MANUAL

GLASS-FIBRE REINFORCED EPOXY AND POLYESTER VESSELS - DESIGN AND INSTALLATION

DEP 31.22.30.14-Gen.

October 1995

DESIGN AND ENGINEERING PRACTICE

PREFACE

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Shell International Oil Products B.V. (SIOP)
and
Shell International Exploration and Production B.V. (SIEP)
and
Shell International Chemicals B.V. (SIC)

The Hague, The Netherlands,

and other Service Companies.

They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Group Operating companies. Where appropriate they are based on, or reference is made to, national and international standards and codes of practice.

The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual operating companies to adapt the information set forth in DEPs to their own environment and requirements.

When Contractors or Manufacturers/Suppliers use DEPs they shall be solely responsible for the quality of work and the attainment of the required design and engineering standards. In particular, for those requirements not specifically covered, the Principal will expect them to follow those design and engineering practices which will achieve the same level of integrity as reflected in the DEPs. If in doubt, the Contractor or Manufacturer/Supplier shall, without detracting from his own responsibility, consult the Principal or its technical advisor.

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NOTE: In addition to DEP publications there are Standard Specifications and Draft DEPs for Development (DDDs). DDDs generally introduce new procedures or techniques that will probably need updating as further experience develops during their use. The above requirements for distribution and use of DEPs are also applicable to Standard Specifications and DDDs. Standard Specifications and DDDs will gradually be replaced by DEPs.

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APPENDICES

1. INTRODUCTION

1.1 SCOPE

This DEP is a revision and combination of DEP 31.22.30.14-Gen. (September 1977) and DEP 31.22.30.24-Gen. (March 1978), and consequently the latter publication is now withdrawn. The contents have been further extended with information on polyester resins.

This DEP covers the general requirements for the design, application, installation, testing and inspection of non-jacketed vessels, manufactured by various wet lay-up processes from glass-fibre reinforced epoxy * (GRE) and from glass-fibre reinforced unsaturated polyester (GRUP), both of which are glass-fibre reinforced thermosetting plastics (GRPs).

Unless otherwise stated, these general requirements apply for both GRE and GRUP. Requirements applicable to only one specific material are so indicated.

This DEP covers also the constructions where a thermoplastics lining is used as an additional chemical barrier.

The main purposes of this DEP are to introduce users to the use of GRPs as vessel materials, giving the advantages and disadvantages of both materials, and to assist bid selection for a particular application.

The vessels shall be manufactured in accordance with DEP 31.22.30.34-Gen.

* Epoxy resins are manufactured by Shell under the trade name "EPIKOTE".

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group company, and to Contractors and Manufacturers/Suppliers nominated by them (i.e. the distribution code is "F", as defined in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, chemical plants, gas plants, oil and gas production facilities, and supply/marketing installations.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, installation, and commissioning or management of a project or operation of a facility. The Principal may sometimes undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant, authorized to act for the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions and abbreviations

GRE: glass-fibre reinforced epoxy (which is a GRP).

GRP: glass-fibre reinforced thermosetting plastic.

GRUP: glass-fibre reinforced unsaturated polyester (which is a GRP).

The word **vessel** is used in general context to also include other items of equipment (e.g. tanks) to be made from GRP. If the context is intended to be specific, then the term 'tank' or 'horizontal vessel', etc., is used.

1.4 CROSS-REFERENCES

Where cross-references are made, the number of the section or sub-section referred to is shown in brackets.

All publications referred to in this DEP are listed in (7).

2. BASE MATERIALS

2.1 RESINS

Both epoxy resins and polyester resins are thermosetting resins, i.e. they form a non-reversible three-dimensional polymer structure after curing by heat or other means.

There are a number of essential criteria that determine the comparative suitability of one GRP in relation to another. These include the curing mechanism, mechanical strength, fire resistance, chemical resistance and processability.

Each of these areas is important since together they determine whether the desired GRP equipment will resist the intended service conditions and perform structurally, or even whether it is feasible to fabricate it.

Epoxy resins require particular care in storage of raw materials, fabrication techniques, curing facilities and quality control during all steps of the manufacture of vessels.

Cross-linking or curing of epoxy resins is obtained with curing agents or hardeners, which, upon curing, become an essential part of the network.

Such curing agents as amines (aliphatic and aromatic), polyamides and acid anhydrides should therefore only be used in the stoichiometric ratio. An excess or a deficit of curing agent has an unfavourable effect on the final properties.

The cross-linking of polyester resins with a co-reactant such as styrene is initiated by free radical polymerization catalysts such as an organic peroxide and can be promoted by organic compounds such as naphthenates and anilines.

The amount and type of catalyst and promoter determine the curing time, while the type of polyester determines the final properties. The mixing ratio is not so critical for polyester resins as it is for epoxy resins.

CAUTION: The promoter shall be mixed into the polyester resin prior to the addition of the catalyst. If promoter and catalyst are combined directly together, an explosion will occur.

The major classes of polyester resins are:

- Orthophthalic polyesters. These resins are not considered of importance for chemical resistant use.
- Isophthalic polyesters. These resins are generally considered to be the simplest chemically resistant polyesters.
- Bisphenol-A polyesters. These resins have an improved chemical resistance.
- Vinylester resins. These resins are epoxy-based; however, with respect to cross-linking they are similar to polyester resins.

2.2 GLASS-FIBRE REINFORCEMENT, FILLERS AND PIGMENTS

A number of glass-fibre materials are used to reinforce the resin matrix, such as:

- woven roving;
- square weave or balanced (bidirectional) cloth;
- unidirectional cloth;
- roving;
- chopped strand mat.

A survey of reinforcing materials is given in Appendix 1.

Fillers shall not be used, except for some thixotropic additives which may need to be added to the resin/curing agent mixture for viscosity control. Pigments may be used only if they do not affect the performance.

2.3 MECHANICAL AND PHYSICAL PROPERTIES

In mechanical and physical properties, there is also a distinct difference between glass-fibre reinforced epoxy and polyester resins (see Appendix 2).

A comparison of the properties of GRE with those of GRUP shows that:

(a) mechanical properties (short term and long term) are about 1.4 times higher;

(b) stiffness at 5% deflection is about 1.5 times higher (ASTM D2412);

(c) impact resistance is better;

(d) weeping strength is 1.6 times higher (ASTM D1599);

(e) beam deflection is 1.4 times higher (ASTM D2925);

(f) temperature resistance is better (150 °C versus 100 °C) *;

(g) weather resistance is better.

* The maximum design temperature should be 30 °C lower than the heat distortion temperature (HDT) of the resin system used.

The impact resistance of GRP compared to steel is relatively low. The impact resistance of GRP is affected by:

1. Wall thickness
   The impact resistance increases with increasing wall thickness.
2. Resin type
   A flexible resin gives a higher impact resistance; however, the heat and chemical resistance is impaired.
3. Various other factors, such as liner thickness, liner reinforcement (if any), manufacturing method, resin content, resin system, top coat thickness, state of cure, and test temperature.

GRP material shall be handled carefully at all times. Liners can be damaged to the point of allowing leakage even though the outside surface may show no signs of mishandling.

2.4 CHEMICAL RESISTANCE

The chemicals for which the use of GRP could be considered can be divided into acid/alkali and solvent environments. However, frequently the acid or alkali also contains small amounts of solvents, which makes selection more complex.

A summary of GRP performance is presented in Appendix 3. Data given therein should be considered to be rough indications, because it is difficult to quantify the effect of trace solvents on acid/alkali resistance or the effect of a short-term temperature excursion or plant upset on GRP life.

Another method to achieve a specific chemical resistance is the application of a thermoplastics inner barrier, for which usually PVC (polyvinylchloride) or PP (polypropylene) in a thickness of at least 3 mm is used.

Alternatively, for very aggressive chemicals the more expensive material PVDF (polyvinylidene fluoride) or FEP (fluorinated ethylene propylene) in a thickness of at least 2 mm can be used.

It should be noted that these inner liners do not contribute to the mechanical properties, whilst the maximum temperature limit is reduced, using PVC or PP, to 70 °C and 100 °C respectively.

3. DESIGN AND FABRICATION

3.1 DESIGN

This section contains the basic information necessary for design, so that the user of GRP vessels will have a better understanding of the capabilities of the material. However, the information given should be considered as guidance only. For an accurate design, the Manufacturer should submit a stress analysis based on the specified design code.

In case a thermoplastics inner lining is used, the allowable strain in the laminate should not exceed the strain at fracture of the welded thermoplastics lining.

The design pressure shall take into account the hydrostatic head of the vessel contents.

The Principal shall select the design code, taking into account any national and local regulations.

The existing national design standards for the determination of the allowable design loadings of GRP vessels can be divided into the following three basic groups, any of which may be used:

(1) Standards where the design method is based on stresses (i.e. force per unit area).

From each specific laminate the strength and stiffness properties are determined by actual tests.

These values are used in the stress formulae to obtain a minimum wall thickness.

This method is described in standards such as:

- D 1402 V, and
- A.D. Merkblatt N1

(2) Standards where the design method is based on unit loadings (i.e. force per unit width).

From each layer of the laminate, the ultimate tensile unit strength and unit modulus values are determined.

The load carrying capacity per layer is related to the glass weight and glass content of that layer and from that a required layer thickness can be obtained.

This method is described in:

- BS 4994

Both methods have their own merits; however, there is a tendency to move in future to the "design on stresses" approach.

The current BS 4994 method will result in more expensive vessels (approx. 15%) than the other design methods.

(3) Standards which are to be considered as a combination of (1) and (2), such as:

- Swedish Plastic Vessel Code, and
- NF T57-900.

A further standard, ASME X, should not be applied due to the consequences and restrictions stated below. ASME X contains two basic design methods, which shall not be mixed.

Class I Design

The qualification of a vessel design is obtained through a destructive test of a prototype.

The cost of a tailor-made vessel will consequently be extremely high.

Class II Design

The design is based on the laminate theory and acceptance testing via acoustic emission.

The vessels are restricted in design pressure (P_1 in bar) and diameter (D_1 in mm) to the product P x D = 4030 with a maximum P of 14 bar and maximum D of 3660 mm.

3.2 FABRICATION

The vessels shall be manufactured in accordance with DEP 31.22.30.34-Gen.

Appendix 4 lists the various manufacturing techniques.

Although the manufacturing techniques are already highly automated processes, allowing ample control and flexibility of the finished product, the conditions for one resin type are more stringent than for another.

Processability of the various resin systems is qualified in Appendix 3.

The minimum reinforced thickness shall be as dictated by the design calculations, but in any case shall be at least 5 mm.

Any machined surface shall be sealed with resin or adhesive (usually epoxy resin-based) to prevent chemical attack of the exposed glass fibres.

All openings and branches shall be compensated by the use of additional laminates. The branches shall be as short as practicable (see Appendix 5 and Appendix 6).

4. APPLICATION ASPECTS

4.1 GENERAL

GRE is applied more often than GRUP because of its better properties, as shown in section (2).

No restrictions exist when using GRE vessels for the containment of flammable, explosive, toxic and aggressive products, provided adequate design criteria are defined and local regulatory requirements are met.

The strength of GRP does not decrease at low temperatures; even in a cryogenic environment (down to minus 196 °C) the ductility of the material is fully retained and its tensile strength is higher than that at room temperature.

Load due to the weight or movement of any attachments (e.g. piping, valves, agitators, etc.) should not be transmitted to the vessel scantlings (4.3). All such attachments should be supported independently of the vessel.

Care shall be taken to limit external forces on the nozzles, e.g. by using bellows or by fixing and supporting connecting valves, level gauges and piping. Vibrations of either connecting piping or equipment should be compensated by expansion bellows.

Failures of GRP vessels are usually caused by:

- insufficient compensation to cope with flexural stresses from displacement due to expansion and contraction;
- improper form of supports, saddles etc;
- lack of skill and knowledge during installation and maintenance;
- welding defects of the thermoplastics inner liner;
- chemical attack of the liner by traces of contaminants in the product to be handled;
- transport damage.

4.2 FLANGED CONNECTIONS

The following flanges are acceptable for GRP vessels:

- Integral-type flange with full-face gasket, used for lower pressures up to about 4 bar (ga), see Appendix 7 - Figure 1.
- Loose steel flange with a GRP stub end, used for higher pressures, see Appendix 7 - Figure 2.

Nozzle flanges shall be aligned such that they can be made leak tight without exceeding the specified bolt torques.

Bolts of integral-type GRP flanges shall be provided with a washer at the bolt and the nut end.

The use of washers is not required for loose steel flanges.

Bolts should be evenly tightened to build the pressure uniformly over the entire flange face. The appropriate torques should be specified by the Manufacturer, as these values are dependent upon the manufacturing method of the GRP flange.

Depending on the service, an approximately 3 mm thick Viton A or butyl rubber full-face gasket with a hardness of 60-70° Shore A, if necessary metal reinforced, should be used.

If a raised-face steel flange is to be joined to a GRP flat-face vessel flange, an appropriate filler ring should be used in order to prevent an additional bending moment on the GRP flange.

Care shall be taken that the nozzle ends are square.

4.3 SUPPORTS

All pipework to the GRP vessels shall be supported so that the total loads local to the branches do not exceed the design values specified by the Manufacturer.

Above-ground GRP vessels shall be adequately supported on firm foundations. Laminating of steel parts into the vessel wall should be avoided, because of the risk of cracking due to thermal stresses.

Supports of GRP vessels shall be designed to avoid excessive load. All supports shall permit free expansion of the vessel.

Vertical vessels

Vertical vessels should be supported by an adequate number of support brackets or by two half rings of steel clamped around the vessel (see Appendix 8). These metal parts should, however, not be laminated into the wall. At the place of the support the wall thickness of the vessel shall be at least 1.5 times the reinforced wall thickness required by the design.

Vessels supported on a base shall be provided with legs or a skirt mounted in the same way as mentioned above.

Horizontal vessels

Support saddles for horizontal vessels shall have a radius matching the vessel; a steel structure is preferred to a concrete saddle.

A packing material such as PVC foam or rubber between vessel and saddle shall be used to avoid spot stresses. The angle of the saddle shall be at least 120°, see Appendix 9.

The saddle width shall be calculated to ensure that the allowable stress in the packing material between vessel and saddle will not be exceeded.

Flat-bottom tanks

If the foundation and the tank bottom are smooth and flat, the tank may be placed directly onto the foundation.

The flatness of the erecting surface should be better than $\pm$ 1 mm/m, but with a maximum deviation of 5 mm over the total diameter.

In case of larger variations, a curable intermediate layer of approx. 25 mm thick, should be used to compensate for the deviations, and which should be hardened prior to commencing erection.

In order to avoid the adhesion of the intermediate layer to the tank bottom, a separating thermoplastic sheet should be inserted between the two.

Underground tanks

Underground tanks should be installed in excavations large enough for ease of installation without damage to the tanks, and should be made in ground which is well drained. They should be on a firm foundation and securely anchored or weighted to prevent flotation from flood water. Where such tanks are likely to be subject to loadings from above ground (e.g. from traffic), they should be protected by a reinforced concrete slab or other adequate cover.

Tanks should be suitably supported within the excavation. The space around the tank should be filled with sand or gravel which shall be free from rocks or other objects likely to damage the resin rich outer layer on the tank. The infilled material should be carefully consolidated.

4.4 EXTERNAL DAMAGE

Protective measures should be applied where impact is likely to occur (even though the properties of GRP are such that there is resistance to rupture in the event of an impact).

4.5 FIRE HAZARDS

GRE has a better flame retardancy than GRUP and does not require the addition of flame-retardant additives.

If a GRUP vessel is to be installed in areas where a fire hazard exists it should contain a flame-retardant agent (this situation, however, should be avoided because the retardant agents may adversely affect the processing characteristics of the resin and the strength and chemical resistance of the laminate).

GRE vessels may be used in processing plants for the containment of flammable products, even in cases where a fire hazard exists.

4.6 STATIC ELECTRICITY

The unintentional generation of static electricity is a common occurrence in many operations, including the flow of liquids or powders, the production of sprays, and the contact and separation of solids. The main hazard is that of explosions and fires initiated by electrostatic discharges, but shocks to personnel can also, on occasion, cause accidents.

Electrostatic ignitions are particularly associated with low conductivity liquids (i.e. those whose electrical conductivity is less than 50 picosiemens per metre). They require both the presence of a flammable atmosphere and an incendive discharge as the result of generation and accumulation of charge. The generation and accumulation of charge is not only dependent on the conductivity of the liquid but also on the nature of the liquid (clean or contaminated), the size and contruction of the vessel (earthing provisions), the method of filling and the filling velocities.

The measures required for the control of static electricity depend on many factors. The Shell Safety Committee publication: "Static Electricity, Technical and Safety Aspects" shall be consulted for more information and to avoid inadequate or superfluous measures being taken.

5. MAINTENANCE AND REPAIR

5.1 PAINTING

External painting is not required since GRP is not subject to atmospheric corrosion. If painting is necessary for other reasons, the surface should be lightly blast-cleaned before the paint system is applied and painting should be carried out after inspection and test of the vessel.

After a number of years, surface degradation of GRUP (and, to a lesser extent, GRE) by ultraviolet light can be expected and, although this will hardly affect the strength of the material, it may be considered necessary to paint the vessel to protect personnel from splinters, in which case the paint system should be one generally used for outdoor service. The surface preparation should consist of cleaning with a detergent solution (e.g. Teepol), followed if necessary by a solvent wash to remove fatty/waxy substances, and subsequent roughening with fine sandpaper (e.g. type No. 400).

5.2 PERIODIC INSPECTION

To ensure satisfactory operation of vessels over a period of years, periodic inspections shall be performed to check that the GRP material is sound. This inspection shall include connections and branches to the wall, bottom corner, supports and the inner liner, if present. Although visual inspection is the most common method of inspection, other non-destructive techniques such as ultrasonics and radiography are being developed with increasingly reliable results.

During inspection, damage to surfaces should be avoided by suitably covering footwear and ladders. Non-metallic, blunt cleaning tools which cannot injure the surfaces should be used.

Cleaning processes shall be checked to ensure that the internal protective surfaces will not be damaged or destroyed by incorrect application.

5.3 REPAIR

If it is necessary to carry out a repair to the shell of a vessel, it is essential to obtain from the manufacturer of the vessel full details of the composites, method and sequence of lay-up, curing etc.

Materials used in the repair should be identical to or compatible with those used in the manufacture and test specimens should be prepared to qualify the bond and strength of the proposed repair.

Repairs shall not be carried out until all loose resin and reinforcement has been removed and the affected areas cleaned and dried. In some cases it will be necessary to roughen the surrounding area to obtain suitable adhesion.

Where the laminate is fractured and repair is considered permissible, the whole of the damaged area should be cut out and the inside edge of the hole chamfered so that the hole is larger on the inside. Care should be taken to ensure that the resin and reinforcement is laid-up overlapping the edges to ensure good adhesion over a wide area.

Where superficial damage to the gel coat has occurred, a thicker film should be applied to allow for shrinkage.

The existing reinforcing materials should be interlaced with repair matting, together with a mechanical interlock in the case of inserted replacement branches.

All repairs to the shell of laminated fibre vessels should be proved sound by the application of a hydrostatic test at maximum operating pressure.

Repairs shall be executed by the Manufacturer, if possible in the manufacturing plant or, if not, under shop conditions on site.

Repairs shall be executed by trained personnel in accordance with approved procedures.

6. HANDLING AND SAFETY

6.1 HANDLING

Upon arrival at site the packaging shall be checked visually for possible transport damage. Vessels should be handled and stored in the original packing for as long as possible to avoid possible damage. The vessel shall be inspected after unpacking.

Care shall be taken at all times to ensure that tools, equipment etc. are not dropped in or on vessels. Personnel working in or on them shall wear soft-soled shoes and equipment shall be suitably padded whenever possible.

Vessels shall not be rolled off or dropped on to the ground. The vessels shall be hoisted by means of a spreader bar and rubber, canvas or nylon hoisting slings. The method of lifting vessels shall be carefully considered to prevent damage. All lifting equipment in contact with them shall be padded and there shall be sufficient lifting points to adequately spread the load on the vessel. If lifting lugs are provided they should be used, but on no account should branches or other attachments be used for lifting.

All branches shall be blanked with either service blanks or temporary covers to prevent the ingress of foreign matter.

Any loose items (e.g. distributors, packing supports, agitators, etc.) which cannot be packed separately shall be checked to prevent movement and damage to the vessel.

Any protective material such as flange covers shall remain in place until immediately before installation of the connecting piping.

During handling, care shall be taken that the vessels are not unduly stressed. Vessels shall not be allowed to come into contact with corners or sharp edges.

When vessels are transported they shall be securely mounted and padded to prevent damage and the mountings shall be secured to the vehicle, allowing adequate clearance between the vessels and vehicle members. Tanks with low structural stability, e.g. thin-walled open tanks, shall be suitably braced to resist deformation in transit.

Vessels should be suitably supported. These supports shall not be placed under the nozzles.

Depending on weather conditions, the vessels should be stored under cover and, if necessary, sufficiently anchored to the ground.

The storage area shall be level and free from sharp protrusions. Consideration shall be given to movements due to wind, and temporary anchors shall be provided if required.

6.2 HEALTH AND SAFETY ASPECTS

Contact with epoxy and polyester resins usually presents no problems, but curing agents, catalysts, etc. may produce irritation if allowed to come into contact with the skin. Operators should therefore observe strict personal hygiene in the handling of these products when in the uncured liquid state.

Skin contact should be prevented by the use of rubber gloves and barrier creams. Any accidentally contaminated skin areas should be thoroughly washed with soap and water.

Subsequent rubbing of the skin with lanoline-containing creams is advisable. Excessive skin contamination should be treated by medical staff.

During machining of GRP, a dust mask and adequate work clothing should be worn in order to prevent inhalation of, or skin irritation by, the glass-fibre dust produced. Machining should be done in a well-ventilated room or in the open air in order to minimize contact with dust. In the workshop a portable dust extraction unit should be used with the point of extraction as close as possible to the work.

The correct mixing sequence in handling polyester resin should be adhered to strictly in order to prevent the risk of an explosion (2.1).

7. REFERENCES

In this DEP reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Glass-fibre reinforced epoxy and polyester vessels - manufacturing requirements	DEP 31.22.30.34-Gen.

SHELL PUBLICATIONS

Static Electricity - Technical and Safety Aspects	Shell Safety Committee

AMERICAN STANDARD

Fibre-reinforced plastic pressure vessels	ASME Section X

Issued by:
American Society of Mechanical Engineers
345 East 47th Street
New York, 10017
USA.

Test method for short-time hydraulic failure pressure of plastic pipe, tubing, and fittings	ASTM D1599
Test method for determination of external loading characteristics of plastic pipe by parallel-plate loading	ASTM D2412
Test method for beam deflection of reinforced thermosetting plastic pipe under full bore flow	ASTM D2925

Issued by:
American Society for Testing and Materials
1916 Race St.
Philadelphia, Pa.19103
USA.

BRITISH STANDARDS

Design and construction of vessels and tanks in reinforced plastics	BS 4994

Issued by:
British Standards Institution
389 Chiswick High Road
London W4 4AL
England
United Kingdom.

DUTCH STANDARD

Rules for pressure vessels - Glass-fibre reinforced plastics	D 1402 V

Issued by:
N.V. SDU Uitgeverij
Postbus 20014
2500 EA The Hague
The Netherlands.

FRENCH STANDARD

Glass-reinforced plastic tanks and apparatus, construction code	NF T57-900

Issued by:
AFNOR
Tour Europe Cedex 7
92049 Paris
France.

GERMAN STANDARD

Pressure vessels of glass fibre reinforced thermosetting plastics	AD-Merkblatt N 1

Issued by:
Beuth-Verlag GmbH
Burggrafenstrasse 4-10
D-1000 Berlin 30
Germany.

SWEDISH STANDARD

Code for stationary vessels (pressure, open and vacuum) of reinforced polyester plastic

Issued by:
Swedish Pressure Vessel Commission
P.O. Box 8132
S-104 20 Stockholm
Sweden.

APPENDIX 1 REINFORCING MATERIALS

Glass-fibre, often made from low-alkali glass (E glass), is the most commonly used reinforcement. Synthetic fibres are sometimes used as a reinforcement of the gel coat or for chemical services which will attack glass. Resin systems reinforced with these synthetic fibres also show good flexibility and impact properties.

Glass fibres are made by drawing molten glass through a bushing with a nozzle having a number of holes (normally 204). Each hole is the source of one filament of glass with a diameter of about 10 µm. The filaments are united to form a strand (end). A number of these strands (ends) are then grouped together, either untwisted to form a roving, or twisted to form a yarn.

During spinning, a size is applied to the glass-fibre filaments. The most important components of a size are: binder, lubricant and finish (coupling agent). The binder binds the individual filaments into a bundle, so as to prevent damage and breakage during further processing. The lubricant protects the filaments from mutual abrasion and facilitates winding. The finish (coupling agent) improves the bond between glass fibre and resin; it is only applied on rovings. The sizes for rovings are generally based on polyvinylacetate. The sizes for yarns are generally based on a blend of dextrin and soluble oil. Before the glass-fibre fabrics made from yarns can be used, the dextrin-based size must be removed (e.g. by heat cleaning at 470 °C). Often, after removal of the size, a finish (coupling agent) in a percentage of 0.2-0.5% wt is applied in order to achieve a good bond between the glass fibre and the resin.

Most finishes are based on either epoxy-silane, amino-silane, vinyl-silane (e.g. Garan), acrylic-silane or chrome complexes (e.g. Volan A).

In general epoxy-silane type, amino-silane type and chrome-complexes finishes are suitable for epoxy resins and vinyl-silane type and acrylic-silane type finishes for unsaturated polyester resins.

The major forms of glass fibres available for reinforcement are summarized below:

Roving

A number of strands (ends) grouped together with appreciable twist.

Fibres and yarns are designated by the unit "tex", indicating the total mass per unit length.

1 tex = 1 gram per 1000 metres, e.g. 2400 tex roving, which is identical to the previously used designation of a 60 ends roving, i.e. 60 strands (ends) grouped together in one roving.

Spun roving

A number of strands which are looped many times, held together with a slight twist.

Woven (spun) rovings

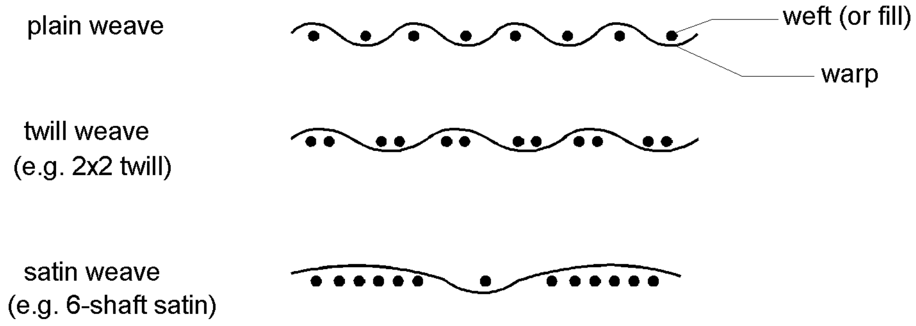
(Spun) rovings woven into a coarse fabric.

Yarn

A number of strands (ends) grouped together by twisting.

Plain weave, twill weave, satin weave

Fabrics woven from yarn in different patterns (see illustrations below). The weaves are specified by mass, e.g. 300 g/m^2.



Weaves can be divided into three types of fabrics; square fabric, balanced fabric and unidirectional fabric.

Square fabric

A fabric of plain weave, with identical count yarns and an equal number of ends and picks per linear metre in both the warp and weft directions.

Balanced fabric

A fabric in which the tensile strength is approximately the same in both warp and weft directions (a square fabric is always a balanced fabric).

Unidirectional fabric

A fabric in which the strength is very high in one direction compared to another.

Mat

A fibrous material consisting of randomly orientated chopped rovings, length 25-50 mm (i.e. chopped strand mat) or swirled filaments, loosely held together either by an adhesive or mechanically (i.e. needled mat).

NOTE: Commercially available chopped strand mats are generally provided with a finish only compatible with polyester resin; a good bond between such a chopped strand mat and any epoxy resin cannot be achieved.

Surfacing mat (tissue or veil)

A thin mat of fine fibres of a chemical-resistant glass (C-glass) or other material (e.g. poly-acrylonitrile, linear polyester), bonded together at random with a binder. This mat is used to reinforce the resin-rich layer and to produce a smooth surface.

APPENDIX 2 TYPICAL MECHANICAL AND PHYSICAL PROPERTIES OF GRP AT 20 °C

The following are average values. Accurate values for the design of GRP laminates should be agreed between Principal and Manufacturer.

The values are highly dependent upon resin system, glass content, temperature etc.

Density		1.7 - 1.9	kg/cm^3
Ultimate tensile unit strength		250	N/mm per kg/m^2 glass-fibre cloth reinforcement
		200	N/mm per kg/m^2 glass-fibre chopped strand mat reinforcement
Unit modulus		16 000	N/mm per kg/m^2 glass-fibre cloth reinforcement
		14 000	N/mm per kg/m^2 glass-fibre chopped strand mat reinforcement
Thermal conductivity		0.24	W/m.K
Linear coefficient of expansion		20×10^{-6}	per °C
Max. allowable temperature *	GRE	150	°C
	GRUP	100	°C

* This temperature also depends on the service conditions.
For continuous service a temperature of 125 °C and 80 °C respectively should not be exceeded.
There is no pratical limit on minimum temperature. See (4.1).

APPENDIX 3 QUALITATIVE SUMMARY OF GRP PERFORMANCE

	Chemical resistance			Other properties		
	Acids	Alkalis	Solvents	Processability	Strength	Heat resistance
EPOXY RESINS						
aliphatic amine-cured	Fair	Fair	Good	Fair	Good	Good
aromatic amine-cured	Fair	Good	Very good	Fair	Very good	Very good
acid anhydride-cured	Good	Poor	Good	Good	Good	Good
POLYESTER RESINS						
isophthalic types	Fair	Poor	Good	Good	Good	Fair
bisphenol-A types	Good	Fair	Fair	Fair	Good	Fair
VINYL-ESTER RESINS						
n = 0 (Note 1)	Good	Fair	Good	Fair	Very good	Good
n = 2 (Note 1)	Good	Good	Fair	Good	Very good	Fair

1) n-value indicates the molecular weight of the epoxy resin-based component.

APPENDIX 4 MANUFACTURING TECHNIQUES

Filament winding

Helically winding of resin-impregnated glass-fibre roving (or spun roving) around a mandrel in a predetermined pattern under controlled tension.

The inside diameter of the finished product is determined by the outside diameter of the mandrel.

Hand lay-up filament winding

Filament winding in which also other reinforcing materials, such as woven glass-fibre cloth or chopped strand mat, are interspersed in order to provide additional longitudinal strength, e.g. for fittings and flanges.

Tape winding

Helically winding of resin-impregnated woven glass-fibre tape with at least 50% overlap around a mandrel, so that the various layers are cross-wise and with staggered seams.

Centrifugal casting

Resin impregnating of woven glass-fibre cloth or chopped strand mat by rotating a cylinder in which a mandrel is present.

The outside diameter of the finished product is determined by the inside diameter of the cylinder.

Pressure moulding

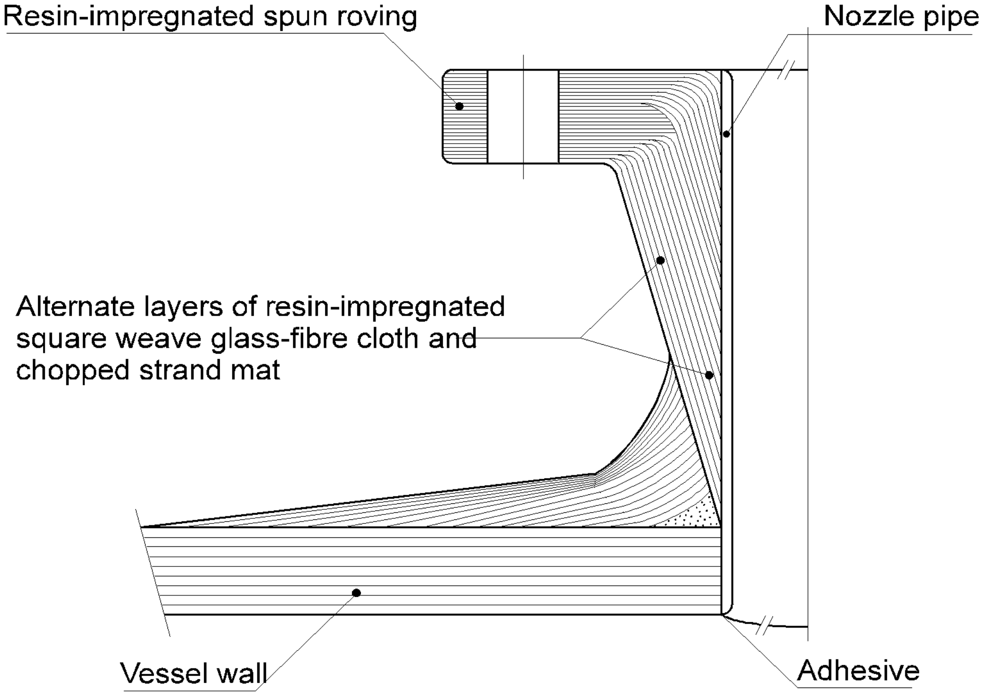
Moulding or laminating of resin-impregnated glass-fibre reinforcing material(s) into a confined cavity by applying pressure and (usually) heat.

Glass-fibre reinforcing materials may be roving, spun roving, woven (spun) roving, woven cloth, chopped strand mat, short fibrous glass or combinations of these materials.

Hand lay-up

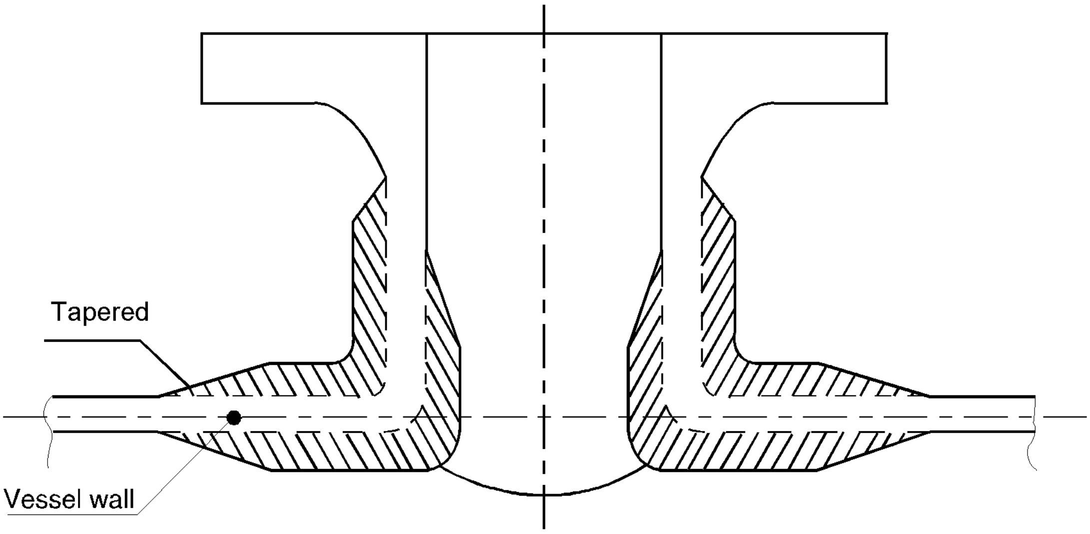
Manually placing and bonding together with resin of two or more layers of woven glass-fibre cloth or chopped strand mat on a mould.

APPENDIX 5 TYPICAL CONSTRUCTION OF NOZZLES



NOTE: If it is possible, internal reinforcement as shown in Appendix 6 may also be considered.

APPENDIX 6 TYPICAL BRANCH



NOTE: The use of this internal reinforcement depends on the construction of the branch connection in the shell and of the pull-out load.

APPENDIX 7 TYPICAL FLANGE CONSTRUCTION

Figure 1 Integral-type flange

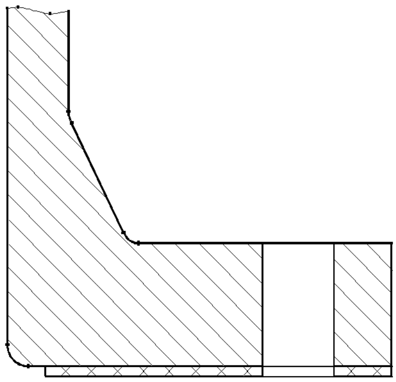
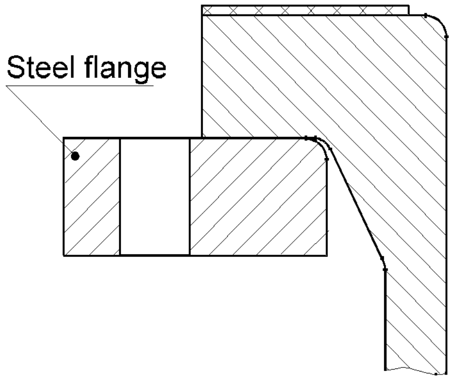
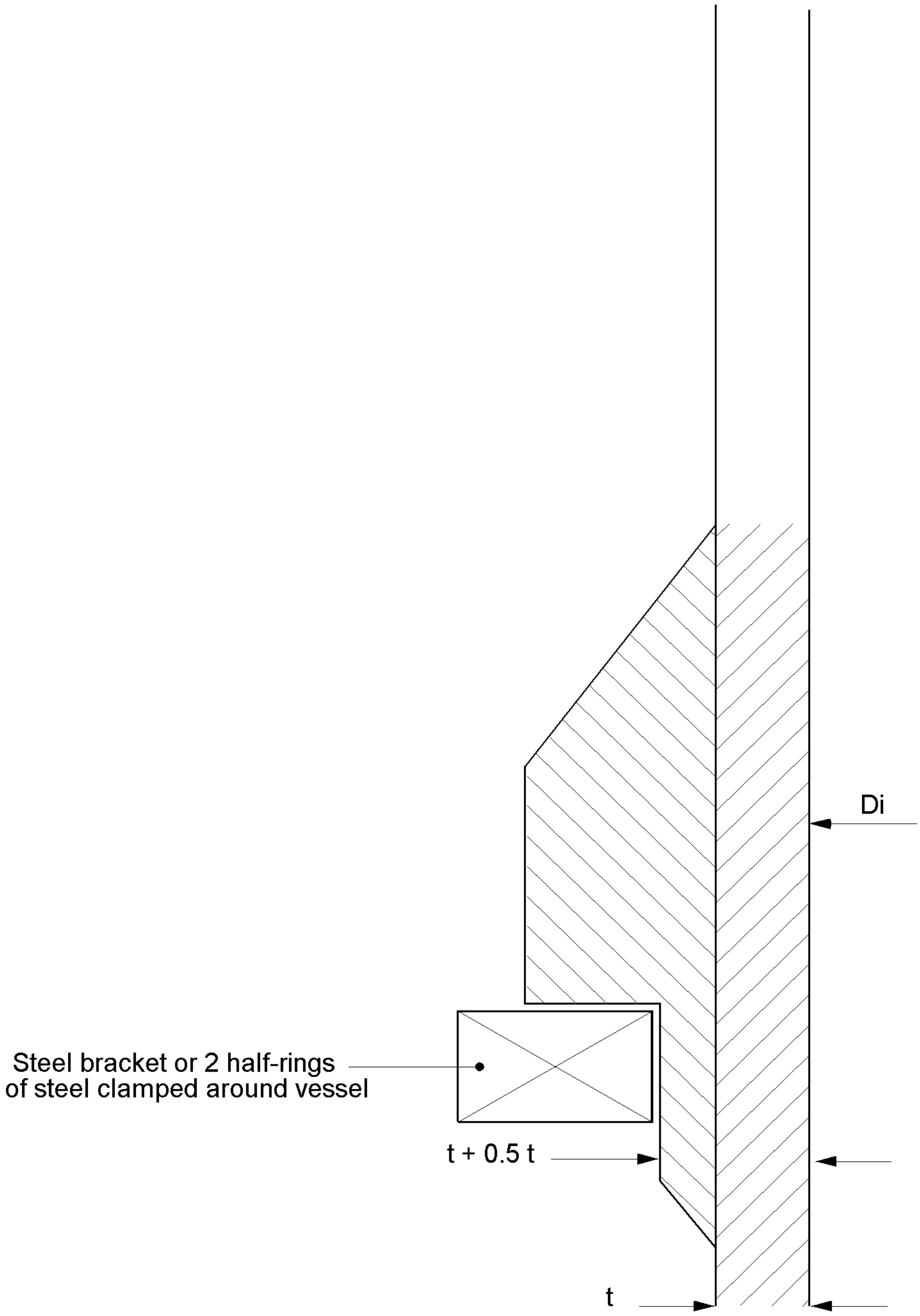


Figure 2 Loose steel flange



APPENDIX 8 TYPICAL DETAIL OF SUPPORT FOR VERTICAL VESSELS



APPENDIX 9 SADDLE FOR HORIZONTAL VESSELS