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BRITISH STANDARD CODE 1501 : 1949
PROVISIONAL

FUSION-WELDED PRESSURE VESSELS

FOR USE IN THE
CHEMICAL AND ALLIED
INDUSTRIES

BRITISH STANDARDS INSTITUTION

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THIS PROVISIONAL BRITISH STANDARD is being issued for comment over a period of 12 months. It will then be reviewed in the light of experience gained and the observations submitted.

Date of issue, 11th November, 1949.

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.

In order to keep abreast of progress in the industries concerned, British Standards are subject to periodical review. Suggestions for improvements will be recorded and in due course brought to the notice of the committees charged with the revision of the standards to which they refer.

A complete list of British Standards, numbering over 1600, indexed and cross-indexed for reference, together with an abstract of each standard, will be found in the Institution's Yearbook, price 5s. post free.

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 edition.

Users wishing to be kept informed of any alteration to this standard should notify Sales and Distribution Department of the Institution, giving the number and title of the standard.

CO-OPERATING ORGANIZATIONS

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

Association of British Chemical Manufacturers
Association of Consulting Engineers, Incorporated
Board of Trade
British Chemical Plant Manufacturers Association
Coke Oven Managers Association
Electrodepositors' Technical Society
Glass Manufacturers Federation
*Institute of Petroleum
*Institution of Chemical Engineers
Institution of Gas Engineers
*Institution of Mechanical Engineers
Institution of Structural Engineers
Iron and Steel Institute
Society of Chemical Industry

The scientific 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 British Standard:—

Associated Offices Technical Committee
British Iron and Steel Federation
Lloyds Register of Shipping
Manufacturers of Pressure Vessels
Ministry of Transport
National Physical Laboratory
Users of Pressure Vessels

PROVISIONAL BRITISH STANDARD CODE

FUSION-WELDED PRESSURE VESSELS

FOR USE IN THE CHEMICAL AND ALLIED INDUSTRIES

B.S. 1500 : 1949

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SCHEME OF CODES

RELATING TO PRESSURE VESSELS

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SUMMARY OF CODE REQUIREMENTS

1	2	3	4	5	6	7	8	9	10	11
Vessel duty	Diameter	Plate thickness	Pressure	Temperature	Material inspection	Construction inspection	Mechanical tests	Radiographic tests	Stress relief	Joint* efficiency 'J'
SEVERE	No limit	No limit	No limit	No limit and fired vessels, all pressures	Full	Full	Full	Full	All vessels	0·95
Clauses	—	—	—	—	20 & 180–193	21 & 180–193	22 & 194–196	23 & 197–207	24 & 172–179	Table 8
MEDIUM	No limit	No limit	No limit	No limit but fired vessels not to exceed 100 lb/sq. in. working pressure	Limited	Limited	Limited	Longitudinal seams only, if exceeding 1½ in. thick or 1000 lb/sq. in. working pressure; or if special materials used	All steel vessels exceeding 0·3 carbon. Vessels with less carbon to Fig. 4	0·89 if stress relieved and radiographed. 0·80 stress relieved only. 0·83 to 0·89 radiographed only. 0·74 to 0·80 not stress relieved or radiographed.
Clauses	—	—	—	—	20 & 180–193	21 & 180–193	22 & 194–196	23 & 197–207	24 & 172–179	Table 9
LIGHT	Limited by ⅝ in. thick and 250 lb/sq. in. hydraulic pressure.	⅝ in. thick	50 lb/sq. in. vapour pressure or 250 lb/sq. in. hydraulic pressure	300°F. (150°C.) unfired	Minimum	Minimum	Minimum	Longitudinal seams only, if special materials used.	All steel vessels exceeding 0·3 carbon. Vessels with less carbon to Fig. 4	0·80 if stress relieved and radiographed. 0·71 stress relieved only. 0·74 to 0·80 radiographed only. 0·65 to 0·71 not stress relieved or radiographed.
Clauses	3	3	3	3	20 & 180–193	21 & 180–193	22 & 194–196	23 & 197–207	24 & 172–179	Table 10

* Double welded butt and weldability = 1.0.

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PROVISIONAL BRITISH STANDARD CODE FOR FUSION-WELDED PRESSURE VESSELS

FOR USE IN THE CHEMICAL AND ALLIED INDUSTRIES

NOTE. *This first edition is intended to serve as a tentative code for comment over a period of 12 months. It will then be reviewed in the light of the experience gained and observations submitted.*

FOREWORD

The industry which makes the greatest use of pressure vessels (other than steam boilers) is undoubtedly the chemical industry in its many branches—petroleum, soap, paper rubber, plastics, etc. There are also many subsidiary 'chemical units' in general industrial plants, such as impregnators in electric cable manufacture and vacuum stills for dry cleaning in laundries.

The petroleum branch operates on a very large scale and it is appropriate to consider the special activities of this branch when reviewing the requirements for pressure vessels. In the preparation of this Code, therefore, full consideration has been given not only to British practice but also to the experience of the American petroleum industry and acknowledgement is made to the American Petroleum Institute and American Society of Mechanical Engineers (A.P.I.—A.S.M.E.) Code.

In this British Standard Code vessels are graded according to the severity of the duty or danger, and inspection and tests of increasing stringency have been applied as the duty becomes more severe.

Section One: General

A. SCOPE

GENERAL

1. *a.* This British Standard Code covers the design, construction, inspection and repair of fusion-welded pressure vessels for use in the chemical and allied industries. The field is very wide and the following list, which is not exhaustive, gives examples of such vessels in common use in the chemical and allied industries :—

Absorbers	Impregnators
Autoclaves (digestors, etc.)	Mixers
Canning 'retorts'	Montejus (acid eggs, etc.)
Coolers	Pressure storage vessels
Condensers	Reactors
Dephlegmators	Receivers
Disinfectors	Scrubbers for gas
Extractors	Separators
Filters	Sterilizers
Fractionators	Stills
Heat exchangers	Tanks
Heaters	Vulcanizers

All of these may be operated under pressure or vacuum according to process requirements.

b. Attention is called to the fact that British Standards exist for a number of pressure vessels, for example :—

(i) *Gas cylinders.*

B.S. 399. 'High carbon' steel cylinders for 'permanent' gases.

B.S. 400. 'Low carbon' steel cylinders for the storage and transport of 'permanent' gases.

B.S. 401. Steel cylinders for the storage and transport of 'liquefiable' gases.

B.S. 1045. Manganese steel gas cylinders for atmospheric gases.

B.S. 1287. 'High carbon' steel gas cylinders for carbon dioxide, nitrous oxide and ethylene.

B.S. 1288. Manganese steel gas cylinders for carbon dioxide, nitrous oxide and ethylene.

(ii) *Unfired pressure vessels.*

B.S. 428. Forge welded steel air receivers.

B.S. 429. Riveted steel air receivers.

B.S. 430. Solid drawn steel air receivers (not intended for transport).

B.S. 487. Fusion welded steel air receivers.

B.S. 1099. Small fusion welded steel air receivers.

B.S. 1101. Pressure paint containers.

(iii) *Boilers.*

B.S. 537. Lancashire and Cornish boilers.

B.S. 609. Horizontal multitubular boilers.

B.S. 665. Vertical cross tube boilers.

B.S. 761. Vertical multitubular boilers.

B.S. 931. Loco-type multitubular boilers.

B.S. 1113. Water-tube boilers.

B.S.*..... Steam receivers and separators.

c. Many of the requirements of the Code are not mandatory, as are those of a specification, which outlines exactly the requirements for a specific article. It is intended to serve as a guide for agreement between the purchaser and manufacturer.

d. Nothing in this Code is intended to contravene any provision of the Factories Act 1937 or of any regulations made thereunder, or any other statutory requirements.

* In course of preparation.

e. The 'Scheme of Codes' (see page 2) shows the ground covered by this Code and also, to complete the subject, other relevant British Standards and Codes.

B. DEFINITIONS

The range of pressures, temperatures, materials and duties, etc., is much wider in the chemical industry than in any other fields, and to avoid confusion users of this Code are recommended to adhere to the following terms :—

DOMED END

2. *Domed end.* An end closure the shape of which is a surface of revolution of a curve, arc or combination of arcs, and this includes all shapes varying from hemispherical to slightly 'dished.' The curves are tangential to the surface of the wall of the shell where the end joins the parallel portion of the vessel shell.

(i) *Semi-ellipsoidal end.* An end having a profile which is truly semi-elliptical.

(ii) *'Dished' end.* An end having a profile formed by two radii.

JOINT EFFICIENCY (OF A JOINT OR LIGAMENT)

3. The ratio of the strength of the joint or ligament to the strength of the plates which it unites, expressed as a decimal fraction.

LININGS AND COATINGS FOR VESSELS

4. *a. Vessels with metal linings.*

(i) Vessels in which the lining is completely loose or secured to the walls of the vessel only from point to point.

(ii) Vessels in which the lining is bonded or rigidly attached to the walls of the vessel. Nickel or stainless 'clad' and 'homogeneous' lead-lined vessels belong to this class.

b. Vessels with non-metallic linings.

(i) Vessels in which linings of stoneware tiles and similar corrosion-resisting materials are set in special cements.

(ii) Vessels in which linings of soft or hard rubber, synthetic compounds, etc., are attached to the walls of the vessel with or without adhesive cements, etc.

c. Vessels with metal coatings. Vessels, the walls of which are provided with thin metallic coatings of zinc, tin, copper, nickel, cadmium, etc., applied by hot processes such as galvanizing, tinning or metal-spraying, electric deposition, etc.

d. Vessels with non-metallic coatings. Vessels, the walls of which are provided with thin non-metallic coatings of special enamels, varnishes, etc., of high corrosion resistance against acids, alkalis, oils, etc. Such coatings are brushed or sprayed on, and fused or baked in position. Vitreous enamels belong to this class.

PEENING

5. A method of hammering weld metal to relieve internal stresses. This is carried out by special shaped hammers or by tools which give hammer-like blows.

PLANISHING

6. A method of increasing the strength of some soft metals and alloys by hammering or beating in the cold condition.

PRESSURE

7. *a. Design pressure.* The maximum differential pressure permitted by the rules of this Code for the weakest element of the vessel. (Particular attention is drawn to vessel walls subject to pressure on one side and accidental vacuum on the other). (See Clause 36.)

b. Disc rupture pressure. The pressure at which safety devices of the rupture disc, or low weight flap type, etc., operate.

c. Hydraulic test pressure. The pressure at which the vessel is tested for porosity, etc. It may be applied by water, or by any other liquid such as paraffin.

d. Maximum permissible working pressure. The maximum pressure at which the vessel or part of the vessel may be operated. It is usually the blow-off pressure of the safety valve or other pressure-relieving device. (See Clause 36.)

e. Normal operating pressure. The pressure at which the vessel is normally to be operated.

NOTE. It is recommended that there should be an adequate margin between the normal operating pressure and the maximum permissible working pressure, in order to prevent unnecessary blowing-off of the safety valves.

f. Safety valve blow-off pressure. The highest pressure at which a safety valve (or valves) is set to prevent the vessel from being worked at a pressure greater than the maximum permissible working pressure.

g. Pneumatic test pressure. The pressure applied to a vessel to facilitate the tracing of leakage. Air or any other gas such as ammonia, etc., may be used for this purpose. (See Clause 212.)

h. Proof hydraulic test. The pressure applied to test the vessel when the strength cannot be satisfactorily calculated. (See Clause 210.)

i. Proof pneumatic test. The pressure applied to test a low pressure or thin walled vessel when the strength cannot be satisfactorily calculated. (See Clause 212.)

j. Vacuum loss (short time) test. The drop in vacuum over a period of one hour under agreed conditions of temperature and of sealing off the vessel.

k. Vacuum loss (long time) test. The total drop in vacuum over a 12 hour period, under agreed conditions of temperature and of sealing off the vessel.

RADIOGRAPHY

8. The process of obtaining, upon sensitive film, a record of the homogeneity of an object by passing radiations of suitable wave length through it.

STRESSES

9. *Safe working stress.* The unit stress from all known sources permitted for the material of construction under the working temperature.

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STRESS RELIEF

10. *a. Relief of internal stresses by heat treatment.*

(i) *Stress relieving.* The heating of a vessel to a suitable temperature at which stresses caused by fabrication and welding are practically annulled. (See Clauses 172 to 174.)

(ii) *Normalizing* (as required by Clause 24c). Heat treating the vessel in such a manner as to change the structure of the metal, e.g., in the case of steel, by raising it to a temperature above the upper critical point and allowing it to cool in still air.

b. Relief of internal stresses by mechanical work. Correcting for the thermal contraction of the weld metal by peening. (See Clauses 5 and 175.)

TEMPERATURES

11. *a. Safe working temperature.* The maximum temperature to which the material of construction may be submitted when in service. (See Clause 35.)

b. Normal operating temperature. The temperature at which the vessel is normally operated.

NOTE. This shall not exceed the safe working temperature.

TOXIC AND LETHAL SUBSTANCES

12. For the purpose of interpreting the references in this Code, toxic and lethal substances shall be regarded as meaning poisonous substances of such a nature that a small amount of the substance (mixed or unmixed with air) is dangerous to life on short exposure. For example, for the purposes of this Code, hydrogen sulphide, carbon monoxide (pure or in mixtures), chlorine, oxides of nitrogen, hydrocyanic acid, carbonyl chloride, cyanogen, ammonia and xylyl bromide are typical of these substances.

Hydrogen, natural gas, 'towns' or petroleum gases are not regarded as toxic or lethal substances.

TYPES OF VESSEL

13. *a. Non-pressure vessels.* Vessels in which the internal pressure is due solely to the static head of the fluid within the vessel, plus any slight pressure or vacuum caused by vapour venting or lightly loaded breathing devices. Figs. 1 and 2 indicate the limits for non-pressure vessels based upon the pressure or vacuum in the vapour space. Attention is drawn to the fact that the scantlings of many vessels falling within the scope of this definition, are determined by questions of stability and the necessity for adequate structural rigidity.

b. Pressure vessels. Vessels in which the fluid in the vessel is subjected to an internal or external pressure falling outside the minimum limits shown in Figs. 1 and 2.

c. Fired vessels. Vessels in which heat is applied direct to the shell or tubes by hot gases of combustion.

STAYS

14. Members giving local support to parts subject to pressure, to which they are attached. (See Clauses 118 to 124.)

a. Staybars. Stays connecting widely spaced surfaces. They are attached to the plates they support by threading the ends of the staybar and fitting nuts, or nuts and washers, on each side of each plate. They may be screwed into the plates and fitted with single nuts or made unscrewed and welded to the plates. (See Figs. 40 m—r.)

b. Stayblocks. Stays connecting closely spaced surfaces. They may be fillet welded to one plate and plug welded to the second, or formed by a spacer block between the two plates and rivets passing through all three members. (See Figs. 40 b—d.)

c. Staybolts. Stays, having a length between the stayed surfaces not exceeding 20 diameters, connecting closely spaced surfaces. They may be threaded for the whole of their length and screwed into the plates they support, or screwed through one plate and into a block welded to the other or welded to the plates. (See Figs. 40 e—l.)

d. Staytubes. Special tubes in a tube nest threaded at each end and screwed into the plates they support, and with or without nuts, or welded into the tube plates. (See Figs. 40 s—u.)

WELDING PROCESSES (FUSION)

15. A group of processes in which metals are welded together by bringing them to the molten state at the surfaces to be joined, with or without the addition of filler metal, without the application of mechanical pressure or blows. This group includes :

a. Arc welding. A fusion-welding process in which the heat is obtained from an electric arc formed between the base metal and an electrode or between two electrodes, with or without the use of shielding gases.

b. Gas welding. A fusion-welding process in which the heat is obtained from a gas flame.

WELDING TERMS

NOTE. B.S. 499 gives in detail nomenclature, definitions and symbols in connection with welding and flame cutting.

16. *a. Double-welded butt joint.* A joint formed by the fusion of two abutting edges with weld metal added from both sides of the joint.

b. Single-welded butt joint with backing strip. A joint formed by the fusion of two abutting edges with weld metal added from one side only, full penetration throughout the joint being obtained by the use of a suitable backing strip or bar.

c. Single-welded butt joint without backing strip. A joint formed by the fusion of two abutting edges with weld metal added from one side only.

d. Fillet weld. A weld of approximately triangular cross-section lying external to the parts joined.

e. Full-fillet weld. A fillet weld brought up to the full thickness of a plate or branch flange that has been joined to a parallel plate, having a throat thickness not less than 0·7 times the thickness of the edge of the plate being welded.

f. Single full-fillet lap joint. A joint in which the overlap edges of two plates are full-fillet welded along one edge only.

g. Double full-fillet lap joint. A joint in which the overlap edges of two plates to be joined are full-fillet welded at the edges of each plate.

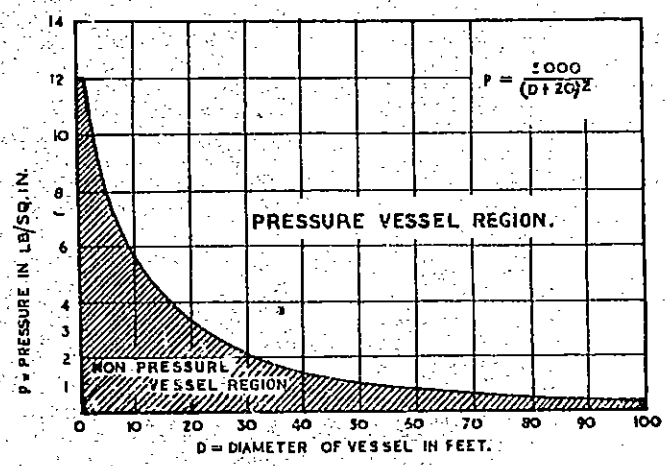

Fig. 1. Limits for pressure vessels covered by the requirements of the Code

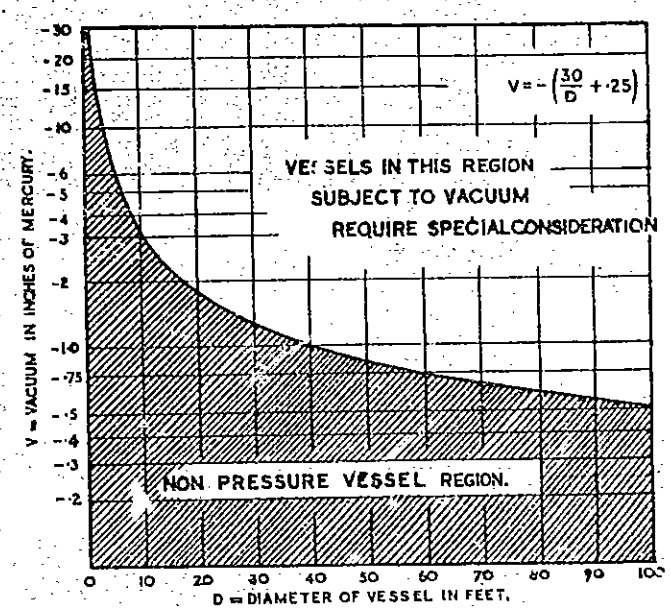

Fig. 2. Limits for vacuum vessels covered by the requirements of the Code

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h. Corner weld. A joint in which the parts joined form approximately a right angle with one another and an edge or end of one part is situated at or near a surface of the other part but does not intersect it.

i. Seal weld. A weld applied in place of, or in addition to, mechanical caulking for the purpose of obtaining tightness of the seam. It is not considered as adding to the strength of the joint.

j. Plug weld. A weld made in a circular or elongated hole formed in one of the parts of a lapped joint to attach the lower part.

k. Backing strip. Material of any kind placed adjacent to the root of the welding groove to aid in obtaining full penetration of the weld and which may or may not be removed after the weld is completed.

l. Weld imperfections. B.S. 499, Part Two, gives terminology of weld imperfections.

C. USE OF CODE

GENERAL

17. In this British Standard Code a common set of rules for design formulae for scantlings, for manufacture and for workmanship is included to cover all requirements for chemical pressure vessels. The amount and nature of the inspection to be carried out is covered by varying the inspection visits and tests to ensure that the finished vessel conforms to the designed requirements.

The formulae given in Section Three of this Code apply to vessels constructed throughout under the conditions prescribed in Sections Four and Five of the Code, and working under normal conditions and adequate supervision.

Where conditions are adverse, or where of necessity maintenance supervision will be inadequate, it is recommended that the scantlings found by calculation from the formulae should be increased.

It is recognized that the design of pressure vessels, particularly in the chemical industry, is the subject of continuous development, and it is intended to review the Code annually in order to incorporate such modifications as are found desirable as a result of progress.

CLASSIFICATION

18. The following classification of pressure vessels is adopted as the basis of this Code, but any particular pressure vessel may be classified in any one of the higher categories where deemed advisable or desirable by the inspecting authority or when agreed between the purchaser or his representative and the manufacturer.

a. Severe duty *vessels* are vessels that are to contain toxic or lethal substances or materials at a temperature above their self-ignition point or fired vessels for pressures exceeding 100 lb/sq. in. They are generally equivalent to what are known as 'Class I vessels.'

b. Medium duty *vessels* are vessels that do not fall within the scope of paragraphs (*a*) and (*c*) and can be rated generally as 'Class II vessels.'

c. Light duty *vessels* are vessels, for relatively light duties, having plate thicknesses not in excess of ⅝ in. built for working pressures not exceeding 50 lb/sq. in. vapour pressure, or 250 lb/sq. in. hydrostatic pressure, at temperatures not exceeding 300°F. (150°C.) and unfired. They can be generally rated as 'Class III vessels.'

d. Vessels for service at sub-atmospheric temperature. All vessels constructed of any of the materials noted in Table I as liable to embrittlement at temperatures below + 32°F. (0°C.) shall be subject to impact tests for the materials, and these shall be carried out at the lowest temperature at which the vessel will be operated. (See Clause 195 and Appendix A.)

INSPECTION AND TESTS : GENERAL

19. The degree of inspection and testing required for vessels is varied according to the classification of the duty as set out in Clause 18. These variable requirements are as follows :—

a. Tests and inspection of material.

b. Degree of inspection during construction.

c. Amount of mechanical testing relating to welded seams.

d. Radiographic examination of welded seams.

e. Stress relief.

See also 'Summary,' page 3, and Section Five.

MATERIAL INSPECTION

20. For details of the mechanical tests and inspection required see the appropriate British Standard and Clause 28.

a. Full inspection of material. Mechanical tests on each plate witnessed by the purchaser's representative and inspection of material at the mills.

b. Limited inspection of material. Mechanical tests on each plate certified by the producer of the material. Inspection of material at the mills *not* required.

c. Minimum inspection of material. Mechanical tests on each batch of material certified by the producer. Inspection of material at the mills *not* required.

CONSTRUCTION INSPECTION

21. This does not cover visits for material inspection, mechanical tests or radiographic examination. These are additional depending upon the requirements for each vessel. See also Clauses 180 to 193.

a. Full inspection during manufacture. The requirements are :—

(i) Approval of drawings.

(ii) Inspection when the shell plates are bent to the circular form, the ends pressed to shape, welding grooves formed, and the parts are assembled ready for welding.

(iii) Inspection when welding of the main seams is actually in progress.

(iv) Inspection when welding at the outside surface has been completed, and the inside surface has been prepared for welding. This examination will be required before the outside surface is 'dressed.'

(v) Inspection when the seams are 'dressed.'

(vi) Inspection when the openings are being prepared for branches, etc., and are being welded in.

(vii) Witnessing by inspector of hydraulic test.

(viii) Inspection of finished vessel.

b. Limited inspection during manufacture. The requirements are :—

(i) Approval of drawings.

(ii) Inspection when the shell plates are bent to the circular form, the ends pressed to shape, welding grooves formed and the parts are assembled ready for welding.

(iii) Witnessing by inspector of hydraulic test.

(iv) Inspection of finished vessel.

c. Minimum inspection. The requirements are :—

(i) Approval of drawings.

(ii) Witnessing by inspector of hydraulic test.

(iii) Inspection of finished vessel.

MECHANICAL TESTS OF WELDED SEAMS

22. For details see Clauses 194 to 196.

a. Full mechanical tests.

(i) Tensile test for joint.

(ii) Impact test for outer surface of shell.

(iii) Impact test for inner surface of shell.

(iv) Tensile test on 'all weld metal' specimen.

(v) Bend test, outer surface of weld in tension.

(vi) Bend test, inner surface of weld in tension.

(vii) Micro test.

(viii) Macro test.

b. Limited mechanical tests.

(i) Tensile test on 'all weld metal' specimen, except in the case of plates less than ½ in. in thickness or lap joints, when a tensile test on a joint test specimen may be substituted.

(ii) Bend test, outer surface of weld in tension.

(iii) Bend test, inner surface of weld in tension.

(iv) Nick break test.

c. Minimum mechanical tests.

(i) Bend test, outer surface of weld in tension.

(ii) Nick break test.

d. New developments. Light or medium duty vessels of materials or methods of construction not covered by the manufacturer's normal experience shall, at the discretion of the inspecting authority, be subject to the full mechanical tests required for severe duty vessels.

The following changes shall be regarded as constituting new developments :—

(i) Change of plate material to be welded.

(ii) Welding seam in plate of a greater or lesser thickness than previously carried out in similar material.

(iii) Change in type of plate preparation involving reduction in the amount of such preparation, i.e., change from double 'U' to single 'U' groove, or 'U' to 'V' type groove, etc.

(iv) Change in type of welded seams, i.e., double butt to single butt with backing strip, etc.

(v) Change in the amount of metal deposited per pass due, for instance, to unusual size of electrode or rate of feed.

(vi) Change of manufacturer of electrode, type or analysis of electrode or filler rod.

e. Research tests on welds are full investigation tests on new methods or new materials to determine their suitability for fusion welding.

RADIOGRAPHIC EXAMINATION

23. *a. Full radiographic tests.* All longitudinal and circumferential seams. (See also Clauses 197 to 207.)

b. Limited radiographic tests. Longitudinal seams only, in all the following cases :—

(i) When the plate thickness exceeds 1½ in.

(ii) When the vessel is to be used for vapours at a pressure in excess of 1000 lb/sq. in. or liquids the vapour pressure of which at the operating temperature is in excess of 1000 lb/sq. in.

(iii) When the material is one of the following and the working pressure exceeds 150 lb/sq. in. :—

All low and medium alloy steels having air hardening characteristics or a 'carbon equivalent' value greater than 0·48—0·06t. (See Clause 168.)

Austenitic stainless steels.

STRESS RELIEF

24. For details see Clauses 172 to 179.

a. All severe duty vessels, and those vessels having proportions within the hatched area of Fig. 4, shall be stress relieved, with the exception of vessels referred to in Clause 176.

b. All vessels constructed of the following materials, in all thicknesses shall be stress relieved by heat treatment after welding (see also notes to Tables Ia—f).

Type 200 low alloy steels.*

c. All vessels welded by gas flame should be normalized.

d. Vessels for service at sub-atmospheric temperatures shall be stress relieved by heat treatment, as required by Fig. 4. When the vessel is constructed of a material liable to embrittlement at the minimum operating temperature (see Table I) any portion of the vessel incorporating connections or access openings larger than 10 in. bore, or complicated support details, shall be stress relieved as a sub-assembly if the vessel is not subsequently stress relieved.

e. Under certain conditions it is possible for corrosion to be accelerated by conditions of high stress in the vessel wall and preferential corrosion may occur in the highly stressed zone adjacent to a weld joint not stress relieved. Caustic embrittlement in mild steel is an example of this phenomenon. It is recommended that all vessels subject to severe corrosion conditions, or for service with media likely to cause stress corrosion, should be stress relieved.

RECOMMENDED INSPECTION AND TESTS ACCORDING TO DUTY OF VESSEL

25. *a. Severe duty vessels.*

(i) Full inspection of materials.

(ii) Full inspection during manufacture.

(iii) Full mechanical tests.

(iv) Full radiographic tests.

b. Medium duty vessels.

(i) Limited inspection of materials.

(ii) Limited inspection during manufacture.

(iii) Limited mechanical tests.

(iv) Radiographic tests on longitudinal seams only, as required by Clause 23*b*.

* See B.S. 1501/1506, Steels for pressure vessels.

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c. Light duty vessels.
(i) Minimum inspection of materials.
(ii) Minimum inspection during manufacture.
(iii) Minimum mechanical tests.
(iv) Radiographic tests on longitudinal seams only, as required by Clause 23*b*.

The 'Summary' given on page 3 covers the above requirements and also tabulates the various clauses dealing in detail with these requirements.

MINIMUM REQUIREMENTS

26. Clause 25 outlines the minimum requirements for any vessel, but the purchaser and/or the inspecting authority may, if they consider it desirable, specify inspection and testing requirements more stringent than those called for in Clause 25.

MINIMUM WEIGHT

27. The increased joint efficiency factors set out for vessels that are radiographed and/or stress relieved may be used in the design formulae when it is desired to reduce scantlings to the minimum, provided that either or both of these operations are carried out even though not normally required by this Code. (i.e., if it is desired to use the factor for a radiographed joint, then the main welded seams shall be radiographed).

Section Two : Materials and Working Stresses

A. MATERIALS

GENERAL

28. *a.* All materials used in the manufacture of pressure parts of pressure vessels constructed to this Code shall be in accordance with the appropriate material specifications referred to in this section.

b. Materials for which test certificates are not available may be used for supporting lugs and skirts, baffles and other similar non-pressure parts of a vessel constructed in accordance with this Code, provided that such material is otherwise suitable for the purpose.

MATERIALS FOR SERVICE AT SUB-ATMOSPHERIC TEMPERATURES

29. All materials intended for service at temperatures below 32°F. (0°C.) shall, when so noted in Table I, show a minimum impact test value of 20 foot pounds Izod at the lowest operating temperature of the vessel. Impact tests may be dispensed with on material having a ruling section greater than 2 in. (i.e., plates over approx. 1 5/16 in. thick) or solely for internal parts such as baffles, heat exchanger tubes, etc., by agreement between purchaser, inspecting authority and manufacturer. Attention is drawn to the 'footnote' in the appropriate sections of Table I, which requires this information regarding impact tests to be given to the steelmaker at the time of the enquiry and/or order.

CONDITION OF MATERIAL

30. All non-ferrous materials shall preferably be supplied in the dead soft condition because of the annealing effect of the welding operation on the plate adjacent to the welded joints. By agreement between purchaser, inspecting authority and manufacturer, hardened materials may be used provided that the parts softened by the welding process are re-hardened to their original condition and are not liable to return to the soft state in subsequent service.

VESSELS CONSTRUCTED OF STANDARD PIPES AND TUBES

31. Vessels may be made of standard pipes and tubes, provided the working stresses given in Tables 1 and 2 are not exceeded, and the special joint efficiencies given in Clause 52 are used where applicable.

OTHER MATERIALS

32. The materials covered by this Code are considered to be specially representative of the requirements of the chemical engineering and allied industries, but nothing in this Code shall be construed to preclude the use of other suitable materials. In such cases the permissible working stresses shall be determined by agreement between purchaser, inspecting authority and manufacturer. The appropriate sections of the Code should be adhered to as far as practicable.

B. WORKING STRESSES

GENERAL

33. The working stresses in Tables 1 and 2 are maximum values to be used in conjunction with the formulae given in this Code and do not make any allowance for corrosion or the efficiency of welded joints or ligaments between openings. (See also Clause 37). If it is desired to keep a vessel in service after the corrosion allowance (see Clauses 40 to 42) has wasted away, the maximum allowable working pressure shall be reduced to ensure that the allowable working stress is not exceeded. (See also Clauses 228 to 246.)

a. Tensile stress. Basic allowable working stresses for suitable materials for the construction of fusion welded pressure vessels built in accordance with this Code, are given in Tables 1 and 2. (See Clause 32.)

b. Shear and bearing (or compressive) stresses. The maximum allowable shear or bearing stress shall not exceed the values given in Tables 1 and 2 multiplied by a factor taken from Table 7 below.

Table 7. Factors for shear and bearing stresses

	Factor	
	Shear	Bearing
Carbon and low alloy steels of less than 35 tons/sq. in. tensile	0·8	1·7
Carbon and low alloy steels 35 tons/sq. in. tensile and over	0·7	2·0
Austenitic stainless steels	0·7	1·4
Aluminium	0·75	1·35
Copper	0·7	1·25
Copper silicon	0·8	1·6
Yellow brass	0·75	1·6
Nickel	0·67	1·43
Nickel chromium iron	0·69	1·45
Nickel copper	0·8	1·4
Cast gunmetal	1·1	2·0

c. Planished vessels. The maximum allowable working stress for parts of vessels which are subjected to a planishing or cold working operation after welding shall be the subject of agreement between the purchaser, inspector and manufacturer. The inspector shall satisfy himself that the planishing or cold working operation has been properly carried out and the strength of the material increased to the desired degree, and that the conditions of service are such that softening of the material will not occur in service. Such vessels should be constructed to permit the planished portion to be removed and re-planished after repairs have been carried out by welding.

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TABLE 1a. DESIGN STRESSES (TENSILE) FOR FERROUS PLATES, BARS AND SECTIONS

Material	*Reference B.S. number	Minimum ultimate tensile strength (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)																
					300°F. 149°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	850°F. 454°C.	900°F. 482°C.	925°F. 495°C.	950°F. 510°C.	975°F. 523°C.	1 000°F. 538°C.	1 050°F. 566°C.	1 100°F. 593°C.	1 150°F. 620°C.	1 200°F. 649°C.
Carbon steel	1501–101	28	(1)	Nil	15 700	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1501–151																					
	Grade A	24	(2) (3)	Nil	13 400	13 400	13 400	13 400	13 400	13 200	—	—	—	—	—	—	—	—	—	—	—	—
	Grade B	26	(2) (3)	Nil	14 500	14 500	14 500	14 500	14 500	14 200	—	—	—	—	—	—	—	—	—	—	—	—
	Grade C	28	(2) (3)	Nil	15 700	15 700	15 700	15 700	15 700	15 200	—	—	—	—	—	—	—	—	—	—	—	—
	1501–154																					
	Grade A	24	(3)	Nil	13 400	13 400	13 400	13 400	13 400	13 200	12 000	10 500	8 500	6 300	4 800	3 350	—	—	—	—	—	—
	Grade B	26	(3)	Nil	14 500	14 500	14 500	14 500	14 500	14 200	12 700	10 900	8 700	6 300	4 800	3 350	—	—	—	—	—	—
	Grade C	28	(3)	Nil	15 700	15 700	15 700	15 700	15 700	15 200	13 400	11 300	8 900	6 300	4 800	3 350	—	—	—	—	—	—
	1501–157																					
	Grade A	24	(2) (4)	Nil	13 400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Grade B	26	(2) (4)	Nil	14 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Grade C	28	(2) (4)	Nil	15 700	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Carbon manganese steel	1501–221	32	(5)	Nil	18 000	18 000	18 000	18 000	18 000	17 700	15 700	12 500	9 400	6 400	4 900	3 350	—	—	—	—	—	—
Carbon molybdenum steel	1501–240																					
	Grade A	27	(5)	Nil	15 100	15 100	15 100	15 100	15 100	15 100	15 100	14 600	13 800	13 000	12 200	9 000	5 200	3 800	—	—	—	—
	Grade B	33	(5)	0·05	18 500	18 500	18 500	18 500	18 500	18 100	17 500	16 800	16 200	14 500	12 600	8 700	4 700	3 000	—	—	—	—
13 per cent Chromium steel	1501–613	28	(4) (6)	0·10	15 700	15 700	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium nickel steel, unstabilized	1501–801																					
	Grade A	35	(7)	See Note 7	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
	Grade B	35	(7)	See Note 7	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium nickel steel, stabilized	1501–821																					
	Grade A	35	(8)	Nil	19 600	19 600	19 600	19 500	19 100	18 700	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250
	Grade B	35	(8)	Nil	19 600	19 600	19 600	19 500	19 100	18 700	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250
18/10/3 Chromium nickel molybdenum steel, unstabilized	1501–844	35	(7)	See Note 7	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
18/10/3 Chromium nickel molybdenum steel, stabilized	1501–845																					
	Grade A	35	(9)	Nil	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
	Grade B	35	(8)	Nil	19 600	19 600	19 600	19 500	19 100	18 700	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

NOTE 1. This material is suitable for the construction of Light Duty vessels only and is not recommended for service at temperatures below 50°F. (10°C.) except for applications where embrittlement would not be considered to create a hazard.

NOTE 2. Where a plain carbon steel is required for service at temperatures in excess of 700°F. (370°C.) it shall be ordered to specification B.S. 1501–154.

NOTE 3. Where a plain carbon steel is required for service at temperatures below 32°F. (0°C.) it shall be ordered to specification B.S. 1501–157.

NOTE 4. This material shall be subjected to Izod impact tests at the lowest operating temperature to which the vessel will be subjected in service. The steelmaker shall be advised of this requirement at the time of the enquiry and/or order (see Clause 29).

NOTE 5. As usually supplied this material may be brittle at sub-atmospheric temperatures. Whenever this material is to be used for service at temperatures below 32°F. (0°C.) Izod impact tests shall be carried out at the lowest temperature to which the vessel will be subjected in service. The steelmaker shall be advised of this requirement at the time of the enquiry and/or order (see Clause 29).

NOTE 6. There is insufficient data available to enable the committee to formulate reliable design stresses for these materials in the higher range of temperature. It is not, however, suggested that this material is unsuitable for service at elevated temperatures but it should be noted that it has a creep strength at temperatures in excess of 950°F. (510°C.) of the same order only as carbon steel.

NOTE 7. This material is essentially a corrosion resisting material and is extensively used for this purpose. It also possesses good resistance to scaling at elevated temperatures but is not recommended for service at temperatures in excess of 700°F. (370°C.). It is recommended that this material be welded in thin gauges only and the designer should consult with the steelmaker regarding its suitability for the proposed application.

NOTE 8. It is not considered that there is sufficient long term data available upon the properties of these materials at elevated temperatures to justify the inclusion of final values for design stresses. For the present, therefore, these figures and stresses have been based largely upon the values given in Table U-2 and paragraph U-200 of the A.S.M.E. Boiler Code Section VIII, Unfired Pressure Vessels, and are included for the guidance of users of this British Standard Code.

NOTE 9. This material is not recommended for service at temperatures in excess of 700°F. (370°C.).

* See B.S. 1501 Carbon and alloy steel plates, sections and bars for use in the chemical, petroleum and allied industries.

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TABLE 1b. DESIGN STRESSES (TENSILE) FOR FERROUS FORGINGS

Material	*Reference B.S. number	Minimum ultimate tensile strength (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)																
					300°F. 149°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	850°F. 454°C.	900°F. 482°C.	925°F. 495°C.	950°F. 510°C.	975°F. 523°C.	1 000°F. 538°C.	1 050°F. 566°C.	1 100°F. 593°C.	1 150°F. 620°C.	1 200°F. 649°C.
Carbon steel	1503-151																					
	Grade A	24	(1)	Nil	13 400	13 400	13 400	13 400	13 400	13 200	12 000	10 500	8 500	6 300	4 800	3 350	—	—	—	—	—	—
	Grade B	28	(1)	Nil	15 700	15 700	15 700	15 700	15 700	15 200	13 400	11 300	8 900	6 300	4 800	3 350	—	—	—	—	—	—
	Grade C	32	(1)	0·05	18 000	18 000	18 000	18 000	18 000	17 200	14 800	12 100	9 300	6 300	4 800	3 350	—	—	—	—	—	—
Carbon manganese steel	1503-221	32	(1)	Nil	18 000	18 000	18 000	18 000	18 000	17 700	15 700	12 500	9 400	6 400	4 900	3 350	—	—	—	—	—	—
Carbon molybdenum steel	1503-240																					
	Grade A	26	(1)	Nil	14 600	14 600	14 600	14 600	14 600	14 600	14 600	14 200	13 400	12 600	11 800	9 000	5 200	3 800	—	—	—	—
	Grade B	32	(1)	0·05	18 000	18 000	18 000	18 000	18 000	17 800	17 000	16 500	15 800	14 500	12 600	8 700	4 700	3 000	—	—	—	—
13 per cent Chromium steel	1503-613	38	(1) (2) (3)	0·20	21 300	21 300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1¼ per cent Chromium molybdenum steel	1503-621	40	(1) (3)	0·10	22 400	22 400	22 400	22 400	22 400	22 400	22 400	21 000	18 000	12 750	8 500	5 500	3 600	2 200	—	—	—	—
3 per cent Chromium molybdenum steel	1503-623	38	(1) (3)	0·20	21 300	21 300	21 300	21 300	21 300	21 300	21 300	19 500	15 100	9 700	7 100	4 800	—	—	—	—	—	—
5 per cent Chromium molybdenum steel	1503-625	40	(1) (2) (3)	0·20	22 400	22 400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium nickel steel, unstabilized	1503-801																					
	Grade A	33	(4)	See Note 4	18 500	18 500	18 500	18 500	18 500	18 500	—	—	—	—	—	—	—	—	—	—	—	—
	Grade B	33	(4)	See Note 4	18 500	18 500	18 500	18 500	18 500	18 500	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium nickel steel, stabilized	1503-821																					
	Grade A	33	(5)	Nil	18 500	18 500	18 500	18 500	18 500	18 500	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250
	Grade B	33	(5)	Nil	18 500	18 500	18 500	18 500	18 500	18 500	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250
18/8/3 Chromium nickel molybdenum steel, unstabilized	1503-844	33	(4)	See Note 4	18 500	18 500	18 500	18 500	18 500	18 500	—	—	—	—	—	—	—	—	—	—	—	—
18/10/3 Chromium nickel molybdenum steel, stabilized	1503-845																					
	Grade A	33	(6)	Nil	18 500	18 500	18 500	18 500	18 500	18 500	—	—	—	—	—	—	—	—	—	—	—	—
	Grade B	33	(5)	Nil	18 500	18 500	18 500	18 500	18 500	18 500	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

NOTE 1. As usually supplied this material may be brittle at sub-atmospheric temperatures. Whenever this material is to be used for service at temperatures below 32°F. (0°C.) Izod impact tests shall be carried out at the lowest operating temperature to which the vessel will be subjected in service. The steelmaker shall be advised of this requirement at the time of the enquiry and/or order (see Clause 29).

NOTE 2. There is insufficient data available to enable reliable design stresses to be formulated for these materials in the higher range of temperature. It is not, however, suggested that these materials are unsuitable for service at elevated temperatures but it should be noted that they are, in general, inferior in creep strength to lower chromium molybdenum steels.

NOTE 3. The 'weld discount factors' given for these materials presuppose that an appropriate welding technique is adopted. The weld metal (as deposited) shall have a chemical composition similar to the parent metal, suitable preheating shall be used and the parts after welding shall be given a suitable heat treatment to produce the specified mechanical properties.

* See B.S. 1503 Carbon and alloy steel forgings for use in the chemical, petroleum and allied industries.

NOTE 4. This material is essentially a corrosion resisting material and is extensively used for this purpose. It also possesses good resistance to scaling at elevated temperatures but is not recommended for service at temperatures in excess of 700°F. (370°C.). It is recommended that this material be welded in thin sections only and the designer should consult with the steelmaker regarding its suitability for the proposed application.

NOTE 5. It is not considered that there is sufficient long term data available upon the properties of these materials at elevated temperatures to justify the inclusion of final values for design stresses. For the present, therefore, these figures and stresses have been based largely upon the values given in Table U-2 and paragraph U-200 of the A.S.M.E. Boiler Code Section VIII, Unfired Pressure Vessels, and are included for the guidance of the users of this British Standard Code.

NOTE 6. This material is not recommended for service at temperatures in excess of 700°F. (370°C.).

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TABLE 1c. DESIGN STRESSES (TENSILE) FOR FERROUS CASTINGS

Material	*Reference B.S. number	Minimum ultimate tensile strength (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)																
					300°F. 149°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	850°F. 454°C.	900°F. 482°C.	925°F. 495°C.	950°F. 510°C.	975°F. 525°C.	1000°F. 538°C.	1050°F. 566°C.	1100°F. 593°C.	1150°F. 620°C.	1200°F. 649°C.
Carbon steel	1504–101																					
	Grade A	26	(1)	0·05	11 600	11 600	11 600	11 600	11 600	11 400	10 200	8 700	7 000	5 000	3 900	2 700	—	—	—	—	—	—
	Grade B	28	(1)	0·05	12 500	12 500	12 500	12 500	12 500	12 200	10 700	9 000	7 100	5 000	3 900	2 700	—	—	—	—	—	—
	Grade C	35	(1)	0·10	15 700	15 700	15 700	15 700	15 700	15 000	12 700	10 200	7 700	5 000	3 900	2 700	—	—	—	—	—	—
	1504–151	31	(1)	Nil	13 900	13 900	13 900	13 900	13 900	13 400	11 600	9 500	7 400	5 000	3 900	2 700	—	—	—	—	—	—
½ per cent Molybdenum steel	1504–240																					
	Grade A	30	(1)	Nil	13 400	13 400	13 400	13 400	13 400	13 400	13 100	12 600	12 000	11 200	10 100	7 000	3 750	2 400	—	—	—	—
	Grade B	32	(1)	0·05	14 300	14 300	14 300	14 300	14 300	14 200	13 700	13 200	12 600	11 200	10 100	7 000	3 750	2 400	—	—	—	—
13 per cent Chromium steel	1504–613																					
	Grade A	35	(1) (2) (3)	0·20	15 700	15 700	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Grade B	45	(4)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Grade C	45	(4)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1¼ per cent Chromium molybdenum steel	1504–621	40	(1) (2)	0·10	17 900	17 900	17 900	17 900	17 900	17 900	17 900	16 800	14 400	10 200	8 800	4 400	2 800	1 750	—	—	—	—
3 per cent Chromium molybdenum steel	1504–623	40	(1) (2)	0·20	17 900	17 900	17 900	17 900	17 900	17 900	17 900	16 000	12 100	7 700	5 600	3 800	—	—	—	—	—	—
5 per cent Chromium molybdenum steel	1504–625	40	(1) (2) (3)	0·20	17 900	17 900	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9 per cent Chromium molybdenum steel	1504–629	40	(1) (2) (3)	0·20	17 900	17 900	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium nickel steel, unstabilized	1504–801	31	(5)	See Note 5	13 900	13 900	13 900	13 900	13 900	13 900	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium nickel steel, stabilized	1504–821	31	(6)	Nil	13 900	13 900	13 900	13 900	13 900	13 900	13 900	13 900	13 700	13 400	13 000	12 600	12 000	11 200	9 500	7 000	4 000	1 800
18/8/3 Chromium nickel molybdenum steel, unstabilized	1504–844	31	(5)	See Note 5	13 900	13 900	13 900	13 900	13 900	13 900	—	—	—	—	—	—	—	—	—	—	—	—
18/10/3 Chromium nickel molybdenum steel, stabilized	1504–845	31	(6)	Nil	13 900	13 900	13 900	13 900	13 900	13 900	13 900	13 900	13 700	13 400	13 000	12 600	12 000	11 200	9 500	7 000	4 000	1 800

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

NOTE 1. As usually supplied this material may be brittle at sub-atmospheric temperatures. Whenever this material is to be used for service at temperatures below 32°F. (0°C.) Izod impact tests shall be carried out at the lowest operating temperature to which the vessel will be subjected in service. The steelmaker shall be advised of this requirement at the time of the enquiry and/or order (see Clause 29).

NOTE 2. The 'weld discount factors' given for these materials presuppose that an appropriate welding technique is adopted. The weld metal (as deposited) shall have a chemical composition similar to the parent metal, suitable preheating shall be used and the parts after welding shall be given a suitable heat treatment to produce the specified mechanical properties.

* See B.S. 1504 Carbon and alloy steel castings for use in the chemical, petroleum and allied industries.

NOTE 3. There is insufficient data available to enable reliable design stresses to be formulated for these materials in the higher range of temperature. It is not, however, suggested that these materials are unsuitable for service at elevated temperatures but it should be noted that they are, in general, inferior in creep strength to the lower chromium molybdenum steels.

NOTE 4. As this grade of material is normally used because of its resistance to erosion in applications where mechanical strength is of secondary importance, no stress figures are provided.

NOTE 5. This material is essentially a corrosion-resisting material and is extensively used for this purpose. It also possesses good resistance to scaling at elevated temperatures but is not recommended for service at temperatures in excess of 700°F. (370°C.). It is recommended that this material be welded in thin sections only and the designer should consult with the steelmaker regarding its suitability for the proposed application.

NOTE 6. It is not considered that there is sufficient long term data available upon the properties of these materials at elevated temperatures to justify the inclusion of final values for design stresses. For the present, therefore, these figures and stresses have been based largely upon the values given in Table U-2 and paragraph U-200 of the A.S.M.E. Boiler Code Section VIII—Unfired Pressure Vessels, and are included for the guidance of users of this British Standard Code.

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TABLE 1d. DESIGN STRESSES (TENSILE) FOR FERROUS BOLTING MATERIAL (OTHER THAN FOR PRESSURE JOINTS)

Material	*Reference B.S. number	Minimum ultimate tensile strength (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)															
					300°F. 149°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	850°F. 454°C.	900°F. 482°C.	925°F. 495°C.	950°F. 510°C.	975°F. 525°C.	1 000°F. 538°C.	1 050°F. 566°C.	1 100°F. 593°C.	1 150°F. 620°C.	1 200°F. 649°C.
Carbon steel	1506–101	28	(1)	—	15 700	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1506–102	28	(2)	—	15 700	15 700	15 700	15 700	15 700	16 200	13 400	—	—	—	—	—	—	—	—	—	—	—
	1506–121	30	(2)	—	16 800	16 800	16 800	16 800	16 800	16 200	14 100	—	—	—	—	—	—	—	—	—	—	—
	1506–155	45	(1)	—	25 200	25 200	25 200	25 200	25 200	22 000	19 000	—	—	—	—	—	—	—	—	—	—	—
Carbon manganese steel	1506–221	35	(2)	—	19 600	19 600	19 600	19 600	19 600	19 000	16 800	—	—	—	—	—	—	—	—	—	—	—
½ per cent Molybdenum steel	1506–240	40	(3)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1½ per cent Nickel chromium molybdenum steel	1506–441	50	(2)	—	23 000	28 000	28 000	28 000	28 000	—	—	—	—	—	—	—	—	—	—	—	—	—
13 per cent Chromium steel	1506–613	45	(2) (4)	—	23 900	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
¾ per cent Chromium molybdenum steel	1506–620	55	(2)	—	30 800	30 800	30 800	30 800	30 800	29 800	28 500	26 100	22 600	12 400	8 400	5 400	3 400	2 200	—	—	—	—
	1506–620	65	(2)	—	36 400	36 400	36 400	35 700	34 400	32 800	30 800	27 800	22 600	12 400	8 400	5 400	3 400	2 200	—	—	—	—
1 per cent Chromium molybdenum steel	1506–621																					
	Grade A	45	(2)	—	23 900	23 900	23 900	23 900	23 900	23 900	22 600	19 600	—	—	—	—	—	—	—	—	—	—
	Grade A	55	(2)	—	28 600	28 600	28 600	28 600	28 200	27 100	25 000	21 000	—	—	—	—	—	—	—	—	—	—
	Grade A	60	(2)	—	30 800	30 800	30 800	30 600	29 800	28 500	26 400	22 000	—	—	—	—	—	—	—	—	—	—
	Grade B	55	(2)	—	30 800	30 800	30 800	30 800	30 800	29 800	28 500	26 100	22 600	12 400	8 400	5 400	3 400	2 200	—	—	—	—
	Grade B	65	(2)	—	36 400	36 400	36 400	35 700	34 400	32 800	30 800	27 800	22 600	12 400	8 400	5 400	3 400	2 200	—	—	—	—
5 per cent Chromium molybdenum steel	1506–625	40	(2) (4)	—	22 400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 per cent Chromium molybdenum vanadium steel	1506–661	55	(2) (5)	—	30800	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium nickel steel, unstabilized	1506–801																					
	Grade A	35	(6)	—	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
	Grade B	35	(6)	—	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium nickel steel, stabilized	1506–821																					
	Grade A	35	(7)	—	19 600	19 600	19 600	19 500	19 100	18 700	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250
	Grade B	35	(7)	—	19 600	19 600	19 600	19 500	19 100	18 700	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250
18/8/3 Chromium nickel molybdenum steel, unstabilized	1506–844	35	(7)	—	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
18/10/3 Chromium nickel molybdenum steel, stabilized	1506–845																					
	Grade A	35	(8)	—	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
	Grade B	35	(7)	—	19 600	19 600	19 600	19 500	19 100	18 700	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

NOTE 1. This material is not recommended for use at service temperatures below 60°F.

NOTE 2. As usually supplied this material may be brittle at sub-atmospheric temperatures. Whenever this material is to be used for service at temperatures below 32°F. (0°C.) Izod impact tests shall be carried out at the lowest operating temperature to which the vessel will be subjected in service. The steelmaker shall be advised of this requirement at the time of the enquiry and/or order. (See Clause 29.)

NOTE 3. Design stress values are not required for this steel as it has been developed for the manufacture of nuts for use with alloy steel bolts for service at high temperatures. The design of such items does not permit a ready analysis of the stresses involved and the criterion of satisfactory performance must be a matter of behaviour of the material under service conditions.

NOTE 4. There is insufficient data available to enable reliable design stresses to be formulated for these materials in the higher range of temperature. It is not, however, suggested that these materials are unsuitable for service at elevated temperatures but it should be noted that they are, in general, inferior in creep strength to the lower chromium molybdenum steels.

* See B.S. 1506 Carbon and alloy steel bolting material for use in the chemical, petroleum and allied industries.

NOTE 5. There is insufficient data available to enable reliable design stresses to be formulated for there materials in the higher range of temperature. It is not implied, however, that these materials are unsuitable for service at elevated temperatures.

NOTE 6. This material is essentially a corrosion resisting material and is extensively used for this purpose. It also possesses good resistance to scaling at elevated temperatures but is not recommended for service at temperatures in excess of 700°F. (370°C.). It is recommended that this material be welded in thin gauges only and the designer should consult with the steelmaker regarding its suitability for the proposed application.

NOTE 7. It is not considered that there is sufficient long term data available upon the properties of these materials at elevated temperatures to justify the inclusion of final values for design stresses. For the present, therefore, these figures and stresses have been based largely upon the values given in Table U-2 and paragraph U-200 of the A.S.M.E. Boiler Code Section VIII—Unfired Pressure Vessels, and are included for the guidance of users of this British Standard Code.

NOTE 8. This material is not recommended for service at temperatures in excess of 700°F. (370°C.).

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TABLE 1e. DESIGN STRESSES (TENSILE) FOR FERROUS PIPES

(FOR USE AS SHELLS, BRANCH PIPES, AND SIMILAR PARTS OF PRESSURE VESSELS)

Material	*Reference B.S. number	Minimum ultimate tensile strength (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)														
					300°F. 149°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	850°F. 454°C.	900°F. 482°C.	925°F. 495°C.	950°F. 510°C.	975°F. 525°C.	1 000°F. 538°C.	1 050°F. 566°C.	1 100°F. 593°C.	1 150°F. 620°C.	1 200°F. 649°C.
Mild steel, seamless	1507–101	22	(1)	Nil	12 300	12 300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mild steel roll lapweld	1507–131	22	(1) (2)	Nil	12 300	12 300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mild steel, seamless	1507–151	23	(1)	Nil	12 900	12 900	12 900	12 900	12 900	12 800	11 800	10 300	8 400	6 300	4 900	3 350	—	—	—	—	—	—
Mild steel, cold drawn, seamless	1507–171	23	(1)	Nil	12 900	12 900	12 900	12 900	12 900	12 800	11 800	10 300	8 400	6 300	4 900	3 350	—	—	—	—	—	—
½ per cent Molybdenum steel, seamless	1507–240 Grade A	25	(1)	Nil	14 000	14 000	14 000	14 000	14 000	14 000	14 000	13 700	13 300	12 400	12 000	9 000	5 [illegible]00	3 800	—	—	—	—
	Grade B	31	(1) (3)	0·05	17 400	17 400	17 400	17 400	17 400	17 400	16 800	16 100	15 400	14 500	12 600	8 700	4 700	3 000	—	—	—	—
1 per cent Chromium molybdenum steel, seamless	1507–621	25	(1) (3)	0·10	14 000	14 000	14 000	14 000	14 000	14 000	14 000	14 000	13 800	~~13 000~~ 12 400	~~12 300~~ 11 200	~~11 400~~ 9 800	~~10 300~~ 8 400	~~9 000~~ 7 000	~~8 100~~ 4 500	—	—	—
3 per cent Chromium molybdenum steel, seamless	1507–623	30	(1) (3) (4)	0·20	16 800	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5 per cent Chromium molybdenum steel, seamless	1507–625	30	(1) (3) (4)	0·20	16 800	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium, nickel, stabilized, seamless	1507–821	35	(5)	Nil	19 600	19 600	19 600	19 500	19 100	18 700	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250
25/20 Chromium, nickel, stabilized, seamless	1507–825	35	(6)	Nil	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
18/10/3 Chromium, nickel, molybdenum, stabilized, seamless	1507–845	35	(5)	Nil	19 600	19 600	19 600	19 500	19 100	18 700	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

The stress values given above apply only for pipes used as parts of pressure vessels with simple loading. They do *not* apply to fabricated pipework.

NOTE 1. This material shall be subjected to Izod impact tests at the lowest operating temperature to which the vessel will be subjected in service. The steelmaker shall be advised of this requirement at the time of the enquiry and/or order. (See Clause 29.)

NOTE 2. The stresses given in this table are subject to appropriate joint efficiency factors in accordance with Clause 52.

NOTE 3. The 'weld discount factors' given for these materials presuppose that an appropriate welding technique is adopted. The weld metal (as deposited) shall have a chemical composition similar to the parent metal, suitable preheating shall be used and the parts after welding shall be given a suitable heat treatment to produce the specified mechanical properties.

NOTE 4. There is insufficient data available to enable reliable design stresses to be formulated for these materials in the higher range of temperature. It is not, however, suggested that these materials are unsuitable for service at elevated temperatures but it should be noted that they are, in general, inferior in creep strength to the lower chromium molybdenum steels.

NOTE 5. It is not considered that there is sufficient long term data available upon the properties of these materials at elevated temperatures to justify the inclusion of final values for design stresses. For the present, therefore, these figures and stresses have been based largely upon the values given in Table U-2 and paragraph U-200 of the A.S.M.E. Boiler Code Section VIII—Unfired Pressure Vessels, and are included for the guidance of users of this British Standard Code.

NOTE 6. There is insufficient data available to enable reliable design stresses to be formulated for these materials in the higher range of temperature. It is not implied, however, that these materials are unsuitable for service at elevated temperatures.

* See B.S. 1507 Steel pipes for use in the chemical, petroleum and allied industries.

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TABLE 1f. DESIGN STRESSES (TENSILE) FOR FERROUS TUBES

(FOR USE IN PRESSURE VESSELS SUCH AS CONDENSERS, HEAT EXCHANGERS, TUBULAR REACTORS, TUBE STILLS AND THE LIKE)

Material	*Reference B.S. number	Minimum ultimate tensile strength (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)															
					300°F. 149°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	850°F. 454°C.	900°F. 482°C.	925°F. 495°C.	950°F. 510°C.	975°F. 525°C.	1 000°F. 538°C.	1 050°F. 566°C.	1 100°F. 593°C.	1 150°F. 620°C.	1 200°F. 649°C.
Mild steel, hot finished, seamless	1508-151	20	(1)	Nil	11 200	11 200	11 200	11 200	11 200	11 050	10 100	8 950	7 350	6 300	4 900	3 350	—	—	—	—	—	—
Mild steel, cold drawn, seamless	1508-171	20	(1)	Nil	11 200	11 200	11 200	11 200	11 200	11 050	10 100	8 950	7 350	6 300	4 900	3 350	—	—	—	—	—	—
½ per cent Molybdenum steel, seamless	1508-240	25	(1)	Nil	14 000	14 000	14 000	14 000	14 000	14 000	14 000	13 700	13 300	12 400	12 000	9 000	5 200	3 800	—	—	—	—
1 per cent Chromium molybdenum steel, seamless	1508-621	25	(1) (2)	0·10	14 000	14 000	14 000	14 000	14 000	14 000	14 000	14 000	13 800	~~15 000~~ 12 400	~~12 300~~ 11 800	~~11 400~~ 9 500	~~10 300~~ 8 400	~~9 000~~ 7 000	~~6 700~~ 4 500	—	—	—
2 per cent Chromium molybdenum steel, seamless	1508-622	27	(1) (2) (6)	0·20	15 100	~~15 100~~	~~15 100~~	~~15 100~~	~~15 100~~	~~15 100~~	~~15 100~~	~~15 100~~	~~14 100~~	~~13 000~~	~~12 350~~	~~11 400~~	~~10 300~~	~~9 000~~	~~6 700~~	—	—	—
3 per cent Chromium molybdenum steel, seamless	1508-623	30	(1) (2) (3)	0·20	16 800	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5 per cent Chromium molybdenum steel, seamless	1508-625	30	(1) (2) (3)	0·20	16 800	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium, nickel, unstabilized seamless	1508-601	35	(4)	See Note 4	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
18/8 Chromium, nickel, stabilized seamless	1508-821	35	(5)	Nil	19 600	19 600	19 600	19 500	19 100	18 700	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250
25/20 Chromium, nickel, stabilized seamless	1508-825	35	(6)	Nil	19 600	19 600	19 600	19 500	19 100	18 700	—	—	—	—	—	—	—	—	—	—	—	—
18/8/3 Chromium, nickel, molybdenum, stabilized seamless	1508-845	35	(5)	Nil	19 600	19 600	19 600	19 500	19 100	18 700	18 300	17 900	17 500	16 700	16 300	15 700	15 000	14 000	11 600	8 800	5 000	2 250

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

The stress values given above apply only for tubes forming an integral part of a pressure vessel.

NOTE 1. This material shall be subject to Izod impact tests at the lowest operating temperature to which the vessel will be subjected in service. The steelmaker shall be advised of this requirement at the time of the enquiry and/or order. (See Clause 29.)

NOTE 2. The 'weld discount factors' given for these materials presuppose that an appropriate welding technique is adopted. The weld metal (as deposited) shall have a chemical composition similar to the parent metal, suitable preheating shall be used and the parts after welding shall be given a suitable heat treatment to produce the specified mechanical properties.

NOTE 3. There is insufficient data available to enable reliable design stresses to be formulated for these materials in the higher range of temperature. It is not, however, suggested that these materials are unsuitable for service at elevated temperatures but it should be noted that they are, in general, inferior in creep strength to the lower chromium molybdenum steels.

NOTE 4. This material is essentially a corrosion-resisting material and is extensively used for this purpose. It also possesses good resistance to scaling at elevated temperatures but is not recommended for service at temperatures in excess of 700°F. (370°C.). It is recommended that this material be welded in thin gauges only and the designer should consult with the steelmaker regarding its suitability for the proposed application.

NOTE 5. It is not considered that there is sufficient long term data available upon the properties of these materials at elevated temperatures to justify the inclusion of final values for design stresses. For the present, therefore, these figures and stresses have been based largely upon the values given in Table U-2 and paragraph U-200 of the A.S.M.E. Boiler Code Section VIII—Unfired Pressure Vessels, and are included for the guidance of users of this British Standard Code.

NOTE 6. There is insufficient data available to enable reliable design stresses to be formulated for these materials in the higher range of temperature. It is not implied, however, that these materials are unsuitable for service at elevated temperatures.

* See B.S. 1508 Steel tubes for use in the chemical, petroleum and allied industries.

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TABLE 2a. DESIGN STRESSES (TENSILE) FOR NON-FERROUS PLATES

Material (For example)	Reference B.S. number	Minimum* ultimate tensile stress (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)														
					150°F. 66°C.	200°F. 93°C.	250°F. 121°C.	300°F. 149°C.	350°F. 177°C.	400°F. 204°C.	450°F. 232°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	900°F. 482°C.	1 000°F. 538°C.	1 100°F. 593°C.	1 200°F 649°C.
Aluminium, Grade A	—	4	—	—																	
Aluminium, Grade B	—	5	—	—																	
Aluminium magnesium alloy	—	9	—	—																	
Aluminium magnesium manganese alloy	—	20	—	—																	
Copper, Grade A	—	13	—	—																	
Copper, Grade B	—	13	—	—																	
Copper silicon	—	24	—	—																	
Aluminium bronze	—	34	—	—																	
Phosphor bronze	—	20	—	—																	
Yellow metal	—	22	—	—																	
Nickel	—	26	—	—																	
Nickel copper alloy	—	30	—	—																	
Nickel chromium iron alloy	—	30	—	—																	

'THE STRESS VALUES ARE UNDER CONSIDERATION'

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

* These figures are illustrative only.

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TABLE 2b. DESIGN STRESS FOR NON-FERROUS FORGINGS

Material (For example)	Reference B.S. number	Minimum* ultimate tensile stress (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)														
					150°F. 66°C.	200°F. 93°C.	250°F. 121°C.	300°F. 149°C.	350°F. 177°C.	400°F. 204°C.	450°F. 232°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	900°F. 482°C.	1 000°F. 538°C.	1 100°F. 593°C.	1 200°F. 649°C.
Aluminium, Grade A	—	4	—	—																		
Aluminium, Grade B	—	5	—	—																		
Aluminium magnesium alloy	—	9	—	—																		
Aluminium magnesium manganese alloy	—	20	—	—				'THE STRESS VALUES ARE UNDER CONSIDERATION'														
Copper, Grade A	—	13	—	—																		
Copper, Grade B	—	13	—	—																		
Copper silicon	—	24	—	—																		
Aluminium bronze	—	34	—	—																		
Phosphor bronze	—	20	—	—																		
Yellow metal	—	22	—	—																		
Nickel	—	26	—	—																		
Nickel copper alloy	—	30	—	—																		
Nickel chromium iron alloy	—	30	—	—																		

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

* These figures are illustrative only.

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TABLE 2c. DESIGN STRESSES (TENSILE) FOR NON-FERROUS CASTINGS

Material (For example)	Reference B.S. number	Minimum* ultimate tensile stress (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)														
					150°F. 66°C.	200°F. 93°C.	250°F. 121°C.	300°F. 149°C.	350°F. 177°C.	400°F. 204°C.	450°F. 232°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	900°F. 482°C.	1 000°F. 538°C.	1 100°F. 593°C.	1 200°F. 649°C.
Phosphor bronze	—	16	—	—																		
88/10/2 (Admiralty gunmetal)	—	16	—	—																		
86/7/5/2 Gunmetal	—	14	—	—							'THE STRESS VALUES ARE UNDER CONSIDERATION'											
85/5/5/5 Gunmetal	—	12	—	—																		
H.T. Brass (manganese)	—	30	—	—																		
Nickel copper alloy	—	29	—	—																		

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

* These figures are illustrative only.

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TABLE 2d. DESIGN STRESSES (TENSILE) FOR NON-FERROUS SECTIONS, AND BARS FOR BOLTING MATERIAL (OTHER THAN FOR PRESSURE JOINTS)

Material (For example)	Reference B.S. number	Minimum* ultimate tensile stress (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)														
					150°F. 66°C.	200°F. 93°C.	250°F. 121°C.	300°F. 149°C.	350°F. 177°C.	400°F. 204°C.	450°F. 232°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	900°F. 482°C.	1 000°F. 538°C.	1 100°F. 593°C.	1 200°F. 649°C.
Aluminium, Grade A	—	4	—	—																		
Aluminium, Grade B	—	5	—	—																		
Aluminium magnesium alloy	—	11	—	—																		
Aluminium magnesium manganese alloy	—	14	—	—																		
Copper, Grade A	—	13	—	—																		
Copper, Grade B	—	13	—	—																		
Copper silicon	—	24	—	—																		
Aluminium bronze	—	34	—	—																		
Phosphor bronze	—	25	—	—																		
Yellow metal	—	22	—	—																		
Nickel	—	26	—	—																		
Nickel copper alloy	—	30	—	—																		
Nickel chromium iron alloy	—	30	—	—																		

'THE STRESS VALUES ARE UNDER CONSIDERATION'

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

* These figures are illustrative only.

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TABLE 2e. DESIGN STRESSES (TENSILE) FOR NON-FERROUS PIPES

(FOR USE AS SHELLS, BRANCH PIPES AND SIMILAR PARTS OF PRESSURE VESSELS IN THE CHEMICAL AND ALLIED INDUSTRIES)

Material (For example)	Reference B.S. number	Minimum* ultimate tensile stress (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in.)														
					150°F. 66°C.	200°F. 93°C.	250°F. 121°C.	300°F. 149°C.	350°F. 177°C.	400°F. 204°C.	450°F. 232°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	900°F. 482°C.	1 000°F. 538°C.	1 100°F. 593°C.	1 200°F. 649°C.
Aluminium, Grade A	—	4	—	—																	
Aluminium, Grade B	—	5	—	—																	
Aluminium magnesium alloy	—	9	—	—																	
Aluminium magnesium manganese alloy	—	20	—	—																	
Copper, Grade A	—	13	—	—																	
Copper, Grade B	—	14	—	—																	
Copper silicon	—	22	—	—							'THE STRESS VALUES ARE UNDER CONSIDERATION'										
Aluminium bronze	—	25	—	—																	
Cupro nickel	—	25	—	—																	
Aluminium brass	—	20	—	—																	
Admiralty brass	—	18	—	—																	
Yellow metal	—	22	—	—																	
Nickel	—	26	—	—																	
Nickel copper alloy	—	29	—	—																	
Nickel chromium iron alloy	—	35	—	—																	

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

The stresses given above apply only for pipes used as pressure vessels with simple loading. They do *not* apply to fabricated pipework.

* These figures are illustrative only.

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TABLE 2f. DESIGN STRESSES (TENSILE)

(FOR USE IN PRESSURE VESSELS SUCH AS CONDENSERS, HEAT EXCHANGERS, TUBULAR

Material (For example)	Reference B.S. number	Minimum* ultimate tensile stress (tons/sq. in.)	Notes	Weld discount factor	150°F. 66°C.	200°F. 93°C.	250°F. 121°C.
Aluminium, Grade A	—	4	—	—			
Aluminium, Grade B	—	5	—	—			
Aluminium magnesium alloy	—	9	—	—			
Aluminium magnesium manganese alloy	—	20	—	—			
Copper, Grade A	—	13	—	—			
Copper, Grade B	—	14	—	—			
Copper silicon	—	22	—	—			
Aluminium bronze	—	25	—	—			
Cupro nickel	—	25	—	—			
Aluminium brass	—	20	—	—			
Admiralty brass	—	18	—	—			
Yellow metal	—	22	—	—			
Nickel	—	26	—	—			
Nickel copper alloy	—	29	—	—			
Nickel chromium iron alloy	—	35	—	—			

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

* These figures are illustrative only.

FOR NON-FERROUS TUBES

REACTORS, TUBE STILLS AND THE LIKE IN THE CHEMICAL AND ALLIED INDUSTRIES)

Permissible design stresses at the design temperature of the metal (lb/sq. in.)														
300°F. 149°C.	350°F. 177°C.	400°F. 204°C.	450°F. 232°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	900°F. 482°C.	1 000°F. 538°C.	1 100°F. 593°C.	1 200°F. 649°C.
			'THE STRESS VALUES ARE UNDER CONSIDERATION'											

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TABLE 3. PERMISSIBLE DESIGN STRESSES (COMPRESSIVE) FOR FERROUS MATERIALS FOR VESSELS SUBJECT TO EXTERNAL PRESSURE

Material	*Reference B.S. number	Minimum ultimate tensile stress (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at design temperature of the metal (lb/sq. in.)									
					150°F. 66°C.	300°F. 149°C.	450°F. 232°C.	600°F. 315°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	850°F. 454°C.	900°F. 482°C.	950°F. 510°C.
Carbon steel	1501–101	28	(1)	Nil	9 000	8 600	—	—	—	—	—	—	—	—
	1501–151													
	Grade A	24	(2) (3)	Nil	7 700	7 400	6 400	4 800	3 950	—	—	—	—	—
	Grade B	26	(2) (3)	Nil	8 300	8 000	6 900	5 200	4 150	—	—	—	—	—
	Grade C	28	(2) (3)	Nil	9 000	8 600	7 500	5 600	4 500	—	—	—	—	—
	1501–154													
	Grade A	24	(3)	Nil	7 700	7 400	6 400	4 800	3 950	3 500	—	—	—	—
	Grade B	26	(3)	Nil	8 300	8 000	6 900	5 200	4 150	3 750	—	—	—	—
	Grade C	28	(3)	Nil	9 000	8 600	7 500	5 600	4 500	4 000	—	—	—	—
	1501–157													
	Grade A	24	(2) (4)	Nil	7 700	7 400	—	—	—	—	—	—	—	—
	Grade B	26	(2) (4)	Nil	8 300	8 000	—	—	—	—	—	—	—	—
	Grade C	28	(2) (4)	Nil	9 000	8 600	—	—	—	—	—	—	—	—
Carbon manganese steel	1501–221	32	(5)	Nil	11 000	10 600	10 000	9 100	8 000	7 200	6 700	—	—	—
Carbon molybdenum steel	1501–240													
	Grade A	27	(5)	Nil	8 800	8 400	7 300	5 800	5 200	5 100	5 000	—	—	—
	Grade B	33	(5)	Nil	11 000	10 300	8 900	7 100	6 400	6 200	6 100	—	—	—
13 per cent chromium steel	1501–613	28	(4) (8)	0·10	8 500	8 500	—	—	—	—	—	—	—	—
18/8 Chromium nickel steel, unstabilized	1501–801													
	Grade A	35	(6)	See Note 6	6 200	5 600	5 200	5 100	5 000	—	—	—	—	—
	Grade B	35	(6)	See Note 6	6 200	5 600	5 200	5 100	5 000	—	—	—	—	—
18/8 Chromium nickel steel, stabilized	1501–821													
	Grade A	33	—	Nil	6 200	5 600	5 200	5 100	5 000	4 950	4 900	4 850	4 750	4 500
	Grade B	33	—	Nil	6 200	5 600	5 200	5 100	5 000	4 950	4 900	4 850	4 750	4 500
18/8/3 Chromium nickel molybdenum, unstabilized	1501–844	35	(6)	See Note 6	9 000	8 200	8 000	7 800	7 700	—	—	—	—	—
18/10/3 Chromium nickel molybdenum steel	1501–814	33	(7)	Nil	9 000	8 200	8 000	7 800	7 700	—	—	—	—	—
	1501–845	33	(7)	Nil	9 000	8 200	8 000	7 800	7 700	7 600	7 500	7 300	7 100	6 850

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

The above stresses are suitable for steels in the form of plates, but other forms of product such as forgings, castings, pipes or tubes may be used if convenient, and the permissible stress shall be adjusted pro rata.

NOTE 1. This material is suitable for the construction of Light Duty vessels only and is not recommended for service at temperatures below 50°F. (10°C.) except for applications where embrittlement would not be considered to create a hazard.

NOTE 2. Where a plain carbon steel is required for service at temperatures in excess of 700°F. (370°C.) it shall be ordered to specification B.S. 1501–154.

NOTE 3. Where a plain carbon steel is required for service at temperatures below 32°F. (0°C.) it shall be ordered to specification B.S. 1501–157.

* See B.S. 1501 Carbon and alloy steel plates, sections and bars for use in the chemical, petroleum and allied industries.

NOTE 4. This material shall be subjected to Izod impact tests at the lowest operating temperature to which the vessel will be subjected in service. The steelmaker shall be advised of this requirement at the time of the enquiry and/or order. (See Clause 29.)

NOTE 5. As usually supplied this material may be brittle at sub-atmospheric temperatures. Whenever this material is to be used for service at temperatures below 32°F. (0°C.) Izod impact tests shall be carried out at the lowest temperature to which the vessel will be subjected in service. The steelmaker shall be advised of this requirement at the time of the enquiry and/or order. (See Clause 29.)

NOTE 6. This material is essentially a corrosion resisting material and is extensively used for this purpose. It also possesses good resistance to scaling at elevated temperatures but is not recommended for service at temperatures in excess of 700°F. (370°C.). It is recommended that this material be welded in thin gauges only and the designer should consult with the steelmaker regarding its suitability for the proposed application.

NOTE 7. This material is not recommended for service at temperatures in excess of 700°F. (370°C.).

NOTE 8. There is insufficient data available to enable reliable design stresses to be formulated for this material in the higher range of temperature. It is not, however, suggested that this material is unsuitable for service at elevated temperatures.

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TABLE 4. PERMISSIBLE COMPRESSIVE DESIGN STRESSES FOR NON-FERROUS MATERIALS FOR VESSELS SUBJECT TO EXTERNAL PRESSURE

Material (For example)	Reference B.S. number	Minimum* ultimate tensile stress (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at design temperature of the metal (lb/sq. in.)		
					150°F. 66°C.	200°F. 93°C.	250°F. 121°C.
Aluminium, Grade A	—	4	—	—			
Aluminium, Grade B	—	5	—	—			
Aluminium magnesium alloy	—	9	—	—			
Aluminium magnesium manganese alloy	—	20	—	—			
Copper, Grade A	—	13	—	—			
Copper, Grade B	—	13	—	—			
Copper silicon	—	24	—	—			
Aluminium bronze	—	34	—	—			
Phosphor bronze	—	20	—	—			
Yellow metal	—	22	—	—			
Nickel	—	26	—	—			
Nickel copper alloy	—	30	—	—			
Nickel chromium iron alloy	—	30	—	—			

300°F. 149°C.	350°F. 177°C.	400°F. 204°C.	450°F. 232°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	900°F. 482°C.	1 000°F. 538°C.	1 100°F. 593°C.	1 200°F. 649°C.
			'THE STRESS VALUES ARE UNDER CONSIDERATION'											

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

* These figures are illustrative only.

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TABLE 5. VALUE OF 'E' (1,000,000 LB/SQ. IN.) FOR FERROUS MATERIALS

Material	Permissible design values at design temperature of the metal (lb/sq. in. (× 10⁶))														
	150°F. 66°C.	300°F. 145°C.	450°F. 232°C.	600°F. 316°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	850°F. 454°C.	900°F. 487°C.	950°F. 510°C.	1 000°F. 538°C.	1 050°F. 566°C.	1 100°F. 5[illegible]3°C.	1 150°F. 621°C.	1 200°F. 649°C.
Carbon steel	29·5	28·8	27·8	26·5	25·5	25·0	24·3	23·3	22·0	20·5	—	—	—	—	—
Carbon manganese steel	29·5	28·8	27·8	26·6	25·5	25·0	24·3	23·3	22·0	20·5	—	—	—	—	—
Carbon molybdenum steel	29·5	28·8	27·8	26·5	25·5	25·0	24·3	23·3	22·0	20·5	—	—	—	—	—
Austenitic chromium nickel steel	27·6	26·6	25·5	24·5	23·8	23·5	23·1	22·8	22·4	22·1	21·7	21·4	21·0	20·7	20·3
Austenitic chromium nickel molybdenum steel	27·6	26·6	25·5	24·5	23·8	23·5	23·1	22·8	22·4	22·1	21·7	21·4	21·0	20·7	20·3

The values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

NOTE. The above values are for purposes of design and shall not form part of the material specifications. The figures given were chosen as an average of a large number of experiments and the experimental error was such as to require a tolerance of from ± 1 per cent at room temperature to ± 7 per cent at 1100°F.

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TABLE 6. VALUE OF 'E' (1,000,000 LB/SQ. IN.) FOR NON-FERROUS MATERIALS

Material (For example)	Reference B.S. number	Minimum* ultimate tensile stress (tons/sq. in.)	Notes	Weld discount factor	Permissible design stresses at the design temperature of the metal (lb/sq. in. (× 10⁶))		
					150°F. 66°C.	200°F. 93°C.	250°F. 121°C.
Aluminium, Grade A	—	4	—	—			
Aluminium, Grade B	—	5	—	—			
Aluminium magnesium alloy	—	9	—	—			
Aluminium magnesium manganese alloy	—	20	—	—			
Copper, Grade A	—	13	—	—			
Copper, Grade B	—	13	—	—			
Copper silicon	—	24	—	—			
Aluminium bronze	—	34	—	—			
Phosphor bronze	—	20	—	—			
Yellow metal	—	22	—	—			
Nickel	—	26	—	—			
Nickel copper alloy	—	30	—	—			
Nickel chromium iron alloy	—	30	—	—			

300°F. 149°C.	350°F. 177°C.	400°F. 204°C.	450°F. 232°C.	500°F. 260°C.	550°F. 288°C.	600°F. 315°C.	650°F. 342°C.	700°F. 371°C.	750°F. 399°C.	800°F. 427°C.	900°F. 482°C.	1 000°F. 538°C.	1 100°F. 593°C.	1 200°F. 649°C.
			'THE STRESS VALUES ARE UNDER CONSIDERATION'											

The stress values are based on the Fahrenheit scale, centigrade equivalents are approximate.

Intermediate values may be obtained by linear interpolation.

* These figures are illustrative only.

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Section Three : Design

A. GENERAL

DESIGN THICKNESS

34. *a. General.* In the clauses that follow methods are given for calculating, for the various parts of pressure vessels, the thicknesses required to withstand whichever of the design loads have to be considered.

It must be emphasized that all such thicknesses are minimum, and may require to be increased to allow for other factors affecting the actual use of the vessels.

For example the thickness may require to be increased from that sufficient as far as pressure considerations are concerned in order to give the vessel sufficient rigidity for practical use.

b. Castings. In particular, the calculated thicknesses of castings shall be increased by an amount sufficient to cover any unevenness of thickness and shall be not less than the minimum thickness necessary to ensure sound castings.

DESIGN TEMPERATURE

35. *a. Maximum or minimum design temperature.* The temperature to be used when determining the safe working stress allowable for the material of construction should be the maximum or minimum temperature it is possible for this material to attain under the operating conditions. Due allowance should be made, where necessary, for varying conditions as stated in the following cases.

b. Internal heating of vessel contents. The temperature of the vessel wall shall be taken to be the highest temperature it is possible for the contents of the vessel to attain in the part of the vessel under consideration. Such vessels are those in which heat is provided by :—

Direct heating.

(i) Injection of hot fluid into contents.
(ii) Chemical reaction of contents.
(iii) Admission of hot charges.

Indirect heating.

(iv) Internal heaters of coil etc., type using hot fluids.
(v) Internal electric heaters.

c. External heating of vessel contents. In these cases heat is supplied through the wall of the vessel and the wall temperature is dependent upon :—

The temperature of the heating media.

The amount of scale or deposit formed by the contents of the vessel.

The possible existence of stagnant fluid zones or other disturbances to the operating conditions.

(i) *Heating by fluids of known temperature.* Where vessels are heated by fluids, the temperature of which is known, this temperature shall be taken as the design temperature when determining the maximum allowable working stress.

Such vessels are those using the following methods of heating, in which the heating fluids have definite temperatures :—

(1) Heating bath using hot fluids and convection.
(2) Heating jacket using hot liquids and circulation.
(3) Heating jacket using hot condensing vapours.
(4) Heating jacket using hot gases and circulation.

(ii) *Indirect heating by radiant heat or with a fluid having an indefinite temperature.* Where vessels are heated by a medium, the exact temperature of which is unknown or not precisely controllable, the design temperature shall be taken at least 50°F. (28°C.) higher than the temperature of the contents of the vessel in the part under consideration, provided such contents are not of a scale-forming or deposit-forming nature.

Such vessels are heated by :—

(1) Hot gases of combustion.
(2) Hot waste products.
(3) Radiant heat from incandescent refractory bed.
(4) External electric heaters.

(iii) *Heating surface liable to fouling by vessel contents.* In these cases a further addition should be made to the temperature determined according to (ii) above, and the following amounts are recommended :—

(1) Contents liable to cause light fouling, add 50°F. (28°C.).
(2) Contents liable to cause moderate fouling, add 100°F. (56°C.).
(3) Contents liable to cause heavy fouling, add 200°F. (112°C.).

Typical examples of vessels subject to heavy fouling conditions are shell type stills used for coal tar distillation. Steam boilers fed with softened water are considered to be in the *non*-scaling group.

(iv) *Stagnant fluid zones, etc.* Where the local metal temperature can be increased by stagnant fluid zones, or other disturbances to the operating conditions, appropriate additions should be made to the *nominal* temperature of the material of construction.

d. Known operating temperature. When the metal temperatures of vessels in service under similar conditions have been ascertained, it shall be permissible to take the temperatures so ascertained, as the design temperature.

e. Inequality of heating and cooling. Where vessels are subjected to alternate heating and cooling, great care should be taken in the design to permit expansion or contraction to avoid severe thermic stresses. Such vessels are those fitted with jackets for heating followed by cooling on which, to avoid sudden changes of temperature, means should always be provided to limit the initial admission of the heating and cooling media and control their even distribution. (See Clause 226.)

f. Thermic stresses. Where the wall of a vessel is of considerable thickness, attention should be given to the stress produced in the metal by the difference in temperature between the side receiving the heat and the side giving it out. This stress is very low in the case of thin shell vessels or materials having good heat transfer coefficients, but can become very important in vessels with thick walls, or with poor conductivity.

To avoid unnecessary calculations on relatively thin walled vessels, the following data are given as a guide as to when to consider such thermic stresses. (See Clauses 62 and 64.)

For a vessel having a wall thickness of one-tenth of its inside diameter, this stress amounts to 150 lb/sq. in./1°F. temperature difference (270 lb/sq. in./1°C.). For mild steel vessels this is about 1 lb/sq. in. per inch of wall thickness for a heat input of 2 B.T.U's/sq. ft. of heating surface/1°F. temperature difference/hour (or 2 C.P.U's/sq. ft/1°C. temperature difference/hour).

For general purposes this thermic stress may be ignored, provided :—

B.T.U's./sq. ft./hour × wall thickness in inches does not exceed 1000 (or if C.P.U.'s/sq. ft/hour × wall thickness in inches do not exceed 557).

g. Low temperature vessels. Vessels for design temperatures below 32°F. (0°C.) should be constructed to special requirements as stated in the various sections of this Code, and designed for the lowest temperature encountered in service. (See Clauses 18 and 29.)

DESIGN PRESSURE

36. *a.* The normal operating pressure is determined by the technical requirements of the process to be used.

The design pressure is usually in excess of this to avoid unnecessary blowing of safety devices and varies according to the use of safety valves or rupture discs.

Details of safety devices are given in Clauses 216 to 227.

b. Design pressure. The pressure to be used in determining the maximum differential pressure acting upon each element of a vessel, for the purpose of calculating the scantlings in accordance with the requirements of the Code, shall be :—

(i) *Vessels protected by directly-mounted safety valves.* The pressure at which the safety valve or valves are set to relieve pressure. To this pressure shall be added any negative pressure due to vacuum which may act on the opposite side of the pressure wall. (See (iv) below). If the vessel is protected by a combination of safety valves and rupture discs, the rupture discs may be designed to burst (at atmospheric temperature) at a pressure not greater than the hydraulic test pressure for the vessel, provided that the aggregate capacity of the safety valves is not less than required by Clause 220.

Safety valves should be arranged to give audible warning.

(ii) *Vessels protected by directly-mounted rupture discs.* The pressure at which the rupture disc or discs are designed to burst (except as permitted by (i) above). To this pressure shall be added any negative pressure due to vacuum which may act on the opposite side of the pressure wall. (See (iv) below). If the vessel is to operate at temperatures other than atmospheric the design of the vessel shall be checked for the operating temperature at which the bursting pressure of the rupture disc is a maximum. Rupture discs are highly stressed in service, therefore it is necessary, in order to avoid premature failure due to the effects of creep and fatigue, to allow a substantial margin (of the order of 50 per cent of the operating pressure but depending upon the particular conditions between the normal operating pressure of the vessel and the designed bursting pressure of the disc).

(iii) *Vessels not protected by directly-mounted safety devices.* The maximum pressure to which the vessel may be subjected in service (see Clause 216d). To this pressure shall be added any negative pressure due to vacuum which may act on the opposite side of the pressure wall. (See (iv) below.)

(iv) *Vessels subject to vacuum only.* These should be designed for the maximum negative pressure to which the vessel may be subjected in service. Except in those cases where a vacuum break valve or a hydraulic seal is provided, it is recommended that such vessels be designed for a full negative pressure of 14·7 lb/sq. in.

c. Pressure margin. Where the maximum pressure is controlled by means of pressure-relieving devices it is recommended that there should be sufficient margin between the design pressure and the normal operating pressure to avoid frequent blowing-off of the safety device. For normal spring-loaded safety valves this is usually 10 per cent of the operating pressure.

d. Pressure control. Safety valves are not regarded as pressure control devices for continuous duty. An additional valve specially designed for this purpose should be provided if necessary.

LOADINGS

37. The loadings to be considered in determining the scantlings of a vessel or part of a vessel should be the combination of such of the following, acting together, as will produce the worst stress/temperature condition.

a. Internal or external operating pressure as specified in Clause 36.

b. Shock loads, including rapid pressure fluctuations and surge loads due to rapid movement of contents of vessel.

c. The weight of vessel and normal contents at operating pressure and temperature, or, if such a load is probable, the weight of vessel full of water at atmospheric temperature (e.g., hydraulic test).

d. Bending moments caused by eccentricity of the centre of the working pressure, relative to the neutral axes of the vessel.

e. Superimposed loads.

f. Wind loads.

g. Local stresses due to supporting lugs, ring girders, saddles, internal structures, or connecting piping.

h. Temperature differences, including the effects of differential expansion caused by different materials connected together.

i. Additional pressure due to static head of contained fluids.

SPECIAL SHAPES

38. Vessels of a special or unusual shape for which the rules given in the Code are inapplicable, should be designed in accordance with good accepted practice, or where calculations cannot be made with a satisfactory assurance of accuracy, a vessel should be deemed to comply with the requirements of this Code if it passes successfully the proof hydraulic test pressure specified in Clause 210

39. (Spare).

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B. CORROSION, EROSION AND PROTECTION

GENERAL

40. Whenever the word 'corrosion' is used in this Code it shall be taken to include oxidation, scaling, abrasion and erosion.

It is impossible to lay down definite rules with regard to the precautions necessary to guard against the effects of corrosion, owing to the many possible variables involved. It cannot, therefore, be too strongly emphasized that designers should give careful consideration to the effect which corrosion may have upon the useful life of the vessel.

Any tests which may be undertaken to determine the probable rate of corrosion should be carried out on the actual metal or *combination* of metals and when exposed to the actual chemicals used in service. It is very dangerous to assume that the major constituent of a m[illegible] of [illegible] is the active agent as, in many cases, su[illegible] impurities exert an accelerating or inhibiting e[illegible] all proportion to the amount of the impurity [illegible]nt. Fluid temperature and velocity conditions should be the same as will be met with in operation. Corrosion tests should be carried on for a sufficiently lengthy period to determine the trend of any change in the rate of corrosion with respect to time.

It is important to note that corrosion may occur on *both* sides of the wall of the vessel, particularly in the case of fired vessels heated by hot gases of combustion.

Pressure vessels may be classified in relation to corrosion under one of the following groups :—

a. Corrosion rate predictable. Vessels in which corrosion rates may be definitely established by reason of accurate knowledge of the chemical characteristics of whatever substances they are to contain. Such knowledge, may, in the case of normal commercial products, be obtained from public sources, or, where special processes are involved, from reliable records compiled by the user or others from results of previous observations under similar conditions of operation.

b. Corrosion rate unpredictable. Vessels in which corrosion rates are either variable throughout the vessel or indeterminate in magnitude.

c. Corrosion rate negligible or absent. Vessels in which corrosion rates are known to be negligible or entirely absent.

ADDITIONAL THICKNESS TO ALLOW FOR CORROSION

41. When both the inner and outer surfaces of the wall of the vessel are subject to corrosive influences, the allowance adopted shall be adequate to cover the total amount of wastage anticipated.

a. Corrosion rate predictable. In cases where the rate of corrosion is closely predictable, additional metal thickness over and above that required for the initial operating conditions should be provided, at least equal to the determined corrosion loss during the desired life of the vessel. For vessels to contain non-corrosive chemical vapours mixed with air, steam or water and constructed of mild steel, the minimum corrosion allowance recommended is 1/16 in. In all the above cases the minimum corrosion allowance may, of course, be increased.

b. Corrosion rate unpredictable. When corrosion effects are unpredictable prior to the designing of the vessel, although known to be inherent to some degree in the service for which the vessel is to be used, the best judgment should be exercised in establishing a reasonable excess shell thickness. This also applies where corrosion is incidental, localized, and/or variable in rate and extent. It should be borne in mind that the provisions of Clause 235 will govern such vessels, therefore an inadequate allowance for the effects of corrosion will result in the vessel being derated or having to be removed from service after a life shorter than that for which it was designed.

For vessels coming under this classification a minimum corrosion allowance of 1/16 in. should be provided unless a protective lining is employed, in which case the provisions of Clause 42 will apply.

c. Corrosion rate negligible or absent. In cases where the corrosion effects can be shown to be negligible or entirely absent, no excess thickness need be provided.

PROTECTIVE LININGS

42. *a. Metal coatings and linings.* When corrosion-resistant metal coatings or linings are used, the basic shell thickness may be the minimum thickness required for design operating conditions : provided, however, that the thickness of such coating or lining is sufficient to afford estimated life equal to at least twice the length of the initial inspection period ; that is, the length of time between first setting the vessel to work on corrosive duty, and the first inspection carried out after this. Metal linings should be so designed that it is impossible for the corrosive agent to get between the lining and the wall of the vessel. (See Clause 4). Where vessels with loose, partly attached, or rigidly bonded linings are subject to wide temperature variation, the lining should, so far as possible, have the same coefficient of expansion as the material of which the vessel is made. Alternatively, allowance should be made in the design to permit relative movement between the vessel and its lining. Neglect of these precautions may produce unexpected corrosion and failure. (See Clauses 231 and 234.)

b. Non-metallic coatings and linings. If the reliably estimated life of the lining is at least twice the length of the first inspection period, the shell thickness need only be thick enough to satisfy the design conditions.

c. Paints. The protection provided by internal painting with ordinary oil-bound paints, such as are used for decorative purposes and protection of structures and equipment exposed to atmospheric corrosion, cannot be regarded as sufficiently reliable to justify a reduction in the corrosion allowance necessary to ensure that the vessel has the desired life.

d. Tell-tale holes. Vessels provided with loose protective linings should have a 'tell-tale' hole through the lowest portion of the shell, and in an easily visible location, to show any leakage of contents.

e. Vessels subject to erosion and abrasion. Where severe conditions of erosion and abrasion arise it is recommended that local protective or 'wear' plates, of an easily renewable type, should be fitted in the direct path of the impinging material.

C. WELDED JOINTS, TYPE AND EFFICIENCY

GENERAL

43. Joint efficiency factor 'J' used in the formulae that follow is intended to provide additional thickness of metal to allow for the assumed lower quality of any welded joint relative to the plate. The factor 'J' is based upon variations in the following :—

a. Type of welded joint.
b. Weldability of metal to be used.
c. Stress relief of joint.
d. Radiographic check on quality of seams.
e. Mechanical tests upon the welded seams, and amount of inspection during manufacture.

JOINT EFFICIENCY FACTOR 'J'

44. Welded joints are rated lower than the parent plate, a seamless shell being given the highest value of $J = 1{\cdot}00$. With changes in the type of joint, as weldability of the material decreases, where stress relief is omitted, radiographic examination reduced and the amount of mechanical testing and inspection reduced, the value of 'J' is decreased by a series of discounts as indicated in Clauses 45 to 49.

JOINT TYPE FACTOR 'J_j' AND LIMITATIONS

45. Fig. 3 shows permitted types and limitations for welded joints.

Column 4 gives the factor 'J_j' for the various types.

As the technique of welding is still in the process of changing and improving, the figures are to be considered as diagrams only and not binding in detail. This applies to the whole of the weld profiles in the body of this Code, except where welds are fully dimensioned.

a. The double-welded butt joints, Figs. 3a, b, c and d should be used wherever possible.

b. The single-welded butt joints Figs. 3e and g *without* backing strips are discouraged. They should only be used when there is no practical alternative.

c. The single full-fillet lap joints Figs. 3k and l are also discouraged.

d. Values for 'J_j' have not been given for single-welded butt joints without backing strips or single fillet lap joints because these constructions may be used only for circumferential joints. Normally, in such cases, the load is approximately one-half of the load on the longitudinal joint and will not necessarily be the limiting feature in design.

WELDABILITY OF METAL FACTOR 'J_w'

46. *a.* Where the material used can be easily welded and the technique is established, the discount factor 'J_w' is zero.

b. In the case of metals which, at the date of publication of this Code, it is considered cannot be easily welded, this discount factor 'J_w' is made into 0·1, 0·2, etc., in order to provide an increased factor of safety for the less easily welded materials. It should be clearly understood that the difference between a completely satisfactory weld and an allowable 'interim' weld, is a question of porosity, slag inclusion, etc. Materials which, when welded, have a tendency to crack either in the parent metal, weld metal or fusion zone, shall not be used for parts which have to be welded.

c. The discount factor 'J_w' is given (where applicable) in Column 5 of the tables of working stresses, Clause 33. As the welding technique improves for each particular material, the value of 'J_w' will be correspondingly decreased. This provision allows the use of new materials, particularly with improved corrosion- or abrasion-resisting properties, without waiting until the improved welding technique is established. The higher value of 'J_w' in the interim stage, ensures increased plate thickness to cover possible wasting.

STRESS-RELIEF JOINT FACTOR 'J_s'

47. The contraction stresses due to welding shall be relieved by heat treatment where required by this Code, (see Clause 24, and Fig. 4). The requirement varies according to material, plate thickness, and diameter of vessel. In the case of vessels not requiring stress relief, the factor 'J_s' is varied according to the value of the contraction stress present. These 'J_s' factors are marked on the curves, the lower values being for best conditions approaching the stress relieved value of zero. The relatively small subdivisions of the factor are of importance when costly materials of construction such as nickel, monel, or stainless steel are used.

RADIOGRAPHIC EXAMINATION FACTOR 'J_r'

48. Where radiography is applicable the following discounts shall be used : radiographic examination of lap joints is not considered to be capable of giving any useful information regarding the quality of the joint, therefore no adjustment can be made.

a. When all seams are radiographed J_r = nil
b. When longitudinal seams only are radiographed $J_r = 0{\cdot}03$
c. When no seams are radiographed $J_r = 0{\cdot}12$

MECHANICAL TESTS AND INSPECTION FACTOR 'J_t'

49. The following discounts shall be used :

a. Full mechanical tests and inspection J_t = nil
b. Limited mechanical tests and inspection $J_t = 0{\cdot}03$
c. Minimum mechanical tests and inspection $J_t = 0{\cdot}12$
d. No tests (applies only to the cases referred to in Clause 52c and d) $J_t = 0{\cdot}17$

FINAL VALUE OF JOINT FACTOR 'J'

50. The final value of joint factor 'J' may be any combination of the foregoing discount factors, according to the requirements of 'Use of Code' Clauses 20 to 25. When all factors are used the value is as follows :—

$$J = J_j - (J_w + J_s + J_r + J_t) \quad . \quad . \quad . \quad .(1)$$

Note that the smaller the value of 'J,' the larger the thickness of plate, because 'J' is the denominator in the formulae for scantlings.

Example.

To calculate allowable joint efficiency factor for a vessel 72 inch internal diameter to be constructed from mild steel plate having a minimum ultimate tensile strength of 26 tons/sq. in. Estimated thickness of vessel wall ½ inch (it is necessary to approximate the thickness

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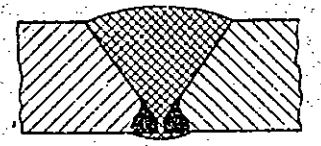
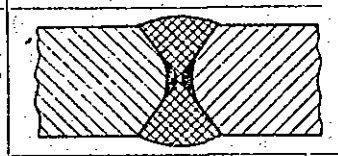
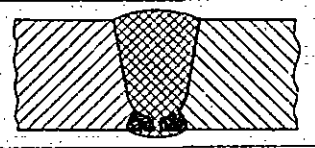
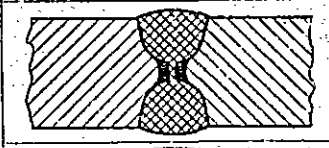
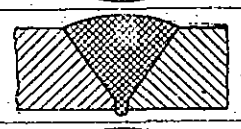
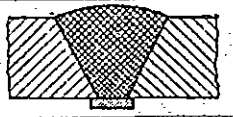
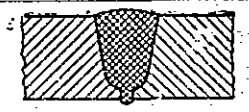
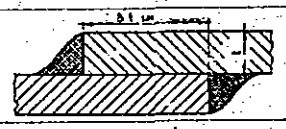
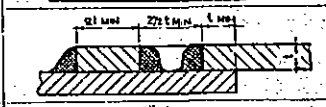
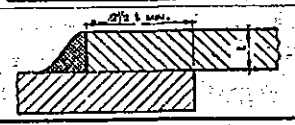
Fig.	Joint	Name	'J' Joint efficiency	Application	
				Longitudinal	Circumferential
3 a		Double-welded butt joint with single 'V'	0·95	All thicknesses	All thicknesses
3 b		Double-welded butt joint with double 'V'	0·95	All thicknesses	All thicknesses
3 c		Double-welded butt joint with single 'U'	0·95	All thicknesses	All thicknesses
3 d		Double-welded butt joint with double 'U'	0·95	All thicknesses	All thicknesses
3 e		Single-welded butt joint with 'V' groove *without* backing strip	No value given because this joint may only be used for circumferential joints	Not allowed	Not exceeding ⅝ in. plate
3 f		Single-welded butt joint with 'V' groove *with* backing strip	0·85	Not exceeding 1¼ in. plate	Not exceeding 1¼ in. plate
3 g		Single-welded butt joint with 'U' groove *without* backing strip	No value given because this joint may only be used for circumferential joints	Not allowed	Not exceeding ⅝ in. plate
3 h		Single-welded square butt joint *without* backing strip	No value given because this joint may only be used for circumferential joints	Not allowed	Not exceeding ¼ in. plate
3 i		Single-welded square butt joint *with* backing strip	0·85	Not exceeding ¼ in. plate	Not exceeding ¼ in. plate
3 j		Double full-fillet lap joint	0·70	Not exceeding ⅜ in. plate	Not exceeding ⅝ in. plate
3 k		Single full-fillet lap joint with plug weld	No value given because this joint may only be used for circumferential joints	Not allowed	Not exceeding 9/16 in. plate. Plugs shall be proportioned to take 20 per cent of total load
3 l		Single full-fillet lap joint	No value given because this joint may only be used for circumferential joints	Not allowed	Not exceeding ½ in. plate

Fig. 3. Typical welded longitudinal and circumferential joints. Weld profiles diagrammatic only.

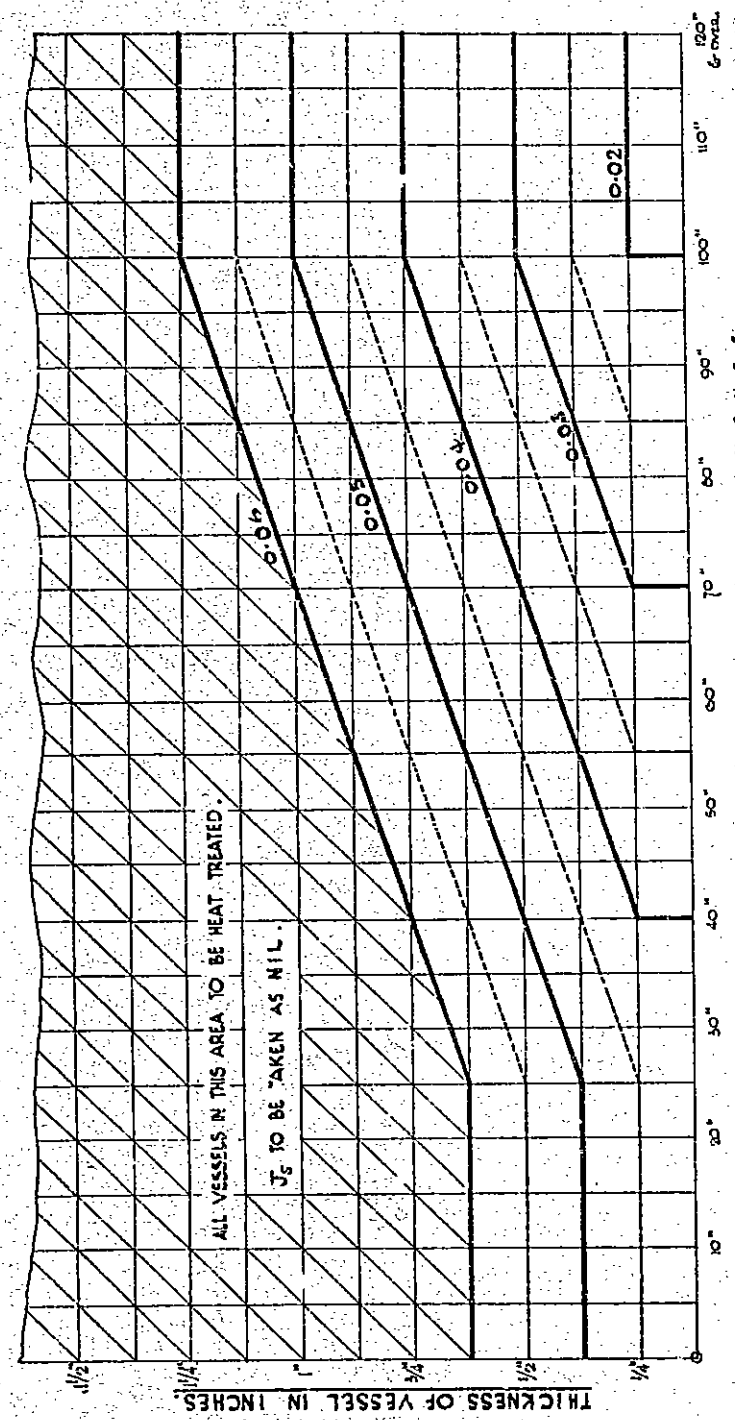


Fig. 4. Chart for heat treatment and stress relief joint factors 'J' for non-heat treatment

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