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SPECIFICATION FOR

PIPING SYSTEMS

FOR PETROLEUM REFINERIES AND PETROCHEMICAL PLANTS



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FOR PETROLEUM REFINERIES AND PETROCHEMICAL PLANTS

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The Institution desires to call attention to the fact that this British Standard does not purport to include all the necessary provisions of a contract.

This standard makes reference to the following British Standards, in addition to those contained in Table 1:

BS 131. Methods for notched bar tests. Part 2. The Charpy-V notch impact test.
BS 639. Covered electrodes for the manual metal-arc welding of mild steel and medium-tensile steel.
BS 1500. Fusion welded pressure vessels for general purposes.
BS 1515. Fusion welded pressure vessels for use in the chemical, petroleum and allied industries.
BS 1723. Brazing.
BS 1821. Class I oxy-acetylene welding of steel pipelines and pipe assemblies for carrying fluids.
BS 2633. Class I arc welding of ferritic steel pipework for carrying fluids.
BS 4165. Electrode wires and fluxes for the submerged arc welding of mild steel and medium-tensile steel.
BS 4300/8. NS 51 Plate, sheet and strip.
BS 4677. Class I arc welding of austenitic stainless steel pipework for carrying fluids.

British Standards are revised, when necessary, by the issue either of amendment slips or of revised editions. It is important that users of British Standards should ascertain that they are in possession of the latest amendments or editions.

CO-OPERATING ORGANIZATIONS

The Petroleum Equipment Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

British Mechanical Engineering Confederation
British Rubber Manufacturers Association
*British Steel Industry
*Council of British Manufacturers of Petroleum Equipment
Gas Council
Ministry of Technology
*Oil Companies Materials Association

The scientific and industrial organizations marked with an asterisk in the above list, together with the following, were directly represented on the Committee entrusted with the preparation of this standard:

Aluminium Federation
British Chemical Engineering Contractors Association
British Non-Ferrous Metals Association
British Valve Manufacturers Association
Chemical Industries Association Ltd.
Engineering Equipment Users Association
Imperial Chemical Industries Ltd.
Lloyd's Register of Shipping

The following BSI references relate to the work on this standard:
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BRITISH STANDARD SPECIFICATION FOR

PIPING SYSTEMS

FOR PETROLEUM REFINERIES AND PETROCHEMICAL PLANTS

FOREWORD

This British Standard is one of a series published under the authority of the Petroleum Equipment Industry Standards Committee.

In the original edition, 1961, the provisions represented standards of design and construction basically similar to those laid down in the American standard code for petroleum refinery piping, ANSI B31.3. Since that time a number of significant differences from that code have been introduced in the light of experience and the technical developments. These differences appear, for example, in the provisions for the application of materials for low temperature service, the requirements for quality control and inspection of fusion welding, and the modifications to design stresses in accordance with currently accepted design stress criteria. Determination of these design stresses has been assisted by the publication of a series of British Standards for pipe, BS 3601–5, wherein are listed proof stress values at temperature and creep and stress to rupture properties.

In some respects, in particular the provisions for the treatment of piping flexibility, identity with the ANSI B31.3 code has been maintained, and acknowledgment is made to the American National Standards Institute for data used in the preparation of this standard.

The continuous development of materials and design makes it necessary for the provisions of this standard to be reviewed periodically, and in consequence it is desirable that experience in its application be conveyed to the Committee by users.

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SPECIFICATION

1. GENERAL

1.1 SCOPE

This British Standard specifies minimum requirements and recommended practice for the selection and application of materials and components of piping systems in petroleum refineries and petrochemical plants and the design, fabrication, installation and testing of these systems.

Piping systems are interpreted as assemblies of pipe, valves, pipe fittings, flanges, bolting, gaskets and pipe supports.

This British Standard applies to piping systems within the plot limits of petroleum refineries, petrochemical plants, gas processing plants, refinery tank farms and marine discharge and loading points, and interconnecting lines between such facilities.

The standard is divided into seven sections, and full details of the scope of each section are given in the first clause of the section.

It does not apply to:

(1) piping systems within the boundaries of steam and power plants, for the design and construction of which British Standards or other accepted national codes are available;

(2) heater tubes, tube fittings and headers, including connections for piping;

(3) pressure vessels, heat exchangers, pumps, and other such equipment, including internal piping and connections for piping;

(4) piping located on refinery property which has been set aside for cross-country piping transmitting oil or gas through, to, or from the refinery;

(5) pilot plants and research equipment generally, except insofar as this standard may be considered as a guide.

1.2 DEFINITIONS

For the purposes of this British Standard the following definitions apply.

1.2.1 Process piping. All piping in a unit used in the processing of hydrocarbon and chemicals.

The term is taken to apply also to process lines directly interconnecting units, and to piping and fittings used to connect instruments to process piping and equipment.

1.2.2 Plot (battery) limits. The boundaries of an area occupied by a processing unit.

It is taken not only to apply to ' processing units ' in the strict sense but also to other locations where it is felt that the restrictions and limitations specified in this standard for certain materials in connection with ' processing units ' should be adhered to.

1.2.3 Non-hazardous service. A service in which failure would not, under normal circumstances, create a hazard to personnel and considered generally to be limited to neutral aqueous solutions and to the low pressure services of water, air, steam and inert gases.

1.2.4 Pipe making processes. The various methods of making pipe or tube, as follows.

1.2.4.1 ***Seamless process.*** A wrought steel tubular product made without a welded seam. It is manufactured by hot working steel and, if necessary, by subsequently cold finishing the hot-worked tubular product.

1.2.4.2 ***Electric fusion welding process (EFW).*** Steel plate formed into tubular shape and the abutting edges joined by manual or automatic electric arc welding with or without the use of filler metal.

1.2.4.3 ***Spiral seam fusion welding process (SFW).*** Steel strip, sheet or plate rolled into tubular shape so as to form a helical seam around the circumference of the pipe. The helical seam is electric fusion welded by an automatic metal arc welding process (SFW), or by electric resistance welding process.

1.2.4.4 ***Electric resistance welding process (ERW).*** A length of steel strip formed into tubular shape and longitudinally resistance welded continuously by the passage of an electric current across the abutting edges without the addition of filler metal.

1.2.4.5 ***Electric induction welding process.*** A length of steel strip or plate formed into tubular shape and longitudinally induction welded continuously by the passage of an electric current across the abutting edges without the addition of filler metal.

1.2.4.6 ***Electric flash welding process.*** A length of steel strip or plate formed into tubular shape and longitudinally flash welded over the full length simultaneously by the passage of an electric current across the abutting edges without the addition of filler metal.

1.2.4.7 ***Butt-welding process (BW).*** A continuous steel strip passed through a tunnel furnace from which it emerges at forge welding temperature to enter a series of rolls which form it into a tube and forge weld the abutting edges together.

1.2.5 Design pressure. The value of pressure to be used in calculations of pipe thickness (see Section 5).

1.2.6 Design temperature. The temperature to be used to establish the appropriate value of design stress.

1.2.7 ***t*** **for weld sizes.** Where in the various figures at the end of this standard the sizes of weld are related to t, then t shall be taken to be the actual metal thickness of the section under consideration.

2. COMPONENTS

2.1 SCOPE OF SECTION 2

This section lists the standards with which the components should comply and gives an outline of requirements in the construction of piping systems.

2.2 GENERAL

2.2.1 The components used shall be in accordance with the relevant standards given in Table 1, except that this shall not preclude the use of other materials, designs or methods of manufacture which can be shown to meet the intent of this standard. In any such cases this shall be explicitly stated as a qualification of any claims that the piping system complies with the requirements of this standard.

2.2.2 Components shall be marked in accordance with the requirements of the relevant standards in Table 1. The marking shall permit the component to be properly identified.

TABLE 1. LIST OF STANDARDS

NOTE. Standards marked 'D' include dimensional requirements. For the purposes of this standard, the standards listed below are intended to apply only to the components listed in the second column.

Material	Component	Standard		Title
		FERROUS		
Steel		BS 449	—	The use of structural steel in building.
		BS 1501–6: 1958	—	Steels for use in the chemical, petroleum and allied industries.
		BS 1510 : 1958	—	Steels for use in the chemical, petroleum and allied industries. (Low temperature supplementary requirements to BS 1501–1506).
	Plates	BS 1501 : Part 1 : 1964	—	Steels for fired and unfired pressure vessels. Plates. Part 1. Carbon and carbon manganese steels. Imperial units.
		BS 1501 : Part 2 : 1970	—	Steels for fired and unfired pressure vessels. Plates. Part 2. Alloy steels. Imperial units.
	Forgings	BS 1503: 1969	—	Steel for fired and unfired pressure vessels. Forgings.
	Castings	BS 1504	—	Carbon and alloy steel castings (not yet published; included in BS 1501–6: 1958).
	Bars	BS 1506	—	Carbon and alloy steel bars for bolting material (not yet published; included in BS 1501–6: 1958).
	Pipe	BS 1600	D	Dimensions of steel pipe for the petroleum industry. Part 1. Imperial units. Part 2. Metric units.
		BS 3601*	—	Steel pipes and tubes for pressure purposes. Carbon steel: ordinary duties.
		BS 3602*	—	Steel pipes and tubes for pressure purposes. Carbon steel: high duties.
		BS 3603*	—	Steel pipes and tubes for pressure purposes. Carbon and alloy steel: low-temperature duties.
		BS 3604*	—	Steel pipes and tubes for pressure purposes. Low and medium alloy steel.
		BS 3605*	—	Steel pipes and tubes for pressure purposes. Austenitic stainless steel.
		API STD. 5L	D	Line pipe.
		API STD. 5LS	D	Spiral-weld line pipe.
	Valves	BS 1414	D	Flanged and butt-welding end steel outside-screw-and-yoke wedge gate valves for the petroleum industry.
		BS 1570	D	Flanged and butt-welding end steel plug valves for the petroleum industry (excluding well-head and flow-line valves).
		BS 1655	D	Flanged automatic control valves for the petroleum industry (face-to-face dimensions).
		BS 1868	D	Flanged steel check valves for the petroleum industry.
		BS 1873	D	Flanged steel globe valves for the petroleum industry.
		BS 2080	D	Summary of face-to-face dimensions of flanged ferrous valves for the petroleum industry.
		BS 2995	D	Cast and forged steel wedge gate, globe, check and plug valves, screwed and socket-welding, sizes 2 in and smaller, for the petroleum industry.
		BS 3808	D	Cast and forged steel flanged, screwed and socket-welding wedge gate valves (compact design), sizes 2 in and smaller, for the petroleum industry.
		BS 4460	D	Steel ball valves for the petroleum industry.
		API STD. 6D	D	Steel gate, plug, ball and check valves for pipe line service.

* See 2.3.1.

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TABLE 1. LIST OF STANDARDS (*contd.*)

Material	Component	Standard		Title
Steel (*cont.*)		FERROUS (cont.)		
	Flanges and fittings	BS 1560, Part 2	D	Steel pipe flanges (nominal sizes ½ in to 24 in) for the petroleum industry (metric dimensions).
		BS 1640	D	Steel butt-welding pipe fittings for the petroleum industry.
		BS 3293	D	Carbon steel pipe flanges (over 24 in nominal size) for the petroleum industry.
		BS 3799	D	Forged steel pipe fittings, screwed and socket-welding for the petroleum industry.
		BS 4368	D	Carbon and stainless steel compression couplings for tubes. Part 1. Metric sizes. Part 2. Inch sizes.
	Pipe supports	BS 3974	D	Pipe supports. Part 1. Components for rod-type pipe hangers for uninsulated and insulated steel and cast iron pipes.
	Bolting	BS 1580	D	Unified screw threads.
		BS 1750	D	Bolting for the petroleum industry.
		BS 1769	D	Unified black hexagon bolts, screws and nuts (UNC and UNF threads). Heavy series.
		BS 2693	D	Screwed studs. Part 1. General purpose studs. Part 2. Recommendations for high grade studs.
Cast iron	**Pipe**	BS 78	D	Cast iron spigot and socket pipes (vertically cast) and spigot and socket fittings. Part 1. Pipes.
		BS 1211	D	Centrifugally cast (spun) iron pressure pipes for water, gas and sewage.
		BS 2035*	D	Cast iron flanged pipes and flanged fittings.
		BS 4622	D	Grey iron pipes and fittings.
	Castings	BS 1452		Grey iron castings.
	Valves	BS 1655	D	Flanged automatic control valves for the petroleum industry (face-to-face dimensions).
		BS 1735	D	Flanged cast iron outside-screw-and-yoke wedge gate valves, Class 125, sizes 1½ in to 24 in, for the petroleum industry.
		BS 2080	D	Summary of face-to-face dimensions of flanged ferrous valves for the petroleum industry.
	Flanges and fittings	BS 78	D	Cast iron spigot and socket pipes (vertically cast) and spigot and socket fittings. Part 2. Fittings.
		BS 2035*	D	Cast iron flanged pipes and flanged fittings.
		BS 4622	D	Grey iron pipes and fittings.
Malleable cast iron	**Pipe fittings**	BS 143 and 1256†	D	Malleable cast iron and cast copper alloy screwed pipe fittings for steam, air, water, gas and oil.
S.G. Cast iron	**Castings**	BS 2789	—	Iron castings with spheroidal or nodular graphite.
Cast iron alloy	**Castings**	BS 1591	—	Acid-resisting high silicon iron castings.
		BS 3468	—	Austenitic cast iron.
	Pipe fittings	BS 1333	D	Acid-resisting silicon iron pipes and pipe fittings.
		NON-FERROUS		
Copper and copper alloys	**Forgings**	BS 2872	D	Copper and copper alloys. Forging stock and forgings.
	Castings	BS 1400		Schedule of copper alloy ingots and copper and copper alloy castings.

* Except that flanges shall be in accordance with the requirements of BS 1735. (For petroleum industry use refer to BS 4622.)
† These components shall have threads to API STD. 5B or ANSI B2.1 (BS 143 only).

TABLE 1. LIST OF STANDARDS (*contd.*)

Material	Component	Standard		Title
		NON-FERROUS (cont.)		
Copper and copper alloys (*cont.*)	Tubes	BS 885	D	Brass tubes for general purposes. 70/30 arsenical brass, aluminium brass.
		BS 1306, Part 2	D	Non-ferrous pipes and tubes for steam services. Part 2. Seamless copper tubes for steam services.
		BS 2017	D	Copper tubes for general purposes.
		BS 2871	D	Schedule of copper and copper alloys. Tubes.
	Valves	BS 1952*	D	Copper alloy gate valves for general purposes.
		BS 1953*	D	Copper alloy check valves for general purposes.
		BS 2060*	D	Copper alloy screw-down stop valves for general purposes.
	Fittings	BS 143 and 1256†	D	Malleable cast iron and cast copper alloy screwed pipe fittings for steam, air, water, gas and oil.
		BS 2051, Part 1	D	Tube and pipe fittings for engineering purposes. Part 1. Copper and copper alloy capillary and compression tube fittings (for use with fractional o.d. sizes of tubes).
		BS 2051, Part 2	D	Tube and pipe fittings for engineering purposes. Part 2. Olive, soldered nipple and flared types of copper and copper alloy tube fittings (for use with fractional o.d. sizes of tubes).
Aluminium and aluminium alloys	Pipes and tubes	BS 1471	D	Wrought aluminium and aluminium alloys. Drawn tube.
		BS 1474	—	Wrought aluminium and aluminium alloys. Bars, extruded round tube and sections.
	Forgings	BS 1472	—	Wrought aluminium and aluminium alloys. Forging stock and forgings.
	Bars, rods and sections	BS 1474	—	Wrought aluminium and aluminium alloys. Bars, extruded round tubes and sections.
	Plate	BS 1474	—	Wrought aluminium and aluminium alloys. Bar, extruded round tubes and sections.
	Castings	BS 1490	—	Aluminium and aluminium alloy ingots and castings for general engineering purposes.
Nickel and nickel alloys	Forgings	BS 3076	—	Nickel and nickel alloys. Rods.
	Plate	BS 3072	—	Nickel and nickel alloys. Sheet and plate.
		BS 3073	—	Nickel and nickel alloys. Strip.
	Pipes and tubes	BS 3074	—	Nickel and nickel alloys. Tube.
		NON-METALLIC		
Jointing	Sheets and gaskets	BS 1737	—	Jointing materials and compounds for water, town gas and low-pressure steam installations.
		BS 1832	—	Oil-resistant compressed asbestos fibre jointing.
		BS 2815	—	Compressed asbestos fibre jointing.
		BS 3381	—	Metallic spiral wound gaskets for the petroleum and petrochemical industry.

* These components shall have threads to API STD. 5B or ANSI B2.1, or flanges to ANSI B. 16.24, where applicable.
† These components shall have threads to API STD. 5B or ANSI B2.1 (BS 143 only).

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TABLE 1. LIST OF STANDARDS (*contd.*)

Material	Component	Standard		Title
		NON-METALLIC (cont.)		
Plastics	Pipe	BS 3284	—	Polythene pipe (Type 50) for cold water services
		BS 3505	—	Unplasticized PVC pipe for cold water services.
		BS 3506	—	Unplasticized PVC pipe for industrial purposes.
		BS 3796	—	Polythene pipe (Type 710) for general purposes including chemical and food industry uses.
		BS 3867	D	Outside diameters and pressure ratings of pipe of plastics materials.
		INSULATING MATERIALS		
Thermal insulation		BS 1588	—	The use of thermal insulating materials in the temperature range 95 °C to 230 °C.
		BS 3708	—	The use of thermal insulating materials between 230 °C and 650 °C.
		BS 3958		Thermal insulating materials.
		CP 3005		Thermal insulation of pipework and equipment.
		THREAD STANDARDS		
	Pipe, couplings, valves, fittings and flanges	API STD. 5B	D	Threading, gauging and thread inspection of casing, tubing and line pipe threads.
		ANSI B.2.1	D	Pipe threads (except Dryseal).

2.3 PIPE

2.3.1 Dimensions of steel pipe up to and including 24 in (600 mm) nominal size shall be in accordance with the requirements of BS 1600. The following nominal sizes are preferred for ferritic steels :

in	(mm)	in	(mm)	in	(mm)	in	(mm)
½	(15)	2	(50)	8	(200)	16	(400)
¾	(20)	3	(80)	10	(250)	18	(450)
1	(25)	4	(100)	12	(300)	20	(500)
1½	(40)	6	(150)	14	(350)	24	(600)

For sizes 14 in and over, the inch nominal size coincides with the outside diameter. For austenitic stainless steel pipe, intermediate sizes may be used by agreement.

It is recommended that pipe intended for threading shall be not less than schedule 80 for sizes smaller than 2 in (50 mm) and schedule 40 for sizes 2 in (50 mm) and larger.

For steel pipe larger than 24 in (600 mm) nominal size, the following nominal sizes are preferred:

in	(mm)	in	(mm)	in	(mm)	in	(mm)
26	(650)	32	(800)	38	(950)	44	(1100)
28	(700)	34	(850)	40	(1000)	46	(1150)
30	(750)	36	(900)	42	(1050)	48	(1200)

NOTE. Sizes listed other than 38 (950), 44 (1100) and 46 in (1150 mm) are ISO recommended sizes.

2.3.2 It is recommended that, for cast iron pipe, the nominal wall thickness be not less than that specified for Class B pipe in BS 78, BS 1211, BS 2035 or pipe to BS 4622, whichever standard applies.

For cast iron pipe, the following nominal sizes are preferred:

in	(mm)	in	(mm)	in	(mm)
3	(80)	10	(250)	18	(450)
4	(100)	12	(300)	20	(500)
6	(150)	14	(350)	24	(600)
8	(200)	16	(400)	30	—
				—	(700)

NOTE. These sizes represent the nominal inside diameter.

2.3.3 Non-ferrous metal pipe and tube should preferably be seamless.

The use of welded non-ferrous pipe shall be the subject of agreement between the purchaser and the manufacturer.

Extruded aluminium pipe shall be made by the mandrel method.

Drawn aluminium pipe shall be made from blooms made by the mandrel method.

Pipe sizes shall be in accordance with the requirements of the relevant standards in Table 1 or, by agreement between the purchaser and the manufacturer, shall conform to those specified for steel pipe in BS 1600.

2.3.4 Dimensions of plastics pipe shall conform to the requirements of BS 3867, within the range of preferred sizes as given in 2.3.1; tolerances shall conform to relevant and individual standards for plastics pipe listed in Table 1.

2.4 VALVES

2.4.1 Valves shall comply with the requirements of the relevant standards listed in Table 1. This does not exclude the use of other valves for which there is no standard at present, provided that they conform, where applicable, to the valve standards listed in Table 1 and are suitable for the intended service.

2.4.2 Valves of plastics material may be used but until such time as standards are published to cover such valves it is recommended that the advice of the manufacturer should be sought as to the most suitable type of valve for a given application (see 3.5).

2.5 FITTINGS

2.5.1 General

2.5.1.1 Seamless forged or cast fittings shall be in accordance with the requirements of the relevant standards listed in Table 1.

2.5.1.2 Components comprising standard fittings involving fusion-welding shall comply with the requirements of Section 6.

2.5.2 Pipe bends. For requirements for pipe bends, see 6.12 to 6.17.

2.5.3 Expansion components. Expansion bends should be used instead of expansion joints wherever practicable. Slip type expansion joints should not be used on process lines and should only be used elsewhere by agreement between the purchaser and the manufacturer. The use of bellows type expansion joints shall be governed by the requirements of 4.6.

When corrugated pipe is used the effect on the system of vibration and the problem of drainage, etc., should be considered.

2.5.4 Special fittings. Fittings not covered by the foregoing shall conform to the requirements for quality of material, inspection and testing as specified for standard fittings, and shall be of a suitable design for the intended service.

2.5.5 Non-metallic fittings. Until such time as British Standards are published to cover plastics fittings for plastics piping, it is recommended that pipe and fittings for a particular installation be purchased where possible from the same source, in order to minimize difficulties with component tolerances.

2.6 BOLTING

All bolting shall be in accordance with the requirements of the relevant standards in Table 1.

2.7 GASKETS AND JOINTING

2.7.1 Gaskets and jointing may be:

natural or synthetic rubber or plastics (including PTFE), with or without reinforcement;

compressed asbestos fibre;
wire mesh reinforced compressed asbestos fibre;
metal jacketed, asbestos filled;
spiral wound metal with filler;
metal rings, flat;
metal rings, corrugated;
metal rings, formed sections.

For limiting dimensions of gaskets, see BS 1560.

2.7.2 Octagonal rings should be used with ring-joint type facings.

3. APPLICATION

3.1 SCOPE OF SECTION 3

This section gives recommendations and restrictions on the application of the materials and components provided for in Section 2.

3.2 STEEL PIPE

3.2.1 The application of steel pipe shall be limited by the temperatures listed in Table 3 and as qualified below.

3.2.2 For carbon steel process piping, as alternatives to seamless pipe, the undernoted welded pipe may be used:

(1) BS 3602, electric resistance welded, steel 23 or 27, with Appendix A, ultrasonic testing;

(2) API. 5L Grade B, submerged arc, electric fusion welded;

(3) API 5LS, Grade B, spiral welded.

3.2.3 In Table 3 no design stresses are shown for any of the welded types of pipe to BS 3601 as these are restricted to non-hazardous service.

3.2.4 Pipe made of air or mixed air/oxygen blown steel shall not be used.

3.3 CAST IRON PIPE

3.3.1 Cast iron pipe shall only be used for water, aqueous solutions and non-volatile chemicals.

3.3.2 The conditions for the application of pipe made of special or alloy cast iron developed for specific duties shall receive separate consideration.

3.4 NON-FERROUS METAL PIPE AND TUBE

Where it is desired to use non-ferrous metal pipe and tube in locations or services where conditions of fire risk exist, the relatively low melting points of most non-ferrous metals shall be taken into consideration.

In all cases the temperature and stress limitations shall be in accordance with the requirements of Tables 3A, 3B, and 3C.

3.5 PLASTICS PIPE AND TUBE

In the application of thermoplastics piping, the recommendations of CP . . . . * shall apply, but the user shall satisfy himself that the material chosen is suitable for the particular application. Screwing should be avoided wherever possible. Non-reinforced thermoplastic materials have low melting points, and piping within process plot limits in such material shall only be used to convey non-flammable fluids. The risk of failures of any plastics pipe due to circumstances other than fire should be considered. Reinforced plastics piping, e.g. glass reinforced epoxy (GRE) or glass reinforced polyester (GRP), unlined or lined with thermoplastics or thermosetting materials, has a superior resistance to damage by fire or other causes and may be considered for use on more onerous duties. In appropriate cases the use of reinforced resin pipe containing flame-retardant additives should be considered.

Where plastics tubing is used in multicore form to convey instrument air, it is recommended that a protective sheathing or armouring, integral with the outer covering, is employed in order to guard against mechanical damage and to increase fire resistance. It is further recommended that single runs branching from multicore tubes be in copper or steel, as single plastic tubes are particularly susceptible to damage, and in some cases have inconveniently large minimum bend radii.

* In course of preparation.

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3.6 VALVES

3.6.1 Steel valves

3.6.1.1 Steel valves 2 in (50 mm) and larger normally have flanged ends, but where they are not subject to frequent removal, butt-welding end valves may be used in order to minimize the number of flanged joints.

3.6.1.2 In sizes up to 1½ in (40 mm) inclusive, screwed, butt-welding, socket-welding or flanged end valves may be used according to service conditions and pipework layout.

3.6.1.3 For corrosive service, or where solid deposits may develop, valves with inside screw stems should not be used.

3.6.1.4 Where steel valves are trimmed with non-ferrous or non-metallic materials the maximum permissible service temperature may be limited by the high temperature characteristics of the particular trim material.

3.6.2 Cast iron valves

3.6.2.1 Cast iron valves may be used for water, aqueous solutions, non-volatile chemicals, air or steam in accordance with the pressure ratings specified in BS 1735. They shall not be used for hydrocarbon service.

3.6.2.2 The use of valves made of special or alloy cast iron developed for specific duties shall receive separate consideration.

3.6.3 Non-ferrous metal valves

3.6.3.1 The use of non-ferrous metal valves shall be subject to the restrictions and conditions specified in 3.4.

3.6.3.2 The maximum permissible service temperature may be limited by the high temperature characteristics of the particular trim material.

3.6.3.3 The use of dissimilar metals in conjunction in a corrosive environment, e.g. steel pipes with non-ferrous metal valves, should be avoided.

3.6.4 By-passes. Where pressure differential is expected to create difficulties in the operation of a valve, a by-pass should be fitted. Alternatively, gear or motor operation may be provided.

3.6.5 Drain valves. Valves installed for draining piping and equipment should be of the straight through type.

3.6.6 When valves with non-metallic trims are used, the temperature limitations of the trim material should be taken into account if there is a possibility of a ' steaming-out ' operation.

3.7 FITTINGS AND FLANGES

3.7.1 Steel fittings

3.7.1.1 ***Butt-welding fittings.*** In steel lines of nominal sizes 2 in (50 mm) and larger, butt-welding fittings are preferred.

3.7.1.2 ***Screwed and socket-welding fittings.*** In steel lines of nominal sizes 1½ in (40 mm) and smaller, screwed or preferably socket-welding fittings may be used, according to service conditions and pipework layout.

Consideration should be given to avoiding the use of socket-welding and threaded joints where severe crevice corrosion or erosion may occur.

3.7.1.3 ***Sleeve joints.*** Single fillet welded sleeve joints over 1½ in (40 mm) nominal size are not recommended and shall not be used within plot (battery) limits, except in the case of pipes having non-metallic internal coatings, when they may be accepted by agreement between the purchaser and the manufacturer.

3.7.1.4 ***Compression fittings.*** The use of steel compression fittings should be confined to non-hazardous service, as defined in 1.2.3.

3.7.1.5 ***Pipe bends.*** If the change in direction does not exceed 30°, pipes may be cut and welded directly together. For greater changes in direction seamless bends are preferred, but gussetted bends may be used and are normally limited to nominal pipe sizes 14 in (350 mm) or greater (see Fig. 11.1).

Wrinkle bends shall be avoided wherever possible and in any case shall be subject to agreement between the purchaser and the manufacturer.

The use of gussetted bends of the ' cut and shut ' type should be avoided except when fabricated in accordance with the requirements of BS 2633*, Section Two, Clause 26.

3.7.2 Cast iron fittings

3.7.2.1 Cast iron fittings may be used for water, aqueous solutions, non-volatile chemicals, air or steam. They shall not be used for hydrocarbon service.

3.7.2.2 The use of fittings made of special or alloy cast iron developed for specific duties shall receive separate consideration.

3.7.2.3 This standard does not provide for the use of screwed cast iron fittings, other than malleable cast iron fittings.

3.7.3 Malleable cast iron fittings. Malleable cast iron fittings, which should be readily identifiable, may be used for water, aqueous solutions, non-volatile chemicals, air or steam within the service limitations of the standard listed in Table 1. These fittings are unsuitable for welding.

3.7.4 Non-ferrous metal fittings

3.7.4.1 The use of non-ferrous metal fittings shall be subject to the provisions of 3.4 (see also 3.6.3.3).

The use of non-ferrous metal compression fittings should be confined to non-hazardous service, as defined in 1.2.3.

3.7.4.2 The use of steel pipe in conjunction with non-ferrous metal fittings shall comply with the recommendations of 3.6.3.3.

3.7.4.3 Where non-ferrous compression fittings are to be used with plastics piping these shall be designed for the specific purpose. Standard fittings normally used with metal pipe are not always suitable for plastics piping of similar nominal dimensions.

3.7.5 Flanges

3.7.5.1 ***Slip-on flanges.*** Where many large temperature cycles are expected, particularly for uninsulated flanges, the use of slip-on flanges should be avoided.

* BS 2633, ' Class I arc welding of ferritic steel pipework for carrying fluids '.

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3.7.5.2 *Steel flanges.* When a steel flange having a raised face is to mate with a cast iron flange having a plain (flat) face, the raised face on the steel flange shall be removed.

3.7.5.3 *Composite flanges.* The joints comprising plastics flanges or plastics to metal flanges should have plain (flat) facings in conjunction with full face gaskets.

3.8 BOLTING

Carbon steel bolting in accordance with the requirements of BS 1750, Part 3, may be used for flanged connections for operating temperatures up to 260°C and at pressures up to 19 bar*.

Carbon steel bolting is not recommended for use in flanged connections incorporating metal or metal-jacketed gaskets.

Alloy steel bolting of an appropriate grade in accordance with the requirements of BS 1750, Part 1, and nuts in accordance with BS 1750, Part 2, shall be used to make flanged connections for operating temperatures above 260°C and pressures above 19 bar*.

3.9 GASKETS AND JOINTING

3.9.1 Oil-resistant compressed asbestos fibre jointing complying with the requirements of BS 1832 may be used for hot oil, oil vapour and gas service up to a temperature of 400°C.

3.9.1.1 With raised face flanges it may be used at pressures up to 50 bar*.

3.9.1.2 With facings which confine the gasket it may be used with no limit as to pressure.

3.9.2 Compressed asbestos fibre jointing complying with Grade A of BS 2815 or BS 1832 may be used for water, inert gases and liquids, and steam, with the same limiting temperature as specified in 3.9.1. Grade B of BS 2815 may be used for water, air and steam services at pressures up to 19 bar* and temperatures up to 260°C.

3.9.3 For more severe conditions than those given in 3.9.1 and 3.9.2, wire mesh reinforced compressed asbestos fibre jointing, metal jacketed asbestos filled, spiral wound asbestos filled, or metal ring gaskets shall be used as required by the service conditions and by the provisions of 2.7.

3.9.4 Gasket materials shall be selected to withstand the pressure, temperature and corrosive conditions inherent in the process in which they are to be used.

3.9.5 Rubber jointing with canvas insertions may be used only in water lines at temperatures up to 65°C.

3.9.6 Where plain (flat) face flanges are used for either cast iron, or steel used in conjunction with cast iron, full face gaskets shall be used (see 3.7.5.2).

3.10 LOW-TEMPERATURE SERVICE

The following requirements shall apply, in regard to design, materials and testing, to all piping systems which may be in service at sub-zero temperatures.

3.10.1 **Ferrous materials.** The minimum design temperatures for ferritic steel components, whether wrought, cast or forged, used in piping systems shall not be lower than indicated in Figs. 1 and 2.

3.10.1.1 Fig. 1 refers to welded carbon and carbon-manganese steel assemblies in the 'as welded condition' and to 3·5% nickel steel in any condition. Fig. 2 refers to unwelded carbon and carbon-manganese steel assemblies and to welded assemblies post heat treated in the stress relieving range of temperature.

3.10.1.2 The application of Figs. 1 and 2 is restricted to the design of piping systems for sub-zero temperatures and to non-shock loading conditions of service and testing. When the steels listed are subject to shock loading and for all other ferritic steels irrespective of the conditions of loading and service, the required notch ductility shall be subject to agreement between the purchaser and the manufacturer. However, the notch ductility requirements for such applications shall in no case be less than those required for non-shock loaded carbon steels from Figs. 1 and 2.

3.10.1.3 The minimum design temperatures indicated by Figs. 1 and 2 may be lowered by 50°C in all cases where the calculated nominal tensile membrane stress does not exceed 50 N/mm², taking into account all loadings, as for example, internal and external pressures, static head, self weight, thermal stresses.

3.10.1.4 In the case of as-welded piping and components, lower temperatures at reduced pressure are only permissible when the component has been subjected to an adequate hydraulic pressure test.

3.10.1.5 The relaxations under 3.10.1.3 apply where the pressure is temperature dependent and where low temperatures only occur coincidentally with reduced pressure/loading (i.e. in refrigeration equipment, or process equipment during properly conducted shut-down operations). Calculated thicknesses should not be increased solely to satisfy the above criteria in order to permit the use of a lower grade of material.

3.10.1.6 3.10.1.6.1 to 3.10.1.6.3 define the terms used in this clause of the standard, which relates to the selection of materials for low-temperature application.

3.10.1.6.1 *Design temperature.* The design temperature shall be the minimum temperature of the part under consideration. Where this is not known the following methods may be used unless there is evidence to show that because of radiation, adiabatic or other effects, this will not provide a reliable estimate of temperature. Under such conditions, the method to be used in assessing the temperature shall be subject to agreement.

(1) In the case of components thermally insulated externally, the minimum temperature of the contents shall be used.

(2) In the case of components not thermally insulated, the minimum temperature of the contents may also be used. However, attention is drawn to the effect that the ambient temperature may have upon the contents under the appropriate operating conditions. For this purpose, in the absence of more certain data, the minimum ambient temperature may be taken as the lowest one day mean ambient temperature plus 10°C.

3.10.1.6.2 *Reference thickness.* The following rules shall be followed in applying Figs. 1 and 2. In all cases the thickness to be considered shall be the specified nominal thickness including any corrosion allowance.

3.10.1.6.2.1 UNWELDED ITEMS. Unwelded items operating at a design temperature colder than − 30°C shall be treated as a post-weld heat treated item (see Fig. 2) or shall have a Charpy V value of 20 J at the design temperature, whichever is less onerous.

* 1 bar = 10^5 N/m².

3.10.1.6.2.2 WELDED ITEMS. Welded items shall be dealt with as follows.

(1) *Butt-welded components.* The effective thickness of both components shall be taken as the thickness of the thicker component measured at the edge of the weld preparation.

(2) *Weld neck flanges, plate and slip-on (or hubbed) flanges, and flat ends.* The Charpy V requirements for flanges and flat ends in all thicknesses for service below − 30°C and in thicknesses greater than 35 mm for service below 0°C, shall be determined by reference to Fig. 1 or Fig. 2, as appropriate, using as the material reference thickness that of the flange or flat end, or that of the branch attached thereto, whichever is thinner. However, no component, when stress relieved by post-weld heat treatment, need exceed a Charpy V value of 20 J at the minimum design temperature.

(3) *Branches and nozzles.* The thickness of the thickest of the shell, branch and compensating plate (if any) shall govern the material selection of all three items. This requirement shall apply to the whole of the thickest part and to the thinner parts connected thereto for a distance of at least 4 times the thickness of the part under consideration or 150 mm, whichever is less, measured from the edge of the weld.

(4) *Attachments.* Non-pressure attachments welded directly to a pressure component shall be regarded as part of the pressure component and shall be considered to have a thickness equal to the thickness of the attachment at the point of attachment. It is recommended that the notch ductility of the material of any attachment should not be inferior to that required for the adjacent pressure component.

3.10.1.6.3 *Material reference temperature.* Material reference temperature is defined as the temperature at which it is required to demonstrate that a given Charpy V-notch impact value has been achieved (under certain conditions impact testing may be waived—see 3.10.1.7). The requirements are as follows.

(1) For carbon and carbon-manganese steels (and steels up to 3½ % nickel maximum) with a specified minimum tensile strength of less than 460 N/mm² the Charpy V impact strength at the ' material reference temperature ' shall be not less than 27 J.

(2) For carbon and carbon-manganese steels (and steels up to 3½ % nickel maximum) with a specified minimum tensile strength of 460 N/mm² or greater, and for all other low alloy steels irrespective of their strength, the Charpy V impact strength shall be not less than 27 J at a temperature 10°C lower than the ' material reference temperature '.

(3) Where a material specification does not specify the temperature corresponding to 27 J Charpy V, the value specified may be converted to the 27 J temperature on the basis of 1·4 J per °C. This conversion shall be permitted in the range of Charpy V energy 20 J to 48 J. For example, 20 J at 0°C may be regarded as equivalent to 27 J at + 5°C.

3.10.1.7 ***Impact testing.*** For design temperatures below 0°C Charpy V impact testing of pipes, plates, forgings and castings is normally mandatory. Impact tests shall be performed in accordance with the requirements of BS 131, Part 2*. The impact properties to be obtained shall be the average of the values from three specimens and no individual value shall be less than 75 % of the specified (average) value.

* BS 131, ' Methods for notched bar tests ', Part 2, ' The Charpy-V notch impact test '.

However, impact testing may be waived by agreement between the purchaser and the manufacturer under the following conditions.

(1) In the case of carbon and carbon-manganese steels having a specified minimum tensile strength less than 460 N/mm² (including API STD. 5L, Grades A and B), as follows:

(*a*) for all points representing combinations of material reference thickness/permissible minimum design temperature lying to the right of Line I, Figs. 1 and 2;

(*b*) in the case of normalized steels where the specified minimum manganese content divided by the specified maximum carbon content is equal to or greater than 4·0, all points representing combinations of material reference thickness/permissible minimum design temperature lying within the shaded zone and to the right of Line I, Figs. 1 and 2.

NOTE. Steels may be supplied in conditions other than normalized, when it is demonstrated to the satisfaction of the purchaser that the manufacturing procedure (for example, controlled rolling) will provide equivalent notch ductility.

Examples of the use of Figs. 1 and 2 are given in Appendix B.

(2) In the case of material thinner than 5 mm or in the case of components too small to permit a 55 mm × 10 mm × 5 mm specimen to be machined. The materials shall comply in all other respects with a material specification covering the required impact properties.

3.10.1.8 ***Design***

3.10.1.8.1 Any attachments to piping and components (i.e. anchors, stools, brackets, etc.) shall be designed to avoid creating stress concentrations at the point of attachment. Clamp type attachments should be used wherever possible or the attachment welded to a loose encircling sleeve around the pipe or component.

3.10.1.8.2 Screwed and socket-weld fittings and connections shall be limited to 1½ in (40 mm) nominal bore and fittings shall be forged.

3.10.1.8.3 For longitudinal and circumferential welds in pipes, butt welds shall be used except as provided for in 3.10.1.8.2.

3.10.1.9 ***Weld metal.*** The foregoing requirements have been formulated on the basis that the weld metal will be specified to satisfy impact test requirements equivalent to:

(1) carbon-manganese steel manual metal arc:
47 J Charpy V at 0°C
(BS 639* Grade 2);

(2) carbon-manganese steel automatic processes:
40 J Charpy V at 0°C
(BS 4165† Grade 350S 2M Grade 350S 2T);

(3) alloy steel manual metal arc:
47 J Charpy V at 0°C;

(4) alloy steel automatic processes;
40 J Charpy V at 0°C.

* BS 639, ' Covered electrodes for the manual metal-arc welding of mild steel and medium-tensile steel '.
† BS 4165, ' Electrode wires and fluxes for the submerged arc welding of mild steel and medium-tensile steel '.

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Furthermore, the manufacturer shall provide evidence that any subsequent working or heat treatment processes will not degrade this property below the minimum specified in these British Standards.

In cases (2), (3), and (4), impact properties of weld metal shall be checked on the procedure tests.

No requirements for impact tests for case (1) shall be made on production tests unless they have been requested for procedure tests.

The minimum design temperature/thickness relationships specified are considered to be acceptable for the most degraded condition of heat affected zone when multi-run welding processes are used. But for single-pass welds made by automatic welding processes which have not been normalized, the notch ductility of the heat affected zone shall, unless agreed otherwise between the purchaser and the manufacturer, also conform to the minimum requirements for weld metal.

3.10.1.10 ***Bolting.*** The permissible lower design temperature for bolting shall not be lower than indicated below.

Material specification		Minimum temperature °C
BS 1750, Part 3		−30
BS 1750, Part 1,	B6	−45
	B7	−45
	B7a	−45
	B8	(see 3.10.2)
	L7	−100
BS 1750, Part 2,	Gr. 2	−30
	Gr. 2H	−45
	Gr. 3	−45
	Gr. 4	−45
	Gr. 6	−45
	Gr. 8	(see 3.10.2)
	Gr. L4	−100

3.10.2 Austenitic steel. Austenitic steel piping and components are not subject to temperature limitations in the sub-zero range and need not be impact tested.

3.10.3 Non-ferrous materials. Non-ferrous metal piping and components are not subject to temperature limitations in the sub-zero range and need not be impact tested.

3.10.4 Non-metallic materials. Non-metallic components which form parts of valves, etc., shall be given special consideration as to the suitability of such materials for service at the proposed temperatures and, in particular, to the effect of hardening and/or embrittlement of plastics and rubber-like materials.

4. INSTALLATION

4.1 SCOPE OF SECTION 4

This section deals with installation requirements for piping systems. The information appearing in 4.2 to 4.8 applies generally to metallic piping. See 4.9 for plastics pipework.

4.2 PRESSURE RELIEF ARRANGEMENTS

Pressure relieving arrangements shall be provided on piping where thermal expansion of the contents can cause the hoop stress in the piping to exceed 133% of the design stress.

Discharge from pressure relieving devices shall be led to a point where its release will not create a hazard.

Discharge lines from pressure relieving devices shall be arranged to facilitate drainage, and to prevent accumulation of liquids where this would interfere with the proper operation of the relief valve.

4.2.1 Stop valves. There shall be no intervening stop valves between piping being protected and its protective device or devices, or between the protective device or devices and the point of discharge, except as follows.

(1) A full-area stop valve may be installed on the inlet side of a pressure relieving device. A full-area stop valve may be placed on the discharge side of a pressure relieving device when its discharge is connected to a common header with other discharged lines from other pressure relieving devices. Valves of less than full-area may be used on both the inlet side and discharge side of pressure relieving devices as outlined in the foregoing, if the stop valves are of such type and size that the increase in pressure drop will not reduce the relieving capacity below that required nor adversely affect the proper operation of the pressure relieving device. Such stop valves shall be so arranged that they can be locked or sealed in both the open and the closed positions. When these stop valves are to be closed while the equipment is in operation, an authorized person shall be present and shall remain in attendance at a location where the operating pressure can be observed and shall have arrangement provided for relieving the system in the event of overpressure. He shall again lock or seal the stop valves in the open position before leaving his station.

(2) When these stop valves are so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure relieving capacity provided by the unaffected relieving devices below the required relieving capacity.

4.3 VALVES

4.3.1 General. The arrangement of piping should permit easy maintenance of valves. Valves should be grouped wherever practicable, and when operated frequently should be readily accessible. Valves in pipe tracks should be accessible. The installation of valves with their stems inclined below the horizontal shall be avoided wherever practicable, except that, where it is desirable for valves to fail safe, e.g. in relief lines, inverted valves are acceptable.

The use of chain operated valves is not recommended. Where the use of chains is unavoidable they shall not hang in the path of personnel or mobile equipment. Valves in trenches or pits should be provided with extension stems if the handwheel would otherwise be more than 150 mm below the trench or pit cover plate.

4.3.2 Control valves. Control valves should be placed in horizontal lines with stems arranged vertically, except where they are liable to silting, when they should be installed in vertical lines with stems horizontal. Where possible, control valves should be so located that maintenance may be carried out without the erection of staging. Where a local indicator is provided, the controlled variable should be visible from the control valve.

Piping arrangements at control valves shall be designed to:

(1) provide sufficient space to ensure that the control valves may be dismantled for overhaul without having to remove the valve body from the line,

(2) permit the removal of the control valve body when required without having to spring the piping unduly, e.g. by providing a removable bend on at least one side between the isolating valve and the control valve.

Isolating valves shall not be bolted direct to control valves.

Control valves shall be provided with by-passes wherever manual control is essential on failure or during maintenance of the control valve. Alternatively, the control valve shall be provided with a handwheel. By-pass valves and lines shall be sized to give adequate manual control.

Control valves which handle flammable fluids should be kept away from hot lines, pumps and other hot equipment, in order to minimize the fire risk when valves are removed and lines drained. Control valves used in process and fuel lines to fired heaters should be located on the sides of the heater away from burners, or at a sufficient distance from the heater so that control valves may be removed and the line drained without danger of flashback. Drain and bleed piping shall carry the liquid to a safe location.

Topworks on control valves shall be kept away from excessive heat to avoid premature failure of diaphragms and electronic components.

4.3.3 Check valves. Check valves should preferably be installed in horizontal flow, but where they have to be installed in vertical flow, they shall either be arranged with the flow in an upwards direction, or if downwards flow is essential, a supplementary device shall be fitted to ensure correct operation. The purchaser shall be responsible for advising the manufacturer of the supplementary requirements.

4.4 CONNECTIONS TO EQUIPMENT

4.4.1 Vessels and units of equipment which require to be isolated for entry of personnel and for cleaning and repairs, should be provided with a block valve and spade or removable spoolpiece.

4.4.2 Pipework between rotating machinery such as pumps, compressors, turbines, etc., and their isolating valves should preferably be removable to facilitate removal of the machinery. Where this is not practicable a removable flanged pipe fitting should be included adjacent to the machinery.

4.4.3 For dimensional flexibility, spoolpieces should be dimensioned to be interchangeable with standard fittings.

4.4.4 Where double valving is unavoidable, a bleed shall be provided of not less than ¾ in (20 mm) bore. One valve shall be directly mounted on the equipment, branch or spoolpiece.

4.5 BRANCH CONNECTIONS IN STEEL PIPE

4.5.1 Branch connections in piping shall be made by the use of standard butt-welding or socket-welding fittings, by special welding outlet fittings, or by attaching a branch pipe or fitting directly to the main pipe by welding. All such branch connections shall comply with the requirements for materials and their applications as given in Sections 2 and 3 and for welding in accordance with Section 6.

Connections made by welding screwed or socket-welding couplings or half couplings directly to the main pipe shall not be used for branches larger than 1½ in (40 mm) nominal pipe size (see Figs. 10.1 and 10.2).

Figs. 8.1*a* to 8.12*b* show typical details of recommended branch connections with minimum dimensions for their attachment welds. Preference should be given to the ' set-on ' type branches. ' Set-in ' type branches should be allowed only by agreement between the purchaser and the manufacturer.

4.5.2 If a standard branch fitting is not used, branch connections for drain, sample or other branch lines up to and including 1½ in (40 mm) nominal size shall consist of socket-welding or screwed couplings, or half couplings, except that for these sizes branches may be welded directly into the pipe run in non-hazardous services up to a pressure of 10 bar* and a temperature of 205 °C.

No socket-welding or screwed couplings lighter than 3000 lb rating shall be used except that, for stainless steel couplings, the wall thickness shall be the subject of agreement between the purchaser and the manufacturer.

4.5.3 It is recommended that no branch connection should be welded to a main line at an angle smaller than 60°. For smaller angles, the use of a suitable type of forged steel fitting is preferred.

4.5.4 Openings in pipe for branches shall be reinforced as and when required by 5.5.

4.6 EXPANSION JOINTS

4.6.1 If expansion joints are used in underground lines, it is recommended that they be enclosed in a suitable pit which will not interfere with their function.

4.6.2 For axial bellows, the piping shall be guided to maintain axiality of the bellows and anchored at adjacent changes in direction to prevent the bellows being subjected to axial load due to fluid pressure.

4.6.3 In cases of slip type expansion joints, care should be taken to anchor or guide the pipe in such a manner that, adjacent to the joint, it can move in an axial direction only.

4.6.4 Bellows units should be provided with temporary ties to maintain their set length at the specified ambient temperature at which they will be installed in the pipeline.

4.7 PIPE SUPPORTS

All supporting equipment shall be suitable for the service, loading and temperature conditions.

Steel shall be used to the greatest extent possible. Cast iron may be used for roller bases, rollers, guides, brackets, etc., where the loading is mainly compressive, but is not recommended for pipe supporting elements subject to impact type loadings resulting from pulsation or vibration. Malleable or nodular iron may be used for pipe clamps, beam clamps, hanger flanges, clips and swivel rings, provided that the metal temperature does not exceed 230 °C. Wood may be used for load bearing elements between pipe and support for insulated piping in low temperature services.

Supporting equipment located in a corrosive environment should be suitably protected or a material corrosion allowance provided.

Piping shall be supported and anchored so as to prevent excessive thrusts and moments on connected equipment and, at the same time, permit expansion and contraction between anchors.

* 1 bar = 10^5 N/m^2.

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Hangers for the support of piping of nominal size 2 in (50 mm) or larger shall, where necessary, permit of adequate adjustment after erection while supporting the load. Screw or equivalent adjustments shall have suitable locking features. Spring hangers shall be so constructed that complete release of the piping load will be impossible in the case of spring failure.

Supporting equipment shall be designed to carry the load caused by the most severe combination of any of the following.

(1) Weight of pipes and associated equipment.

(2) Weight of operating or testing medium, whichever is the heavier; alternatively, weight of the operating medium only, provided that the pipe can be temporarily supported during hydrostatic tests.

(3) Weight of insulation when used.

(4) Expansion or contraction loads.

(5) Reaction from lines discharging to atmosphere.

(6) Weight of equipment installed to counteract or direct the loads under (4) and/or (5).

(7) Wind or earthquake loads, whichever is the greater.

(8) Snow and ice loads.

Weight calculations for springs and counterweights shall be based on normal operating conditions of the piping.

The calculated stresses shall not exceed the *S* values given in Tables 3, 3A, 3B and 3C.

Design stress values in shear shall be 0·80 of the values given in Tables 3, 3A, 3B, and 3C, and design stress values in bearing shall be 1·60 of the values given in these tables.

When steel materials not listed in Table 1 are used, reference should be made to BS 449 for design stresses.

Contact surface between pipe and pipe bearer should be designed to avoid water retention.

For those lines in which pocketing of liquid is to be avoided it is necessary to pitch the line in the direction of flow in such a way that the pipe in any span will not sag below the elevation of the support at the lower end of the span.

Anchors for bellows or slip type expansion joints shall be designed to withstand the algebraic sum of the following forces:

(1) the force required to deflect the joint,

(2) the force due to fluid pressure under operating conditions,

(3) the force required to overcome the static friction of the pipe in expanding or contracting on its supports.

(1) shall be specified by the manufacturer.

(2), where not specified by the manufacturer, may be taken as the product of the working pressure times the maximum internal cross-sectional area of the joint.

4.8 PIPE INSULATION

Reference should be made to CP 3005.

4.8.1 The insulation of piping systems shall be considered for the following purposes:

(1) saving of energy by minimizing the transfer of heat to or from the equipment,

(2) maintenance of process temperature,

(3) minimizing the influence of climatic variations,

(4) protection of personnel from injury through contact with equipment,

(5) to prevent condensation on the surface of pipework carrying fluids at low temperature.

4.8.2 Insulating materials in accordance with the requirements of standards listed in Table 1 may be used.

4.8.3 All metal surfaces at temperatures above 65°C or below −18°C which could be touched by personnel in the course of their normal duties, should be insulated unless otherwise effectively guarded.

4.8.4 On steam lines and on low-temperature service, all flanges, valves and fittings should be insulated.

4.8.5 Surfaces to be insulated with a plastic composition shall be clean and free from scale or rust. It is recommended that they be suitably coated to provide good adherence of the composition.

4.8.6 On surfaces where insulation will be subject to periodic removal for inspection, cleaning or other reasons, the use of removable sections is recommended. On surfaces where the insulation will remain undisturbed a plastic insulating composition producing a monolithic covering may be used. To facilitate taking thickness measurements removable sections of insulation may be provided.

4.8.7 All cold insulation shall be effectively vapour sealed.

4.8.8 Insulation exposed to the weather shall be suitably protected, e.g. by metal cladding. Where the service is such that the pipe is not continuously heated above 90°C, the insulation shall be waterproofed to prevent external corrosion of the pipe.

4.8.9 Where necessary, according to the type of insulating material and type of cladding used, the inner surface of the cladding shall be protected against corrosion. Cladding over soft insulation should be supported on spacer rings or distance pieces to maintain the correct insulation thickness.

4.8.10 Flashing or sealing is required to prevent rain from percolating behind cladding and causing corrosion.

4.8.11 Insulation should not be applied over pipe joints or connections before the completion of pressure testing.

4.8.12 When flanges and valve bodies on hot oil lines require to be insulated, this should be done after commissioning.

4.8.13 The water penetration of insulation containing chlorides can result in the stress corrosion cracking of chromium-nickel austenitic steel pipes. This is caused by chlorides leached out of the insulation by the water being concentrated on the pipe surface. This problem can be avoided by a number of alternative methods, e.g. covering the pipe with thin aluminium foil before applying the insulation.

4.9 PLASTICS PIPEWORK

Plastics piping shall be treated as such and not as a substitute for metal piping. For PVC, polyethylene and other thermoplastic materials covered by British Standards, the installation recommendations of CP . . . . * shall apply. In particular, methods of jointing and support shall receive close attention.

Plastics piping should be suitably isolated so that damage cannot be caused from adjacent steam and other hot lines. Where lines are to be buried, the possibility of attack from contaminated soil shall be considered.

* In course of preparation.

5. DESIGN

5.1 SCOPE OF SECTION 5

This section specifies minimum requirements for design of piping systems. For pressure/temperature ratings for steel flanges and valves see Tables PE-1 to PE-12.

5.2 PIPE

5.2.1 Steel pipe. The internal pressure design thickness t shall be not less than that calculated from the following formula when t is less than $\frac{D}{4}$:

$$t = \frac{pD}{20S + p}$$

where: t = internal pressure design thickness in millimetres,

p = internal design pressure in bar*,

D = outside diameter of pipe in millimetres,

S = design stress in N/mm².

Pipe with t equal to or greater than $\frac{D}{4}$ requires special consideration.

The thickness as calculated above shall be increased, if necessary, to meet the requirements of Notes 6, 7, 8, and 9.

For the design of piping systems subject to external pressure, reference should be made to BS 1500† and BS 1515‡.

5.2.1.1 The design pressure is the maximum pressure expected in normal operation. Where, in normal operation, a pipe is subjected to more than one pressure/temperature condition, the thickness shall be determined for that condition which results in the maximum value of t.

5.2.1.2 The design temperature is the temperature coincident with the design pressure as defined in 5.2.1.1. On insulated piping systems, the design temperature for all components shall be the fluid temperature, unless tests or experience substantiate the use of other temperatures. On uninsulated systems the design temperature for the piping shall be the fluid temperature; for flanged valves, fittings and flanges (except lapped joints) it shall be 90 % of fluid temperature; for lapped joint flanges it shall be 85 % of the fluid temperature; for bolting it shall be 80 % of the fluid temperature, or as established otherwise by tests.

5.2.1.3 The outside diameter of pipe shall be obtained from the appropriate standards listed in Table 1, taking into account the recommendations of 2.3.1.

5.2.1.4 The values of S shall be obtained from and shall not exceed those given in Table 3 for the design temperatures indicated therein. Linear interpolation for intermediate design temperatures is permitted.

5.2.1.5 The term 'corrosion allowance', as used in this standard, is an allowance to cover wastage resulting from chemical action, oxidation, scaling, abrasion and erosion.

Where it is known that no significant wastage will occur, no corrosion allowance need be made.

Where wastage is anticipated, the corrosion allowance shall not be less than the total wastage estimated for the desired life of the pipe, which in no case shall be less than the period covered by two inspection cycles.

Allowances for threading or grooving shall be equal to the height of thread or depth of groove.

5.2.1.6 The wall thickness selected, less the manufacturing tolerance, shall be not less than the internal pressure design thickness plus the allowances for corrosion and/or threading or grooving.

NOTE 1. Variations in the temperature or pressure, or both, from normal operating conditions are characteristic of certain services. If these variations are infrequent and of short duration, the pressure/temperature ratings (or the allowable stresses) of the piping components may be adjusted as follows.

(1) If the increased operating condition will not exceed 10 h at any one time or 100 h per year, it is permissible to increase the pressure rating (or the allowable stress) at the temperature existing during the increased operating condition by a maximum of 33 %.

(2) If the increased operating condition will not exceed 50 h at any one time or 500 h per year, it is permissible to increase the pressure rating (or the allowable stress) at the temperature existing during the increased operating condition by a maximum of 20 %.

NOTE 2. For large diameter pipe, consideration may need to be given to selecting a wall thickness in excess of that calculated in accordance with the requirements of 5.2.1, in order to reduce deformation during transportation, handling and fabrication of pipe.

NOTE 3. For pipe of 1½ in (40 mm) nominal size and less, the wall thickness may need to be in excess of the minimum calculated, in order to provide adequate robustness in service.

5.2.2 Cast iron pipe. The maximum permissible working pressure shall be appropriate to the test pressures specified in the standards listed in Table 1 for the type and class of pipe used.

5.2.3 Non-ferrous metal pipe. The design thickness of pipe and tube shall be determined in the same way and by means of the same formula as given in 5.2.1 for steel pipe, subject to the following.

The values of S shall be obtained from and shall not exceed those given in Tables 3A, 3B and 3C for the design temperatures indicated therein. Interpolation for intermediate temperatures is permitted. Attention is drawn to Note 1 at the foot of Table 3A. Normally no corrosion allowance is necessary.

Where it is intended to use materials not included in Tables 3A, 3B, and 3C, BSI should be consulted, and will base their recommendations for allowable stress values on the physical properties of the proposed material at the design temperature.

5.2.4 Plastics pipe. The design is based upon the maximum stated pressure capability of the particular grade of pipe. British Standards include this either as a bursting pressure which must be reduced considerably by a safety factor, or an arbitrary pressure rating based on water at 20°C. In either case, reductions in working pressure are necessary for increases in temperature, or with certain jointing methods.

Since most plastics slowly deteriorate in ultraviolet light, resistant grades should be selected for outside locations.

* 1 bar = 10^5 N/m².

† BS 1500, 'Fusion welded pressure vessels for general purposes'.

‡ BS 1515, 'Fusion welded pressure vessels for use in the chemical, petroleum and allied industries'.

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5.3 VALVES

5.3.1 For standard valves (see Table 1) reference should be made to the appropriate standards for information relating to design and materials.

If for such valves it is necessary to use materials other than those for which pressure/temperature ratings are provided, BSI should be consulted for pressure/temperature ratings for such valves.

5.3.2 The suitability of valves which are not covered by one of the standards listed in Table 1 shall be determined by tests representative of the intended service conditions.

5.4 FITTINGS

5.4.1 General

5.4.1.1 For standard fittings (see Table 1) reference should be made to the appropriate British Standard for information relating to design and materials.

5.4.1.2 Fittings which are not covered by the standards in Table 1 shall be designed and manufactured in all essential details in accordance with the requirements for standard fittings, and their ratings established from the available material data.

5.4.1.3 Special components fabricated by welding shall be made in accordance with the requirements of Section 6 and shall be designed on the basis of the maximum pressure/temperature conditions for the piping systems in which they are to be incorporated.

5.4.2 Expansion joints

5.4.2.1 Expansion joints may be used in conjunction with, or as an alternative to, the methods specified in 5.6 to provide flexibility in piping systems and to minimize reaction forces on equipment due to expansion or contraction of interconnecting pipework. When expansion joints are used, the advice of the manufacturer should be sought with regard to the guiding, anchoring and supporting of adjacent pipework.

5.4.2.2 Bellows type expansion joints shall not be subject to torsional loads.

5.4.2.3 Bellows assemblies fitted with tie bars or hinges may be used where lateral deflection is required. Units fitted with tie bars will, in addition, absorb any axial movement within the tie bars.

5.4.2.4 Where gas velocities through bellows units are in excess of 30 m/s, consideration should be given to fitting sleeves to prevent vibration of the convolutions.

5.4.2.5 Bellows assemblies (see 4.6) shall be fitted with limit rods or equalizing rings to limit movement and prevent overstressing of the convolutions.

5.4.2.6 Expansion bellows installed in a line carrying solid particles, such as fluidized catalyst lines, shall be fitted with an internal sleeve and connections for purging, to prevent the build-up of solids and the blockage of the convolutions of the bellows.

5.5 REINFORCEMENT OF WELDED BRANCH CONNECTIONS

5.5.1 Pipe having a branch or branches attached by fusion-welding shall be reinforced as and when required by the following paragraphs, except that welded branch connections having a nominal size not exceeding 2 in (50 mm) or one quarter of the nominal size of the pipe run, whichever is smaller, do not require to be reinforced.

5.5.2 Reinforcement may consist of:

(1) Excess thickness in the pipe wall and branch wall over the minimum thickness calculated by the formulae of 5.2.

(2) Added reinforcement in the form of rings or sleeves. The cross-sectional area of such reinforcement shall only be considered within the limits shown in Figs. 4 and 5.

(3) Added reinforcement in forms other than rings or sleeves, the effectiveness of which can be demonstrated to be at least equal to that of conventional reinforcement.

NOTE. An example of alternative design is the provision of reinforcement by means of horseshoe-shaped plates as detailed in the paper 'Reinforcement of Branch Pieces' by Dr. J. S. Blair in Engineering, 1946. This design should be examined, within the scope of the paper mentioned above, in cases when conventional reinforcement requires heavy plate thicknesses. Such an examination should take into consideration that any ribbed form of construction in high temperature service can result in appreciable thermal gradients (see Fig. 8.13).

5.5.3 The use of gussets and stays shall not be considered as a method of reinforcement but may be used for the purpose of supporting a branch. Such gussets or stays should preferably be welded to the reinforcing rings or saddles in order to avoid local stresses in the pipe wall.

5.5.4 A ring or sleeve fitted to the outer surface of a pipe shall be provided with a vent hole not exceeding 10 mm diameter. Each sealed section shall be provided with a vent hole.

5.5.5 When piping contains more than one branch and when any two adjacent openings are spaced at less than twice their mean diameter, no part of the reinforcement required for either opening shall be considered as applying to both openings.

5.5.6 Whenever possible a reinforcement should be obtained by increasing the thickness of the pipe wall and branch wall in preference to added reinforcement. Increasing the pipe wall thickness is particularly desirable in the case of multiple branch headers.

5.5.7 When the stress in the pipe calculated in accordance with the requirements of 5.2.1 exceeds 80 % of the tabulated design stress and the ratio of branch diameter to pipe diameter is large, it is recommended that added reinforcement should be in the form of an encircling sleeve. Such a sleeve may be assembled in halves, the two halves being first offered up to the pipe and then joined by butt-welding, the ends being fillet-welded to the pipe. The sleeve thickness at the ends should not exceed the thickness of the pipe.

5.5.8 If the design stress value of the material of added reinforcement is less than that of the pipe material, the thickness of the reinforcing material shall be increased proportionally. No credit shall be given for the additional strength of reinforcing material having a higher design stress value than that of the pipe to be reinforced.

5.5.9 The reinforcement specified in this clause refers to reinforcement of branches in respect of stress arising from internal pressure. Further consideration should be given to the strength of branch connections subject to external loading that may result from thermal expansion and contraction, pipe settlement and dead weight of valves and fittings.

5.5.10 Reinforcement of branches shall be calculated by the following method and as illustrated in Figs. 8.11 and 8.12. The openings to be compensated by reinforcement

shall be measured on the diameter of the branch parallel to the axis of the run. The boundaries of the cross-sectional area within which reinforcement may be considered are determined by the maximum dimensions shown in Figs. 4 and 5.

5.5.10.1 ***Method.*** The notations in Figs. 4 and 5 are defined as follows:

T = actual pipe thickness

T_b = actual branch thickness

NOTE. For design purposes T and T_b may be taken as nominal wall thickness less 12·5 %.

t = design thickness of pipe

t_b = design thickness of branch

$\sin\frac{d}{x}$ = major axis of finished opening in corroded condition (= d for a branch at 90° to the run)

x = angle between pipe and branch in degrees (see Note at end of 5.5.10.1)

T_r = thickness of reinforcing ring

c = corrosion allowance.

Cross-sectional area requiring to be reinforced:

$$A = \frac{dt}{\sin x}.$$

Reinforcement provided by excess pipe thickness:

$$B = \frac{d}{\sin x}(T - t - c).$$

Reinforcement provided by excess branch thickness:

C with no added reinforcement =

$2 \times 2{\cdot}5\,(T - c)\quad (Tb - t_b - c)$;

C with added reinforcement =

$2\,(2{\cdot}5\,(T_b - c) + T_r)\,(T_b - t_b - c)$,

except that, when reinforcement is added, the smaller value of C as determined by the above expressions shall be used.

If the value of $B + C$ (with no added reinforcement) is less than the value of A, reinforcement shall be added having a cross-sectional area not less than $A - (B + C)$.

NOTE. It is recommended that the angle of branch to run should not be less than 60°. In cases where it is necessary to have such angle less than 60° the design and fabrication will require special study, and the procedure for reinforcement given above may not be adequate.

5.5.10.2 ***Example 1.*** A 200 mm nominal bore (219·1 mm o.d.) Tee branch 12·5 mm nominal thickness is welded to a 400 mm nominal bore (406·4 mm o.d.) pipe 12·5 mm nominal thickness. Design pressure 25 bar*, design temperature 150°C, corrosion allowance 3·0 mm. Pipe and branch are seamless carbon steel. Design stress at 150°C is taken as 126·5 N/mm².

Pipe wall thickness required by 5.2.1:

$$t = \frac{pD}{2OS + p} = \frac{25 \times 406{\cdot}4}{2530 + 25} = 3{\cdot}90 \text{ mm}.$$

Nominal pipe wall thickness less mill tolerance of 12·5 %:

$T = 12{\cdot}5 \times 0{\cdot}875 = 10{\cdot}90$ mm.

Branch wall thickness required by 5.2.1:

$$t_b = \frac{25 \times 219{\cdot}1}{2530 + 25} = 2{\cdot}14 \text{ mm}.$$

Nominal branch wall thickness less mill tolerance of 12·5 %:

$T_b = 12{\cdot}5 \times 0{\cdot}875 = 10{\cdot}90$ mm.

Diameter of finished opening:

d = branch o.d. $- 2\,(T_b - c)$

$= 219{\cdot}1 - 2\,(10{\cdot}9 - 3) = 203{\cdot}3$ mm.

Then area A (angle $X = 90°$)

$= 203{\cdot}3 \times 3{\cdot}90 = 808$ mm².

Area B $= 203{\cdot}3\,(10{\cdot}9 - 3{\cdot}9 - 3) = 813$ mm².

Area C $= 2\,[2{\cdot}5\,(10{\cdot}9 - 3)\quad (10{\cdot}9 - 2{\cdot}14 - 3)]$

$= 5 \times 7{\cdot}9 \times 5{\cdot}76 = 228$ mm².

The sum of areas B and C exceeds the value of A, therefore the branch needs no added compensation.

5.5.10.3 ***Example 2.*** The 200 mm branch of Example 1 is welded at an angle of 60° to the 400 mm nominal bore (406·4 mm o.d.) pipe and the assembly is required to operate at 25 bar* and 350°C with a corrosion allowance of 3·0 mm.

Design stress at 350°C = 102·5 N/mm².

Pipe wall thickness required by 5.2.1:

$$t = \frac{25 \times 406{\cdot}4}{2050 + 25} = 4{\cdot}90 \text{ mm}.$$

Branch wall thickness required by 5.2.1:

$$t_b = \frac{25 \times 219{\cdot}1}{2050 + 25} = 2{\cdot}64 \text{ mm}.$$

$\sin 60° = 0{\cdot}8660$, d from Example 1 = 203·3 mm,

then area A $= \frac{203{\cdot}3}{0{\cdot}8660} \times 5{\cdot}62 = 1303$ mm²,

area B $= \frac{203{\cdot}3}{0{\cdot}8660}\,(10{\cdot}9 - 4{\cdot}9 - 3)$

$= \frac{203{\cdot}3}{0{\cdot}8660} \times 3 = 705$ mm²,

area C $= 2\,[2{\cdot}5\,(10{\cdot}9 - 3)\quad (10{\cdot}9 - 2{\cdot}64 - 3)]$

$= 5 \times 7{\cdot}9 \times 5{\cdot}26 = 207$ mm².

Thus, the area of added reinforcement required:

$A - (B + C) = 1303 - (705 + 207) = 391$ mm².

Such a small value of required reinforcement would conveniently be provided by increasing the pipe or branch wall thickness. For example, to increase the value of B, i.e. the reinforcement area provided by excess pipe thickness, by 391 mm² to 1096 mm² the increased value of T is determined.

$$\frac{d}{\sin x}(T - t - C) = 1096 \text{ mm}^2,$$

where $T = 12{\cdot}58$ mm and the required nominal pipe wall,

$$T + 12{\cdot}5\,\% = 14{\cdot}15 \text{ mm}.$$

If the required added reinforcement were considerable, say 1290 mm², reference to Fig. 2 shows that the inside dimension of the reinforcing ring is determined by the branch o.d. at 219 mm and the outside dimension must not exceed $\frac{2d}{\sin x}$, therefore the minimum thickness T_r is given by:

$$\left(\frac{2d}{\sin x} - 219\right) T_r = 1290 \text{ mm}^2$$

and $T_r = 5{\cdot}2$ mm.

*1 bar = 10^5 N/m².

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If pipe having a welded longitudinal seam is used and the branch intersects this seam, the calculation for pipe wall thickness t shall include the stress value appropriate to the welded pipe.

If the branch contains a welded longitudinal seam, the calculation for t_b shall include the appropriate stress value.

5.6 FLEXIBILITY

5.6.1 Loadings

5.6.1.1 The primary loadings causing stress in a piping system are:

(1) internal or external pressure,

(2) weight of pipe, fittings, valves, contained fluid, and insulation,

(3) thermal expansion or contraction of the pipe and connected equipment.

A secondary loading due to wind may have to be considered in certain piping systems such as large overhead vapour lines, but need not be included in most piping stress analysis. Pressure loading has been considered in 5.2; the other loadings are considered below.

Piping may be subject to loadings other than those listed above, such as, for example, those due to earthquake, pulsation or subsidence, and the designer shall include in an analysis all significant loadings acting on the system. These loadings need not be considered as acting together.

5.6.1.2 Reference may be made to Appendix A for clarification of the terms used in the stress analysis of piping systems and for a description of the methods of analysis available.

5.6.2 Design requirements. Piping systems shall be designed to ensure that loadings do not cause:

(1) fatigue failure of the piping material due to repeated overstress,

(2) failure of the piping material due to excessive plastic strains,

(3) leakage at any flanged joints,

(4) overloading of valves and other components in the system which would impair their operation,

(5) detrimental distortion of connected equipment resulting from excessive thrusts and moments.

5.6.3 Methods of providing flexibility. The flexibility of a piping system is a measure of its ability to absorb its own expansion, and that of connected equipment, while satisfying the design requirement. Flexibility should be provided, preferably by changes in direction of the piping through the use of bends, loops and offsets, or by corrugated pipe. Alternatively, expansion joints of the bellows, ball joint or slip type may be used.

5.6.4 Methods of flexibility analysis. Methods of flexibility analysis may be divided into two groups:

(1) comprehensive methods,

(2) simplified methods.

Both methods shall be capable of evaluating stresses and reactions in piping systems as a whole, and shall determine that all components, reduced sections and other critical areas are safely designed.

Comprehensive methods shall include all the effects of components such as welding elbows, Tee junctions, rigid sections, etc. The neglect of any or all of these effects in a simplified method is permissible provided that an assessment is made of their probable influence.

Minor approximations in the configuration of the pipe work may be made in conjunction with either of the above methods.

5.6.5 Requirement for flexibility analysis. A flexibility analysis is required if the designer is in any doubt as to the ability of the system to satisfy the design requirement. Should the correct interpretation of a simplified analysis indicate that any of the effects listed in the design requirement may occur, then a comprehensive analysis will be required. Piping design within the scope of 3.10 requires a flexibility analysis.

5.6.6 Basis of flexibility analysis

5.6.6.1 The flexibility of a piping system is calculated between anchor points, which may be actual pipe anchors or relatively inflexible pieces of equipment to which the pipe is connected—pumps, exchangers, vessels, etc. The system between anchor points shall be treated as a whole, and the effects of any movement at anchor points and of any intermediate restraints shall be included if they limit the free expansion of the piping system.

In very rigid lines consideration shall be given to the effect of axial and shear forces.

5.6.6.2 The total range from the minimum to the maximum temperatures normally expected during operation, start-up and shut-down (except as noted below) both for the piping system and for the equipment to which it is attached, shall be used in all analyses when determining thermal expansions. For hot lines, the minimum may usually be taken as an erection temperature of 20 °C. For lines operating below erection temperature the minimum may usually be taken as the normal operating temperature. Coefficients of thermal expansion are given in Tables 4 and 4A. For materials not included in this table, reference shall be made to authoritative source data. The analysis shall consider the combination of pipe and equipment expansion which will give the maximum loading acting on the piping system.

Special consideration shall be given to the reactions exerted on load sensitive equipment such as pumps, compressors, turbines, etc. (see Appendix A). In such cases the reactions shall be calculated using the total range from the minimum to the maximum temperature expected during operation, start-up and shut-down. The expansion stress range may still be calculated using normal operating temperatures.

5.6.6.3 The variation of the modulus of elasticity with temperature is shown for ferrous metals in Table 5 and for non-ferrous metals in Table 6. For materials not included in these tables reference shall be made to authoritative source data. The calculation of the expansion stress range shall be based on the use of the modulus at the minimum normal operating temperature, for the reasons given in Appendix A.

5.6.6.4 Poisson's ratio shall be taken as 0·3 for all metals at all temperatures, except that more accurate data may be used if available.

5.6.6.5 Nominal dimensions of pipe and fittings shall be used in flexibility calculations.

5.6.6.6 No credit for cold spring may be given in calculating the expansion stress range, but cold spring may be taken into account when calculating the end reactions of the piping system.

5.6.6.7 The stress-intensification factors known to exist in components other than plain straight pipe shall be considered, and credit may be given for the extra flexibility of such components. The flexibility factors and stress intensification shown in Chart 1 may be used. The values of the latter factor for Tees are based on tests carried out on equal outlet intersections. They may be used on smaller than header outlets until more applicable values are developed, but it is recommended that piping be so designed as to minimize the moments on such intersections. It is recommended that in austenitic stainless steel pipes at high temperatures only forged or cast Tees be used for intersections.

5.6.6.8 Design stresses shall be taken from Tables 3, 3A, 3B and 3C.

5.6.7 Austenitic stainless steels

5.6.7.1 Design, fabrication and erection should ensure as far as possible the elimination of local stress raisers, and particular care should be taken in material selection, heat treatment, and inspection.

5.6.7.2 It is recommended that cold spring be applied to pipes of these materials operating above 400°C to reduce plastic strains.

5.6.8 Evaluation of expansion stress range and end reactions

5.6.8.1 On the above basis, the expansion stress range shall be computed at all possible points of high stress such as elbows, Tees and reduced sections, using the following formula:

$$S_e = \sqrt{(S_b^2 + 4\,S_t^2)},$$

where S_e = expansion stress range (N/mm²),

$S_b = \dfrac{iM_b}{z \times 10^3}$ = resultant bending stress (N/mm²),

$S_t = \dfrac{M_t}{2z \times 10^3}$ = torsional stress (N/mm²),

M_b = resultant bending moment (N m),

M_t = torsional moment (N m),

z = section modulus of pipe (mm³),

i = stress intensification factor.

5.6.8.2 The reactions R (forces and moments) derived from the flexibility analysis are based on the modulus of elasticity E_c at the minimum metal temperatures normally expected during operation or shut-down.

They shall be converted to the reaction R_h and R_c at the maximum and minimum normal operating temperatures respectively as follows:

$$R_h = (1 - \tfrac{2}{3}C)\,\frac{E_h R}{E_c}$$

R_c = the greater in absolute value of CR or

$$\left(1 - \frac{S_h\,E_c}{S_E\,E_h}\right) R.$$

The second expression for R_c shall be ignored if $\dfrac{S_h\,E_c}{S_E\,E_h}$ is greater than 1·0,

where C = cold spring factor varying from zero for no cold spring to 1 for 100 % cold spring,

E_h = modulus of elasticity in the hot condition,

E_c = modulus of elasticity in the cold condition,

S_h = design stress at maximum normal operating temperature (from Tables 3, 3A, 3B, 3C),

S_E = maximum computed value of S_e from 5.6.8.1.

5.6.9 Allowable expansion stress range and end reactions

5.6.9.1 At no point, subject to the provisions of 3.10, shall S_e exceed the allowable expansion stress range S_A given by:

$$S_A = f\,(1{\cdot}25S_c + 0{\cdot}25S_h + S_D),$$

where S_c = design stress at the minimum metal temperature normally expected during operation or shut-down,

S_h = design stress at maximum normal operating temperature,

} from Tables 3, 3A, 3B, 3C

S_D = stress difference from 5.6.10.2,

f = stress range reduction factor to be applied for cyclic conditions having values as listed below:

Total number of full temperature cycles during expected life of active operation	Stress range reduction factor (f)
7 000 and less	1·0
7 000 to 14 000	0·9
14 000 to 22 000	0·8
22 000 to 45 000	0·7
45 000 to 100 000	0·6
Over 100 000	0·5

In the computation of S_A, the longitudinal joint efficiency of welded pipe may be disregarded, and the values of S_c and S_h may be taken as those for seamless pipe of the same material.

5.6.9.2 The reactions R_h and R_c shall not exceed limits which the connected equipment can safely sustain. Special consideration should be given to the loads imposed on pumps, compressors, turbines and other equipment containing moving parts with close clearances.

5.6.10 Pipe supports, wind loading and stress difference

5.6.10.1 Pipe supports not considered in a flexibility analysis as intermediate restraints shall be designed to minimize interference with the thermal expansion of the line.

5.6.10.2 Pressure, weight, pipe supports and wind loading all cause sustained stresses in a piping system which, in the corroded state, shall satisfy the following condition:

$S_p + S_g + S_w$ shall not exceed S_h,

where S_p = longitudinal pressure stress,

S_g = longitudinal bending stress due to weight of supported pipe,

S_w = longitudinal bending stress due to wind,

S_h = design stress at maximum normal operating temperature.

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The stress difference S_D (see 5.6.9.1) shall be obtained from

$$S_D = S_h - (S_p + S_g + S_w).$$

5.6.10.3 The longitudinal pressure stress (S_p) in N/mm² shall be obtained from:

$$S_p = \frac{pd^2}{10(D^2 - d^2)},$$

where p = internal pressure (bar*),
D = outside diameter of pipe (millimetres),
d = D minus twice the corroded pipe wall thickness (millimetres).

Longitudinal bending stresses due to weight and wind (S_g and S_w) may often be evaluated by simple beam formulae. However, certain piping systems, involving for example long unsupported offsets, may require more refined analysis. Sustained longitudinal bending stresses in components other than plain straight pipe shall include the stress intensification factors shown in Chart 1.

6. FABRICATION

6.1 SCOPE OF SECTION 6

This section specifies minimum requirements for metal pipe in respect of:

(1) the fabrication of pipework by fusion-welding (6.2),
(2) bending requirements and heat treatment (6.3),
(3) mechanical joints in piping using materials conforming to and applied in accordance with other sections (6.4).

The fabrication of plastics pipework is not included in this section. For details refer to CP ....†, the recommendations of which will apply.

6.2 FABRICATION BY FUSION-WELDING

6.2.1 General requirements. Electric arc welding and gas welding of steel assemblies shall be conducted in accordance with the requirements of BS 2633, BS 1821 or BS 4677‡, except as modified or amended by the requirements of this section.

The oxy-acetylene welding process is acceptable for butt-welding carbon steel pipes 4 in (100 mm) nominal size or smaller provided they are not thicker than 8 mm, and for butt-welding all pipes thinner than 5 mm irrespective of their diameter. Normalizing or other post-weld heat treatment of these welds in pipes thinner than 8 mm is not required unless specified by the purchaser.

Oxy-acetylene welding is not permitted for root or filler runs in steel containing more than 0·5 % of one or more of the following elements: chromium, nickel or molybdenum.

Carbon steel pipes having a wall thickness 6 mm or greater are normally butt-welded by an arc welding process, especially if 2 in (50 mm) nominal size or larger. Metal arc welding is not recommended for butt welds in carbon and alloy steel pipes 1½ in (40 mm) nominal size and smaller but is preferred for socket welds in all sizes.

* 1 bar = 10^5 N/m².
† In course of preparation.
‡ BS 2633, ' Class I arc welding of ferritic steel pipework for carrying fluids '.
BS 1821, ' Class I oxy-acetylene welding of steel pipelines and pipe assemblies for carrying fluids '.
BS 4677, ' Class I arc welding of austenitic stainless steel pipework for carrying fluids '.

The welding of materials other than those covered by the above standards and the use of other processes shall as far as possible comply with the requirements of this standard, any additional requirements being subject to agreement between the purchaser and the fabricator.

Fabricators shall be responsible for the quality of their welding. They shall maintain a record of the welders employed by them, giving particulars of each individual welder's qualification tests, certifying that welders are capable of making welds of the types required. These certified records shall be available to the purchaser or his representative. The purchaser or his representative shall have the right to stipulate and witness tests on any welder prior to commencing work on the contract. Steps shall be taken to ensure that each weld can be subsequently identified with the individual welder concerned. Records of welder identification should be maintained until the piping system has been finally accepted by the inspection authority. The fabricator shall provide sufficient competent supervision to ensure that quality requirements are maintained during the progress of the contract.

6.2.2 Weld metal

6.2.2.1 ***General.*** Ferritic weld metal shall be in accordance with the requirements of BS 2633, except that the alternative chemical composition given in Table 5 of that standard shall not be permitted without the purchaser's specific agreement.

Austenitic weld metal shall not be used for joints between ferritic material except when specifically agreed between the purchaser and the manufacturer. Post-weld heat treatment is not recommended for such joints, and they are not suitable for conditions liable to cause stress corrosion.

6.2.2.2 ***Filler wire composition.*** For the oxy-acetylene, submerged arc and inert gas processes the filler wire shall be of the same nominal composition as that of the parent metal being welded, except that the wire may contain additional alloying elements to compensate for losses during welding. When a separate flux addition is made, as for example in the submerged arc process, the addition of alloying elements to that flux, other than that necessary to make up for losses in the arc, is not permitted except by specific agreement between the purchaser and the manufacturer.

6.2.2.3 ***Back purging gas.*** Unless otherwise agreed, the back of the weld shall be protected from oxidation during the inert gas welding of root runs by the use of argon. Other gases or gas mixtures may be used for this purpose but only with the purchaser's agreement.

6.2.3 End preparation. Joint preparations differing from those specified in Figs. 6.1 to 6.7 are only permitted by prior approval of the purchaser.

For pipes less than 4 in (100 mm) the maximum out of alignment of the bore for processes other than inert gas and oxy-acetylene, without backing rings, may be increased to 1·5 mm maximum.

6.2.4 Backing rings. The use of permanent backing rings is not permitted except by agreement between the purchaser and the fabricator. Temporary and consumable backing rings shall comply with the requirements of BS 2633.

If temporary backing rings are used and are to be fused during the welding process, they shall be of the same nominal composition as the parent material. If rings are fused to the weld they shall be removed by machining so that the inner surface is smooth.

6.2.5 Proximity of welds. The attachment of branches and fittings by welds which cross or are in the immediate vicinity of circumferential or longitudinal seams in main pipe should be avoided. Where this is unavoidable, care shall be taken to minimize as far as possible local stress concentrations. When openings occur in welded seams, or are within 15 mm of any main seam, special inspection shall be provided to prove the soundness of the welds affected and they shall be radiographed for a distance on each side of the hole not less than the diameter of the opening, using the techniques and applying the acceptance limits defined in BS 2633*.

6.2.6 Branches. Typical 'set on' branch details are illustrated in Figs. 8.1 to 8.4 and Figs. 8.7 and 8.8; other forms of joint preparation shall be as agreed between the purchaser and the manufacturer. 'Set through' connections are only permissible if welded from both sides; see Figs. 8.5 and 8.6 for acceptable forms of preparation.

Procedure qualification tests are required for branches as specified in BS 2633, but the angle of branch to main used in the test shall not be greater than that to be used in production.

As an alternative to the requirements of BS 2633, procedure tests on branch welds may, by agreement between the purchaser and the manufacturer, be assessed by a combination of ultrasonic testing and crack detection or radiography and crack detection in lieu of the sectioning method specified.

6.2.7 Socket-welded joints. In making up socket-welded joints, care shall be taken to ensure that the required clearance exists between the pipe end and the bottom of the socket (see Fig. 7 for details of joint).

6.2.8 Flange attachment welds. These shall conform to one of the types illustrated in Figs. 9.1 to 9.4. The throat thickness of the fillet-welded portion of the weld connecting the back of the flange to the pipe shall not be less than the thickness of the pipe (Figs. 9.2 to 9.4).

Care shall be exercised when welding flanges and other fittings to ensure that the procedure used is satisfactory and capable of producing sound welds, e.g. flanges with a carbon content in excess of 0·26 % may be subject to special welding precautions, including preheat.

6.2.9 Heat treatment

6.2.9.1 The necessity for post-weld heat treatment depends not only upon material composition and thickness, but also upon service conditions during testing, operation and shut-down; for example, when ferritic pipework is subject to stress corrosion by means of caustic embrittlement or wet H_2S attack, post-weld heat treatment should be applied irrespective of thickness.

6.2.9.2 The post-weld heat treatment normally to be applied is that defined in BS 2633 and in Table 8 of that standard. Pipework to this standard shall be so treated except that post-weld heat treatment is not required under the following circumstances, unless specified by the purchaser.

* BS 2633, 'Class I arc welding of ferritic steel pipework for carrying fluids'.

(1) *Carbon steel.* For carbon steels, welded joints up to 0·25 % carbon, in thicknesses up to and including 32 mm, unless protection from brittle fracture, stress corrosion or similar effects is required.

(2) *Chrome molybdenum and molybdenum-bearing steels.* For chromium and molybdenum bearing steels with a nominal composition up to and including 1·25 % Cr 0·5 % Mo in thicknesses up to and including 20 mm, provided that the maximum hardness of the metal and heat affected zone does not exceed 240 H.B. and that such joints are not required for low temperature service.

(3) *Nickel steels.* Post-weld heat treatment is required for welds in 3·5 % nickel steel with the following exceptions:

when Ni-Cr-Fe weld metal is used, post-weld heat treatment is not required for pipes thinner than 12·5 mm for service temperatures above −105 °C;

if the Ni content of the weld metal exceeds 3 %, post-weld heat treatment is not required for pipes less than 20 mm in thickness for service temperatures above −75 °C.

NOTE. The use of austenitic stainless steel weld metal is not recommended for the welding of 3·5 % Ni steels required to be post-weld heat treated, or for joints subject to stress corrosion, e.g. chloride attack.

(4) *Austenitic steels.* Welded joints in stabilized or ELC austenitic stainless steel pipework not subject to stress corrosion effects in service need not be post-weld heat treated unless this is specified by the purchaser.

It is recommended that joints in austenitic stainless steel pipe work subject to such effects, e.g. chloride attack, should be stress relieved by post-weld heat treatment at a temperature of 875–950 °C for one hour per 25 mm of thickness with a minimum period of one hour followed by cooling in still air, and this treatment shall be applied to joints which may be subjected to stress corrosion unless agreed otherwise by the purchaser and the manufacturer.

When unstabilized stainless steel having a carbon content exceeding 0·03 % is used, fabrications intended for corrosive service should be given a full solution anneal after welding. When such steels are intended for service under non-corrosive conditions, as for example in low temperature applications, post-weld heat treatment is not required.

6.2.9.3 When local post-weld heat treatment is applied it is recommended that the minimum width of the heated band should not be less than $5\sqrt{Rt}$, where R is the radius of the pipe and t the pipe wall thickness. The weld should be located in the centre of the heated band. This may not provide full protection against stress corrosion attack and when additional precautions are necessary the width of the band should be specified by the purchaser. For local post-weld heat treatment the limit on the rate of heating specified in BS 2633 need not apply, provided that the pipe work is not damaged by the treatment. When the method employed for heating precludes the use of thermocouples, the reproducibility of the technique shall be proved by appropriate alternative methods which shall be subject to agreement between the purchaser and the manufacturer.

6.2.10 Welder's competence qualification

6.2.10.1 *General.* The following requirement supersedes Part 8, Section 2, of BS 2633, 'Qualifying tests for welders', and shall be read in conjunction with 6.2.10.6.

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Where a manufacturing firm can furnish proof satisfactory to the customer in conjunction with the inspecting authority, that all welders assigned to manual or machine welding on pipe work have within the previous six months completed satisfactorily welder competence qualification tests for the type of work and procedure concerned, or have been successfully engaged in the fabrication of pipework within the previous six months in accordance with the requirements of this British Standard, then all such welders shall be exempt from the necessity of requalifying under these rules so long as the welders remain in the employment of the same manufacturer.

Where such proof is not forthcoming, welders shall have passed the welder's competence test for the type of work and procedure concerned before being assigned to manual or machine welding. This qualification holds only as long as the welder remains in the employment of the same manufacturer.

The competence qualification tests of a welder accepted by one inspecting authority should normally be accepted by other inspecting authorities as long as the welder remains in the employment of the same manufacturer and there is no significant change in the environmental conditions.

6.2.10.2 ***Qualification requirements.*** Butt-welded test joints for welder competence qualification shall be submitted to visual and radiographic examination, as well as to macro-etching of a cross section of the weld.

In the case of welds made by the oxy-acetylene process or by the dip transfer (short arc) process, test welds of the butt-welded type of welder's competence qualification on pipes or tubes shall be tested by means of bend test pieces of the following number, width and conditions of bending:

Nominal diameter of pipe (D)	Face bend	Root bend	Width of bend* test specimen
Up to 2 in (50 mm)	—	2	$t + \frac{D}{10}$
Over 2 in (50 mm)	1	3	$t + \frac{D}{20}$

* Maximum width 40 mm.

The reinforcement shall be dressed off and the edges may be rounded to approximately 1·5 mm radius. The specimen shall then be bent around a former of diameter $3t$ through 90° or an agreed angle, depending on parent metal.

Test welds for welder's competence qualification shall be carried out in exactly the same way and under the same conditions as laid down for the welding procedure qualification. Changes in the procedure which entail requalification shall also require new welder competence tests, except for the following requirements (see 6.2.10.3) which are based upon the assumption that for all processes, except the oxy-acetylene and dip transfer processes, qualification is by means of radiography supplemented by other methods where this is considered to be necessary. If mechanical testing methods are used to evaluate the performance test welds the procedure used shall be exactly the same as for the procedure test plate. The oxy-acetylene and dip transfer processes may be approved by radiography provided that, in addition, the bend test requirements specified are also met.

6.2.10.3 ***Essential variables for welder performance qualification***

6.2.10.3.1 *Parent metal composition*

6.2.10.3.1.1 ALL PROCESSES. A change from ferritic to austenitic or from ferrous to non-ferrous or any change in the composition of a non-ferrous metal or alloy shall require requalification, unless otherwise agreed between the purchaser and the manufacturer.

6.2.10.3.1.2 OXY-ACETYLENE PROCESS. An increase of more than 25% in the content of chromium or nickel or molybdenum shall entail requalification.

6.2.10.3.2 *Position of pipe.* Qualification by means of welding a pipe in the horizontal fixed position shall qualify for welding pipes in all positions, except for circumferential welds in vertical pipes. For circumferential welds in vertical pipes the test weld made in the vertical fixed position shall qualify for all intermediate positions; alternatively a test in the 45° inclined position qualifies for all positions.

6.2.10.3.3 *Thickness.* When only part of the seam is to be welded by a particular process, e.g. for root runs, etc., partially welded seams may be tested. However, the number of runs used in the test weld shall not be less than may be required in production. The range of approval shall be within the following limits.

(1) *Oxy-acetylene process.* A test in the range up to and including 4 mm shall qualify for any other thickness in that range. A test plate thicker than 4 mm shall qualify for any thickness greater than 4 mm up to and including the thickness of the test plate.

(2) *Inert gas process.* A test in the range 2 mm to 4 mm shall qualify for any other thicknesses in that range. Tests on thicknesses below 2 mm shall be made in material no thicker than the material to be fabricated.

A test in the range above 4 mm up to and including 20 mm shall qualify for any other thickness in that range.

A test plate thicker than 20 mm shall qualify for any thickness over 20 mm.

(3) *Automatic, semi-automatic or manual electric process.* A test in the range 2 mm to 6 mm shall qualify for any other thicknesses in that range. Tests on thicknesses below 2 mm shall be made in material no thicker than the material to be fabricated.

A test in the range 6 mm up to and including 20 mm shall qualify for any thickness in that range.

A test plate thicker than 20 mm shall qualify for any thickness over 20 mm.

6.2.10.3.4 *Filler metal plus shielding gas*

6.2.10.3.4.1 ALL PROCESSES. A change from ferritic to austenitic or from ferrous to non-ferrous or any change in the composition of a non-ferrous metal or alloy shall require requalification, unless otherwise agreed between the purchaser and the manufacturer.

6.2.10.3.4.2 OXY-ACETYLENE WELDING. An increase of more than 25 % in the content of Cr or Ni or Mo in the filler wire shall entail requalification.

6.2.10.3.4.3 DIP TRANSFER PROCESSES. Any change in the composition or in the wire manufacturing process which has a significant effect upon the welding or running characteristics or any change in the composition of the shielding gas shall entail requalification.

6.2.10.3.4.4 METAL ARC PROCESS. Generally, qualification is limited to within the four main groups, viz: basic, cellulosic, rutile and acid. However, a change in electrode make or type need not be cause for requalification, provided that there is no significant change in welding or running characteristics.

Qualification shall extend to a change in electrode size of ±1 nominal diameter for the flat position; for other positions the range shall be limited to the size tested and one nominal diameter smaller.

6.2.10.3.4.5 TUNGSTEN INERT GAS PROCESS. Any change in gas composition shall entail requalification but not a change in filler metal within the limits of composition defined in 6.2.10.3.4.1.

6.2.10.3.5 *Automatic and semi-automatic processes.* Each process shall be subject to individual qualification, but a change in flux, wire size, in the speed of welding or in the electrical parameters, e.g. voltage, current intensity, a.c. or d.c., etc., need not be cause for requalification.

6.2.10.3.6 *Joint preparation.* By agreement, a change in the form of joint preparation need not be cause for requalification unless the alteration adversely affects the ease of welding.

For branch and nozzle welds, etc., a change in joint preparation within the range of typical forms recommended herein need not be cause for requalification.

6.2.10.3.7 *Pipes and tubes.* Qualification for welds in pipes and tubes shall be subject to all the essential variables specified herein and in addition shall be limited to the following limits of diameter:

(1) a test in a pipe with a nominal diameter less than 2 in (50 mm) shall qualify for all nominal diameters below 2 in (50 mm);

(2) qualification in a pipe with a nominal diameter 2 in (50 mm) or larger shall qualify for all nominal diameters 2 in (50 mm) or larger.

6.2.10.3.8 *Branches and other openings.* Welders engaged in welding branch connections, boxes, plate flanges and similar joints in all positions shall be qualified on pipe in accordance with the requirements of 6.2.10.3.2.

6.2.10.4 ***Requirements of test welds.*** The appearance of the test welds, the macrographs, where required, and the radiographs of the test welds shall conform to the requirements of BS 2633*, Clauses 47 and 60 *f* (ii).

6.2.10.5 ***Records and validity of tests***

6.2.10.5.1 *Records of test.* Records of test shall be kept by the manufacturer and shall be available for examination if required.

6.2.10.5.2 *Validity of competence qualification.* A welder who has successfully carried out a welding procedure qualification is thereby qualified for welder's competence in the procedure concerned.

6.2.10.6 ***Repeating of tests.*** The required test shall be repeated at any time if in the course of the previous six months the records of the welder show unsatisfactory production work or if the welder has not been employed by the same manufacturer on the same type of work in pipework fabrication for a period of six months or more. When access is limited or other special conditions prevail, supplementary tests may be required.

* BS 2633, ' Class I arc welding of ferritic steel pipework for carrying fluids '.

6.3 BENDING OF PIPES

6.3.1 Thickness of pipe bends. The minimum thickness of a pipe bend on completion of bending, taking into account any possible thinning of the pipe wall, shall not be less than that required for straight pipe calculated by the method specified in 5.2.1.

6.3.2 Out-of-roundness. The out-of-roundness of a bend, as measured by the difference between the maximum and minimum diameters at any cross section, shall not exceed 8 % and 3 % of the nominal outside diameter for internal and external pressures respectively, except that the out-of-roundness of the ends shall comply with that for the associated pipe. This shall not prohibit the use of bends designed as creased or corrugated bends.

6.3.3 Workmanship. Apart from minor irregularities defined in the Note, all bends shall be free of cracks, wrinkles, bulges, kinks and other serious defects.

An irregularity will be acceptable if the height does not exceed 25 % of the wall thickness, with the base or width at least eight times the height, and if it blends smoothly into adjoining surfaces. The out-of-roundness tolerances as specified in 6.3.2 shall not be exceeded by the cross section containing the irregularity.

6.3.4 Hot and cold bending

6.3.4.1 The bending of carbon and alloy steel pipe may be done in the hot or cold condition and shall conform to the requirements of Table 2. Water quenching shall not be permitted for alloy steel pipe, but methods of bending control involving a fine water spray may be permissible by agreement between the purchaser and the fabricator.

6.3.4.2 The bending of copper tubes may be done in the cold or hot condition.

6.3.4.3 The bending of copper alloy, aluminium and aluminium alloy tubes is usually done in the cold condition, but where hot bending is done, special precautions as recommended by the tube manufacturer should be adhered to.

6.3.4.4 The bending of nickel and nickel alloy pipe shall be done in the cold state only. If the bending is carried out using low melting point fillers, these should be removed prior to any subsequent welding or heat treatment.

6.3.5 Heat treatment. Heat treatment after hot and cold bending shall comply with the requirements of Table 2. Additional post-heat treatment shall be performed where necessary to restore or obtain the physical properties such as strength, ductility, etc., with respect to material, design and end use requirements.

Cold bent carbon and low alloy steel pipes in all thicknesses shall be stress relieved when impact tested. All pipes intended for caustic or other service likely to induce stress corrosion cracking shall also be stress relieved.

Heat treatment of bent aluminium alloy pipes is only required when the original material was in the W temper, and the heat treatment is required to age it to the WP condition.

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TABLE 2. BENDING OF PIPES—HEAT TREATMENT REQUIREMENTS

Material	Cold bending		Hot bending	
	Maximum allowable bending temperature	Heat treatment* after bending	Allowable bending temperature range	Heat treatment* after bending
	°C		°C	
C	650	None	850–1050	None
C—0·5 % Mo	650	None	900–1100	None
0·5 % Cr—0·5 % Mo	650	None	900–1100	None
1·25 % Cr—0·5 % Mo	650	None	900–1100	Anneal, or normalize and temper
2·25 % Cr	690	None	900–1100	
5–9 % Cr	720	None	900–1100	
Austenitic stainless steels	425	None	925–1150	Solution anneal
3·5 % Ni	640	Stress relieve	950–1100	Normalize and temper
0·5 % Cr 0·5 % Mo 0·25 %V	690	None	950–1100	Normalize and temper
Aluminium and aluminium alloys†	150‡	§	§	§
Copper‖	190	None	600–650	None
Copper alloys ‖	190	Stress relieve	§	None
Nickel and nickel alloys¶	190	None	—	—

NOTE. Heating to just below the lower critical point is a limiting definition of cold bending for the purpose of this standard.

* See 6.3.5.
† See Table 3B.
‡ Excluding alloys exceeding 3 % magnesium, where specialist advice should be sought.
§ See 6.3.4.3.
‖ See Table 3A.
¶ See Table 3C.

6.3.6 Fabricated special components. When fabricated special components (not covered by the standards listed in Table 1) are required, they may be fabricated from materials listed in Table 1 and shall comply with the general requirements of 6.2.

6.4 MECHANICAL JOINTS

6.4.1 Connections in ferrous pipework. Connections may be made by:

(1) screwed pipe fittings;

(2) bolted flanges, using screwed, slip-on, welding-neck, socket-welding or lapped flanges;

(3) other types of connections, provided they are suitable for the conditions encountered and meet the requirements of other sections.

6.4.2 Connections in non-ferrous pipework. Connections may be made by:

(1) screwed pipe fittings;

(2) bolted flanges connected to the pipe by expanding and flaring, screwing, brazing-on or using slip-on, welding-neck or lapped flanges;

(3) brazed joints, only permitted in non-hazardous service. They shall be of the capillary type and shall meet the requirements of BS 1723*. The brazed joint shall extend the full depth of the socket. Fillet brazed joints are not permitted;

(4) other types of connections, provided they are suitable for the service conditions encountered and meet the requirements of other sections.

6.4.3 Screwed joints

6.4.3.1 All screwed joints shall be taper threaded in accordance with the requirements of API STD. 5B for line pipe threads, or ANSI STD. B2.1. If, in exceptional cases, a parallel thread is required, it shall conform to the appropriate requirements in ANSI STD. B2.1.

* BS 1723, ' Brazing '.

6.4.3.2 All threads shall be cut clean and true to their full length and depth and shall comply with the gauging requirements of the standards quoted in 6.4.3.1.

6.4.3.3 Pipe to which screwed flanges Class 600 in sizes 3 in (80 mm) and over and screwed flanges of higher classes are attached, shall have the length of thread increased as provided for in Appendix D of BS 1560, to ensure that the ends of pipe will be brought close to the face of flanges when parts are assembled by power.

6.4.3.4 To facilitate tightening during assembly and to promote long-time pressure-tightness of screwed joints, the use of a compound or tape having lubricating, sealing and suitably stable properties for the intended service is recommended, except when the joints are to be seal-welded.

6.4.3.5 Screwed joints may be seal-welded when:

(1) the materials are weldable,

(2) the joint is made up clean and dry,

(3) all exposed threads can be covered by the seal-weld,

(4) no other satisfactory means of jointing are available.

6.4.4 Bolted connections

6.4.4.1 Bolting shall be of sufficient length to permit nuts to engage for their full thickness when tightened up. Bolt threads shall be clean and undamaged. The use of more than one washer, or of packing pieces to prevent nuts from binding on the thread run-out, is not permitted. A high temperature-resistant lubricant should be applied to the threads of bolting intended to operate at elevated temperatures, to prevent or minimize galling.

Lubricants containing lead or copper should not be used on austenitic steels at high temperatures.

6.4.4.2 The surfaces on which bolting tightens shall be clean and undamaged.

7. INSPECTION AND PRESSURE TESTING

7.1 SCOPE OF SECTION 7

This section specifies inspection and pressure testing requirements for components and fabricated items and for completed piping systems, other than plastics pipework, for which reference should be made to CP . . . .*.

7.2 GENERAL REQUIREMENTS

7.2.1 General. The purchaser or his representative shall have access at all reasonable times to those parts of the works engaged in the preparation, fabrication and testing of the pipe assemblies. The fabricator shall afford the purchaser or his representative all reasonable facilities for inspection during progress and on completion of the work.

7.2.2 Inspection of components. All the components of a piping system shall be subject to the inspection requirements described below.

7.2.2.1 The inspection of such components may be carried out by the purchaser or his representative at the manufacturer's works.

Alternatively, by agreement with the purchaser, the manufacturer shall supply a certificate stating that the components comply in all respects with the specified requirements.

7.2.2.2 Components which are listed in Column 2 of Table 1 shall be subject to the inspection requirements of the relevant standards listed in Column 3.

7.2.2.3 Components for which no standards are listed in Table 1 shall be subject to the inspection requirements specified in the order.

7.2.3 Shop fabricated piping assemblies. Assemblies shall be subject to the inspection requirements of this section. Inspection shall be carried out by the purchaser or his representative at the fabricator's works.

7.2.4 Pipework constructed on site. Site construction shall be subject to the inspection and testing requirements of this section.

7.3 INSPECTION OF WELDED JOINTS

7.3.1 The first butt joint welded by each operator shall be fully examined by means of radiography. Unless specified otherwise by the purchaser the extent of examination of subsequent joints need not exceed the following, provided that the quality of the work is shown to be satisfactory.

7.3.1.1 For carbon steel pipe joints a minimum of 5 % of the joints shall be spot radiographed for thicknesses up to and including 10 mm and 10 % for all other thicknesses.

Joints in carbon steel pipes less than 2 in (50 mm) nominal size need not be radiographed if agreed between the purchaser and the manufacturer.

7.3.1.2 For ferritic alloy steel pipe joints a minimum of 25 % of the joints shall be spot radiographed irrespective of thickness and diameter.

7.3.1.3 All joints in austenitic steel and in non-ferrous metals shall be fully radiographed, except where otherwise agreed between the purchaser and the manufacturer. All joints in stabilized stainless steel in thickness 20 mm and over shall be fully radiographed after any post-weld heat treatment which may be required.

7.3.2 Ultrasonic methods of examinations may be used in place of radiography if agreed between the purchaser and the fabricator. Other forms of non-destructive testing such as magnetic particle and dye-penetrant crack detection may be used to supplement these tests.

7.3.3 All carbon and ferritic alloy steel branch welds in pipes over 32 mm in thickness shall be magnetic crack detected. When electrical probes are used, care shall be taken to ensure that the pipe surfaces are not damaged by arcing.

All welds in austenitic steels and in non-ferrous metals shall be examined by dye penetrants.

7.3.4 **Weld quality—circumferential butt welds.** The weld reinforcement shall not exceed 3 mm and shall be of uniform profile. The edges of welds shall merge smoothly into the pipe surface. Fillet welds shall be regular in form, of uniform leg length and without undercut. Any of the following

* CP ....., in course of preparation.

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imperfections as disclosed by visual examination or non-destructive testing shall be sufficient cause for rejection.

(1) Any type of crack or lack of fusion.

(2) Positive penetration exceeding 1·5 mm for pipe up to and including 2 in (50 mm) size or 3 mm for pipe greater than 2 in (50 mm) size.

(3) Lack of penetration in carbon steel butt joints exceeding 1·5 mm in depth or 25 mm in any 300 mm length of weld with no single length exceeding 15 mm, or in alloy steel butt joints if exceeding 0·8 mm depth or 10 mm in 150 mm length of weld with no single length exceeding 10 mm in length.

Under certain operating conditions complete root penetration throughout the joint may be considered an essential requirement. Such cases shall be the subject of agreement between the purchaser and the fabricator.

(4) Undercut exceeding 0·8 mm in depth or of a total length exceeding 5 % of weld length.

(5) Slag inclusions or voids exceeding 6 mm length or 1·5 mm width. The cumulative total length in carbon steel welds shall not exceed 25 mm in any 300 mm length of weld, or in alloy steels 6 mm in any 80 mm.

(6) The total area of porosity projected radially through the weld shall not exceed 10 mm² in any 1000 mm² of projected weld area (equal to approximately five pores of 1·5 mm diameter). No single pore shall exceed 1·5 mm diameter for wall thickness 6 mm and over, or 0·8 mm diameter for wall thickness less than 6 mm.

7.3.5 Weld quality—longitudinal butt welds. Longitudinal butt welds in welded piping components shall comply with the weld quality requirements for the appropriate fusion-welded pipe specification listed in Table 3.

7.3.6 Defective work. When defective work is disclosed, the cause shall be established and rectified; the purchaser shall decide on the steps to be taken to determine the limits of unacceptable welding. The method and extent of repairs of any defective welding shall be subject to agreement between the purchaser and the fabricator.

7.4 PRESSURE TESTING

Unless called for by the purchaser, fabricated piping is not required to be pressure tested prior to its erection on site.

Erected piping systems shall be pressure tested in accordance with the following requirements.

7.4.1 The testing medium shall be water for carbon and ferritic alloy steels, unless otherwise agreed.

With austenitic stainless steel pipe, to avoid the possibility of subsequent failure due to stress corrosion cracking or pitting, it is recommended that potable water having a chloride content of less than 30 p.p.m. should be used. Water having a chloride content above 100 p.p.m. should not be used in any circumstances, and where it is necessary to use water within a range of 30 to 100 p.p.m., lines shall be flushed with a chloride-free liquid within a short period of testing.

If there is a possibility of damage due to freezing, or if the operating fluid or piping material would be adversely affected by water, a testing medium suitable for the conditions may be used, as agreed between the purchaser and the manufacturer.

7.4.2 If hydrostatic testing is not considered practicable by the purchaser, a pneumatic test may be substituted by agreement between the manufacturer and purchaser, using air or other non-flammable gas.

The dangers associated with pneumatic testing and the consequences of failure of any part of the system under test due to the stored energy in a compressed gas should be recognized, and suitable precautions taken.

Any pneumatic test shall include a preliminary check of not more than 1·5 bar*. The pressure shall be increased gradually in steps, providing sufficient time to allow conditions to stabilize and to check for leaks.

Pneumatic pressure tests of any piping system, which has not previously been subjected to a hydraulic pressure test at a pressure exceeding the pneumatic test pressure, shall be carried out at a temperature at least 20°C above the permissible design temperature indicated by Fig. 1 for the nominal material thickness and material reference temperature concerned. This requirement shall apply to each welded component which has not been post-weld heat treated in accordance with the requirements of 6.2.9.

7.4.3 Where pipework or its components are subjected to any form of stress relieving, the pressure test shall be carried out after the stress relieving treatment.

7.4.4 Individual components

7.4.4.1 The pressure testing of standard components shall be in accordance with the requirements of the relevant standards in Table 1.

7.4.4.2 Components for which no standards are listed in Table 1 shall be tested in accordance with the requirements for comparable standard components.

7.4.5 Preparation and procedure

7.4.5.1 On completion of erection, the inside of all pipe, valves, fittings and other associated equipment shall be clean and fresh from loose mill scale and foreign matter, and prepared for the inspection procedure specified in this section.

7.4.5.2 Vents shall be located at the high points in the system or section thereof to be tested, in order to ensure complete displacement of air from the system or section.

7.4.5.3 Insulation should not be applied over welded or mechanical joints, and connections or welds should not be painted before the completion of pressure testing.

7.4.5.4 Wherever possible, underground lines should be tested before back-filling. Where it is essential to back-fill any section of a line before testing it is recommended that such section should be subjected to test pressure for a period of at least two hours and checked for pressure drop.

7.4.5.5 A line supported by springs or counter-weights should be supported temporarily, if necessary, to a degree sufficient to sustain the load of the line filled with the test liquid.

7.4.5.6 Mechanical equipment and pressure relieving devices should be blanked off or removed from the line during pressure testing and control valves should be set in the open position for the duration of the test.

* 1 bar = 10^5 N/m².

7.4.5.7 Orifice plates should not be installed until after testing is completed.

7.4.5.8 Lines containing check valves should have the source of test pressure located on the upstream side.

7.4.5.9 Expansion joints, instruments, filters and similar equipment for which the maximum permissible cold test pressure is lower than the hydrostatic test pressure applied to the system, shall be removed or blanked off from the line before testing.

Such equipment should be inspected during the commissioning test.

7.4.5.10 When conditions require a test pressure to be maintained for a period of time, during which the testing medium in the system might be subject to thermal expansion, provision should be made for the relief of resulting excess pressure.

7.4.5.11 On completion of a hydrostatic test in cold weather or under conditions where remaining moisture might react with the contents of the system when starting operations, it is important that the system be drained of water and if necessary dried, in order to avoid damage.

7.4.5.12 Where there may be residual moisture in the valve packings after hydrostatic testing, consideration should be given to repacking of valves used in low temperature and corrosive chemical service.

7.4.6 Test pressures

7.4.6.1 Piping systems tested hydrostatically shall be tested to a pressure of not less than 1·3 times the design pressure adjusted to 50°C, but in no case less than 7 bar*. T

* 1 bar = 10^5 N/m².

determine the test pressure the following formula shall be used:

$$P_t = 1{\cdot}3\,\frac{P_o S_c}{S_h},$$

where P_t = hydrostatic test pressure, bar*,

P_o = design pressure, bar* (gauge),

S_c = design stress at 50°C (see Tables 3, 3A, 3B, and 3C),

S_h = design stress at the maximum operating temperature (see Tables 3, 3A, 3B, and 3C).

However, in no case shall the test pressure exceed that specified in the standards listed in Table 1 for the weakest element in the system or section thereof being tested.

It is recommended that no part of the piping be subjected to a pressure exceeding that corresponding to 90 % of the specified minimum yield stress of the material.

7.4.6.2 If piping is tested pneumatically, the test pressure shall be 110 % of the design pressure, unless otherwise specified.

NOTE. ATTENTION IS DRAWN TO THE IMPLICATIONS OF NOTE 3 OF 5.2.1 CONCERNING SHORT DURATION OVERPRESSURES FOLLOWING VARIATION IN THE OPERATING TEMPERATURE OR PRESSURE.

7.4.6.3 In special cases where it is not possible to carry out a pressure test on an erected piping system, other agreed means of ensuring the safety of the system shall be employed. For this purpose consideration should be given to pressure testing fabricated piping prior to erection in addition to increasing the amount of inspection of weld preparations, welding and completed welds. In general, increased radiographic examination supplemented by other non-destructive testing should be applied. It should be noted that 100 % radiography alone will not necessarily provide complete assurance of the safety of the system.

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TABLE 3. DESIGN STRESSES FOR FERROUS PIPES

Material	Notes	Values of S for metal temperatures in °C not exceeding																
		50	100	150	200	250	300	350	400	425	450	475	500	525	550	575	600	
		N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	
BS 3601 HFS, CDS, Steel 22	1	125·5	114·5	103·9	99·3	94·5	89·7	85·0	75·0	65·7	56·9							
BS 3601 HFS, CDS, Steel 27	1	154·5	141·3	127·5	121·7	114·2	110·0	104·0	87·7	75·8	62·0							
API 5L Grade A, seamless; steels open hearth, electric furnace and basic oxygen		122·5	111·9	101·3	95·8	91·3	86·5	82·0	73·1	64·8	55·8							
API 5L Grade B, seamless, submerged arc, spiral weld; steels open hearth, electric furnace and basic oxygen	2	153·0	139·8	126·5	119·0	113·8	108·5	102·5	89·3	75·5	62·0							
BS 3602 CDS, HFS and ERW, steel 23	2	130·0	125·5	120·6	117·3	111·5	96·5	88·9	78·2	67·9	57·7	47·5	35·8					
BS 3602 CDS, HFS and ERW, steel 27	2	154·5	143·0	132·0	127·0	119·0	110·0	104·2	89·7	75·9	62·3	48·6	35·8					
BS 3602 EFW Grade 28 B	2,3	123·5	116·5	109·6	104·0	95·2	90·4	87·0	73·8	62·0	50·3	39·3	24·8					
BS 3603 HFS, CDS, steel 27 LT 30	4,5	154·5	143·3	132·0	126·5	119·0												
BS 3603 HFS, CDS, steel 27 LT 50	4,5	154·5	143·3	132·0	126·5	119·0												
BS 3603 HFS, CDS, steel 503 LT 100	4,5	159·0	147·8	135·3	129·3	121·9												
BS 3604 620 HFS, CDS, steel 27		166·5	144·2	144·0	139·0	124·5	114·0	109·5	104·0	101·5	98·5	92·3	81·0	62·8	43·8	28·9	17·2	
BS 3604 621 HFS, CDS, steel 27		144·5	144·2	144·0	139·0	124·5	115·5	110·5	106·0	103·8	100·0	92·8	81·2	64·3	49·3	34·2	24·4	
BS 3604 622 HFS, CDS, steel 27		144·5	134·2	129·6	125·0	120·5	115·5	111·0	106·0	103·8	101·0	92·5	82·8	63·8	47·5	36·2	26·8	
BS 3604 622 HFS, CDS, steel 31		164·0	164·0	164·0	164·0	156·5	150·5	144·0	137·2	134·0	130·2	107·5	82·8	63·8	47·5	36·2	26·8	
BS 3604 660 CDS, HFS		172·0	172·0	167·0	164·0	156·5	150·5	144·0	137·2	134·0	130·2	127·5	115·6	79·9	53·7	36·9		
BS 3604 625 HFS		137·0	131·0	125·5	119·5	114·0	108·5	103·0	97·0	92·8	86·5	81·0	72·4	59·0	43·8	31·3	21·1	

See page 32 for Notes.

TABLE 3. DESIGN STRESSES FOR FERROUS PIPES (*cont.*)

Material	Notes	Values of S for metal temperatures in °C not exceeding*																							
		−200 to +50	100	150	200	250	300	350	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800	825
		N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²
BS 3605 Grade 801 (304)	6	126·0	113·5	103·5	95·0	87·5	81·9	76·3	71·7	68·9	66·8	64·8	63·3	61·3	59·7											
BS 3605 Grade 811 (304H)	6															55·8	48·0	37·6	30·7	22·4	17·6	13·4	10·3	7·9	6·2	4·5
BS 3605 Grade 801L (304L)	6	106·8	102·8	90·3	76·5	68·2	63·3	60·0	57·2	55·8																
BS 3605 Grade 822Ti (321)	6	129·3	127·5	117·0	108·5	105·5	102·8	102·0	101·3	100·5	99·0	97·5	96·0	94·0												
BS 3605 Grade 832Ti (321H)															91·7	88·5	75·8	51·3	34·5	25·5	19·6	15·2	11·8	9·3	7·6	6·5
BS 3605 Grade 845 (316) and Grade 845Ti and Grade 846 (317)	6	129·3	128·2	123·5	120·6	118·7	118·0	117·5	116·5	115·5	114·0	111·5	106·0	99·3	90·3	79·3	67·6	56·2	46·6	36·8	28·3	22·0	17·6	14·4	11·8	9·6
BS 3605 Grade 845L (316L)	6	107·5	106·2	100·0	83·4	79·3	74·3	66·9	62·3	60·7	58·6															

* Intermediate values may be obtained by linear interpolation.

NOTE 1. Limited application (see Section 3).

NOTE 2. The design stress values for pipe with a longitudinal or spiral weld seam incorporate weld joint factors as follows:

API 5L submerged arc welded:	1·0
API 5LS Grade B:	1·0
BS 3602 E.R.W. with Appendix A:	1·0
BS 3602 E.F.W.:	0·8.

NOTE 3. The values for BS 3602 E.F.W. are based on material to BS 1501–151 or 161, Grade 28B (certified or hot tested).
For temperatures over 400°C, 161 material should be used.

NOTE 4. The BS 3603 pipes listed are impact tested and are intended for use in low temperature service.

NOTE 5. Up to 250°C to cover ' steaming-out ' and flexibility calculations.

NOTE 6. The figures in parenthesis alongside the grades are equivalent AISI types. There is no AISI equivalent of 845Ti.

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For temperatures over 400°C, 161 material should be used.
NOTE 4. The BS 3603 pipes listed are impact tested and are intended for use in low temperature service.
NOTE 5. Up to 250°C to cover ' steaming-out ' and flexibility calculations.
NOTE 6. The figures in parenthesis alongside the grades are equivalent AISI types. There is no AISI equivalent of 845Ti.

TABLE 3A. DESIGN STRESSES FOR COPPER AND COPPER ALLOY SEAMLESS PIPE AND TUBE

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Material	British Standard	Condition	Minimum tensile strength	Values of S for metal temperatures in °C not exceeding*											
				75	100	125	150	175	200	225	250	275	300	325	350
			N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²
Copper	2871 C106 or C107	Annealed	216·5	46·8	44·4	42·4	33·9	27·2	18·8	11·4					
		Hard	289·0	98·3	70·5	67·2	54·1	37·6	20·3	4·3					
70/30 Brass	2871 CZ105	Annealed	331·0	85·6	84·2	84·2	81·8	55·2	26·6	16·2					
Aluminium brass 76/22/2	2871 CZ110	Annealed	331·0	85·6	84·2	84·2	81·8	55·2	26·6	16·2					
Admiralty brass 70/29/1	2871 CZ111	Annealed	331·0	85·6	84·2	84·2	81·8	55·2	26·6	16·2					
95/5 Copper-nickel-iron	2871 CN101	Annealed	278·0	68·7	67·2	65·3	64·0	62·3	60·3	58·2	54·1	49·2	43·8		
90/10 Copper-nickel-iron	2871 CN102	Annealed	309·0	73·3	72·3	71·2	70·0	67·8	63·1	58·2	54·1	49·2	43·8		
70/30 Copper-nickel-iron	2871 CN107	Annealed	386·0	95·8	92·3	89·3	86·2	83·2	80·8	77·8	76·6	73·4	70·0	67·8	64·7
Aluminium bronze	2871 CA102	Annealed	386·0	95·8	92·3	89·3	82·3	71·0	46·8	32·1	19·6				

Material ordered for the application of these design stresses shall be specified to the minimum tensile strength shown in Column 4.

* Intermediate values may be obtained by linear interpolation.

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