

Specification for

Reinforced plastics pipes, fittings and joints for process plants

UDC 621.643.2:678.067.5:66.026

Confirmed January 2009

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

BSI
Documents

AVA

Document Sharing Hub

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Plastics Standards Committee (PLM/-) to Technical Committee PLM/9 upon which the following bodies were represented:

- British Chemical Distributors' and Traders' Association Ltd.
- British Gas Corporation
- British Plastics Federation
- British Steel Industry
- British Valve Manufacturers' Association Ltd.
- Copper Tube Fittings Manufacturers' Association
- Department of the Environment (Housing and Construction)
- Department of the Environment (PSA)
- Electricity Supply Industry in England and Wales
- Engineering Equipment and Materials Users' Association
- Institution of Civil Engineers
- Institution of Municipal Engineers
- Institution of Public Health Engineers
- Institution of Water Engineers and Scientists
- National Association of Plumbing, Heating and Mechanical Services Contractors
- Plastics and Rubber Institute
- Plastics Land Drainage Manufacturers' Association
- Royal Institute of Public Health and Hygiene
- STC Water Regulations and Fittings Scheme
- Water Companies Association
- Water Research Centre

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- British Adhesive Manufacturers' Association
- British Board of Agrément
- Greater London Council
- Heating and Ventilating Contractors' Association
- Institute of Plumbing
- Ministry of Agriculture, Fisheries and Food
- Pitch Fibre Pipe Association of Great Britain

This British Standard, having been prepared under the direction of the Plastics Standards Committee, was published under the authority of the Board of BSI and comes into effect on 28 September 1984

© BSI 03-1999

The following BSI references relate to the work on this standard:
Committee reference PLM/9
Draft for comment 76/50861 DC

ISBN 0 580 13776 7

Amendments issued since publication

Amd. No.	Date	Comments
6294	November 1990	Indicated by a sideline in the margin

Contents

	Page
Committees responsible	Inside front cover
Foreword	iii
Section 1. General	
1 Scope	1
2 Definitions	1
3 Nomenclature, symbols and units for design	1
Section 2. Materials and properties	
4 Thermosetting resin systems	2
5 Fibrous reinforcement	2
6 Aggregates and fillers	2
7 Thermoplastics liners	2
8 Cement for bonding spigot and socket joints	2
9 Mechanical properties	3
10 Thermal properties	3
11 Chemical properties	4
12 Construction of a chemical liner	4
13 Flammability	4
Section 3. Design and design calculations	
14 General	5
15 Laminate design and thickness	6
16 Design calculations for pipes subject to internal pressure	7
17 Design calculations for pipes subject to vacuum	7
Section 4. Dimension markings and information	
18 Dimensions	8
19 Tolerances on dimensions of pipes and fittings	9
20 Marking	9
21 Information	9
Section 5. Construction and workmanship	
22 Manufacturing conditions in works involving the cure of resins	10
23 Manufacturing procedure	10
24 Thermoplastics liners	10
25 Fittings	11
26 Joints	15
Section 6. Testing	
27 Tests for design	18
28 Production testing	19
29 Welding procedure tests for thermoplastics linings	20
30 Tests for production welds in thermoplastics linings	20
31 Production samples for mechanical tests on a laminate	20
Section 7. Inspection and testing	
32 Facilities for inspection and testing	20
33 Certification of inspection and testing	20
Appendix A Information to be given with an enquiry or tender or on receipt of an order	22
Appendix B Methods of test	22
Appendix C Worked examples of the design method specified in section 3	28
Appendix D Methods of manufacture of reinforced plastics pipes	34
Appendix E Acceptable limits of visual defects	35

	Page
Appendix F Pipework fabrication methods	36
Figure 1 — Limits of pressure and diameter	37
Figure 2 — Relationship between thickness and glass content for laminates with resin of relative density, (+), 1.1 to 1.3	38
Figure 3 — Relationship of unit modulus to winding angle	39
Figure 4 — Factor related to temperature	39
Figure 5 — Factor related to cyclic loading	40
Figure 6 — Butt joint build-up for lined pipe	41
Figure 7 — Pipework shapes for fabrication methods 1 and 2	42
Figure 8 — Flanged pipe fittings for method 3	43
Figure 9 — Typical stub flanges (type A)	44
Figure 10 — Typical full faced flanges (types B and C)	45
Figure 11 — Butt joint build-up for unlined pipe	46
Figure 12 — Test piece for the determination of shear strength of bond between thermoplastics lining and laminate	46
Figure 13 — Test piece for the determination of lap shear strength of laminate	47
Figure 14 — Test for the determination of peel strength of bond between thermoplastics liner and laminate	48
Figure 15 — Test piece for the tensile strength of thermoplastics sheet and welds	49
Figure 16 — Typical examples of laminate construction	50
Figure 17 — Biaxial failure envelope	51
Table 1 — Derivation of definitions relating to symbols	3
Table 2 — Minimum mechanical properties of reinforced laminate layers	4
Table 3 — Factors to be applied to design unit load of continuous rovings for different winding angles	3
Table 4 — Factor relating to method of manufacture	5
Table 5 — Factor relating to loss in ultimate tensile strength	6
Table 6 — Minimum socket depths	12
Table 7 — Equations for calculating fittings dimensions	13
Table 8 — Minimum separation dimensions to be used in equations of Table 7	13
Table 9 — Dimensions of flanges	14
Table 10 — Thickness and mating dimensions of flanges and backing flanges	15
Table 11 — Minimum butt joint overlay lengths including taper	17
Table 12 — Acceptable limits of visual defects	35
Table 13 — Pipework fabrication methods	36
Publications referred to	Inside back cover

Foreword

This British Standard has been prepared under the direction of the Plastics Standards Committee. Its purpose is to establish a general standard for the design and manufacture of reinforced plastics pipes and fittings for process plant. The manufacture of pipes and fittings in reinforced plastics involves a number of materials, plastics and reinforcing systems and a number of different methods of manufacture.

Metallic pipes, being made from materials which are isotropic, may conveniently be designed by calculating permissible stresses, based on measured tensile and ductile properties. Reinforced plastics are usually anisotropic, and the design method adopted in this standard, being based on unit loading, is particularly suited to the design of composite materials.

This standard includes a method of calculation for an appropriate laminate construction based on the allowable unit loading and unit modulus for the type of composite concerned. Design factors are included to cover such variables as:

- a) deterioration of the composite properties over a long period;
- b) effect of temperature on the properties of the composite;
- c) repeated or alternating loading.

The nominal pipe sizes specified in this standard have been selected from those under consideration within Technical Committee 138, Plastics pipes and fittings for the transport of fluids, of the International Organization for Standardization (ISO).

It is implicit that pipes and fittings covered by this standard should be made only by manufacturers and operators (see **23.1** and **24.4**) who are competent and suitably equipped to fulfil all the requirements of this standard.

It is expected that these principles will be proved by documentation of past experience or by prototype testing, being supplied to the satisfaction of the purchaser or the nominated inspecting authority as appropriate.

Attention is drawn to BS 5480 which covers pressure and non-pressure GRP pipes, joints and fittings intended for conveying, above or below ground, liquids including potable and non-potable water, foul sewage and storm water.

The following publications give information on stress/strain analysis of laminates (see clause **9** and **15.1**).

Jones, R M, "Mechanics of composite materials", McGraw Hill (1975)

Calcote, L R, "The analysis of laminate composite structures", van Nostsand (1969)

Eckold, G C, Leadbetter, D, Soden, P D, and Griggs, P R, "Lamination theory in the production of pipeline envelopes for filament wound materials subject to biaxial loading", Composites (1978)

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 52, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1 Scope

This British Standard specifies requirements for the materials, properties, design calculations, manufacture, inspection and testing of reinforced plastics pipes, fittings and joints consisting of thermosetting resin systems with glass fibre reinforcement (GRP) for process plants.

Constructions both with and without a lining of thermoplastics are included. The information to be supplied for designs for pipes and fittings to this standard is given in Appendix A.

This British Standard is not applicable in the following circumstances:

- a) where the product of the design pressure in bar¹⁾ and the nominal diameter in millimetres is more than 11 000 (see Figure 1);
- b) where the operating temperature is outside the limits of – 10 °C to + 110 °C;
- c) where the pipes may be subject to some applied external pressure other than that due to soil loading or vacuum;
- d) where there is a non-taint requirement, e.g. for the water and food industries, as no requirements are given for the effect of GRP on those materials.

NOTE 1 In addition to the specific exclusions above, the following points are emphasized and it should not be assumed that pipes made in accordance with this standard will necessarily be universally suitable for chemical plant use.

1) Unstressed dip coupon testing of sample laminates may not necessarily give a valid indication of the long term resistance of the material to the actual internal and external chemical environment.

2) Relatively small changes in the concentration of organic solvents and fluctuations in the operating temperatures can have marked effect on the chemical resistance of a GRP laminate.

3) Most of the practical experience and design data on which this standard is based relates to pipes which were made by the hand lay-up process and contained large proportions of chopped strand mat reinforcement, and most of the practical experience under operating conditions was obtained with small diameter pipes which were only subject to low positive pressure.

4) In many chemical plants pipework may be subject to occasional applied loads or impacts, which are not a part of the normal operating conditions. Care should be taken where such hazards are liable to arise.

It is recommended therefore that manufacturers of GRP pipes should demonstrate their ability to produce satisfactory pipe and fittings for any specific duty, either by producing documentary evidence of past performance under similar conditions or by making and testing prototype units.

NOTE 2 The titles of the publications referred to in this standard are listed on the inside back cover.

¹⁾ 1 bar = 10⁵ N/m² = 100 kPa.

²⁾ These definitions differ from those given in BS 1755-1.

2 Definitions

For the purpose of this British Standard the definitions given in BS 1755-1 apply, together with the following.

2.1 curing²⁾

the chemical reaction resulting in the final polymerized product

NOTE It may be effected at ambient temperature or by the use of heat. In certain resin systems the full cure has to be effected in two stages of which the first may, and the second does, involve the application of heat. This second stage is known as the “post-cure”.

2.2 laminate²⁾

a resin reinforced with a form of glass fibre material

2.3 laying-up²⁾

a process of applying or producing laminates in position on a former prior to cure

2.4 aggregates

an inert granular material of a size range between 5 mm and 0.05 mm used as a design part of the structure

NOTE Aggregates, such as silica sands, may be incorporated where they are a design part of the composite structure.

2.5 inert fillers

a fine material with a particle size below 0.05 mm

2.6 angle of lay, θ

the angle of the application of continuous rovings with respect to the horizontal axis

3 Nomenclature, symbols and units for design

Several terms relating to the strength and load carrying capacity of individual layers of composite laminate are used in this standard. Some have similar but quite distinct meanings and because of their similarity and their application, particular care is required in their use. The terms concerned are listed in Table 1, with their definitions, symbols and units.

The following additional symbols with their terms are used in the design calculations:

K	overall design factor determined from the equation (1),
k_1	factor relating to method of manufacture,
k_2	factor relating to long term behaviour,
k_3	factor relating to temperature,
k_4	factor relating to cyclic loading,
k_5	factor relating to curing procedure,
n_x	number of layers of type x in construction under consideration,
m_x	mass of reinforcement per unit area (kg/m^2 glass) in one layer of type x,
u_x	design unit loading [N/mm {per kg/m^2 glass}] for a selected layer of type x,
X_x	unit modulus of a selected layer of type x [N/mm {per kg/m^2 glass}]
ϵ_x	allowable strain for each type of reinforcing material,
ϵ	allowable strain, determined from resin properties,
ϵ_d	maximum design strain,
ϵ_R	strain to failure of the unreinforced resin determined by the method described in Method 320C of BS 2782:Method 320 A to F:1976.

Section 2. Materials and properties

4 Thermosetting resin systems

NOTE 1 The thermosetting resins used for the manufacture of pipes and fittings may be of a number of types. There are many resin systems in each type and the properties of these systems vary, especially with respect to chemical resistance and heat distortion point.

Polyester and epoxy resin systems shall comply with BS 3532 and BS 3534 respectively.

In order for the chemical reaction, resulting in the final polymerized product, to take place hardeners, catalysts and accelerators shall be added to the resin in accordance with the manufacturer's recommendations.

NOTE 2 The amount of hardener, catalyst and/or accelerator used is critical, as it can affect both the rate of reaction and extent of the cure.

NOTE 3 If specified at the placement of an order, the outer layer of resin may incorporate pigments, dyes or specific ultraviolet light absorbers to prevent the transmission of UV light and/or for identification purposes.

5 Fibrous reinforcement

The glass fibre reinforcement used in the body of the laminate shall comply with BS 3396, BS 3496, BS 3691 or BS 3749, as appropriate, and shall have a surface treatment compatible with the resin.

6 Aggregates and fillers

The resin used shall contain only fillers as required for viscosity control; they shall be limited to a maximum of 5 % of the mass of the resin and shall not interfere with the capability to visually inspect the laminate.

Special additives, such as aggregates, graphite and fire retardants, etc., shall only be used to impart special properties, e.g. stiffness, conductivity.

7 Thermoplastics liners

If thermoplastics liners are used, the material shall be selected on the basis of resistance to the fluid to be carried.

If unplasticized polyvinyl chloride (uPVC) is the specified liner, uPVC pipe complying with BS 3505 or BS 3506 shall be used. In the case of nominal sizes greater than 500 mm uPVC sheet complying with BS 3757 shall be used for fabrication (see clause 24).

The minimum thickness for uPVC shall be 2.5 mm.

If used, the minimum thickness of polypropylene shall be 2 mm except for pipe of diameter 80 mm or less, for which the minimum thickness shall be 1.5 mm.

NOTE Specialized liners such as CPVC, FEP, PVDF and PTFE may be required for very difficult process conditions.

8 Cement for bonding spigot and socket joints

The manufacturer shall ensure that the bonding cement will be satisfactory for the chemical conditions specified, and shall state the minimum ambient conditions required for the bonding system to cure properly.

The bonding cement shall develop a minimum internal shear strength of 7 N/mm^2 , when tested in accordance with the method described in B.2.

When tested in accordance with the method described in BS 5350-C5, using double overlapped joint test pieces, bond materials to be used to join GRP sockets and spigots shall have a minimum bond strength of 7 N/mm^2 .

Table 1 — Derivation of definitions relating to symbols

Term	Definition	Derivation	Symbol	Unit
Ultimate tensile unit strength	The strength of a constituent layer of a laminate, expressed as force per unit width, per unit mass of reinforcement.	Obtained from the fracture load of a laminate of known construction, in a tensile test.	u	N/mm (per kg/m ² glass)
Layer design unit loading	The load permitted to be applied to a constituent layer of a laminate, for the pipe or fitting under consideration.	Determined by multiplying the unit modulus, X , by the allowable strain for the particular laminate layer.	u_x	N/mm (per kg/m ² glass)
Unit modulus	The ratio of the load per unit width per unit mass of glass to the corresponding direct strain, in a loaded tensile test piece.	Obtained from the measured load at 0.2 % strain in a tensile test.	X	N/mm (per kg/m ² glass)
Laminate design unit loading	The load permitted to be applied to a laminate, expressed as force per unit width. The subscripts indicate a main (U_{LAM}) or an overlay (U_{OVL}) laminate.	Obtained by summing the load carrying capacities of all the layers in the laminate.	U_{LAM} U_{OVL}	N/mm width
Unit load	The force per unit width carried by a laminate resulting from pressure or other loads applied to the pipe or fitting.	Obtained from the appropriate design calculations for the pipe or fitting under consideration.	Q	N/mm width

9 Mechanical properties

The mechanical properties of the laminate layers shall be not less than the values given in Table 2 when tested in accordance with the appropriate methods described in Appendix B.

The values given in Table 2 apply to laminates incorporating only E glass reinforcement and complying with BS 3396, BS 3496, BS 3691 or BS 3749, and having a glass content by mass as determined by the method described in BS 2782:Method 1002 within the range shown in Figure 2.

If higher values for mechanical properties are used as a basis for design the manufacturer shall demonstrate their accuracy.

If continuous rovings are filament wound at an angle θ to the pipe axis, values of circumferential and longitudinal unit modulus shall be calculated by application of the graph in Figure 3 and the factors given in Table 3 as appropriate to the angle.

The use of other values for the factors in Table 3 is permitted if a rigorous anisotropic elastic analysis is carried out (see 14.1). This analysis shall allow for the contribution from each layer in the laminate and for interaction between normal and shear strains (see foreword). It shall be ensured that the strain transverse to the fibre direction is less than 0.1 %. In the absence of a rigorous anisotropic elastic analysis the axial strain shall be not more than 0.1 % for winding angles greater than 75°.

Table 3 — Factors to be applied to design unit load of continuous rovings for different winding angles

Filament winding angle to axis θ	Circumferential factor	Longitudinal factor
$0^\circ < \theta \leq 15^\circ$	0	1
$15^\circ < \theta \leq 75^\circ$	0.5	0.5
$75^\circ < \theta \leq 90^\circ$	1	0

10 Thermal properties

The heat distortion temperature of the fully cured resin system used for the reinforced laminate, when determined in accordance with BS 2782:Method 121A, shall be not less than 20 °C higher than the design temperature of use of the pipe and fitting.

Table 2 — Minimum mechanical properties of reinforced laminate layers

Type of reinforcement	Property		
	Ultimate tensile unit strength (see B.3)	Unit modulus (see B.4)	Lap shear strength (see B.5)
	N/mm (width per kg/m ² glass)	N/mm (width per kg/m ² glass)	N/mm ²
Chopped strand mat	200	14 000	7.0
Woven roving cloth	250	16 000	6.0
square woven			
biased woven less than 5.1 : 1	430	23 000	6.0
major direction	90	10 000	6.0
minor direction			
baised woven equal or more than 5.1 : 1	450	25 000	6.0
major direction			
Continuous rovings	500	28 000	6.0

11 Chemical properties

NOTE 1 The chemical resistance of resins varies with the type, the source and the state of cure.

In the absence of case histories, the suitability of a laminate for a particular duty shall be established by tests carried out in accordance with the methods described in BS 4618-4.1. The test pieces shall be representative of the pipe when made and test conditions shall be consistent with conditions of the intended use. Particular attention shall be paid to maintaining the concentration of trace materials in test liquors and to the temperature of the test.

When assessing the chemical resistance of a laminate, in addition to determining changes in mass, dimensions, and strength, the laminate shall be examined for blisters, resin crazing, change in appearance of the fibres and loss of gloss, any of which may be significant.

NOTE 2 Attention is drawn to the fact that the chemical resistance of a laminate under stress may be different to that of an unstressed coupon. The duration of the tests is important, as the results of short term tests can be misleading.

12 Construction of a chemical liner

NOTE The basis of the design of GRP pipes is the strength of the glass reinforcement. Glass is adversely affected by many chemicals and therefore it is necessary to protect the structural laminate from process liquors. The type and extent of the protection required depends upon the operating conditions and it may be that more than one of the liners described will be satisfactory for any particular process condition. It is important that the integrity of the selected liner is maintained throughout the pipework system.

12.1 Thermoplastics liners. Where a thermoplastics lining is used the minimum bond strength of the reinforcement to the lining shall be 7.0 N/mm² in direct shear and 7 N/mm width in peel, when tested by the methods described in B.6 and B.7.

NOTE This strength will normally be achieved by the inclusion of a laminate with a minimum of 450 g/m² chopped strand mat and glass content between 25 % and 33 % immediately behind the thermoplastics liner.

12.2 Thermoset liners. Thermoset liners available in constructions shall be as follows.

Type 1 shall comprise a corrosion barrier consisting of a resin rich layer reinforced with C glass or synthetic fibre tissue with a thickness of between 0.25 mm and 1.0 mm. This barrier shall be followed by an initial laminate containing a minimum of 900 g/m² chopped strand mat with glass content of between 25 % and 33 % by mass when determined by the method described in BS 2782:Method 1002.

Type 2 (epoxide resin construction only) shall comprise a corrosion barrier consisting of a resin rich layer reinforced with C glass or synthetic fibre tissue with a uniform thickness of 0.25 mm to 1.0 mm.

Type 3 shall comprise a corrosion barrier consisting of a resin rich layer of thickness between 1 mm and 2 mm which shall be reinforced.

13 Flammability

Where pipe is intended to convey flammable fluids the resin in the external surface layers shall be modified so as to have a surface spread of flame characteristic that complies with clause 2 of BS 476-7:1971. The test shall be carried out on a laminate representative of that to be used for the pipe.

Section 3. Design and design calculations

14 General

14.1 Considerations for design. The manufacturer shall ensure that the information set out in Appendix A is available before commencing a design.

All pipes, fittings and joints shall be designed to the maximum continuous pressure rating under the most severe combination of all loads due to the following:

- a) internal pressure or vacuum;
- b) test pressure requirement;
- c) bending loads from pipe and contents;
- d) earth loading;
- e) design temperature change and consequent thermal expansion or contraction;
- f) bending moments due to applied external loads;
- g) vibration;
- h) all anchor loads.

The design of fittings shall be confirmed as satisfactory by the testing of prototypes.

NOTE 1 All pipes should be designed to take the maximum design end load due to pressure except when rubber ring seals are used when the end load requirement may be waived.

NOTE 2 The anchor loads should be determined from the pipeline flexibility calculations and pressure thrust, the latter being equal to the maximum pressure times the largest internal cross section of the pipe.

NOTE 3 In the consideration of the membrane strains an equal strain in all layers should be assumed.

NOTE 4 Loads may be imposed by personnel during erection and operation and should be acknowledged.

14.2 Basis for design

NOTE 1 The design procedure in this standard takes advantage of the ease with which the laminate details can be varied to suit the loads imposed by operating and test conditions in the different regions.

When designing for process plant pipework in reinforced plastics it is most desirable to work in terms of unit load (i.e. force per unit width per unit mass of glass) rather than stresses (i.e. force per unit area).

Where the design calculations require the use of allowable compressive unit loadings these shall be determined by the method of substituting the ultimate compressive unit loading for the ultimate tensile unit loading in equation (2).

Ultimate compressive unit load shall be determined, when required, for each laminate layer concerned by the method described in BS 2782:Method 345A.

Where the design incorporates reinforcement with directional properties (e.g. woven rovings), the orientation of the fibres shall be specified in order to ensure that the structural properties required by the design are attained.

NOTE 2 Worked examples of this design method are given in Appendix C.

14.3 Conditions for design

14.3.1 Design temperature. The design temperature shall be the maximum temperature it is possible for the pipe to attain under operating conditions (including boil-out, where applicable).

14.3.2 Design pressure. The design pressure (i.e. the pressure to be used in the equation for the purpose of calculation) shall be not less than:

- a) the pressure that will exist in the system when the pressure relieving device starts to relieve, or the set pressure of the pressure relieving device, whichever is the higher;
- b) the maximum pressure that can be attained in service where this pressure is not limited by a relieving device.

The value of the design pressure to be used in the equations in this section shall include the static head where applicable, unless this is taken separately into account in the equation.

14.3.3 Design vacuum

NOTE The design vacuum is the lowest pressure to be generated in the pipe during operation.

Pipes subject to vacuum shall be designed to avoid the risk of failure due to elastic instability.

14.4 Factors for design

14.4.1 Design factor. The design factor K shall be calculated from equation (1).

$$K = 3 \times k_1 \times k_2 \times k_3 \times k_4 \times k_5 \quad (1)$$

k_1 to k_5 represent part factors determined by the method of manufacture and operating conditions. The intention of this procedure is that no pipe or fitting designed in accordance with this standard shall have a design factor of less than 6.

Values for part factors k_1 to k_5 are determined as follows:

- a) Factor relating to method of manufacture, k_1 . This factor shall be the value taken from Table 4 appropriate to the method of manufacture to be adopted.

Table 4 — Factor relating to method of manufacture

Method of manufacture	Part factor k_1
Handwork	1.5
Repeatable machine controlled work	1.5
Spray application	3.0

b) Factor relating to long term behaviour, k_2 . This factor shall be 1.2 for pipe having a thermoplastics liner. The factor for pipe without a thermoplastics liner shall be chosen within the range 1.2 and 2.0 based on the following criteria. If data are not available a factor of 2.0 shall be used.

After exposing unstressed laminate to the process conditions expected for the design lifetime of the pipe the loss in ultimate tensile strength shall be used to fix the value of the factor in accordance with Table 5.

Table 5 — Factor relating to loss in ultimate tensile strength

Loss in tensile strength	Factor k_2
$\leq 20 \%$	1.2
$> 20 \% \leq 50 \%$	Interpolate between 20 % = 1.2 50 % = 2.0
$> 50 \%$	Material unsuitable

NOTE It is emphasized that thermoplastics liners are used for chemical resistance only and should not be considered as contributing to the strength of the pipe, but they may influence other properties of the pipe, e.g. thermal expansion.

c) Factor relating to temperature, k_3 . This factor is dependent on the heat distortion temperature of the resin system and shall be determined from Figure 4.

d) Factor relating to cyclic loading, k_4 . This factor shall be determined from Figure 5, having regard to the expected operating conditions of the pipe.

e) Factor relating to the curing procedure, k_5 . Where the pipe is subjected to a complete curing procedure, including a full post-cure at elevated temperature in the manufacturer's works, this factor shall be 1.1; for all other curing procedures the value of 1.4 shall be used.

14.4.2 Allowable design strain

14.4.2.1 The allowable design strain for the constituent components of the pipe, i.e. liner, resin system and each type of reinforcing material, in the principal direction shall be calculated.

14.4.2.2 The allowable strain for the thermoplastics liner portion of the pipe shall be taken as a value of 0.2 %.

14.4.2.3 The allowable strain, ϵ , for each type of resin system shall be 0.1 ϵ_R or 0.2 % whichever is the lesser.

NOTE If confirmation is required by testing a laminate the method described in BS 2782:Method 320C should be used.

14.4.2.4 The allowable strain for each type of reinforcing material shall be calculated from equation (2).

$$\epsilon_x = \frac{u}{X_x K} \quad (2)$$

14.4.2.5 Considering all the constituent parts in 14.4.2.2 to 14.4.2.4 the allowable design strain, ϵ_d , shall be the lowest value so calculated.

14.4.3 Allowable unit loading. The allowable unit loading for each type of resin and reinforcing material shall be calculated from equation (3).

$$u_x = \epsilon_d X_x \quad (3)$$

15 Laminate design and thickness

15.1 Laminate design. For each pipe or fitting a proposed laminate construction shall be determined by taking into account the design unit loading for each constituent layer (as calculated from 14.4.3). These loadings shall be related to the unit loads to be carried in the region concerned.

The overall unit modulus for the proposed laminate construction shall be calculated from equation (4).

$$X_{LAM} = (X_1 m_1 n_1 + X_2 m_2 n_2 + \dots X_x m_x n_x) \quad (4)$$

The laminate design unit loading U_{LAM} shall be calculated from equation (5).

$$U_{LAM} = \epsilon_d X_{LAM} \text{ (axial direction)} \quad (5)$$

The above procedure shall not apply where continuous rovings are filament wound at an angle $\pm \theta$ to the pipe axis. Values of circumferential and longitudinal unit modulus for individual layers shall be obtained by reference to Figure 3. Values of circumferential and longitudinal design unit load shall be calculated by application of the factors given in Table 3.

NOTE 1 It is possible that more than one combination of layers may satisfy the requirements of the laminate.

Alternatively, all but one (or two interdependent) values of n_x may be fixed and the remaining value(s) determined.

The suitability of purpose of a laminate construction shall be checked in every case using equation (6).

$$U_{LAM} \geq Q \quad (6)$$

If the sum of the X , m and n terms exceeds Q by a large margin, the laminate is overdesigned. If the sum of the terms is less than Q , one or more of the values of n shall be increased or a different laminate construction proposed. In all cases the calculation shall be repeated for the new construction.

The response of continuous roving wound pipe to biaxial loading applied simultaneously is different from the response when loads are applied independently. To assess the behaviour of combined loads a complete anisotropic stress/strain analysis shall be carried out and the response of the laminate to the combined load examined (see foreword). The normal or shear strain in each layer shall be less than that calculated in 14.4.2.5. If the analysis is not available a biaxial failure envelope shall be constructed as shown in the worked example in Appendix C.

NOTE 2 Additional considerations are necessary if the pipework is to be subject to vacuum or external pressure considerations (see clause 17).

15.2 Thickness. Where values of thickness are required in the equations in this section the thickness of the laminate in the region under consideration shall be taken as the sum of the thicknesses of the individual layers making up that laminate.

The nominal thickness of each layer, for design purposes, shall be determined from the glass content for that layer by using the graph (see Figure 2).

In no case shall the actual laminate thickness (excluding any corrosion barrier) be less than 4 mm for pipes manufactured with chopped strand mat and 2 mm for filament wound pipes.

Abrupt changes in laminate thickness shall be avoided. The blending taper between regions of differing thickness shall be not steeper than 1 in 6.

16 Design calculations for pipes subject to internal pressure

NOTE The equations in this section are derived from thin shell theory.

16.1 Pipes subject to internal pressure.

The circumferential and axial unit loads Q_c and Q_a (in N/mm) shall be calculated from equations (7) and (8).

$$\text{Circumferential unit load } Q_c = \frac{pD_i}{2} \quad (7)$$

$$\text{Axial unit load } Q_a = \frac{pD_i}{4} \quad (8)$$

where

p is the internal pressure (gauge) (in N/mm²);

D_i is the internal diameter (in mm).

16.2 Pipes subject to combined loads

16.2.1 Horizontal pipes. The maximum axial unit load, Q_a , shall be calculated from equation (9) for the combined effects of the following:

- a) pressure and/or vacuum;
- b) bending moments due to self-mass;

- c) bending moments due to mass of contents;
- d) bending moment due to any other external source.

$$\text{Axial unit load } Q_a = \frac{pD_i}{4} \pm \frac{4M}{\pi D_i^2} \quad (9)$$

where

M is the total bending moment.

16.2.2 Vertical pipes. The maximum axial unit load for conditions a) to d) in 16.2.1 plus the addition of the mass of pipe, fittings, contents, and attachments above or below the point of consideration shall be calculated from equation (10).

$$\text{Axial unit load } Q_a = \frac{pD_i}{4} \pm \frac{4M}{\pi D_i^2} \pm \frac{F}{\pi D_i} \quad (10)$$

where

F is the algebraic sum of all the appropriate vertical forces acting on the pipes adjacent to the support.

Vertical forces causing tension in the pipe shall be considered positive, and forces causing compression shall be considered negative.

16.3 Permissible axial compressive load.

A check calculation shall be made to ensure that the region of the pipe subject to the highest compressive load is adequate to resist collapse by local buckling. To make this check the overall unit modulus, X_{LAM} , (for the axial direction using axial compressive properties) for the proposed construction shall be calculated from equation (4).

The permissible maximum axial compressive unit load, Q_p , to resist buckling shall then be calculated from equation (11) which includes a safety factor of 4.

$$Q_p = \frac{0.6tX_{LAM}}{4D_i} \quad (11)$$

The maximum compressive unit load shall in no case exceed the value calculated in equation (6). If in the original design it does, the laminate construction shall be modified, and the necessary calculations repeated until this condition is satisfied.

17 Design calculations for pipes subject to vacuum

17.1 Pipes without stiffening rings. The circumferential unit load, Q_c , shall be calculated from equation (7).

The maximum direct axial unit load, Q_a , shall be calculated from equations (9) or (10) as appropriate. From each of these values the appropriate thickness of laminate shall be calculated and the largest value obtained shall be used for calculations. Using as a basis a laminate construction which satisfies this requirement, the total thickness of the laminate, t , shall be determined as described in 15.2.

The composite modulus of the laminate, E_{LAM} (in N/mm²), shall also be calculated from equation (12).

$$E_{\text{LAM}} = \frac{X_{\text{LAM}}}{t} \quad (12)$$

where

X_{LAM} is the overall unit modulus of the laminate under consideration determined from equation (4);

t is the total thickness of the laminate.

The value of t shall be greater than the value of the minimum wall thickness, t_m , obtained using equation (13) which includes a safety factor of 4.

$$t_m = D_o \left(\frac{4p}{2E_{\text{LAM}}} \right)^{0.33} \quad (13)$$

If in the proposed design this condition is not fulfilled the design shall be changed either by re-designing the laminate or by providing additional stiffening rings (see 17.2). The calculation shall then be repeated until an acceptable construction is indicated.

17.2 Pipes with stiffening rings. If the calculations in 17.1 indicate an unacceptable laminate thickness it may be preferable to re-design the pipe to include stiffening rings.

The design of pipes with stiffening rings may be approached by two methods.

a) *Method 1.* To fix the distance between stiffeners by utilizing the spacing between flanges, anchors, or additional stiffeners and checking the minimum thickness required to prevent collapse by using equations (13) or (14), which includes a safety factor of 4, dependent on the value of the stiffener distance/diameter ratio:

$$\begin{aligned} \text{if } \frac{J}{D_o} &\geq 1.35 \left(\frac{E_{\text{LAM}}}{4p} \right)^{0.17} \\ \text{then } t_m &= D_o \left(\frac{4p}{2E_{\text{LAM}}} \right)^{0.33} \\ \text{or if } \frac{J}{D_o} &< 1.35 \left(\frac{E_{\text{LAM}}}{4p} \right)^{0.17} \end{aligned} \quad (13)$$

$$\text{then } t_m = D_o \left(\frac{0.4 \times 4 \times p}{E_{\text{LAM}}} \times \frac{J}{D_o} \right)^{0.4} \quad (14)$$

where

J is the distance between the centre line of stiffeners;

D_o is the outside diameter $= D_i + 2t$.

b) *Method 2.* To fix the construction and hence thickness and calculate the required distance between stiffeners from equation (15).

$$J = \left(\frac{t}{D_o} \right)^{2.5} \left(\frac{E_{\text{LAM}} D_o}{0.4 \times 4 \times p} \right) \quad (15)$$

The distance between stiffeners in either case shall not exceed the value of J calculated from equation (15).

For a proposed stiffening ring profile and composition it is then necessary to determine the diameter (D_s) of the neutral axis of the stiffening ring. Subsequently it shall be ensured that the second moment of area of the designed stiffening ring, I , is not less than the value obtained from equation (16):

$$I = \frac{0.18 D_o J D_s^2 p}{E_{\text{LAM}}} \quad (16)$$

where E_{LAM} has been calculated from equation (12).

The permissible length of shell, J_s , which may be regarded as effectively contributing to the amount of the stiffening ring section shall be

$$J_s = 0.75 \sqrt{D_o t} \quad (17)$$

but in no case shall J_s be taken as greater than J .

Stiffening rings shall extend completely round the circumference of the pipe and any joints in the stiffener shall be so designed as to develop the full stiffness of the ring.

Section 4. Dimension markings and information

18 Dimensions

18.1 Diameters

18.1.1 Unlined pipelines. The nominal size of pipes and fittings shall be one of the following values:

25	32	40	50	65	80	100	125
150	200	250	300	350	400	450	500
600	700	800	900	1 000			

The manufacturer shall declare the actual internal diameter, in mm, of the pipes and fittings related to the relevant nominal size.

18.1.2 *uPVC lined pipelines using extruded pipe and moulded fittings.* The nominal size of pipe and fittings up to and including 500 shall be based on the nominal size of the extruded pipe (see clause 7).

NOTE Account should be taken, on sizing of the system, of any consequential reduction of the bore size below that of unlined pipe.

18.1.3 *uPVC lined pipelines using fabricated linings.* The nominal size of pipe and fittings above 500 shall be one of the relevant sizes specified in 18.1.1.

18.1.4 *Polypropylene lined pipelines using fabricated lining.* The nominal size of pipe and fittings above 80 shall be one of the relevant sizes specified in 18.1.1.

19 Tolerances on dimensions of pipes and fittings

19.1 Diameters. The tolerances on the declared diameter measured at 23 ± 2 °C shall be as follows:

- ± 1.5 mm for pipes up to and including 150 nominal size;
- ± 3 mm for pipes over 150 and up to 600 nominal size;
- ± 0.5 % of the declared internal diameter for pipes over 600.

All deviations from roundness, such as ovality, with the exception of pipe deformation due to its own weight, shall be contained within these tolerances.

19.2 Length. The tolerances on length shall be as follows:

- ± 1.5 mm for cut or fabricated lengths of pipe up to 4 m in length;
- ± 3.0 mm for cut or fabricated pipe larger than 4 m in length.

19.3 Squareness of ends. All unflanged pipe shall be cut square with the axis of the pipe to within ± 3 mm for all nominal sizes up to and including 400 and to within ± 4 mm for all nominal sizes over 600.

19.4 Deviation from straightness. For pipes of nominal size greater than 150 the deviation from straightness of the bore of the pipe shall not exceed 0.3 % of the effective length of the pipe or 15 mm, whichever is the smaller. Deviation from straightness shall be measured with the pipe in an unstrained vertical position. Measurements shall be taken at four equidistant points around the circumference. The average value of the maximum and minimum vertical distance between a straight edge, or taut chord, touching the ends of a pipe, and the wall of the pipe in the case of a concave curve or, in the case of a convex curve, between a straight edge or taut chord which touches the wall of the pipe and is equidistant from the wall at the two ends of the pipe, and the wall of the pipe at the end, is expressed as a percentage of the effective length of the pipe.

19.5 Fittings. Tolerances on angles of fittings shall be ± 1° for nominal sizes up to 600 and ± 0.5° for nominal sizes greater than 600.

20 Marking

Each pipe and fitting shall be permanently marked with the following information:

- a) manufacturer's name or initials and identification code;
- b) nominal size;
- c) pressure rating and temperature rating;
- d) number and date of this standard, i.e. BS 6464:1984³⁾;
- e) resin type and thermoplastics liner type if used.

21 Information

21.1 The manufacturer shall declare the lining and laminate system to be employed which shall be specified in full including the following details determined at the design stage:

- a) lining system;
- b) number of layers and notional thickness of each layer;
- c) total minimum thickness of the laminate system;

³⁾ Marking BS 6464:1984 on or in relation to a product is a claim by the manufacturer that the product has been manufactured to the requirements of the standard. The accuracy of such a claim is therefore solely the manufacturer's responsibility. Enquiries as to the availability of third party certification to support such claims should be addressed to the Director, Quality Assurance Division, BSI, Maylands Avenue, Hemel Hempstead, Herts HP2 4SQ for certification marks administered by BSI or to the appropriate authority for other certification marks.

d) composition of each layer, including:

- 1) type and mass of reinforcement, e.g. chopped strand mat, woven cloth, continuous rovings etc.;
- 2) percentage by mass of fibrous reinforcement;
- 3) type of resin system.

NOTE Information on different methods of manufacture is given in Appendix D.

21.2 The manufacturer shall give recommendations for the installation of pipes and fittings complying with this standard either for above ground or below ground situations.

Section 5. Construction and workmanship

22 Manufacturing conditions in works involving the cure of resins

Materials shall be stored and used in compliance with the supplier's instructions; reinforcement materials shall be stored dry.

Unless a hot curing resin system is being used the temperature of the working area shall be maintained above 15 °C for any laminating process and the cure cycle of the resin system. All other laminating work shall be discontinued whenever the air temperature falls to 10 °C or the dew point is reached (when condensation occurs).

The working area shall be suitably divided into clearly defined sections for preparation of reinforcement, mixing of resins, application, trimming and finishing.

23 Manufacturing procedure

23.1 The manufacturer shall eliminate as many variables as possible to ensure consistency in both materials and fabrication, and shall provide adequate supervision at all stages of manufacture.

NOTE All operators to be employed should be experienced in carrying out the type of work involved in the order. Representative test pieces of laminate should be submitted to prove the competence of each operator unless evidence of prior satisfactory work is available.

23.2 The requisite amount of resin, catalyst or hardener and any other ingredient such as accelerator or permitted filler, shall be accurately measured and thoroughly mixed. The amounts of mixed resin and reinforcement used in the laminate and the number and type of layers applied shall be recorded where applicable; the records shall be made available to the purchaser or inspecting authority.

23.3 Where hand lay-up is used in the manufacturing procedure, rolling shall be used to consolidate the laminate. Whilst good rolling is essential, the rolling pressure shall not be sufficient to cause disturbance of the distribution of the reinforcement or to break the fibre strands.

The manufacturer shall ensure that good adhesion is obtained between successive layers of the laminate either by appropriate scheduling of the manufacturing operation or by removing the surface of the cured resin to expose the fibres.

Adjacent pieces of reinforcement shall be overlapped by not less than 50 mm. The edges shall be worked out by brushing with a stippling action and all joints shall be staggered through the thickness of the laminate.

Where directionally biased reinforcement is used care shall be taken to ensure that the high strength fibres are adequately aligned in the correct direction to give the required strength.

The number, size and distribution of air bubbles, pits or inclusions shall be not greater than previously submitted samples. Acceptable limits of visual defects shall be in accordance with Appendix E.

23.4 Care shall be taken to avoid low exotherm, monomer loss (in polyester resins) and resin drainage. Excessive exotherm shall be avoided in all laminates. An elevated temperature post cure shall be applied where this is required by the design procedures (see 14.4).

24 Thermoplastics liners

24.1 If uPVC is the required liner uPVC pipe complying with BS 3505 or BS 3506 shall be used for lining pipe up to 500 mm diameter. In the case of larger pipes uPVC sheet complying with BS 3757 shall be used and this shall be stress relieved in an oven at temperatures between 120 °C and 140 °C for 15 min from attaining this temperature.

All forming operations of uPVC shall be performed at a temperature between 120 °C and 140 °C.

24.2 Polypropylene and PVDF liners if required shall be formed from extruded sheets to which is attached a glass fibre backing. The thickness of the sheet shall be as specified in clause 7.

24.3 All welds shall be butt welds

Before welding of the liner commences the edges to be welded, together with a filler rod, shall be suitably cleaned. In addition, glass backed thermoplastics liners shall have the glass backing stripped back to a distance between 3 mm and 6 mm on either side of the weld preparation to ensure that no glass filaments are included in the welded joint.

If welding is done by the hot gas filler rod technique, nitrogen or compressed air free from moisture, dirt and oil shall be used for welding. In all cases the grade of material of the filler rod shall be compatible with the liner material being welded. All edges to be butt welded by filler rod shall be chamfered to give an included angle and a land as shown in Figure 6.

24.4 All welds shall be fully penetrating. Welds completed from one side only shall have at least 70 % of the material strength; where there is reasonable access to the weld from both sides the weld shall have at least 85 % of the material strength.

Tests shall be made by the method described in **B.8**. There shall be no obvious undercutting, degradation of the material or breaks in the weld run.

NOTE All welders engaged on the fabrication of thermoplastics liners should be required to demonstrate their ability to weld to the requirements of liners to this standard.

24.5 The external surface of the weld shall be finished to a smooth contour before laminating and tested by the use of a high frequency spark tester at a voltage of 20 kV $\pm$ 10 %. Any weld that shows evidence of notches, lack of fusion or holes shall be rejected. (See clause **30**.)

24.6 In the case of flanged pipes the lining material shall be carried over the face of the flange.

25 Fittings

25.1 The minimum dimensions of sockets shall be as specified in Table 6.

25.2 The minimum dimensions of fittings, dependent upon the method of fabrication to be used for the pipeline described in Appendix F, shall be calculated from the appropriate method given in Table 7 using the relevant values given in Table 8.

NOTE 1 The location of the dimensions in Table 7 and Table 8 are shown in Figure 7 and Figure 8.

NOTE 2 The preferred method of manufacture for fittings from 25 to 600 nominal size is by one-piece moulding.

25.3 The minimum thicknesses of flanges shall be as given in Table 9. The minimum dimensions of GRP backing flanges and drilling dimensions in accordance with class 150 of BS 1560, class 150 of BS 3293 and Table 10 of BS 4504 shall be as given in Table 10.

NOTE The relationships of these dimensions are given in Figure 9 and Figure 10.

25.4 Pipe supports shall have a minimum width of 25 mm and a minimum contact arc of 120° on the underside of an above ground pipe.

NOTE The frequency of support shall be such that the ratio of deflection to span should not exceed 1 : 300 when the pipe is filled with the process fluid at the design temperature.

Piping should be supported and anchored so as to prevent undue loads on connected equipment, and at the same time to permit controlled expansion and contraction between anchors and changes of direction.

Anchors should be so designed that the loads are properly transmitted into the wall of the pipe.

Table 6 — Minimum socket depths

Nominal size of pipe	Minimum socket depth at various pressures							
	Up to 2.5 bar	4 bar	6 bar	10 bar	16 bar	25 bar	40 bar	64 bar
	mm	mm	mm	mm	mm	mm	mm	mm
25	25	25	25	25	25	25	50	58
32	25	25	25	25	25	40	50	75
40	25	25	25	32	40	40	50	
50	36	36	36	36	40	40	75	95
65	40	40	40	40	50	65	95	150
80	40	40	40	40	60	85	115	185
100	50	70	70	70	70	100	145	230
125	60	75	75	75	75	120	180	290
150	65	75	75	75	85	135	215	—
200	75	75	75	75	110	180	285	—
250	100	100	100	100	150	220	—	—
300	100	100	100	100	180	270	—	—
350	100	100	105	120	220	300	—	—
400	100	100	120	135	240	—	—	—
450	105	105	120	143	270	—	—	—
500	105	110	125	165	300	—	—	—
600	110	115	150	200	—	—	—	—
700	115	120	175	235	—	—	—	—
800	120	120	200	265	—	—	—	—
900	135	135	225	300	—	—	—	—
1 000	150	150	250	—	—	—	—	—