVE
1.19 (16)	0
0.590 (30)	0 - 5
0.420 (40)	15 - 25
0.297 (50)	49 - 60
0.177 (80)	20 - 40
0.149 (100)	0 - 5
> 0.149 (> 100)	0 - 2

16.2.7 Fly ash and raw or calcined pozzolans should conform to ASTM-C-618 and API Spec. 10, Section 11.

The loss on ignition for fly ash, conforming to ASTM-C-618, should not exceed 4 percent.

16.2.8 The Purchaser may require the applicator to furnish satisfactory reports of analyses which certify that the pozzolanic materials meet the ASTM requirements set forth in 16.1.8.

16.2.9 Pozzolanic material shall consist of siliceous or a combination of siliceous and aluminous material in a finely divided from that in the presence of moisture will react with calcium hydroxide, at ordinary temperatures, to form compounds possessing cement properties.

16.2.10 Water for mixing the lining material, clear potable water should be used.

16.2.11 Chemical Additives-Chemical admixtures may be used by agreement between the applicator and purchaser.

16.2.12 Cement, sand, and pozzolans should be kept clean, dry and free from contaminants. They should be stored in separate bins, tanks or other containers closed to weather and contamination. Cement and pozzolans should be passed through a (6.4 mm) or less mesh screen, to remove lumps and other extraneous matter, before mixing. All materials should be handled and transferred in such a manner that all foreign matter is excluded.

16.2.13 Cement-mortar shall be composed of cement, sand and water, well mixed and of proper consistency to obtain a dense, homogeneous lining that will adhere firmly to the pipe surface. To improve workability, density and strength in the mortar, admixtures conforming to the latest edition of ASTM-C-494, may be used at the option of the contractor, provided the ratio of admixture to cement does not exceed that used in the qualification tests of ASTM-C-494. The soluble chloride-ion (Cl^-) content of the cement-mortar mix shall not exceed 0.15 percent, expressed as a percentage of cement weight. No admixture shall be used that would have a deleterious effect on potable water flowing in the pipe after the lining has been placed.

16.3 Cement-Mortar Lining Thickness

Cement-mortar lining shall be uniform in thickness, except in joints or other discontinuities in the wall. In selecting lining thickness it is important to consider the dimensions of any tools or instruments that must pass through the pipe. In considering the clearance for such items, the allowable eccentricity of both lining and pipe shall be considered. Tables 19 and 20 and list the variations in lining thickness being applied in shop and in place along the range of tolerances permitted.

16.4 Application of Cement-Mortar Lining

16.4.1 Application of cement-mortar lining either in shop or in place shall be as specified by the Company. The application method and requirements of the finished work shall be in accordance with IPS-C-TP-352.

16.4.2 The contractor is required to furnish an affidavit that all materials and work furnished under the Company's order will comply or have complied with the applicable requirements of this Standard and construction standard IPS-C-TP-352.

16.5 Typical Problems Experienced with Cement-Lined Tabular Goods

16.5.1 Cause of failure

Off specification materials, improper mix properties, or poor application techniques, can result in defective cement lining which can fail by mechanical or chemical mechanisms.

16.5.2 Chemical attack

16.5.2.1 Cement linings can not withstand strong acids and will be deteriorated by acid environments. Cement linings shall not be used where the pH of the fluid is below 5.0.

16.5.2.2 Cement linings have been successfully used in the following environments; however, cement linings are known to deteriorate after reaction with water containing high concentrations of any one of several critical individual ions or a mixture of ions. Recognized as troublesome are high concentrations of sulfate, sulfide, chloride carbon dioxide, or mixtures of sulfide and oxygen.

16.5.2.3 Chemical attack can cause holes, grooves or thinning of the lining.

16.5.2.4 Chemical attack can also cause softening, shrinkage of the cement lining from the pipe wall.

16.5.3 Voids

A void is a place in the pipe where the cement lining is not continuous. Voids occur during the spinning process when the lining does not distribute to cover all of the steel pipe.

16.5.4 Thickness of lining

16.5.4.1 Cement lining of uniform circumferential thickness which is too thick or too thin along the length of the pipe is a result of:

- Too little or too much cement mix.
- Use of improper sizing cone.
- Poor initial longitudinal distribution of cement mixture.
- Loss of cement from the ends of the pipe during spinning.
- Build-up of cement at the ends of the pipe during spinning.

16.5.4.2 Cement lining which is too thin on one side and too thick on the other side of the pips is a result of:

- Trying to line bent or out-of-round pipe.
- Pipe spinning rollers not aligned.
- Pipe spinning assembly too short for pipe length.
- Excessive lateral (sidewise) movement during spinning.
- Cement slurry too thick or too thin for spinning speed time.

16.5.5 Sags

If the forces of hoop strength and adhesion in the fresh cement lining are not greater than the force of gravity, the lining will sag or pull away from the steel at some points along the top of the pipe.

16.5.6 Detective ends

16.5.6.1 Some types of end defects are:

- Lining end not located as specified.
- Lining end not square.
- Lining end chipped or cracked.
- Lining thickness not as specified.
- Threads, welding bevel or land not cleaned of cement.
- Lining separated from steel pipe.
- Lining end not perpendicular to longitudinal axis of the pipe.

16.5.6.2 If the ends of the cement-lined pipe are not as recommended, a corrosion-resistant joint is difficult to make. This is a major cause of lining failure.

16.5.7 Foreign material and poor mixing

16.5.7.1 Bubbles visible on the surface of set cement lining.

16.5.7.2 The appearance of spots or small rough lumps in the fresh lining.

16.5.8 Cracks

16.5.8.1 Most cracking occurs when the lining is allowed to dry out during curing, transportation or storage.

16.5.8.2 Each joint of lined pipe shall be inspected for cracks after curing, transportation, storage, and handling. The intent in cement lining is always to produce a crack-free lining; however, cracking does occur. Acceptance or rejection of pipe with cracked lining should be left to the discretion of the inspector of the Purchaser and the inspector of the applicator.

16.6 Shop Applied Cement-Mortar Lining

16.6.1 General

16.6.1.1 When specified by the company the cement-mortar lining shall be applied in shop.

16.6.1.2 The lining materials shall be as specified by the Company based on the duty for which it is intended (see Clause 17.2)

16.6.1.3 The quality control inspector shall ensure that the lining plant is operated and maintained so that no foreign material is introduced into the cement lining or its components during handling, mixing, storage or at any other time. He shall also ensure that all components are thoroughly mixed in the correct proportions. foreign material or poor mixing are indicated by the appearance of spots or small rough lumps in the fresh lining.

16.6.1.4 Wire-fabric reinforcement (ASTM-A-185 or ASTM-A-497) or ribbon-mesh reinforcement shall be applied to the interior of fittings larger than 610 mm (24 in) and shall be secured at frequent intervals by tack welding to the pipe, by clips, or by wire.

16.6.2 Thickness

16.6.2.1 Cement-mortar lining shall be uniform in thickness, except at joint or other discontinuities in the pipe wall. Lining thickness of pipes shall be as listed in Table 22 as a minimum along with the range of tolerances permitted or as specified by the Purchaser (see also 16.3).

TABLE 22 - CEMENT MORTAR LINING THICKNESS OF PIPE (SHOP APPLIED)

NOMINAL PIPE SIZE mm	in	LINING THICKNESS mm	in	TOLERANCE mm	in
50 - 75	2 - 3	4	5/32	-0.8 + 3.2	-1/32 + 1/8
100 - 250	4 - 10	6	¼	-1.6 + 3.2	-1/16 + 1/8
280 - 580	11 - 23	8	5/16	-1.6 + 3.2	-1/16 + 1/8
600 - 900	24 - 36	10	3/8	-1.6 + 3.2	-1/16 + 1/8
> 36	> 900	13	½	-1.6 + 3.2	-1/16 + 1/8

16.6.2.2 Lining thickness shall be determined at intervals frequent enough to ensure compliance. Thickness shall be determined while the mortar is wet.

16.6.3 Application

Application of shop-applied cement-mortar lining, and field joints, requirements, inspection of the works and performance criteria shall be in accordance with IPS-C-TP-352.

16.6.4 Installation

16.6.4.1 Inside joints

16.6.4.1.1 Material

Cement mortar used for the joints shall be composed of a minimum of 1 part cement to not more than 2 parts sand, by weight, dry mixed, and moistened with sufficient water to permit packing and troweling without crumbling. Sand shall be graded within the limits for plaster sand conforming to ASTM C35. Water shall be clean and free from injurious quantities of organic matter, alkali, salts, and other impurities, (potable water). If permitted by the Purchaser, workability of the mortar may be improved by replacing not more than 7 percent, by weight, of the cement with hydrated lime, or by replacing not more than 20 percent, by weight, of the cement with pozzolan.

16.6.4.1.2 Application

16.6.4.1.2.1 Inside joints of mortar-lined pipe shall be filled with cement mortar and finished off smooth and flush with the inside surface of the pipe by troweling or by equivalent means. Before placing the joint mortar material against the surfaces of the lining, the surfaces shall be carefully cleaned, have all soap removed, and then be wetted to ensure a good bond between the lining and the joint mortar. The pipeline shall not be put into service until the mortar has cured for a minimum of 24 hrs.

16.6.4.1.2.2 When pipe is 560 mm (22 in.) in diameter and larger, the joints shall be finished smooth with the inside surface of the lining by troweling.

16.6.4.1.2.3 When the pipe is smaller than 560 mm (22 in.), the joint shall be finished by placing a sufficient amount of the joint mortar in the bell end of the Section against the shoulder of the lining, just before installing it in the line. When the Section has been laid in place, the joint shall be finished by pulling a rubber ball or the equivalent through the joint to finish it off smooth with the inside surface of the lining.

16.7 Field Applied Cement-Mortar Lining

16.7.1 General

16.7.1.1 When specified by the Company the cement-mortar lining shall be applied in place.

16.7.1.2 The lining materials shall be as specified by the Company based on the duty for which it is intended (see Clause 16.2).

16.7.1.3 Mortar shall be mixed long enough to obtain maximum plasticity. The mortar shall be used before initial set.

16.7.2 Thickness of lining

16.7.2.1 The lining shall be uniform in thickness within the allowable tolerance, except at joints or deformations in the pipeline. Cement-mortar lining thickness shall be in accordance with Table 20 as a minimum, unless otherwise specified by the Purchaser. If a cement-mortar lining thickness greater than 13 mm (1½ in) is required by the Company, it shall be at the contractor's option to apply the mortar lining in multiple application.

16.7.2.2 The thickness of cement-mortar lining over the top of rivet heads and lockbar longitudinal seams of steal pipe shall not be less than 3.2 mm unless otherwise specified by the Purchaser.

TABLE 23 - CEMENT-MORTAR LINING THICKNESS FOR PIPELINES IN PLACE

TYPE OF PIPE							
OLD CAST IRON AND DUCTILE IRON		OLD STEEL		NEW CAST IRON AND DUCTILE IRON		NEW STEEL	
Diameter mm	Nominal Thickness of Lining* mm	Diameter mm	Nominal Thickness of Lining* mm	Diameter mm	Nominal Thickness of Lining* mm	Diameter mm	Nominal Thickness of Lining* mm
100 - 250	3.2	100 - 300	6.4	100 - 250	3.2	100 - 300	4.8
300 - 900	4.8	350 - 560	7.9	300 - 900	4.8	350 - 900	6.4
> 900	6.4	600 - 1500	9.5	> 900	6.4	1070 - 1500	9.5
		> 1500	12.7			1700 - 2300	11.1
						> 2300	12.7

*** For badly deteriorated pipe or abnormal use, the Purchaser should specify such greater thickness of lining as engineering judgment indicates. In all instances, tolerance for lining shall be 3.2 mm (+ 1/8 in.) with no minus tolerance.**

16.7.3 Application of lining

16.7.3.1 Application requirements of the cement-mortar lining for pipeline are as follows:

16.7.3.1.1 The lining of all straight pipe sections and long radius bends shall be accomplished by a machine that progresses uniformly through the pipe, applies cement-mortar against the pipe surfaces, and is provided with an attachment for mechanically trowelling the mortar to obtain a smooth transitions over joints.

16.7.3.1.2 That the lining of bends, specials, and areas adjacent to valves shall be machine sprayed and hand troweled or, where machine placing is impractical, shall all be performed by hand methods.

16.7.3.2 Application of field applied cement mortar lining, requirements, inspection of the works and performance criteria shall be in accordance with IPS-C-TP-352 (Lining).

17. BITUMEN (ASPHALT) AND COAL TAR LINING

17.1 General

17.1.1 Bitumen and coal tar materials are suitable for protecting internal surfaces of steel pipes, fittings, tanks, vessels and cementitious concrete or brick work equipments (see Tables 24 and 25).

17.1.2 Both of bitumen and coal tar lining are available in two groups, cold applied (solvent base) and hot applied materials. Hot applied lining have more resistance than cold applied lining.

17.1.3 These linings are used for the transport and storage of fluids with temperature within 4°C to 32°C.

17.1.4 Bitumen and coal tar lining material shall not be applied to surface having a temperature below 4°C to avoid poor wetting of the surface and slow drying of the lining.

17.1.5 The lining shall never be applied to a surface having a temperature below the dew point of the surrounding atmosphere because of the possibility of entrapping moisture beneath the coating.

17.1.6 A lining material shall never be applied to a surface having a higher temperature than that recommended by manufacturer of the coating because blistering and sagging of the lining can result.

17.1.7 For contact potable water or in air conditioning systems, special linings shall be specified, which on drying impart no taste or odor to the water or air. For contact with potable water only bitumen material conforming to BS 3416 shall be applied.

17.1.8 The excellent resistance to water and the durability of coal tar lining are attested by the fact that they have provided many years of trouble-free service on ships, floating dry docks, lockgates, tanks, water lines, penstocks, cooling towers, and sewage disposal plants. The coal tar lining shall not be used in contact with foods and potable water.

17.1.9 Coal tar lining are not recommended for atmospheric exposure since they tend to alligator and crack on prolonged exposure to direct sunlight although they still give protection.

17.1.10 Bitumen lining shall not be used where contamination of petroleum products is expected.

17.1.11 All materials shall be applied in compliance with the manufacturer’s instructions. Care shall be exercised to ensure there is no mixing of material from different sources or of different types unless examination shows that the final product has satisfactory properties. In particular it shall be recognized that the chemical and physical characteristics of coal-tar-based coatings differ from those of bitumen-based coatings and that the two kinds of coatings shall not be blended in protective linings. It is also essential to clean out plant thoroughly when the use of bitumen lining materials follows that of coal tar lining materials or vice versa.

17.1.12 In selection of bitumen and coal tar lining in addition to above consideration the provision of Selection 8 shall also be considered.

TABLE 24 - RESISTANCE OF COAL TAR AND BITUMEN LINING IN CHEMICAL ENVIRONMENTS

MEDIA	TYPE OF LINING		MEDIA	TYPE OF LINING	
	HOT APPLIED	COLD APPLIED		HOT APPLIED	COLD APPLIED
Acids:			Gases:		
Sulfuric, 10%	LR	NR	Chlorine	NR	NR
Sulfuric, 50%	NR	NR	Ammonia	LR	LR
Hydrochloric, 10%	LR	NR	Carbon dioxide	R	R
Hydrochloric, 20%	NR	NR	Sulfur dioxide	LR	LR
Nitric, 10%	LR	NR	Hydrogen sulfide	R	R
Nitric, Conc	NR	NR			
Phosphoric, 10%	LR	NR	Solvents:		
Phosphoric, 85%	NR	NR	Alcohols	LR	LR
Acetic, 10%	LR	NR	Aliphatic hydrocarbons**	LR	LR
Acetic, glacial	NR	NR	Aromatic hydrocarbons	NR	NR
Fatty acids	NR	NR	Ketons	NR	NR
Water:			Ethers	NR	NR
Tap	R	R*	Esters	NR	NR
Distilled	R	R*	Chlorinated hydrocarbons	NR	NR
Sea	R	R			
			Salts:		
Alkalies:			Sodium chloride	R	R
Sodium hydroxide, 10%	R	LR	Calcium chloride	R	R
Sodium hydroxide, 70%	NR	NR	Sodium sulfate	R	R
Ammonium hydroxide, 10%	R	LR	Sodium bisulfite	R	R
Calcium hydroxide,			Sodium carbonate	R	R
slaked lime slurry	R	R	Sodium nitrate	R	R
Ammonium salts	R	R	Alum	R	R
			Sodium sulfite	R	R
Oxidizing Agents:			Sodium acid sulfate	R	R
Concentrated solutions	NR	NR	Zinc chloride	R	R
Dilute solutions	LR	R	Sodium metassilicate	R	R
			Sodium bichromate	R	R
Fast and oils:					
Mineral	LR	LR	Miscellaneous:		
Animal	LR	LR	Sodium hypochlorite	LR	LR
Vegetable	LR	LR			

Code: R = Recommended; NR = Not Recommended; LR = Limited Recommendation.

*** Coal tar is not recommended.**

**** Bitumen is not recommended.**

TABLE 25 - MAXIMUM ALLOWABLE SERVICE TEMPERATURE FOR COAL TAR AND BITUMEN LINING IN CHEMICAL ENVIRONMENTS

CORROSIVE MEDIA	SUGGESTED Max. OPERATING TEMP. °C	CORROSIVE MEDIA	SUGGESTED Max. OPERATING TEMP. °C
Alum	66	Magnesium sulfate	66
Aluminum chloride	66	Mercuric acetate	66
Aluminum nitrate	66	Methyl alcohol	66
Aluminum potassium sulfate	66	Nickel chloride	66
Aluminum sulfate	66	Nickel nitrate	66
Ammonium chloride	66	Nickel sulfate	66
Ammonium hydroxide	27	Oxalic acid	66
Ammonium nitrate	66	Phosphoric acid	66
Ammonium sulfate	66	Phosphorous acid	66
Barium chloride	66	Phosphorous trichloride	66
Barium hydroxide	66	Phthalic acid	66
Barium nitrate	66	Potassium bicarbonate	66
Benzoic acid	66	Potassium carbonate	66
Boric acid	66	Potassium chloride	66
Cadmium chloride	66	Potassium cyanide	66
Cadmium nitrate	66	Potassium ferricyanide	66
Cadmium sulfate	66	Potassium ferrocyanide	66
Calcium bisulfite	66	Potassium hydroxide, 30%	27
Calcium chloride	66	Potassium nitrate	66
Calcium hydroxide	27	Potassium sulfate	66
Calcium nitrate	66	Salicylic acid	66
Chlorine gas, dry	66	Silver nitrate	66
Chlorine gas, wet	27	Sodium acetate	66
Citric acid	66	Sodium bicarbonate	66
Copper chloride	66	Sodium carbonate	66
Copper nitrate	66	Sodium chloride	66
Copper sulfates	66	Sodium cyanide	66
Ethyl alcohol	66	Sodium hydroxide, 30%	27
Ethylene glycol	66	Sodium nitrate	66
Glycerin	66	Sodium potassium tartrate	66
Gold cyanide (auric cyanide)	66	Sodium sulfate	66
Hydrochloric acid, 10%	27	Sodium sulfite	66
Hydrochloric acid, conc.	66	Sodium thiosulfate	66
Hydrocyanic acid	66	Sodium thiosulfite	66
Hydrogen sulfide gas, dry	66	Sulfur dioxide gas, dry	66
Hydrogen sulfide gas, wet	66	Sulfur dioxide gas, wet	66
Iron chlorides (ferric and ferrous)	66	Sulfur trioxide gas, dry	66
Iron nitrates (ferric and ferrous)	66	Sulfur trioxide gas, wet	66
Iron sulfates (ferric and ferrous)	66	Sulfurous acid	66
Lactic acid	66	Tannic acid	66
Lead acetate	66	Tartaric acid	66
Lead nitrate	66	Urea	66
Magnesium chloride	66	Zinc chloride	66
Magnesium hydroxide	66	Zinc nitrate	66
Magnesium nitrate	66	Zinc sulfate	66

17.2 Thickness

The lining thickness varies with regard to duty for which it is intended, but shall company with the requirements specified in Table 26.

TABLE 26 - THICKNESS OF COAL TAR AND BITUMEN LINING

LINING MATERIAL	TOTAL THICKNESS mm	NUMBER OF COAT
Cold applied coal tar	1.0 - 2.6	2 - 3
Hot applied coal tar	1.6 - 3.2	3 - 4
Cold applied bitumen	1.6 - 3.5	3 - 4
Hot applied bitumen	2.0 - 4.5	2 - 3

APPENDICES

APPENDIX A
CLADDING OF PRESSURE VESSELS

A.1 General

A.1.1 This appendix covers the requirements for design, fabrication, process, repair, and inspection of pressure vessels constructed of steel with corrosion resistant integral cladding and weld metal overlay cladding.

A.1.2 Cladding involves a surface layer of sheet metal usually put on by rolling two sheets of metal together, or centrifugal casting (extrusion and explosion) or a thin liner is spot-welded to the walls of a steel equipment.

A.1.3 A higher alloy rod is necessary for welding clad parts to avoid dilution of the weld deposit and loss of corrosion resistance (see Table A.1).

A.1.4 Cladding presents a great economic advantage in that the corrosion barrier or expensive material is relatively thin and is backed up by inexpensive steel. Costs might be astronomical if the entire wall were made of highly corrosion-resistant material.

A.1.5 Cladding material is chosen for its corrosion resistance a particular environment, such as sea water, sour gas, high temperature. Specific uses include heat exchangers, reaction and pressure vessels, furnace tubes, tubes and tube elements for boilers, scrubbers, and other systems involved in the production of chemicals.

A.2 Selection of Cladding Material

A.2.1 Clad Plate

A.2.1.1 Integral clad plate bonded by the rolling or expansion method shall be homogeneously made to have a material quality and a thickness as specified. The clad plate to be used for pressure vessel shall meet one of the following standard specifications or equivalent.

- **a)** ASME SA 263 "Corrosion-Resisting Chromium Steel-clad Plate, Sheet, and Strip"
- **b)** ASME SA 264 "Stainless Chromium-Nickel Steel Clad Plate, Sheet, and Strip"
- **c)** ASME SA 265 "Nickel-Base Alloy Clad Steel Plate"
- **d)** ASME B 432 "Copper and Copper Alloy Clad Steel Plate"

A.2.1.2 The integral clad plate bonded by explosion method shall not be used for hydrogen service vessels operating at elevated temperature and high pressure at a hydrogen partial pressure 7 kg/cm² A and over (hereinafter referred to as "hydrogen service"). However, its use for removable parts such as manhole covers and tube sheets may be permitted.

A.2.2 Weld metal overlay cladding

A.2.2.1 Weld metal overlay cladding shall be mainly used for "hydrogen service" vessels as above mentioned (item A.2.1.2).

A.2.2.2 When the "hydrogen service" vessel is to be operated at a special condition such as in "Hydrocracking Process" and "Hydro-Desulferization Process" (hereinafter referred to as "special hydrogen service"), the weld metal overlay cladding shall be strictly adopted for all inside surface of the vessel.

(to be continued)

APPENDIX A (continued)

A.3 Design

A.3.1 Nozzles and manholes

A.3.1.1 Nozzles with sleeve lining shall be flanged and be sized to a minimum of 38.1 mm (1½ in.) nominal pipe size (NPS).

A.3.1.2 All nozzles and manholes shall be fabricated with integral cladding or weld metal overlay cladding in case where possible. However, the nozzle sized 100 mm (4 in). NPs and smaller may be fabricated with sleeve lining which behind space shall be vented to atmospheric with 3.2 mm (1/8 in) NPT telltale hole and the hole is filled with grease.

A.3.1.3 The flange facings and neck connection weld of shell to nozzles and manholes shall be lined with weld metal overlay cladding as shown in Fig. A.1.

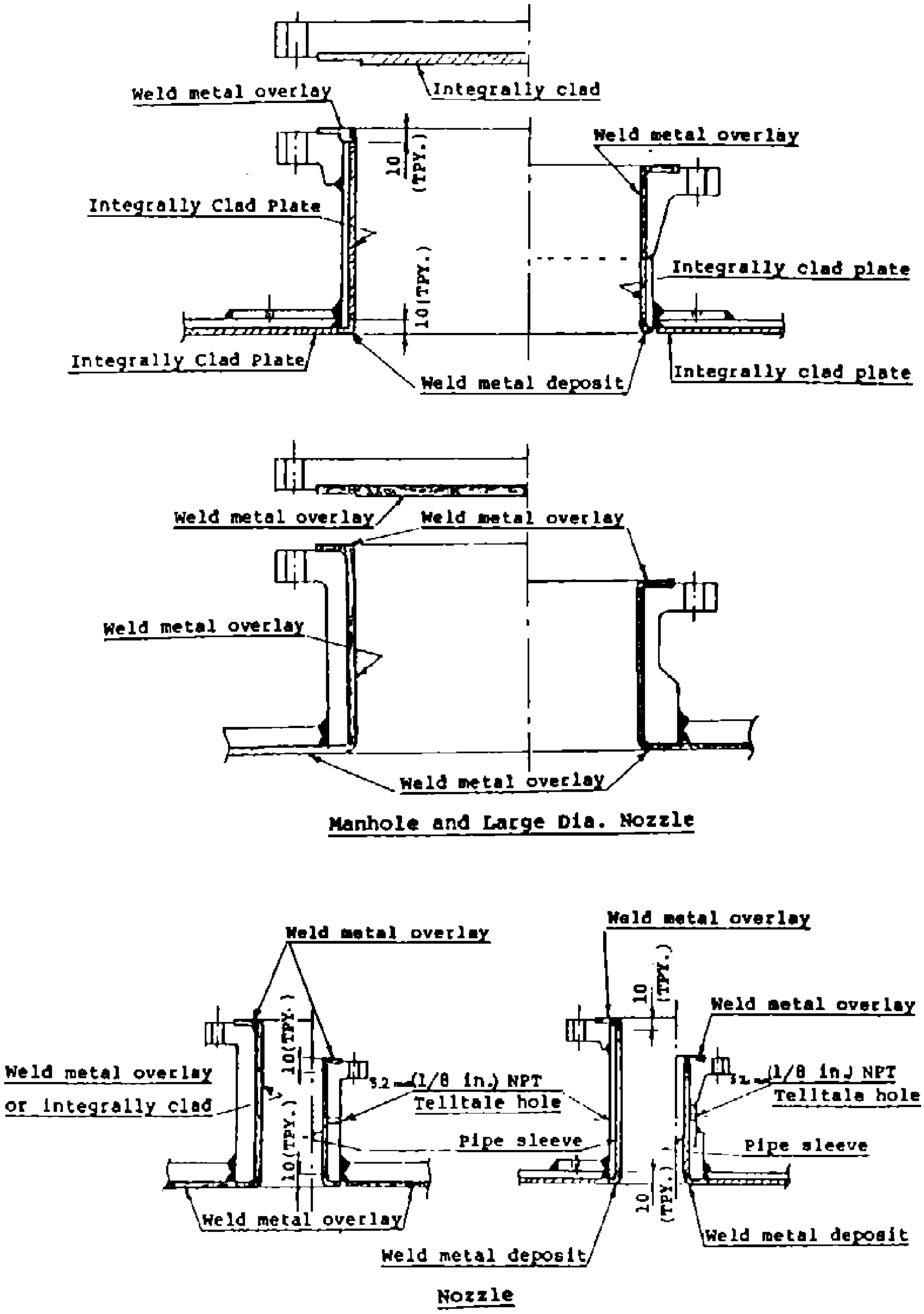
A.3.1.4 All nozzles and manholes for special hydrogen service vessel shall be employed the weld metal overlay cladding. In the case, the raised face type with spiral wound gasket shall be recommended for the flange connection. Where the ring joint type facing is unavoidably employed, the corner radius of the ring joint groove of flange facing shall be made as large as possible, and the final weld metal overlayer of the groove shall be made after final post weld heat treatment.

A.3.2 Internal attachment

Welding of internal support lugs and rings to be directly attached to the shell or head of special hydrogen service vessel shall be performed with full penetration prior to post weld heat treatment, and the final weld overlayer around the support lugs and rings shall be applied after post weld heat treatment, (P.W.H.T) as shown in Fig. A.2.

(to be continued)

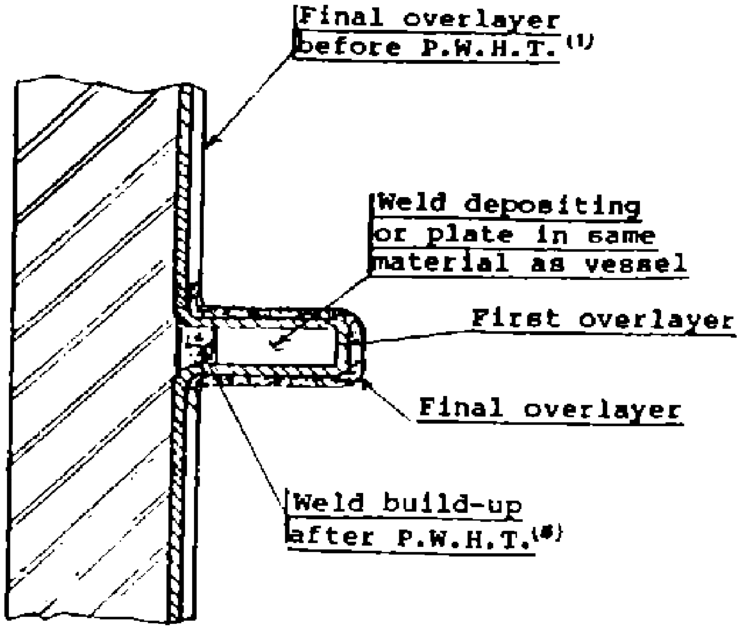
APPENDIX A (continued)



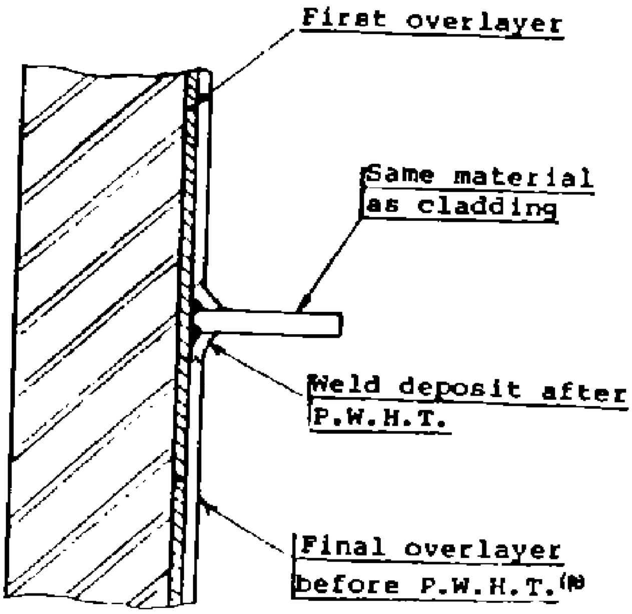
TYPICAL DETAIL OF LINED NOZZLES AND MANHOLES
Fig. A.1

(to be continued)

APPENDIX A (continued)



1) Heavy Duty Support



2) Light Duty Support

LINED DETAILS OF INTERNAL SUPPORT
Fig. A.2

* P.W.H.T: Post Weld Heat Treatment

(to be continued)

APPENDIX A (continued)

A.4 Fabrication

A.4.1 Welding electrodes

Welding electrodes for cladding materials shall be used as shown in Table A.1.

TABLE A.1 - WELDING ELECTRODES FOR CLADDING MATERIALS

ASME/ASTM SPEC.	CLADDING MATERIAL	AWS - WELDING ELECTRODE SPECIFICATIONS *	
		Weld to Base Metal	Weld with Cladding Metal
SA 263	Type 405 or 410S	E 310 - xx or E 309 - xx	E 310 - xx or E 309 - xx
SA 264	Type 304		E 308 - xx
	Type 304 L		E 308 L - xx
	Type 316	E 310 - Mo - xx or E 309 - Mo - xx	E 316 - xx
	Type 316 L		E 316 L - xx
	Type 321 or 347	E 310 - xx or E 309 - xx	E 347 - xx
SA 265	UNS 04400 (Ni - Cu Alloy)	ENi Cu - 7	ENi Cu - 7
B 432	UNS C 70600 UNS C 72200 UNS C 71500 (Cu - Ni Alloy)	ENi Cu - 7 or ENi - 1	Ni Cu - 7 or E Cu Ni

*** AWS electrode designation xx are 15 to 16. The equivalent grade of AWS specifications may be used.**

A.4.2 Clad disbonding prevention

Preventives of weld metal overlay clad disbonding, which may occur during, operation of the "special hydrogen service" vessel, shall be provided in the vessel fabrication.

A.5 Thickness

1) No corrosion allowance shall be added to the base plate.

2) Thickness of cladding material which is made from integral cladding or weld metal overlay cladding shall not be included in design calculation of wall thickness.

3) The thickness of the integral clad and/or weld metal overlay clad materials shall be considered as corrosion allowance.

A.6 Cladding Process

A.6.1 The principle cladding techniques include cold roll bonding, hot roll bonding, hot pressing, explosion bonding, and extrusion bonding.

(to be continued)

APPENDIX A (continued)

A.6.2 All the techniques involve some form of deformation to break up surface oxides, to create metal-to-metal contact, and to heat in order to accelerate diffusion.

A.6.3 The techniques differ in the amount of deformation and heat used to form the bond and in the method of bringing the metals into intimate contact.

A.6.4 Cold and hot roll bonding apply primarily to sheet (less than 5 mm. thick), but explosion bonding is usually restricted to thicker gages (up to several centimeters).

A.6.5 The material shall be free from injurious defects, shall have a workmanlike appearance, and shall conform to the designated finish.

A.6.6 Stainless chromium-nickel steel and corrosion-resisting chromium steel plates shall be blast-cleaned and pickled (see ASTM A 240 and IPS-C-TP-101) prior to cladding.

A.6.7 Nickel base alloy plate shall be furnished in the as-rolled condition prior to cladding, unless otherwise specified.

A.6.8 The welding procedure and the welders or welding operators shall be qualified in accordance with Section IX of the ASME Code.

A.6.9 Heat-treatment

A.6.9.1 Unless otherwise specified or greed upon between the Purchaser and the manufacturer, all clad plates shall be furnished in the normalized or tempered condition or both. For example all austenitic stainless steel clad plates shall be given a heat treatment consisting of heating to the proper temperature for the solution of the chromium carbides in the cladding followed by individual air cooling. For base methods of air-hardening low-alloy steels the above heat treatment shall be followed by a tempering treatment.

A.6.9.2 When plates over 25 mm in thickness are to be cold formed, the Purchaser may may specify that such plate be heat treated for grain refinement of the base metal.

A.7 Repair of Cladding

Unless otherwise specified the material manufacturer may repair defects in cladding by welding Provided the following requirements are met:

A.7.1 Prior approval is obtained from the Purchaser if the repaired area exceeds 3 percent of the cladding surface.

A.7.2 The defective area is removed and the area prepared for repair is examined by a magnetic particle method (see A.8.3) or a liquid penetrate method (see A.8.4) to insure all defective area has been removed. Method of test and acceptance standard shall be agreed upon by the Purchaser and the manufacturer.

A.7.3 The weld will be deposited in a suitable manner so as to leave its surface condition equivalent in corrosion resistance to the alloy cladding.

A.7.4 The repaired area is examined by a liquid penetrate method (see A.8.4).

A.7.5 The location and extent of the weld repairs together with the repair procedure and examination results are transmitted as a part of certification.

A.7.6 All repairs in CRA [1)] type 410, or repair penetrating into the base steel shall be stress relieved to eliminate residual stresses.

Notes:

1) Corrosion Resistance Alloy Nickel.

2) For stainless steel clad, at the request of the Purchaser or his inspector, plates shall be reheat treated following repair by welding.

(to be continued)

APPENDIX A (continued)

A.8 Inspection and Test Methods

A.8.1 Scope of inspection and testing

The inspection and testing shall be shown in accordance with Table A.2.

TABLE A.2 - SCOPE OF INSPECTION AND TESTING

INSPECTION ITEM	DIVISION OF WORK		ACCORDING TO TEST METHOD OF
	PR	MFR	
1. Material Inspection	R	Tr & S	A.8.2
2. Welding Inspection 2.1 Magnetic Particles Examination For weld build-up and weld deposit ofheavy duty support for special hydrogen service vessel	W/R	Tr & S	A.8.3
2.2 Liquid Penetrate Examination 2.2.1 Weld overlay and groove weld 2.2.2 Internal attachment weld on the weld overlay or clad metal 2.2.3 Entire weld surface of final layer and gasket seating surface	 W/R W/R W/R	 Tr & S Tr & S Tr & S	A.8.4
2.3 Ultrasonic Examination 2.3.1 For cladding of general service vessel 2.3.2 For cladding of special hydrogen service vessel 2.3.3 For weld build-up and weld deposit for heavy duty support	 R W/R W/R	 Tr & S Tr & S Tr & S	A.8.5
2.4 Ferrite check for austenitic stainless steel weld overlay	R	Tr & S	A.8.6
2.5 Chemical Analysis for Weld Overlay	R	Tr & S	A.8.7
3. Inspection for Completed Vessel 3.1 Leak Test for Weld of Pipe Sleeve	R	Tr & S	A.8.8

Abbreviation:

PR: **The Purchaser**
MFR: **The manufacturer**
R: **Verify by reviewing the manufacturer's inspection/testing record**
W: **Witness inspection/testing**
Tr: **Manufacturer's own inspection/testing with the record to be prepared**
T: **Manufacturer's own inspection/testing**
S: **Submission of manufacturer's inspection/testing record**

A.8.2 Material Inspection

The materials of integral clad plate to be used for vessels shall be inspected by ultrasonic examination so as to check the quality of the bonding in accordance with ASME SA 578 "Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications, and the acceptance level shall be S6 as specified in the Standard. However the band having a width not less than 75 mm along with cut edge shall have no defects.

A.8.3 Magnetic particle examination (MT)

A.8.3.1 In case of vessels in "special hydrogen service", the entire surface of the build-up weldment and weld deposit for heavy duty support as shown in Fig. A.2.1 shall be checked by magnetic particle examination before placement of first layer of weld metal overlay cladding, to confirm that no cracks or other defects exist.

A.8.3.2 The method of MT is in accordance with Appendix 6 in ASME Code Sect. VIII Div. 1.

(to be continued)

APPENDIX A (continued)

A.8.4 Liquid penetrate examination (PT)

A.8.4.1 Liquid penetrate examination shall be performed at the following portions of weldments to check that no cracks or other defects exist.

a) All final weld metal overlay surfaces and final layer of groove welds for clad plate after PWHT*.
b) All final welds of internal attachments on the weld metal overlay or clad metal.

A.8.4.2 The method of PT in accordance with Appendix 8 in ASME Code Sect. VIII Div. 1.

A.8.5 Ultrasonic examination

A.8.5.1 Ultrasonic examination for clad vessel in general service shall be performed as follows:

a) All surfaces of integrally bonded clad plate after cold forming when the resulting extreme fiber elongation is more than 5% from as-rolled condition and all hot forming shall be examined to detect gross lack of bonding.

b) All overlay weld deposit including but joint of clad plate shall be examined to detect gross lack of fusion.

c) The acceptance level shall be S6 shown in ASME SA 578.

A.8.5.2 For clad vessels in "Special Hydrogen Service", ultrasonic examination shall be performed as follows:

a) All surface of weld metal overlay cladding and all weld metal overlay deposits of butt joints shall be examined from the counter side of the clad surface in accordance with the requirements of para T-543 in ASME Code Section V, Article 5. after "PWHT". The acceptance standard shall be as follows:

- No imperfection interpreted to be cracks, or lack of bond.

- No indication exceeding 40% of the reference level by Cathode Ray Tube (CRT).

- Indications of amplitude 20 thru 40% by CRT shall be recorded, when the indication has the maximum length of 25 mm and over before post weld heat treatment, the defect portion shall be repaired in accordance with the approved welding procedure specification.

b) The entire surface of weld build-up and weld deposit for heavy duty support as shown in Fig. A.2(1) shall be examined to detect any lack of fusion. The acceptance level shall be level I in ASME SA 578.

A.8.6 Ferrite check

A.8.6.1 Austenitic stainless steel weld metal overlay cladding shall be subject to a ferrite check. The ferrite content of the weldment at 1.5 mm from the surface of the overlay as shown in Fig. A.3, shall be limited within 3 to 10% value of the Schaeffler diagram. Where inert gas shielded welding process is employed, the De Long Diagram and the nitrogen analysis evaluation shall be applied.

A.8.6.2 A ferrite check shall be performed for each overlay welding procedure.

A.8.6.3 The ferrite check sample may be made from test pieces.

A.8.7 Chemical analysis

A.8.7.1 Chemical analysis of weld metal overlay shall be performed by taking samples from 1.5 mm in depth from the surface as shown in Fig. A.3, to assure that the chemical composition conforms to the requirements of the applicable material specification in ASME Section II Part C.

*** PHWT: Post Weld Heat Treatment.**

(to be continued)

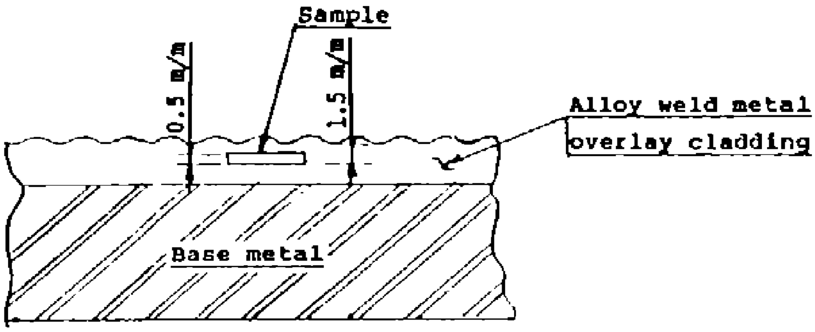
APPENDIX A (continued)

A.8.7.2 Such analysis need not be performed on those of monel metal and copper alloy.

A.8.7.3 A chemical analysis shall be performed for each overlay welding procedure.

A.8.7.4 The chemical analysis sample may be made form test coupons.

A.8.7.5 Chemical analysis shall be in accordance with applicable ASTM Methods.



SAMPLE FOR CHEMICAL ANALYSIS
Fig. A.3

A.8.8 Air test

A.8.8.1 Air test for the weld of pipe sleeves shall be performed before PHWT [1)] where it is to be conducted.

A.8.8.2 No leak shall be permitted.

Note:

1) PWHT: Post Weld Heat Treatment.

APPENDIX B
CLADDING OF PIPELINE (WITH CRA)*

B.1 General

- Clad pipe consists of a composite material with CRA on the inside and carbon steel on the outside (see Table B1).

- CRA selection is based on a battery of tests using in-service coupon testing, ASTM G 28, ASTM A 262 E and ASTM G 48 tests for intergranular corrosion pitting, crevice corrosion testing, etc.

B.2 Pipe

- The commonly used processes for pipe are forming but seamless clad pipe is generally made by metallurgical bonding using co-extrusion, explosion bonding of the liner or centrifugal casting.

- Clad thickness should be considered as corrosion allowance and thickness of the outer pipe is calculated from pressure and mechanical considerations.

B.3 Fittings

Bimetallic fittings can be produced by forming from clad pipe or clad plate using closed die forming or hot extrusion processes. But generally the quantities are not enough to interest the manufacturer. In such a situation, manual/automatic weld overlay on a standard carbon steel fitting is the viable route. For fittings made from clad pipe or plate, the same requirements as applied to the pipe can be used. However, for manual/automatic weld, compatibility of the weld material with pipe outer material must be considered. Additionally, the wall thickness and tolerances on the outer wall have to be matched. Further, to get good uniform coverage with weld overlays, a minimum two passes of overlay should be specified. The deposits with two overlays generally make the total thickness of the fitting more than the total thickness of the pipe. This problem can be pre-empted by specifying inside taper on the end of fittings to ensure proper match to the pipe beveled end. The intent is to taper the inside of the outer wall and not build a taper on the overlay thickness because that reduces the corrosion resistance and consequently the life of the fitting (see Fig. B.1).

B.4 Flanges

To obtain a proper overlay on a flange face, the raised face of the flange shall be machined off. To achieve a dilution-free overly on the raised face, undercut the fang face by 1.58 mm (1/16 in.)minimum. After machining the flange face, overly of the inside and face of the flange shall be conducted in the same way as for the fittings. Finally, the proper gasket seating flange finish shall be prepared by re-machining the flange face (see Fig. B.2).

B.5 Ball Valves

applying overlay on the wetted parts of ball valves is a viable alternative at higher pressure classes and usually sizes larger than 100 mm (4 in). Overlay of 316 stainless steel, duplex stainless steel, inconel 825, etc., have been successfully applied. The valve bodies to be overlayed are first machined over size then overly material is applied. After overlaying, heat treatment as required is carried out and then surfaces are machined to their finished dimension. The overlay shall be thick enough to provide as effective erosion barrier, but at the same time thin enough to be economical over solid alloy valves. Additionally, while deciding on thickness overlay the possibility of delusion of carbon steel into the surface of overlay material shall also be considered.

B.6 Other Valves

Most commonly used valves such as gate, globe and checks have not yet been made in clad construction. However, special oil field-type choke valves and through conduit gate valves have been manufactured in clad construction.

*** CRA: Corrosion Resistant Alloys (Nickel Base)**

(to be continued)

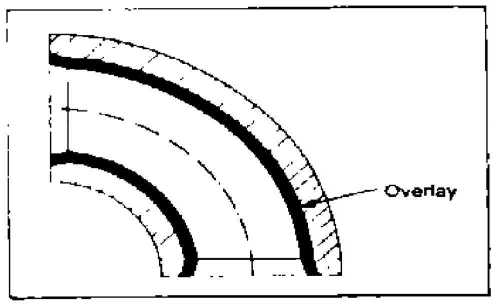
APPENDIX B (continued)

B.7 Welding

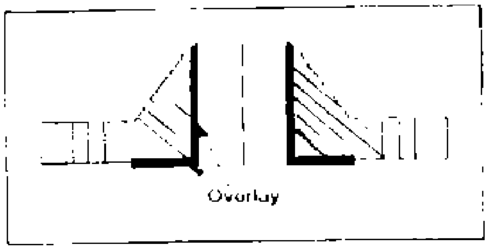
Dilusion of carbon steel and CRA into each other is a major problem resulting in crack formation potential and lowered corrosion resistance. Welding clad piping systems must be take into consideration the base material and the CRA material requirements in the selection of electrodes. It is essential to provide a weld deposit that will match the strength of base material (in this case CRA) and be compatible with welding onto CRA material. It is good practice to specify a minimum of two passes for overlay. The filler material for carbon steel outer pipe can be steel weld. The weld procedure specification, procedure qualification and welder qualifications shall clearly specify the requirements for chemistry of material, shield gas composition, preheat, interpass parameters, hardness testing requirements in overlay, heat affected zone and base metal liquid penetrant examination, ultrasonic examination, mechanical properties, impact testing, micro and macro structure examination, etc. The procedure shall also address the question of coupons for testing.

TABLE B.1 - COMMONLY USED OUTER AND INNER LAYERS

OUTER PIPE	INNER CRA LINER PIPE
ASTM A 106 Gr. B API 5L Gr. B API 5LX Gr. 42 API 5LX Gr. 60 ASTM A 516 Gr. 60/65	Super austentic stainless steel 904 Duplex stainless steel 2205 Alloy 625 Alloy 825 Alloy B-2 Alloy C-276 Monel 400

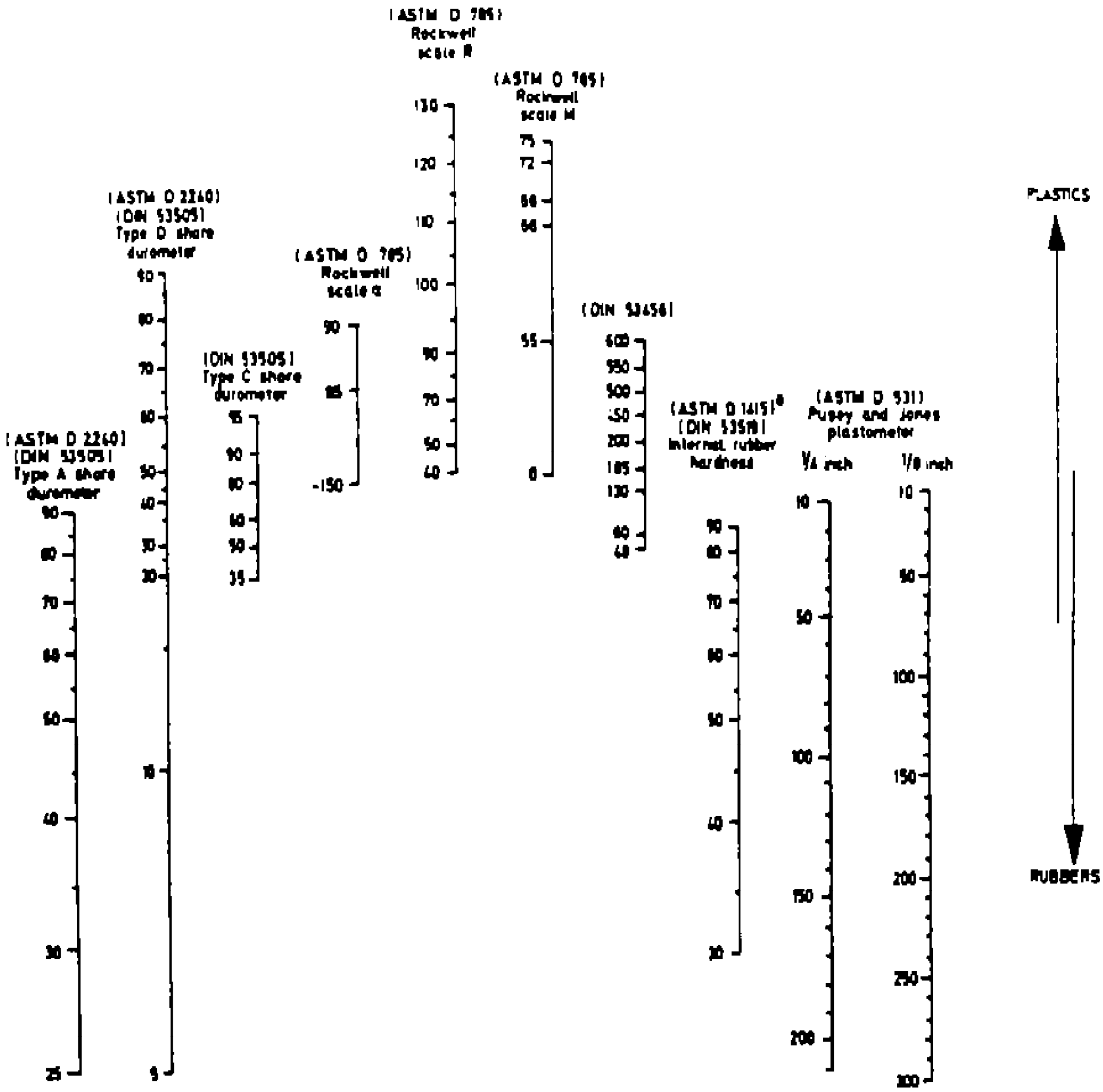


OVERLAYED ELBOW CROSS-SECTION
Fig. B.1



OVERLAYED FLANGE CROSS-SECTION
Fig. B.2

APPENDIX C
HARDNESS COMPARISON CHART
FOR PLASTICS AND RUBBERS



Note:

Equivalent hardness readings lie on the same horizontal line.

The hardness comparison is not accurate.

An indication of the hardness of plastics is also given.

APPENDIX D
EFFECT OF LINING MATERIALS ON WATER QUALITY

When used under the conditions for which they are designed, materials in contact with or likely to come into contact with potable water shall not constitute a toxic hazard, shall not support microbial growth and shall not give rise to unpleasant taste or odor, cloudiness or discoloration of the water.

Concentrations of substances, chemicals and biological agents leached from materials in contact with potable water, and measurements of the relevant organoleptic/physical parameters shall not exceed the maximum values recommended by the world health organization in its publication "Guidelines for Drinking Water Quality" Vol. 1 "Recommendations" (WHO, Geneva 1984) or as required by the EEC council directive of 15 July 1980 relating to the quality of water intended for human consumption (official journal of the European communities L 229 pp 11-29), whichever in each case is the more stringent.

Notes:

1) Requirements for the testing of non-metallic materials in these respects are set out in the UK water fittings Byelaws Scheme Information and Guidance Note No. 5-01-02, ISSN 0267-0313, obtainable from the water research center, fittings testing station, 660 Ajax avenue, slough, Berkshire SL 1 4BG.

2) Requirements for the testing of metallic materials in these respects are set out in DD 82.

3) Pending the determination of suitable means of characterizing the toxicity of leachates from materials in contact with potable water, materials approved by the Department of the Environment Committee on Chemicals and Materials of Construction for use in Public Water Supply and Swimming Pools are considered free from toxic hazard for the purposes of compliance with this Appendix. A list of approved chemicals and materials is available from the Department of the Environment Water Division, Romney House, 43 Marsham Street, London SW1P 3PY.

4) Products manufactured for installation and use in the United Kingdom which are verified and listed under the UK Water Fittings Byelaws Scheme administration by the Water Research Center, (address as in note 1) are deemed to satisfy the requirements detailed in this Appendix.