

Specification for

**Design and manufacture of
water-tube steam generating
plant (including superheaters,
reheaters and steel tube
economizers)**

Conception et construction des générateurs de
vapeur à tubes d'eau (y compris les
surchauffeurs, rechauffeurs et économiseurs à
tubes d'acier) - Spécifications

Konstruktion und Herstellung von
Wasserrohr-Dampferzeugungsanlagen
(einschließlich Überhitzer, Zwischenerhitzer
und Stahlrohrvorwärmer)

Committees responsible for this British Standard

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Association of Consulting Engineers
British Steel Industry
Electricity Supply Industry in England and Wales
Engineering Equipment and Materials Users' Association
Health and Safety Executive
Independent Engineering Insurers' Committee
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Foreword

This British Standard, first published in 1943 under the title 'Water tube boilers and their integral superheaters' and subsequently revised in 1951, 1958, 1969, 1985 and 1989 has been prepared under the direction of the Pressure Vessel Standards Policy Committee. This edition supersedes the 1989 edition which is withdrawn.

The 1969 edition incorporated the requirements of ISO/R 831 published by the International Organization for Standardization (ISO). The 1985 edition deviated from these requirements and incorporated a number of developments from BS 5500. Most of these developments, and particularly the adoption of stress tables incorporating a range of design lifetimes related to the creep rupture properties of the material, were subjects of amendments to the 1969 edition. Where design stresses in the creep range were significantly different from those hitherto used successfully, provision was made for alternative design stresses to be used in conjunction with a 'continued service' review at a specified fraction of the design life.

This approach recognized the limitations inherent in any simple design method for boiler components operating in the creep range and also provides a flexible basis that might be used in cases where the design stress values, which have been derived from ISO data, are significantly different from those used with success in the past.

Whilst recognizing that in practice the operating life of a component designed on a time-dependent basis might be extended beyond design lifetime, this aspect of plant operation was recognized as being under the control of the plant owner and therefore outside the scope of this standard. It is the subject of other British Standard publications.

This 1992 edition incorporates all technical changes up to and including Amendment No. 4 (31 May 1991) associated with the 1989 edition. Changes of significance are to:

- (a) recommend the operation of a quality system to BS 5750;
- (b) modify section on compensation and local loads;
- (c) modify section on non-destructive testing.

Because of the wide range of types of water-tube steam generating plant that may be designed and manufactured in accordance with this standard, general guidance has been given on some aspects with specific requirements being for agreement between the parties concerned according to the particular design and manufacturing details.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

It is recognized that clauses concerning inspection facilities and testing facilities which have traditionally been incorporated into boiler standards are a contractual matter. Nevertheless their importance is such that the purchaser in agreeing a contract should not overlook them. These clauses are reproduced in appendix G.

As with the previous edition, it is intended to keep this standard up to date by the issue from time to time of replacement pages, or by the addition of pages where necessary. Each replacement or added page will carry an issue number (with date) indicating its relationship to the original standard, the pages of which are marked 'Issue 1'. For example:

Issue 1 will indicate an original page or one that has been added to the original standard and has not been amended since insertion;

Issue 2 will indicate a first revision of either an original page or an added page;

Issue 3 will indicate either an original page revised for the second time since publication or an added page revised for the second time since insertion.

Side-lining on replacement pages will indicate that changes of technical or reference significance have been made at that point.

The purchaser is recommended, as an aid to demonstrating the boiler supplier's capability of achieving the required quality level, to specify in the contract, that the manufacturer operates a quality system in compliance with the appropriate parts of BS 5750.

This standard is included in the list of 'Standards significant to health and safety at work' published by the UK Health and Safety Executive (HSE)* and is also referred to by HSE in giving guidance.

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

* Health and Safety Executive, Baynards House, 1 Chepstow Place, London, W2 4TF.

Section one. General

1.1 Scope

1.1.1 This British Standard specifies requirements for the design and the manufacture, including materials and design stresses, workmanship, inspection, testing, documentation and marking, valves, gauges and fittings of:

- (a) water-tube steam generating plant subject to internal pressure; and
- (b) parts of steam and water heating plant used in association with steam generating plant.

1.1.2 In addition to the definitive requirements, this standard also requires the items detailed in 1.5 to be documented. For compliance with this standard, both the definitive requirements and the documented items have to be satisfied.

1.1.3 This British Standard applies to the following types of plant.

- (a) Water-tube boilers including their integral steel tube economizers and superheaters and all other parts connected to the boiler without the interposition of a shut-off valve with the exception of valves and fittings specified in section seven.

Water-tube boilers are divided, for the purposes of this British Standard, into the following three classes.

- (1) Natural circulation boilers, in which the circulation of the water through the tubes is a result of the thermo-syphonic head produced by heating.
- (2) Forced, assisted or controlled circulation boilers, in which a pump is used either entirely or partly to promote circulation of the water through the tubes.
- (3) Once-through boilers, in which the feed pump is used to force the flow of water and steam through the tubes.

- (b) Steam reheaters (either integral with the boiler unit or independently fired) receiving steam which has passed through part of a turbine or other prime mover.

- (c) Independently fired steam superheaters.

- (d) Integral superheaters separated by a shut-off valve from the evaporative circuits.

- (e) Steel tube economizers (either integral with the boiler or independently fired) separated by a shut-off valve from the boiler.

NOTE. For convenience, the term 'boiler' used throughout this standard includes the types of plant described in (a) to (e).

1.1.4 This standard applies to the pressure parts of boilers and superheaters (as described in 1.1.3(a) and (d)) containing water and steam up to and including the valves separating these water and steam spaces from the steam pipes to other equipment, water supply pipes, drain pipes and the surrounding atmosphere (safety valves and vents).

In the case of reheaters (see 1.1.3(b)), the standard applies to pressure parts from the piping connection(s) at the inlet header to the piping connection(s) at the outlet header except that where a device is provided in reheat piping to blank off the reheater for hydraulic testing, this standard applies up to and including this device. In the case of independently fired superheaters (see 1.1.3(c)), and economizers (see 1.1.3(e)), the standard applies to the pressure parts containing steam and water respectively between the inlet and exit valves, including the respective valves and connections to drain pipes and to the atmosphere.

1.1.5 Section four of this standard (manufacture and workmanship) includes requirements applicable to the normal function of the boilermaker. Requirements for the quality of workmanship of plates, tubes, forgings and castings in the condition in which they are normally supplied to the boilermaker are included in the standards in the series specifying such materials.

1.1.6 This standard does not apply to brickwork or other settings or supports, or to insulation, or to air preheaters, mechanical stokers, fuel burning or ash disposal equipment, forced or induced draught equipment or their accessories. These items are matters for mutual agreement between the purchaser and the manufacturer.

NOTE. Where such items are required or contemplated, it is recommended that all particulars which could affect the boiler(s) should be disclosed by the purchaser to the manufacturer at the time of the enquiry.

1.1.7 This standard applies only to boilers manufactured under the survey of a competent engineering inspecting Authority or organization. The intent of this requirement may be regarded as satisfied where inspection is carried out by competent personnel of a separate engineering inspection department maintained by the purchaser of the boiler. An inspection department maintained by the manufacturer does not satisfy this requirement except:

- (a) that specific responsibilities may be delegated at the discretion of the Inspecting Authority or organization; or
- (b) in the case of boilers for the manufacturer's own use and not for resale.

This standard applies only to boilers made by manufacturers who can satisfy the Inspecting Authority or organization that they are competent and suitably equipped to fulfil the requirements specified.

In assessing the competence of a manufacturer, the Inspecting Authority or organization shall take into consideration any related nationally approved certification against the BS 5750 series of quality system standards.

NOTE. The titles of the publications referred to in this standard are listed on the last page.



1.2 Interpretation

If any ambiguity be found or doubt arise as to the meaning or effect of any part of this standard or as to whether anything ought to be done or omitted to be done in order that this standard should be complied with in full, the question shall be referred to the Boiler Technical Committee (PVE/2) of the British Standards Institution, whose interpretation of the requirements of this standard upon the matter at issue shall be given free of charge and shall be final and conclusive. Parties adopting this standard for the purposes of any contract shall be deemed to adopt this provision unless they expressly exclude it or else import an arbitration provision in terms extending to interpretation of this standard. However, this provision is limited to questions of interpretation and does not confer upon the committee any power, duty or authority to adjudicate upon the contractual rights or duties of any person under a contract except in so far as they may necessarily be affected by the interpretation arrived at by the committee.

Findings or rulings of the committee upon all enquiries, including matters of interpretation, which are of sufficient importance that both enquiries and replies be made public as soon as possible will be published in an enquiry-reply form for inclusion in the BS 1113 ring binder as Enquiry Cases. Their availability will be notified in *BSI News*.

After taking into account any public comment thereon, Enquiry Cases may be incorporated, as appropriate, into the standard as amendments which will form part of the next convenient annual updating.

1.3 Definitions

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

1.3.1 purchaser. The individual or organization that buys the completed boiler from the manufacturer.

1.3.2 manufacturer. The organization that designs, fabricates and erects the boiler in accordance with the purchaser's order. The design, fabrication and erection functions may be carried out by separate organizations.

1.3.3 Inspecting Authority. The body or association that checks that the design, materials and construction comply with this standard.

1.3.4 Regulating Authority. The authority in the country of installation that is legally charged with the enforcement of the requirements of the law and regulations of that country relating to boilers.

1.3.5 maximum permissible working pressure. For design purposes, one of the following:

(a) for natural or assisted circulation boilers and directly connected economizers, the highest set pressure of any safety valve mounted on the steam drum;

(b) for once-through boilers, the highest set pressure of any safety valve mounted on the final superheater outlet; or

(c) for steam reheaters, independently fired superheaters and economizers separated by a shut-off valve from the boiler, the highest pressure of any safety valve mounted on the steam or water outlet.

1.3.6 calculation pressure. For calculation purposes, either:

(a) except as defined in (b), the maximum permissible working pressure as defined in 1.3.5, increased where applicable to take account of the pressure drop and hydraulic head corresponding to the most severe conditions of operation; or

(b) for those components whose design stresses are time-dependent (see table 2.1.2 and A.4), the lowest set pressure of any superheater or reheater safety valve mounted on the steam outlet, increased to take account of the pressure drop corresponding to the most severe conditions of operation.

1.3.7 design temperature. The temperature to be used in the establishment of the minimum scantling thickness of pressure parts.

1.3.8 design lifetime. The operating lifetime to be used in the evaluation of design stresses for a component whose design temperature at calculation pressure is such that its design stress value is time-dependent.

1.3.9 continued service review. A review or series of reviews carried out to establish if a component, designed to the higher of alternative design stresses in the creep range is fit for continued service up to its design life.

1.3.10 design stress. The stress value, f , used in the formulae in this standard for the calculation of the minimum scantling thickness of pressure parts.

1.3.11 pressure part. A component that contains pressurized water or steam or a mixture of the two.

1.3.12 drum. A cylindrical pressure part having a diameter sufficiently large to admit personnel, by design intent, for which purpose an access opening or branch is provided.

NOTE. A drum may have the function of a header, or additionally or alternatively other functions, such as to separate steam from water or to act as a reservoir for boiler water.

1.3.13 header. A pressure part whose principal purpose is to collect fluid from, or distribute fluid to, arrays of tubes directly connected to it.

1.3.14 tube. A tubular pressure part that is either exposed over much of its length to hot gases for purposes of heat transfer, or is directly butt welded to such a tubular pressure part.

NOTE. This definition includes a tube stub on a drum or header.

1.3.15 integral pipe. A tubular pressure part that is not a tube, drum or header.

NOTE 1. The term 'pipe' implies there is no design intent to effect heat transfer through the wall of the pressure part.



NOTE 2. The term 'integral' implies that the pressure part is connected directly to other pressure parts without any intervening valve.

NOTE 3. The term 'integral pipe', subject to note 2, includes those parts of pipes that carry a flow of steam or water during normal operation, those that carry intermittent flow, e.g. drain pipes, and those in which no flow occurs, e.g. instrument piping.

NOTE 4. The terms tube and pipe are used freely in British Standards for material and certain standards (e.g. BS 3602) state that they are interchangeable. The use of the term pipe or tube in any standard for material does not pre-empt the definitions given in 1.3.14 and 1.3.15 and likewise material described as pipe or tube may be used for any duty defined, if appropriate. The selective reference to British Standard materials in section four of this standard is intended for guidance based on the general usage of these standards.

1.4 Responsibilities

1.4.1 Responsibilities of the purchaser

The purchaser shall be responsible for furnishing the manufacturer with the information required by 1.5.1.

Where the Inspecting Authority is nominated by the purchaser, the purchaser shall be responsible for ensuring that any information which the manufacturer is required to supply, as specified in this standard, is made available to the Inspecting Authority.

Where necessary, it shall be the responsibility of the purchaser to ensure that the Inspecting Authority is acceptable to the Regulating Authority. This should be done at the time of the order.

1.4.2 Responsibilities of the manufacturer

The manufacturer shall be responsible for the completeness and accuracy of all design calculations and for compliance with all applicable requirements of this standard for the whole boiler. During fabrication, unexpected factors may arise which justify deviations from the specified requirements but which do not affect the safety as intended by this standard. Such deviations shall be submitted to the Inspecting Authority for approval and shall be recorded as part of the boiler dossier (see 6.1.3(b)).

In cases where the design, fabrication and erection functions are carried out by separate organizations, the manufacturer's responsibilities as laid down in this standard shall be discharged in a manner agreed between the parties concerned (see 1.5.2.2(a)).

Examinations carried out by the Inspecting Authority shall not absolve the manufacturer from his responsibility for compliance with the applicable requirements of this standard.

A certificate of conformity shall be provided by the manufacturer; see section six.

1.4.3 Responsibilities of the Inspecting Authority

The Inspecting Authority shall be responsible for checking that the design of the boiler components complies with this standard and that all inspections and tests required during the manufacture of the boiler are carried out.

1.5 Information and requirements to be agreed and to be documented

1.5.1 Information to be supplied by the purchaser

The following information shall be supplied by the purchaser and shall be fully documented (see 6.1.3(c)). Both the definitive requirements specified throughout the standard and the documented items shall be satisfied before a claim of compliance with the standard can be made and verified.

- (a) A specification of the normal working conditions of the boiler, together with details of any transient and/or adverse conditions under which the boiler is required to operate and of any special requirements for in-service inspection.
- (b) The name of the Inspecting Authority to be commissioned by the purchaser, see 1.1.7.
- (c) Any additional requirements not given in this standard (see 2.2.1.3(a)(1), 2.2.1.3(b)(3), 3.7.1.2 and 4.1.3).
- (d) Any special statutory or other regulations with which the finished boiler is required to comply.
- (e) The name of the Regulating Authority (if any).

1.5.2 Requirements to be agreed and documented

1.5.2.1 General. The items listed in 1.5.2.2 and 1.5.2.3 to be agreed, as appropriate, between the parties concerned, which are specified in the clauses referred to, shall be fully documented. Both the definitive requirements specified throughout this standard and the documented items shall be satisfied before a claim of compliance with this standard can be made and verified.

NOTE. Users of this standard should appreciate that a number of items of agreement, i.e. those listed under 1.5.2.3, cannot be agreed/documented at the time of placing the contract or order for the boiler and do not necessarily apply in every case; they make provisions for individual agreements that may be necessary during the manufacturer's operations to deal with certain practical eventualities (see also 1.4.2). It is important to distinguish these items (1.5.2.3) from those listed under 1.5.2.2, which do need to be agreed and documented when the contract or order is placed.

1.5.2.2 Requirements to be agreed and documented at the contract or order stage. The following items, as appropriate, shall be agreed and documented (see 6.1.3(d)).

- (a) The manner in which the manufacturer's responsibilities are to be discharged in cases where the design, fabrication and erection functions are carried out by separate organizations (see 1.4.2).
- (b) Increased design stresses for certain alloy steels (see note 6 to table 2.1.2).
- (c) The design lifetime, related to the creep rupture properties of the material, for each component whose design temperature is such that the nominal design stress given in table 2.1.2 is time-dependent (see 2.2.4).



(d) Design stress values and the basis for extrapolation for design temperatures above those for which design stress values are given in table 2.1.2 (see general note (b) and note 1(c) to table 2.1.2).

(e) The maximum values for forces and moments imposed by external piping at the boiler terminals for main steam, reheat steam and feedwater (see 3.1.2).

(f) If applicable, design parameters for wind and earthquake loads (see 3.1.2).

1.5.2.3 Requirements to be agreed and documented during the manufacturer's operations. The following items, as appropriate, shall be agreed and documented (see also 1.4.2 and 6.1.3(j)).

(a) The use, for pressure parts, of materials not covered by table 2.1.2 (see 2.1.2.1(b)) and whether elevated temperature yield point or proof stress properties related to tests in accordance with BS EN 10002-5 are not required for such materials (see 2.1.2.2.5).

(b) The heat treatment condition for materials not covered by table 2.1.2, if an alternative to the condition appropriate to the nearest equivalent British Standard material is required (see 2.1.2.2.7).

(c) The use of design stress values (*f*) determined by reference to appendix A from the properties of the actual materials, where these properties have been proved by test to be higher than those given in the relevant material specification (see 2.2.1.1(b)).

(d) The method of calculating the thicknesses of the cylindrical shells of drums and headers, for time-dependent (creep) conditions where the resultant thickness exceeds half the internal diameter (see 3.3.2.2(b)).

(e) The scantlings for headers of rectangular section that are not straight (see 3.5.3).

(f) Assembly tolerances for middle line alignments (see 4.2.5.1.1).

(g) The welding materials to be used if these are not covered by British Standards (see 4.3.1.2(b)).

(h) For post-weld heat treatment:

- (1) the heat treatment conditions if other than those given in table 4.5.4 (see 4.5.4.1.2(a)(2)); or
- (2) waiver of post-weld heat treatment (see 4.5.4.1.2(b)).

(i) Post-weld heat treatment of joints between any combinations of ferritic steels not included in table 4.5.4 (see 4.5.4.6.3).

(j) The requirement for heat treatment of austenitic steel tubes or pipes that are hot or cold bent for integral piping (see 4.2.3.5), the bending temperature range to be used for hot bending, and the post-bend heat treatment procedures to be used (see 4.5.2.2.3).

(k) Where necessary, acceptance, as fit for the intended purpose, of welds represented by charpy V-notch impact test specimens from boiler drum production control test plates that give impact values less than required by 5.5.7.3 (see 5.5.7.4(b)).

(l) Where necessary, acceptance of computations if any tensile test specimen from the boiler drum production control test plates fails to comply with specified requirements (see 5.5.8).

(m) Where necessary, remedial measures to be adopted if either of the bend retest specimens from the boiler drum production control test plates fails to comply with the specified requirements (see 5.5.8).

(n) A reduction in the percentage rate of non-destructive examination for welds, where the manufacturer has demonstrated that the welds consistently comply with the standards of acceptance given in 5.9 (see 5.8.1.1).

(o) Non-destructive examination before final stress relief, for the following weld types in carbon, carbon manganese type 620 and type 621 steels (see 5.8.1.4):

- (i) butt welds in drums and headers;
- (ii) branch, nozzle and stub welds;
- (iii) attachment welds.

(p) Where necessary, the use of a fitness for purpose analysis to assess the acceptability of particular flaws in excess of the acceptance levels specified in 5.9.3 to 5.9.8 (see 5.9.2(b)(2)).

(q) Disregarding of ultrasonic indications of flaws in zone A (see figure 5.9.3.2(4)) of butt welds in drums and headers ≥ 20 mm thickness (see 5.9.3.2.4(a)).

(r) The procedure to be used with regard to small pockets of trapped air which may remain after filling following venting or evacuation of air prior to hydraulic testing (see 3.1.5(h)).

Section two. Materials and design stresses

2.1 Materials

2.1.1 General

2.1.1.1 The selection of the materials of construction for pressure-containing parts of boilers and their integral attachments shall take into account the suitability of the material with regard to fabrication, e.g. cold forming, weldability and expanding, as appropriate, and the conditions under which they will eventually operate.

2.1.1.2 Welding material shall comply with 4.3.1.2.

2.1.1.3 Cast iron shall not be used in the construction of pressure parts, except for valves and fittings within the limits specified in BS 759 : Part 1 or BS 6759 : Part 1.

2.1.1.4 Studs, bolts and nuts shall be in accordance with the material specifications given in BS 4882.

2.1.1.5 Pipe fittings shall comply with BS 1640, BS 1965 : Part 1 or BS 3799, as appropriate.

2.1.1.6 Flanges shall comply with BS 10, BS 1560 : Section 3.1 or BS 4504 : Section 3.1.

2.1.2 Materials for pressure parts

2.1.2.1 General. With the exceptions of the materials covered by 2.1.1.2 to 2.1.1.6, all the materials used in the manufacture of pressure parts shall either:

- (a) comply with the appropriate British Standards given in table 2.1.2; or
- (b) be agreed between the manufacturer and the purchaser and comply with 2.1.2.2 (see 1.5.2.3(a)).

A combination of materials given in table 2.1.2 and corrosion resistant material is permitted for metallurgically bonded co-extruded tubes.

NOTE The requirements of this British Standard have been drafted largely on the basis of experience with the materials specified in the British Standards referred to in table 2.1.2; the selection of such materials should therefore be preferred. However, it is accepted that special circumstances may occur in which the selection of materials other than those covered by table 2.1.2 is necessary; the requirements of 2.1.2.2 have been specified to provide a basis for material selection in such circumstances.

2.1.2.2 Materials not covered by table 2.1.2

2.1.2.2.1 The material shall be covered by a written specification at least as comprehensive as the British Standards listed in table 2.1.2 for the nearest equivalent material. For ferritic steels, the phosphorus and sulphur content shall not exceed 0.05 % (m/m) each in the ladle analysis.

NOTE For ferritic steels intended for welding, the upper limit of the carbon range (in the ladle analysis) shall not exceed 0.25 % (m/m). Steels with a higher carbon content that are intended for welding may be used subject to appropriate welding procedures and heat treatment.

2.1.2.2.2 The design stresses shall be determined in accordance with the principles described in appendix A.

2.1.2.2.3 The deoxidation practice shall be appropriate to the type of steel ordered. Semi-killed steel shall be used

only for plates, and seamless and welded tubes in carbon and carbon manganese steels with an upper limit of the specified tensile strength range of 640 N/mm² and with a thickness not exceeding 100 mm. Rimming steel shall be used only for welded tubes in carbon and carbon manganese steel with an upper limit of the specified tensile strength range of 490 N/mm² and under service temperature conditions of 400 °C or less.

2.1.2.2.4 Mechanical properties at room temperature shall be determined by means of acceptance tests covering tensile strength, yield stress and elongation.

The specified minimum percentage elongation at fracture referred to a gauge length of $5.65\sqrt{s_0}$ * shall be appropriate to the type of steel, with a lower limit of 16 % for plates, 15 % for castings and 14 % for tubes and forgings.

The rate of testing and methods of acceptance testing shall be generally in alignment with the appropriate British Standards for similar product forms.

2.1.2.2.5 For all pressure parts, elevated temperature yield point or proof stress properties related to tests in accordance with BS EN 10002-5 shall be specified unless otherwise agreed between the manufacturer and Inspecting Authority (see 1.5.2.3(a)).

Where no elevated temperature yield point or proof stress property values exist or where the material cannot be related to another material for which values exist, property values shall be verified using the procedure described in BS 3920 or shall be established by the recognized standards of other countries.

2.1.2.2.6 Stress rupture properties shall be specified for materials which will be used in the creep range.

The manufacturer of the boiler shall be assured by the material supplier that the product supplied is capable of complying with the specified properties by a statement that the manufacturing processes have remained equivalent to those for the steel for which the test results were obtained.

2.1.2.2.7 Materials shall be supplied in a heat treated condition appropriate to the nearest equivalent British Standard material unless otherwise agreed between the interested parties (see 1.5.2.3(b)).

NOTE Plates for hot forming may be supplied in any suitable condition, e.g. hot finished, normalized, normalized and tempered.

Carbon and carbon manganese steel plates for cold forming shall be supplied in the normalized condition.

Low alloy steel plates for cold forming shall be supplied in the normalized and tempered condition except that, where metallurgically suitable and where post-weld heat treatment will suffice as the tempering treatment, plates supplied in the normalized condition shall be permitted.

Electric resistance welded or induction welded tubes shall be used in the as welded condition only where the specified upper limit of tensile strength does not exceed 540 N/mm².

* s_0 is the original cross-sectional area of the gauge length of the tensile test specimen (see BS EN 10 002-1).



2.1.2.2.8 In the case of withdrawn British Standard materials listed in this and previous issues of this standard, by agreement between the manufacturer and Inspecting Authority (see 1.5.2.3(a)), compliance with the requirements of 2.1.2.2.1 and 2.1.2.2.3 to 2.1.2.2.7 may be waived. The requirements of 2.1.2.2.2 for the determination of design stress shall however continue to apply.

NOTE. This waiver may be applied for a period of up to 3 years from the date of withdrawal of the material from listing in this standard.

2.1.3 Materials for non-pressure parts

Materials for supporting lugs, baffles and similar non-pressure parts welded to boilers shall be of established identity and shall be compatible with the material to which they are attached.

2.2 Design stresses

2.2.1 General

2.2.1.1 For materials covered by table 2.1.2, the design stress (f) shall be either:

- (a) not more than the appropriate nominal design stress value given in table 2.1.2 for the material of construction at the design temperature; or
- (b) where the materials used have properties proved by a test to be higher than those given in the relevant material specification, the use of those higher properties to determine the design stress value (f) at the design temperature by reference to appendix A shall be permitted subject to agreement between the manufacturer and the Inspecting Authority (see 1.5.2.3(c)).

NOTE The design stresses provided by table 2.1.2 in accordance with (a), which have been derived on the basis of accepted principles and established by practice, are intended for general application. However, it is recognized that, during fabrication, unexpected situations may arise where use may be made of the design stresses derived from the mechanical properties of the actual materials being used; the provisions of (b) are intended to be used in such special circumstances rather than as a general rule.

2.2.1.2 For materials not covered by table 2.1.2, and for materials conforming to BS EN 10028 : Parts 1, 2 and 3, the design stresses shall be determined in accordance with the principles described in appendix A.

2.2.1.3 In determining the design stress, the following points shall be taken into account:

- (a) *Carbon and carbon manganese steels.* The following points shall be taken into account:

- (1) The nominal design stresses given in table 2.1.2 are intended for general use with the steels listed and acceptance tests on material heat treated with a complete component are not required, any reduction in properties of such steels due to post-weld heat treatment being consistent with the overall benefit obtained by stress relief of the structure. A purchaser requiring such tests, or tests on samples subject to non-standard heat treatments, shall specify them in the supplementary specification together with appropriate acceptance criteria (see 1.5.1(c)).
- (2) In designs where slight deformation is important, or where post-weld heat treatment conditions other

than those specified in table 4.5.4 are agreed (see 4.5.4.1.2(a)(2)), materials that will comply with the properties in the material specification in the normalized plus simulated post-weld heat treated condition shall be specified.

- (b) *Alloy steels.* The following points shall be taken into account:

- (1) The nominal time-independent design stresses given in table 2.1.2 shall be used provided that the proposed post-weld heat treatment conditions are in accordance with 4.5.4 and table 4.5.4.
- (2) Where post-weld heat treatment conditions other than those specified in table 4.5.4 are agreed (see 4.5.4.1.2(a)(2)), the effect of any proposed heating or reheating during fabrication shall be determined in liaison with the material supplier before selecting the appropriate time-independent design stress. The time-independent properties in the material specification, or such properties determined from the selected nominal design stress, shall be satisfied by the testing of material in the simulated heat treated condition.
- (3) Acceptance tests on materials heat treated with the completed component are not required. A purchaser requiring such tests or tests on samples subject to non-standard heat treatments shall specify them together with the appropriate acceptance criteria (see 1.5.1(c)).

2.2.2 Cast steels

The allowable design stress for castings tested in accordance with BS 1504 test category I shall be not greater than 90 % of the values given in table 2.1.2, and for those tested in accordance with BS 1504 test category II shall not be greater than 80 % of the said value. The acceptance level for both test categories shall be accordance with 5.7.5.

2.2.3 Design temperature

2.2.3.1 General. The design temperature shall not be less than the highest of:

- (a) the maximum mean wall temperature of the pressure part, calculated by the manufacturer. In the case of pressure parts carrying superheated steam the factors specified in 2.2.3.8 shall be taken into account;
- (b) the design temperatures specified in 2.2.3.2 to 2.2.3.7.

2.2.3.2 Drums and headers. Where drums and headers are not heated by hot gases or are adequately protected by insulation from hot gases, the design temperature shall be equal to the maximum temperature of the internal fluid.

NOTE. A covering of refractory or insulating material that may be liable to become dislodged is not considered to be adequate protection.

Where drums and headers are heated by hot gases, the design temperature shall be taken as not less than 25 °C in excess of the maximum temperature of the internal fluid

2.2.3.3 Boiler tubes. The design temperature shall be taken as not less than:

- (a) 50 °C for tubes subject to radiant heat from the combustion chamber;
- (b) 25 °C for other tubes;

in excess of the saturated steam temperature at the calculation pressure

2.2.3.4 Superheater and reheater tubes. The design temperature shall be taken as not less than:

- (a) 50 °C for tubes subject to radiant heat from the combustion chamber;
- (b) 35 °C for other tubes;

in excess of the steam temperature expected in the part being considered.

2.2.3.5 Economizer tubes. The design temperature shall be taken as not less than 25 °C in excess of the maximum temperature of the internal fluid.

2.2.3.6 Integral pipes and those parts of tubes not heated by gases. The design temperature shall be taken as the maximum temperature of the fluid inside the pipe or tube.

2.2.3.7 Parts beyond the final superheater header(s). Where, because of design arrangements, factors such as inequalities in gas temperature and flow occurring in any cross section of the gas path cannot have any sustained effect on the steam temperature, the design temperature shall be the rated steam temperature at the superheater outlet, provided that in service:

- (a) the average temperature during any one year of operation does not exceed the design temperature; and
- (b) for systems having a rated temperature of 380 °C and below, fluctuations in temperature do not exceed the design temperature by more than 10 %; or
- (c) for systems having a rated temperature above 380 °C:
 - (1) normal fluctuations in temperature do not exceed the rated temperature by more than 8 °C; and
 - (2) abnormal fluctuations in temperature do not exceed the rated temperature by more than 20 °C for a maximum of 400 h in any one year or 30 °C for a maximum of 100 h in any one year or 40 °C for a maximum of 60 h in any one year.

Where the maximum temperature will exceed these limits, the design temperature shall be increased by the amount of the excess.

NOTE. The limits in (a), (b) and (c) represent realistic figures for modern control systems and boilers meeting normal load demands. It is the responsibility of the purchaser to advise the manufacturer, before design of the plant is commenced, of any circumstances that could prevent these limits being complied with (see 1.5.1(a)); it is the responsibility of the purchaser also to ensure that the boiler is operated within these or any other agreed limits.

2.2.3.8 Additional factors

2.2.3.8.1 In determining the maximum temperature of superheated steam and the related pressure part mean wall temperature, the following factors shall be taken into account:

- (a) variation in the steam flow, from the mean value, in individual tubes of a tube bank, produced by entry and exit conditions and by manufacturing tolerances on thickness and diameter;
- (b) variation in the heat input to the tube bank under consideration, resulting from deviation in the performance of preceding heating surfaces and deviation from ideal combustion conditions;
- (c) variation in steam inlet temperature resulting from deviation in gas temperature and flow occurring in any cross section of the gas path.

2.2.3.8.2 For drums, headers and parts beyond the superheater header(s), where the expected steam temperature is not in excess of 425 °C in the part under consideration, an addition of 15 °C shall be deemed to cover the factors listed in 2.2.3.8.1.

2.2.3.8.3 For superheater and reheater tubes where, in the part under consideration:

- (a) the tube is not subjected to direct radiant heat from the combustion chamber;
- (b) the expected steam temperature is not in excess of 425 °C;

the factors listed in 2.2.3.8.1 shall be deemed to be included in the requirements of 2.2.3.4.

2.2.4 Design lifetime

A design lifetime related to the creep rupture properties of the material shall be agreed between the manufacturer and the purchaser for each component whose design temperature is such that the nominal design stress given in table 2.1.2 is time-dependent (see 1.5.2.2(c)).

NOTE 1. It is not necessarily intended that one lifetime be used to cover all components; therefore replaceable items may be designed for lifetimes shorter than the general life expectancy of the boiler.

NOTE 2. The basis of the design in this standard is that no component remains in service after its operational hours have exceeded the design lifetime. However, experience has demonstrated that components designed to these rules can be expected to exceed their design life and reference may be made to PD 6510 for procedures for assessing whether the life could be extended.

Components of certain alloy materials designed on the basis of increased design stress value (see note 3) shall be identified on the drawings and listed by the manufacturer. Continued service reviews shall be instituted at not later than two-thirds of the design lifetime.

NOTE 3. The design stress values of certain alloy materials may be increased by agreement between the manufacturer and purchaser; see note 6 to table 2.1.2.

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Table 2.1.2 Design stress values (N/mm ²)																		
Plates																		
Type—grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Thickness mm	Values of f for design temperature (° C) not exceeding													Design lifetime h	Notes
				250	300	350	390	400	410	420	430	440	450	460	470	480		
BS 1501 : Part 1 — Carbon steel (semi- or fully-killed) 151—, 161—360 (A and B)	360	205 195 185 175 170	3 to 16 40 63 100 150	100	86	81	78	77	76	69	60	52	44	36	100 000 150 000 200 000 250 000	7, 16		
				96					74	65	56	48	40	32				
				95					71	62	53	45	37	28				
				91					68	59	51	42	35	26				
				88														
151—, 161—400 (A and B)	400	225 215 205 200 195	3 to 16 40 63 100 150	117	97	92	89	88	87	79	69	60	52	44	36	100 000 150 000 200 000 250 000	16	
				110				88	83	74	65	56	48	40	32			
				108				88	80	71	62	53	45	37	28			
				105				87	78	68	59	51	42	35	26			
				102														
151—, 161—430 (A and B)	430	250 240 230 220 210	3 to 16 40 63 100 150	128	107	102	100	99	98	88	79	69	60	52	44	36	100 000 150 000 200 000 250 000	16
				121				99	93	83	74	65	56	48	40	32		
				119				99	90	80	71	62	53	45	37	28		
				115				97	87	78	68	59	51	42	35	26		
				110														

Table 2.1.2 Design stress values (N/mm ²) (continued)																																												
Plates																																												
Type—grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Thickness mm	Values of f for design temperature (° C) not exceeding										Design lifetime h	Notes																													
				250	300	350	390	400	410	420	430	440	450			460	470	480																										
BS 1501 : Part 1 — Carbon steel (fully-killed aluminium treated)																																												
164—360A	360	255	3 to 16	97	86	79	73	73	72	71	69	60	52	44	36	100 000	7, 13																											
		235	40															71	65	56	48	40	32	150 000																				
		220	63																						71	62	53	45	37	28	200 000													
		202	100																													68	59	51	42	35	26	250 000						
		180	150																																									
164—360B	360	255	3 to 16	107	95	87	83	82	81	79	69	60	52	44	36	100 000	13																											
		235	40															81	74	65	56	48	40	32	150 000																			
		220	63																							80	71	62	53	45	37	28	200 000											
		202	100																															78	68	59	51	42	35	26	250 000			
		180	150																																									
164—400A	400	275	3 to 16	111	98	91	86	85	84	79	69	60	52	44	36	100 000	7, 13																											
		265	40															83	74	65	56	48	40	32	150 000																			
		245	63																							80	71	62	53	45	37	28	200 000											
		225	100																															78	68	59	51	42	35	26	250 000			
		201	150																																									
164—400B	400	275	3 to 16	121	108	101	95	94	88	79	69	60	52	44	36	100 000	13																											
		265	40															93	83	74	65	56	48	40	32	150 000																		
		245	63																								90	80	71	62	53	45	37	28	200 000									
		225	100																																	87	78	68	59	51	42	35	26	250 000
		201	150																																									



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Table 2.1.2 Design stress values (N/mm²) (continued)

Table 2.1.2 Design stress values (N/mm ²) (continued)																					
Plates																					
Type—grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Thickness mm	Values of f for design temperature (°C) not exceeding																Design lifetime h	Notes
				250	300	350	390	400	410	420	430	440	450	460	470	480					
BS 1501 : Part 1 — Carbon manganese steel (fully-killed niobium treated)																					
223—460A	460	340	3 to 16	1143	130	124	117	115	114	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	7, 13			
		330	40																		
		320	63																		
		294	100																		
		262	150																		
223—460B	460	340	3 to 16	1158	139	131	125	124	121	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	7, 13			
		330	40																		
		320	63																		
		294	100																		
		262	150																		
223—490A	490	355	3 to 16	1158	139	131	125	124	121	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	7, 13			
		345	40																		
		340	63																		
		313	100																		
		279	150																		
223—490B	490	355	3 to 16	1168	147	137	133	132	121	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	7, 13			
		345	40																		
		340	63																		
		313	100																		
		279	150																		

Table 2.1.2 Design stress values (N/mm²) (continued)

Plates

Type — grade and method of manufacture	R_m N/mm ²	R_e N/mm ²	Thickness mm	Values of f for design temperature ($^{\circ}$ C) not exceeding															Design lifetime h	Notes																									
				250	300	350	390	400	410	420	430	440	450	460	470	480																													
BS 1501 : Part 1 — Carbon manganese steel (fully-killed aluminium treated)																																													
224 — 400A	400	275	3 to 16	1111	98	91	86	85	84	83	77	65	56	48	42	100 000	7, 13																												
		265	40															84	81	68	58	50	43	38																					
		245	63																																										
		225	100																						84	75	63	54	46	40	34														
		201	150																																										
224 — 400B	400	275	3 to 16	1121	108	101	95	94	93	90	77	65	56	48	42	100 000	13																												
		265	40															93	81	68	58	50	43	38																					
		245	63																						88	75	63	54	46	40	34														
		225	100																													83	70	59	51	43	37	32							
		201	150																																										
224 — 430A	430	305	3 to 16	1121	108	101	95	94	93	90	77	65	56	48	42	100 000	7, 13																												
		285	40															93	81	68	58	50	43	38																					
		275	63																						88	75	63	54	46	40	34														
		253	100																													83	70	59	51	43	37	32							
		225	150																																										
224 — 430B	430	305	3 to 16	1132	117	111	105	104	103	90	77	65	56	48	42	100 000	13																												
		285	40															104	95	81	68	58	50	43	38																				
		275	63																							104	88	75	63	54	46	40	34												
		253	100																															98	83	70	59	51	43	37	32				
		225	150																																										
224 — 460A	460	325	3 to 16	1132	117	111	105	104	103	90	77	65	56	48	42	100 000	7, 13																												
		315	40															104	95	81	68	58	50	43	38																				
		305	63																							104	88	75	63	54	46	40	34												
		281	100																															98	83	70	59	51	43	37	32				
		250	150																																										
224 — 460B	460	325	3 to 16	1142	128	121	116	115	114	105	90	77	65	56	48	42	100 000	13																											
		315	40																115	111	95	81	68	58	50	43	38																		
		305	63																									115	104	88	75	63	54	46	40	34									
		281	100																																		115	98	83	70	59	51	43	37	32
		250	150																																										
224 — 490 (A and B)	490	325	3 to 16	1142	128	121	116	115	114	105	90	77	65	56	48	42	100 000	13																											
		315	40																115	111	95	81	68	58	50	43	38																		
		305	63																									115	104	88	75	63	54	46	40	34									
		281	100																																		115	98	83	70	59	51	43	37	32
		250	150																																										

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Table 2.1.2 Design stress values (N/mm²) (continued)

Plates

Plates				Values of f for design temperature ($^{\circ}$ C) not exceeding														Design lifetime h	Notes
Type—grade and method of manufacture	R_m N/mm ²	R_e N/mm ²	Thickness mm	250	300	350	390	400	410	420	430	440	450	460	470	480			
BS 1501 : Part 1 — Carbon manganese steel (fully-killed niobium and aluminium treated)																			
225—490A	490	355 345 340 313 279	3 to 16	158	139	131	125	124	121	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	7, 13	
			40				124	111	95	81	68	58	50	43	38				
			63				127	104	88	75	63	54	46	40	34				
			100				115	98	83	70	59	51	43	37	32				
			150																
225—490B	490	355 345 340 313 279	3 to 16	168	147	137	133	132	121	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	7, 13	
			40				128	111	95	81	68	58	50	43	38				
			63				121	104	88	75	63	54	46	40	34				
			100				115	98	83	70	59	51	43	37	32				
			150																

Table 2.1.2 Design stress values (N/mm²) (continued)

Table 2.1.2 Design stress values (N/mm ²) (continued)																											
Plates				Thickness mm	Values of <i>f</i> for design temperature (°C) not exceeding																	Design lifetime h	Notes				
Type-grade and method of manufacture	<i>R_m</i> N/mm ²	<i>R_e</i> N/mm ²	Up to 25		250	300	350	400	410	420	430	440	450	460	470	480	490	500	510	520	530			540	550		
271 MnCrMoV	640	500	Up to 25	237	237	237	234					231	209	181	155	129	107	87	69	54	41	30	16				
281 NiCrMoV	610	460	75	226	226	226	221					219	209	181	155	129	107	87	69	54	41	30	16				
281 NiCrMoV	590	430	150	219	207	201	195					193	190	181	155	129	107	87	69	54	41	30	16				
281 NiCrMoV	640	500	Up to 25	237	237	237	234	233	233	226	209	188	168	145	124	103	85	69	55	44	33	24	16				
281 NiCrMoV	610	460	75	226	226	226	221					220	209	188	168	145	124	103	85	69	55	44	33	24	16		
281 NiCrMoV	590	430	150	219	207	201	195					193	188	168	145	124	103	85	69	55	44	33	24	16			

Table 2.1.2 Design stress values (N/mm²) (continued)

Plates		Type-grade and method of manufacture	R_m N/mm ²	R_e N/mm ²	Thickness mm	Values of r for design temperature (°C) not exceeding																	Design lifetime h	Notes
						250	300	350	400	450	460	470	480	490	500	510	520	530	540	550	560	570		
BS 1501 : Part 2 — Low alloy steel																								
620 A 1Cr½Mo	480	340	Up to 75	154	143	134	132	129	127	106	92													13
	450	280	100	136	121	113	110	108																
	430	255	150	125	108	99	96	94																
620 B 1Cr½Mo	480	340	Up to 75	165	152	143	141	137	136	135	134	112	93	76	62	52	42	33	27					13
	450	280	100	145	129	121	117	115	113	112	111	93	76	62	52	42	33	27						13
621 A 1¼Cr½Mo	430	255	150	133	115	105	103	100	98	97	93	76	62	52	42	33	27							13
621 B 1¼Cr½Mo	515	340	Up to 75	175	166	159	157	153	152															16
	500	320	100	166	156	149	146	143	141															
	490	310	150	160	149	142	139	136	134															
	515	340	Up to 75	187	177	170	167	163	162	161	160	136	112	93	76	62	52	42	33	27				16
	500	320	100	177	167	159	156	152	150	149	136	112	93	76	62	52	42	33	27					16
	490	310	150	171	159	151	148	145	142	142	136	112	93	76	62	52	42	33	27					16

Table 2.1.2 Design stress values (N/mm²) (continued)

Table 2.1.2 Design stress values (N/mm ²) (continued)																																
Plates																																
Type-grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Thickness mm	Values of f for design temperature (° C) not exceeding																								Design lifetime h	Notes			
				250	300	350	360	370	380	390	400	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580						
Low alloy steel to BS 1501 : Part 2																																
622-515 A 2 1/4Cr1Mo	515	310	Up to 100 150	166	163	158																							13			
	500	285		155	151	147	153	146	143	134																						
622-515 B 2 1/4Cr1Mo	515	310	Up to 100	177	173	168																							2, 6, 13			
					163	156	154	152	143	131	118	105	94	82	72	61	53	45	39	34	154	148	135	122	108	97	85	73	63	56	48	42
																															200 000	
																															200 000	
																															250 000	
	500	285	Up to 150	165	161	157																									13	
					143	141	139	131	118	105	94	82	72	61	53	45	39	34	141	135	122	108	97	85	73	63	56	48	42	36	31	
																															150 000	
																															200 000	
																															250 000	
622-690 A 2 1/4Cr1Mo	690	555	Up to 50	256	256	256	256																								13	
622-690 B 2 1/4Cr1Mo	690	555	Up to 50	256	256	256	256																								2, 6, 13	
																															100 000	
																															150 000	
																															200 000	
																															250 000	

Plates

BS 1501: Part 3 – Austenitic stainless steel

Table 2.1.2 Design stress values (N/mm²) (continued)

Table 2.1.2 Design stress values (N/mm ²) (continued)					
Plates		Notes	Yield strength R_e N/mm ²	Tensile strength R_m N/mm ²	Steel grade
Name	Material no.				
Plates to BS EN 10028 : Part 2					
P235GH	1.0345	14, 15	185 to 235	350 to 480	
P265GH	1.0425	14, 15	200 to 265	400 to 530	
P295GH	1.0481	14, 15	235 to 295	440 to 580	
P335GH	1.0473	14, 15	295 to 355	480 to 650	
16 Mo 3	1.5415	14, 15	220 to 275	420 to 590	
13 CrMo 4-5	1.7335	14, 15	255 to 300	430 to 600	
10 CrMo 9-10	1.7380	14, 15	250 to 310	460 to 630	
11 CrMo 9-10	1.7383	14, 15	310	520 to 670	
Plates to BS EN 10028 : Part 3					
P275N	1.0486	14, 15	275	350 to 510	
P275NH	1.0487				
P275NL1	1.0488				
P275NL2	1.1104				
P335N	1.0562	14, 15	355	450 to 630	
P335NH	1.0565				
P335NL1	1.0566				
P335NL2	1.1106				
P460N	1.8905	14, 15	460	520 to 720	
P460NH	1.8935				
P460NL1	1.8915				
P460NL2	1.8918				

Table 2.1.2 Design stress values (N/mm^2) (continued)

Sections and bars		Type — grade	R_m N/mm ²	R_s N/mm ²	Nominal diameter/thickness (values in parenthesis apply to sections and flat bars)		Values of f for design temperature (° C) not exceeding													Design lifetime t_h	Notes
Over mm	Up to and including mm				250	300	350	400	410	420	430	440	450	460	470	480	490	500			
BS 1502 — Carbon steel (semi- or fully-killed)																					
151, 161	430	250	—	25 (16) 63 (40) 100 (63) 160 (100)	128 121 119 115	107	102	99	98	88	79	69	60	52	44	36	28		100 000		
		240	25 (16)					99	93	83	74	65	56	48	40	32	22		150 000		
		230	63 (40)					99	90	80	71	62	53	45	37	28	18		200 000		
		220	100 (63)					97	87	78	68	59	51	42	35	26			250 000		
BS 1502 — Carbon manganese steel (semi- or fully-killed)																					
211, 221	430	250	—	25 (16) 63 (40) 100 (63) 160 (100)	128 121 119 115	107	102	99	98	97	90	77	65	56	48	42	36	32	100 000		
		240	25 (16)						95	81	68	58	50	43	38	32	26		150 000		
		230	63 (40)						88	75	63	54	46	40	34	28			200 000		
		220	100 (63)						83	70	59	51	43	37	32	25			250 000		
BS 1502 — Carbon manganese steel (fully-killed aluminium treated)																					
224—430	430	275 265 245 240	— 25 (16) 63 (40) 100 (63)	25 (16) 63 (40) 100 (63) 160 (100)	121 121 119 115	108	101	95	94	93	90	77	65	56	48	42	36	32	100 000		
			25 (16)							93	81	68	58	50	43	38	32	26	150 000		
			63 (40)							88	75	63	54	46	40	34	28		200 000		
			100 (63)							83	70	59	51	43	37	32	25		250 000		
224—490	490	325 315 305 300	— 25 (16) 63 (40) 100 (63)	25 (16) 63 (40) 100 (63) 160 (100)	142 128 121 115	128	121	115	114	105	90	77	65	56	48	42	36	32	100 000		
			25 (16)						111	95	81	68	58	50	43	38	32	26	150 000		
			63 (40)						104	88	75	63	54	46	40	34	28		200 000		
			100 (63)						98	83	70	59	51	43	37	32	25		250 000		

Table 2.1.2 Design stress values (N/mm²) (continued)

Table 2.1.2 Design stress values (N/mm ²) (continued)																														
Sections and bars					Values of f for design temperature (° C) not exceeding																								Design lifetime h	Notes
Type- grade	R _m N/mm ²	R _e N/mm ²	Limiting ruling section mm		250	300	350	400	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600					
BS 1502 — Low alloy steel																														
271	560	370	160		208	204	199	192	188	186	181	155	129	107	87	69	54	41	30								10			
																											100 000			
																											150 000			
																											200 000			
																									250 000					
620—440	440	265	160		139	123	113	109	107																	10				
																											100 000			
																											150 000			
																											200 000			
																								250 000						
620—470	470	300	160		159	144	136	133	130																	10				
																											100 000			
																											150 000			
																											200 000			
																								250 000						
620—540	540	375	160		200	196	189	186	182	181	180	162	136	112	93	76	62	52	42	33	27				10					
																											100 000			
																											150 000			
																											200 000			
																								250 000						
622	490	275	160		157	153	149	145	137	135	132	131	118	105	94	82	72	61	53	45	39	34	29	26	2, 6, 10					
																											100 000			
																											150 000			
																											200 000			
																								250 000						
629—590	590	400	160		219	217	215	211	208	207	195	176	159	144	129	115	103	91	80	68	58	48	38	31	26	100 000				
																											150 000			
																											150 000			
																											200 000			
																								250 000						

Sections and bars

Type— grade	R_m N/mm ²	R_e N/mm ²	Limiting rolling section mm	Values of f for design temperature (°C) not exceeding																			Design lifetime h	Notes	
				250	300	350	400	450	500	540	550	560	570	580	590	600	620	640	650	660	680	700			720
BS 1502 — Austenitic stainless steel																									
304S51	490	230	160	103	98	93	89	87	85	83	82	81	76	65	55	50	45	38	33	28				100 000 150 000 200 000 250 000	
											82	82	81	76	65	55	50	45	38	33	28				
											82	82	78	72	61	51	46	42	36	31					
											81	75	69	58	48	44	40	34	30						
											78	72	66	55	46	42	38	33	29						
316S51	510	240	160	111	106	101	99	96	93	90	89	88	88	74	58	53	46	35	28	23	19	18		100 000 150 000 200 000 250 000	6
												88	85	66	52	46	41	32	25	19	16				
											88	79	62	48	43	38	29	22	18	15					
											85	75	58	45	40	35	27	22	18	15					
321S51—490	490	190	160	93	87	84	81	79	78	77		76	76	68	55	49	44	34	26					100 000 150 000 200 000 250 000	
													76	62	50	44	38	29							
														72	58	46	41	35	27						
													68	55	44	38	33	25							
321S51—510	510	235	160	121	117	113	110	107	104	103 102 102	95	86	78	71	57	42	36	31	24	18				100 000 150 000 200 000 250 000	
										103 101 93	86	78	72	64	49	36	32	27							
										103 97 89	82	74	66	58	45	33	28	25							
										100 93	85	78	71	62	55	42	31	26	22						
347S51	510	240	160	127	123	120	118	116	115	114 113 113	109	99	91	82	66	53	47	41	31	23	17			100 000 150 000 200 000 250 000	
										113 112 102	93	84	75	61	48	42	37	28	22						
										113 106	98	88	79	72	58	45	39	34	25	19					
										112 102	94	85	76	68	55	42	37	32	24	19					

Table 2.1.2 Design stress values (N/mm²) (continued)
Forgings

Type – grade and method of manufacture	R_m N/mm ²	R_e N/mm ²	Ruling section (see note (d)) mm	Values of f for design temperature (°C) not exceeding																Design lifetime h	Notes
				250	300	350	390	400	410	420	430	440	450	460	470	480					
BS 1503 – Carbon manganese steel (fully-killed)																					
164	490	305 280	≤ 100 > 100 ≤ 150	142 137	128	121	116	115	114	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10			
										111	95	81	68	58	50	43			38		
										104	88	75	63	54	46	40			34		
										98	83	70	59	51	43	37			32		
221 – 410	410	215 205	≤ 100 > 100	112 108	100	95	92	92	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10					
									92	81	68	58	50	43			38				
									88	75	63	54	46	40			34				
									83	70	59	51	43	37			32				
221 – 430	430	225 215	≤ 100 > 100	119 115	107	102	99	99	98	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10				
									99	95	81	68	58	50	43			38			
									99	88	75	63	54	46	40			34			
									98	83	70	59	51	43	37			32			
221 – 460	460	245 235	≤ 100 > 100	129 125	117	112	108	108	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10				
									108	95	81	68	58	50	43			38			
									104	88	75	63	54	46	40			34			
									98	83	70	59	51	43	37			32			
221 – 490	490	265 255	≤ 100 > 100	140 135	128	122	119	118	118	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10			
									118	111	95	81	68	58	50	43			38		
									118	104	88	75	63	54	46	40			34		
									115	98	83	70	59	51	43	37			32		
221 – 510	510	285	≤ 100	147	135	129	125	124	121	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10			
									124	111	95	81	68	58	50	43			38		
									121	104	88	75	63	54	46	40			34		
									115	98	83	70	59	51	43	37			32		

Table 2.1.2 Design stress values (N/mm²) (continued)

Table 2.1.2 Design stress values (N/mm ²) (continued)																				
Forgings																				
Type – grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Ruling section (see note (d)) mm	Values of f for design temperature (° C) not exceeding															Design lifetime h	Notes
				250	300	350	390	400	410	420	430	440	450	460	470	480				
BS 1503 – Carbon manganese steel (fully-killed)																				
223 – 410	410	245 230	≤ 100 > 100	120 115	106	99	92	91	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10				
223 – 430	430	260 245	≤ 100 > 100	128 123	114	107	100	98	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10				
223 – 460	460	290 270	≤ 100 > 100	140 135	127	119	111	110	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10			
223 – 490	490	320 295	≤ 100 > 100	152 146	139	131	125	123	121	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10		
223 – 510	510	340	≤ 100	159	147	138	132	131	121	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10		
224 – 410	410	235 220	≤ 100 > 100	114 109	101	94	89	88	88	88	88	77	65	56	48	42	100 000 150 000 200 000 250 000	1(a), 10		



Table 2.1.2 Design stress values (N/mm²) (continued)

Table 2.1.2 Design stress values (N/mm ²) (continued)																		
Forgings																		
Type-grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Ruling section (see note (d)) mm	Values of f for design temperature (° C) not exceeding													Design lifetime h	Notes
				250	300	350	390	400	410	420	430	440	450	460	470	480		
BS 1503 — Carbon manganese steel (fully-killed)																		
224-430	430	250	≤ 100	121 117	108	101	96	95	95	90	77	65	56	48	42	1(a), 10		
		235	> 100															
224-460	460	275	≤ 100	132 127	118	111	105	105	104	90	77	65	56	48	42			
		255	> 100															
224-490	490	305	≤ 100	142 137	128	121	116	115	115	105	90	77	65	56	48	1(a), 10		
		280	> 100															
224-510	510	315	≤ 100	149	135	128	124	122	121	105	90	77	65	56	48		1(a), 10	
225-490	490	340	≤ 100	160 154	147 145	137	131	130	121	105	90	77	65	56	48	1(a), 10		
		300	> 100															

Table 2.1.2 Design stress values (N/mm²) (continued)

Forgings

Type-grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Ruling section (see note (d)) mm	Values of f for design temperature (° C) not exceeding																										Design lifetime h	Notes
				250	300	350	400	410	420	430	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600	610	620		
BS 1503 — Ferritic alloy steel																															
620-440 1Cr½Mo	440	275		131	123	113	108		105			101	101	93	76	62	52	42	33	27		100 000	1(a), 10								
												101	83	67	55	44	35	29	24		150 000										
												94	76	61	49	40	32	26	22		200 000										
												88	70	57	45	37	30	25	20		250 000										
620-540 1Cr½Mo	540	375	≤200	200	196	189	186		182	181	180	162	136	112	93	76	62	52	42	33	27	100 000	1(a), 10								
												181	174	149	124	102	83	67	55	44	35	29		24		150 000					
												181	162	138	114	94	76	61	49	40	32	26		22		200 000					
												179	155	131	107	88	70	57	45	37	30	25		20		250 000					
621-460 1½Cr½Mo	460	275		145	137	127	122		117			115	114	112	93	76	62	52	42	33	27	100 000	1(a), 10								
												114	102	83	67	55	44	35	29	24		150 000									
												114	94	76	61	49	40	32	26	22		200 000									
												107	88	70	57	45	37	30	25	20		250 000									
660-460 CrMoV	460	300		161	150	144	139		135			134	133	131	115	100	87	76	66	56	100 000	1(a), 10									
												133	122	106	92	80	69	59	47		150 000										
												132	115	100	87	75	65	55			200 000										
												128	111	96	83	72	62	50			250 000										
271-560 MnCrMoV	560	370		208	204	199	192		188	186	181	155	129	107	87	69	54	41	30		100 000	1(a), 10									
												173	145	118	95	76	60	44	32	23			150 000								
												160	132	108	87	68	51	38	26	18			200 000								
												157	129	105	83	65	48	35	23	14			250 000								
622-490 2½Cr1Mo	490	275		157	153	149	145		137	135	132	131	118	105	94	82	72	61	53	45	39	100 000	1(a), 6, 10								
												132	122	108	97	85	73	63	56	48	42	36		31		150 000					
												130	117	104	92	79	68	59	52	45	38	33		28		200 000					
												126	113	100	87	75	65	57	49	42	36	32		27		250 000					
622-560 2½Cr1Mo	560	370		207	207	201	197	196	195	194	183	170	157	143	131	118	105	94	82	72	61	53	45	39	34					100 000	1(a), 6, 10
												195	186	173	161	148	135	122	108	97	85	73	63	56	48	42	36	31		150 000	
												195	182	169	156	143	130	117	104	92	79	68	59	52	45	38	33	28		200 000	
												190	178	165	152	139	126	113	100	87	75	65	57	49	42	36	32	27		250 000	
622-690 3Cr1Mo0.3Va	690	490	≤ 250	240	233	227	219		206			190	187	173	155	138	122	107	93	80	68	58	48	40	33					100 000	1(a), 10
												184	168	152	135	115	98	85	72	62	52	44	37	30					150 000		
												180	164	146	128	110	94	80	68	58	40	41	34	28					200 000		
												176	160	142	124	106	90	77	65	55	46	38	32	25					250 000		

Table 2.1.2 Design stress values (N/mm²) (continued)

Table 2.1.2 Design stress values (N/mm ²) (continued)																							
Forgings																							
Type-grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Ruling section (see note (d)) mm	Values of f for design temperature (°C) not exceeding																		Design lifetime h	Notes
				250	300	350	400	450	500	520	540	550	560	580	590	600	620	640	650	660	680		
BS 1503 — Austenitic stainless steel																							
304S51	490	230		103	98	93	89	87	85	83	82	82	81	76	65	55	50	45	38	33	28	100 000 150 000 200 000 250 000	1(a).
316S51	510	240		111	106	101	99	96	93	90	89	88	88	74	58	53	46	35	28	23	100 000 150 000 200 000 250 000	1(a), 6	
321S51-490	490	190		93	87	84	81	79	78	77	76	76	76	68	55	49	44	34	26	100 000 150 000 200 000 250 000	1(a)		
321S51-510	510	235		121	117	113	110	107	104	103	102	102	86	71	57	42	36	31	100 000 150 000 200 000 250 000	1(a)			
347S51	510	240		127	123	120	118	116	115	114	113	113	99	82	66	53	47	41	31	23	100 000 150 000 200 000 250 000	1(a)	

Table 2.1.2 Design stress values (N/mm ²) (continued)																	
Castings																	
Type—grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Thickness mm	Values of f for design temperature (° C) not exceeding												Design lifetime h	Notes
				250	300	350	390	400	410	420	430	440	450	460	470		
BS 1504 — Carbon steel 161 — 430A	430	230		115	104	95	87									1(b), 1(c)	
161—430E	430	230		115	104	95	93	93	92	84	71	60	51	44	37	1(b) 100 000 150 000 200 000 250 000	
161—480A	480	245		128	115	105	101									1(b), 1(c)	
161—480E	480	245		128	115	109	107	107	106	99	84	71	60	51	44	1(b) 100 000 150 000 200 000 250 000	
161—540A	540	280		144	130	119	109									1(b), 1(c)	

1(b), 1(c)

1(b)

1(b), 1(c)

1(b)

1(b), 1(c)

Castings

Type—grade and method of manufacture	R_m N/mm ²	R_e N/mm ²	Thickness mm	Values of / for design temperature (° C) not exceeding																	Design lifetime h	Notes		
				250	300	350	400	440	450	460	470	480	490	500	510	520	530	540	550	560			570	580
BS 1504 — Low alloy steel																								
245E ½Mo	460	260		140	121	116	113	110	109	108	95	78	62	51	41	32							1(b)	
																							100 000	
																								150 000
																								200 000
																								250 000
621A ¼CrMo	480	280		141	136	123	114	108														1(b), 1(c)		
660A CrMoV	510	295		145	137	128	118	112					106									1(b), 1(c)		
622E 2½CrMo	540	325		197	193	187	182	174	170	153	137	120	107	95	85	76	65	61	53	45	39	34	100 000	
								174	161	144	129	112	98	88	77	68	63	56	48	41	36	31	150 000	
								172	156	139	124	107	94	83	71	63	59	52	45	38	33	28	200 000	
								170	152	135	119	103	91	79	68	60	57	49	42	36	32	27	250 000	

Table 2.1.2 Design stress values (N/mm ²) (continued)																								
Castings																								
Type — grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Thickness mm	Values of f for design temperature (° C) not exceeding																	Design lifetime h	Notes		
				250	300	350	400	450	500	520	540	550	560	580	600	620	640	650	680	700			720	740
BS 1504 — High alloy steel																								
629A 9Cr1Mo	620	420		184	176	157	144	123	87		55	21												1(b)
BS 1504 — Austenitic stainless steel																								
304C15A	480	240		109	104	101	99	95	92	90	81	75	68	57	47	38	31	27	23	18	100 000 150 000 200 000 250 000	1(b), 11		
										90	76	68	62	52	42	33	26	23	20	15				
										85	72	65	58	48	38	31	24	21	18					
										82	68	61	56	45	36	28	22	19	17					
347C17A	480	240		132	128	126	122	119	116	114	113	109	99	82	66	53	41	35	31	22	100 000 150 000 200 000 250 000	1(b), 11		
										112	102	93	75	61	48	37	32	28	22					
										106	98	88	72	58	45	34	29	25	19					
										102	94	85	68	55	42	32	28	24	19					
316C71	510	260		122	116	110	106	102	96		93	92	91	74	58	46	41	35	28	23	100 000 150 000 200 000 250 000	1(b), 11		
													85	66	52	41	36	32	25	19				
													79	62	48	38	33	29	22	18				
													75	58	45	35	31	27	22	18				

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Table 2.1.2 Design stress values (N/mm^2) (continued)
Steel boiler and superheater tubes

Type — grade and method of manufacture	R_m N/mm ²	R_e N/mm ²	Thickness mm	Values of f for design temperature (°C) not exceeding													Design lifetime h	Notes
				250	300	350	390	400	410	420	430	440	450	460	470	480		
BS 3059 : Part 1 — Carbon steel																		
320 HFS, CFS, ERW and CEW	320	195		86	77	71	68											
BS 3059 : Part 2 — Carbon and carbon manganese steel																		
360 S1, S2, ERW and CEW	360	235		111	97	87	78	77	76	69	60	52	44	36			100 000 150 000 200 000 250 000	7
440 S1, S2, ERW and CEW	440	245		134	119	106	101	101	100	90	77	65	56	48	42		100 000 150 000 200 000 250 000	7

Table 2.1.2 Design stress values (N/mm ²) (continued)																											
Steel boiler and superheater tubes																											
Type—grade and method of manufacture	R _m N/mm ²	R _p N/mm ²	Thickness mm	Values of f for design temperature (* C) not exceeding																				Design lifetime h	Notes		
				250	300	350	400	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590			600	610
BS 3059 : Part 2 — Alloy steel																											
243 0.3 Mo S1, S2, ERW and CEW	480	275		149	128	120	117	115	113	112	95	78	62	51	41	32											
620 1Cr½Mo S1, S2, ERW and CEW	460	180		129	129	129	120	116	114	113	112	93	76	62	52	42	33	27									
622—490 2½Cr1Mo S1, S2,	490	275		157	153	149	145	137	135	133	131	118	105	94	82	72	61	53	45	39	34	29	26				
629—590 9Cr1Mo S1, S2,	590	400		219	217	215	211	208	207	195	176	159	144	129	115	103	91	80	68	58	48	38	31	26			
762 12CrMoV S1, S2,	720	470		241	234	230	225	215	205	201	191	173	155	138	122	107	93	80	68	58	48	40	33				

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Table 2.1.2 Design stress values (N/mm²) (continued)
Steel boiler and superheater tubes

Type – grade and method of manufacture	R _m N/mm ²	R _e N/mm ²	Thickness mm	Values of f for design temperature (°C) not exceeding																			Design lifetime h	Notes		
				250	300	350	400	450	500	540	550	560	570	580	590	600	610	620	630	640	650	660			680	700
BS 3059 : Part 2 – Austenitic stainless steel																										
304S51 CFS	490	230		101	97	94	91	88	86	83	82	82	81	76	71	65	60	55	50	45	38	33	100 000	7		
																									150 000	
																									200 000	
																									250 000	
316S51, S52 CFS	510	240		111	106	102	98	96	93	90	89	88	88	82	74	66	58	53	46	35	28	100 000	7 6			
																								150 000		
																								200 000		
																								250 000		
321S51 (1010) CFS	510	235		121	117	112	110	107	104	102	102	102	101	95	86	78	71	63	57	49	42	36	100 000			
																							150 000			
																							200 000			
																							250 000			
321S51 (1105) CFS	490	190		93	87	84	82	79	77	76	75	75	75	68	60	55	49	44	38	29		100 000	7			
																								150 000		
																								200 000		
																								250 000		
347S51 CFS	510	240		135	130	124	122	119	119	117	117	116	109	99	91	82	74	66	59	53	47	41	31	23	100 000	7
																								150 000		
																								200 000		
																								250 000		
215S15 CFS	540	270		141	139	136	135	133	132	130	126	125	124	123	107	87	71	52	40				100 000			
																							150 000			
																							200 000			
																							250 000			

Steel pipes and tubes for pressure purposes

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Table 2.1.2 Design stress values (N/mm^2) (continued)
Steel pipes and tubes for pressure purposes

Type — grade and method of manufacture	R _m N/mm ²	R _s N/mm ²	Thickness mm	Values of f for design temperature (°C) not exceeding																								Design lifetime h	Notes
				250	300	350	400	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600	610	620			
BS 3604 : Part 1 — Seamless and electric resistance welded alloy steel																													
591 1½ NiCuMoNb HFS, CFS	610	440		226 226 226 226																									12
620—440 1Cr½Mo HFS, CFS, ERW and CEW	440	290		157	128	121	116	112	112	111	111	93	76	62	52	42	33	27									100 000		
																											150 000		
																												200 000	
																												250 000	
621 1½Cr½Mo HFS, CFS, ERW and CEW	420	275		145	116	110	105	101	100	100	93	76	62	52	42	33	27									100 000			
																										150 000			
																											200 000		
																											250 000		
660 ½CrMoV HFS, CFS	460	300		161	150	144	139	135	134	133	131	115	100	87	76	66	56									100 000			
																										150 000			
																											200 000		
																											250 000		
622 2½Cr1Mo HFS, CFS	490	275		157	153	149	145	137	135	133	131	118	105	94	82	72	61	53	45	39	34	29	26			100 000			
																										150 000			
																											200 000		
																											250 000		
629—590 9Cr1Mo HFS, CFS	590	400		219	217	215	211	208	207	195	176	159	144	129	115	103	91	80	68	58	48	38	31	26		100 000			
																										150 000			
																											200 000		
																											250 000		
762 12CrMoV HFS, CFS	690	490		240	232	227	217	206	191	187	173	155	138	122	107	93	80	68	58	48	40	33			100 000				
																										150 000			
																											200 000		
																											250 000		

Table 2.1.2 Design stress values (N/mm²) (concluded)

Table 2.1.2 Design stress values (N/mm ²) (concluded)																											
Steel pipes and tubes for pressure purposes																											
Type - grade and method of manufacture	R _m N/mm ²	R _t N/mm ²	Thickness mm	Values of f for design temperature (°C) not exceeding																	Design lifetime h	Notes					
				250	300	350	400	450	500	520	540	550	560	580	600	620	630	640	650	660			680	700	720	740	750
BS 3605 - Seamless austenitic stainless steel																											
304S51 HFS, CFS, HFM	490	230		101	97	94	91	88	86			83	82	82	76	65	60	55	50	45	38	33	28		100 000		
																									150 000		
																										200 000	
																										250 000	
316S51, S52 HFS, CFS, HFM	510	240		111	106	102	98	96	93		90		89	88	74	66	58	53	46	35	28	23		100 000	6		
																									150 000		
																									200 000		
																									250 000		
321S51 (1010) HFS, CFS, HFM	510	235		121	117	112	110	107	104		102	102	101	86	71	57	49	42	36	31				100 000			
																									150 000		
																									200 000		
																									250 000		
321S51(1105) HFS, CFS, HFM	490	190		93	87	84	82	79	77		76		76	75	68	60	55	49	44	34	26			100 000			
																									150 000		
																									200 000		
																									250 000		
347S51 HFS, CFS, HFM	510	240		135	130	124	122	119	119		117	117	116	99	82	66	59	53	47	41	31	23		100 000			
																									150 000		
																									200 000		
																									250 000		
216S15 HFS, CFS, HFM	540	270		141	139	136	135	133	132		130			126	124	123	107	87	71	52	40			100 000			
																									150 000		
																									200 000		
																									250 000		



Notes to table 2.1.2

General notes

(a) Table 2.1.2 gives the nominal design stress values (f) of various British Standard materials for design temperatures ($^{\circ}\text{C}$) not exceeding those stated at the head of each column. Time-dependent values which are given for design lifetimes of 100 000, 150 000, 200 000 and 250 000 h are italicized. Values at intermediate temperatures and intermediate times shall be obtained by linear interpolation; values obtained by linear interpolation involving only one italicized value may be regarded as time-independent.

Interpolated values shall be rounded to two decimal places in accordance with BS 1957.

For design temperatures below 250°C the design stress values for 250°C shall be used.

- (b) The design temperature as specified in 2.2.3 should not exceed the upper temperature for which a value of (f) is given except where note 1(c) applies; where extrapolation of the values given is required, this shall be on the basis agreed between the manufacturer and the purchaser (see 1.5.2.2(d)).
- (c) If required for stress analysis purposes, the transition from linear elastic to linear plastic behaviour for all materials except austenitic steels may be assumed to occur at a stress for $1.5 \times f$ unless f is time-dependent; for austenitic steels, the corresponding stress may be taken as $1.35 \times f$.
- (d) Overall thickness limits are as defined in the relevant material specification. In the case of forgings, the term 'ruling section' shall be interpreted in accordance with BS 5046.
- (e) For values between the thicknesses stated, design stresses shall be obtained by linear interpolation.

Notes applicable to individual materials

- 1(a). The values for forgings may be increased up to (but not more than) the values permitted for plate in the equivalent material grade and equivalent ruling section on provision by the forgemaster of appropriate supporting data showing that the minimum acceptance criteria for equivalent plate are satisfied.
- 1(b). An appropriate casting quality factor, as specified in 2.2.2, should be applied to these values.
- 1(c). Design stress values at higher temperatures are subject to agreement (see 1.5.2.2(d)).
- 2. At temperatures at or above 580°C the effect of scaling becomes significant and due allowance should be made for this.

3. This material is available only in a limited range of thickness and in the normalized condition. It has a restricted carbon content to obviate the necessity for stress relief subsequent to fabrication. A nominal design stress of 129 N/mm^2 may be assumed at temperatures below 350°C .

4. *Text deleted.*

5. *Text deleted.*

6. Subject to continued fitness for service reviews being instituted at two-thirds of the design lifetime indicated (see 2.2.4) and by agreement between the manufacturer and the purchaser (see 1.5.2.2(b)), time-dependent values may be increased by up to 10 %, providing the resulting value does not exceed the lowest time-independent stress given.

7. Design stresses are not strictly based on specified yield/proof stress values in relevant material standard (see appendix A).

8. Use of LAW tubing is conditional on its being subjected to the same non-destructive examination requirements as those laid down for longitudinal seams in drums; see 5.8.2.1.

9. *Text deleted.*

10. Material will (or may be) supplied in the quenched and tempered condition, in which case time-dependent properties may be susceptible to degradation as a result of subsequent fabrication processes (see 2.2.1).

11. Time-dependent design stress values apply only if the minimum carbon content equals or exceeds 0.04 %.

12. The use of steel 591 shall be limited to applications at design temperatures not exceeding 400°C .

13. The British Standard covering these materials was withdrawn on 15 February 1993 in favour of BS EN 10028 : Parts 1, 2, and 3. These materials are regarded as obsolescent but their use may be continued under the provisions of 2.1.2.2.8 using the design stress values given in this table.

14. The material strengths given are indicative only and vary according to thickness. Reference should be made to the material specification for specific information.

15. Reference should be made to the appropriate Parts of the material specification BS EN 10028 for the material property data to be used for design purposes. Design stress values should be determined in accordance with Appendix A of this standard as indicated in 2.2.1.2.

16. The British Standard covering these materials was withdrawn on 15 February 1993 in favour of BS EN 10028 : Parts 1, 2 and 3. These materials are now included in the national annex NC of BS EN 10028 : Part 2 to which reference should be made for the technical details and limitations applicable to the steels.

For design purposes the design stress values given in this table should continue to be used.

Section three. Design

3.1 General

3.1.1 The thickness and other dimensions of pressure parts, sufficient to withstand the calculation pressure at the design temperature sustained (where relevant) for the design life time, shall be determined in accordance with this section.

NOTE 1. In determining the minimum permissible thickness in millimetres the calculated value may be rounded down to the next lowest single decimal place.

The design for loadings arising from the following shall also be determined in accordance with this section:

- (a) the bending of a drum or header as a beam under self-weight and imposed loads;
- (b) local support loads on drums;
- (c) thermally-induced forces and moments within or arising from systems of integral piping; and
- (d) local loading of tubes by structural attachments.

NOTE 2. The purpose of this section is to give specific design rules for common forms of loading to which boiler pressure parts are subject and general rules on how other loadings are to be considered. It does not give specific design methods for loadings other than those described in (a) to (d).

The design rules are adequate for boilers of established construction, installed and operated in accordance with the manufacturer's instructions.

In such cases, thermally-induced forces and moments within or arising from properly designed and erected tube systems do not require analysis.

Determination of the dimensions of pressure parts when any of the following conditions are present requires special consideration outside the scope of this standard:

- (1) abnormally corrosive products of combustion;
- (2) highly pressurized products of combustion;
- (3) poor feedwater;
- (4) abnormally rapid or frequent changes of pressure or temperature.

3.1.2 The strengths of the pressure parts shall be such as to withstand the following normally present loads;

- (a) the weight of all pressure parts, contents, components depending on them and any superimposed slag, ash or dust;
- (b) loads caused by pressure differentials over the flue gas containment envelope;
- (c) loads arising at connections between the boiler system and other plant. The maximum values for forces and moments imposed by external piping at the boiler terminals for main steam, reheat steam and feedwater shall be agreed between manufacturer and purchaser (see 1.5.2.2(e)).

If applicable, the pressure parts shall adequately withstand wind and earthquake loads. Design parameters for such loads shall be agreed between the manufacturer and the purchaser (see 1.5.2.2(f)).

3.1.3 The results of any stress calculations carried out for loadings not explicitly covered by equations in this section shall be assessed using the criteria given in appendices A and B of BS 5500 : 1991.

Transient, uncontrolled pressure differentials over the flue gas containment envelope shall be treated as wind loads not

coincident with true wind loads, when using appendix B of BS 5500 : 1991.

3.1.4 The cyclic loadings to which boilers are normally subject are such that fatigue analysis of pressure parts made from materials listed in table 2.1.2 is unnecessary. When pressure parts are to be subject to abnormal cyclic loading, the assessment of the need for a fatigue analysis and any resulting analysis shall be in accordance with appendix C of BS 5500 : 1991.

3.1.5 Cognizance shall be taken of the following requirements in sections four and five:

- (a) branches and nozzles (see 4.3.1.1.6 and 4.3.1.1.7);
- (b) welds between dissimilar materials (see 4.3.2.5.4 and 4.5.4.6);
- (c) the distance of nozzles or branches from locally heat treated butt welds (see 4.5.1.1.3);
- (d) the length of branches to which pipes are to be butt welded and the weld stress relieved (see 4.5.1.1.4);
- (e) design of joints subject to non-destructive examination (see 5.6.1.7);
- (f) identification of load-bearing attachments (see 5.6.1.7, 5.8.2.3, 5.8.3.3 and 5.8.4.3.1);
- (g) test category for pipes and tubes (see 5.7.4).

NOTE. Pipes and tubes complying with test category 2 of BS 3059 : Part 2, BS 3602 : Part 1, BS 3604 : Part 1 and BS 3605 comply with this standard. Selection of pipes and tubes to test category 1 of these standards is at the option of the designer, taking into account the service conditions of the boiler.

(h) venting or evacuating of air prior to hydraulic testing (see 5.10.4.2). Small pockets of trapped air may remain after filling and the procedure with regard to these shall be the subject of agreement between the Inspecting Authority and the manufacturer (see 1.5.2.3 (r)).

3.2 Metal wastage

NOTE. For the purpose of design in accordance with this section, metal wastage includes oxidation, corrosion, erosion and abrasion.

3.2.1 Internal wastage is normally small and shall not be considered for boilers operated with water in accordance with BS 2486.

NOTE. Suitable means should be provided within the boiler design to enable regular water analysis to be safely undertaken in order to ensure the water quality remains within acceptable limits.

3.2.2 External wastage of pressure parts not exposed to flue gases is normally small and the thickness determined by this section shall be adequate without further addition.

Tubes exposed to flue gases experience wastage to a varying extent. If the boiler design data indicate that wastage will be significant, the tubes shall be increased in thickness (see 3.7.1.2). It is permitted to provide for wastage by means of metallurgically bonded co-extruded tubes.

NOTE. In such cases it may be necessary for the manufacturer and the purchaser to agree on a design life for components designed to time-independent stresses as well as for those for time-dependent stresses (see 2.2.4).

For tubes designed to time-dependent stresses, consideration of the effects of creep and wastage shall be permitted so



that failure is predicted at a time not less than the design lifetime even though the tube thickness over the latter part of its life is less than that required by equations 31 and 32 (see 3.7.1.1).

3.2.3 Unless exceptional conditions of chemical concentration are expected to occur, only austenitic materials shall be considered liable to the effect of stress corrosion. The phenomenon shall be considered adequately dealt with in the design if austenitic materials are not used to carry steam having at full boiler load an enthalpy less than 2900 kJ/kg or that corresponding to 425 °C, whichever is less.

Where exceptional chemical concentrations are predicted, consideration shall be given to the materials and heat treatment of components.

NOTE. It is not possible to provide compensation for stress corrosion by increasing the thickness of components.

3.3 Cylindrical shells of drums and headers

NOTE. This clause specifies the design rules for drums and headers. An example of the design of a boiler drum is given in appendix B.

3.3.1 Shell thickness

3.3.1.1 The thickness of the shells of drums and headers shall be the greatest of those required by the following:

- (a) a minimum of 9.5 mm for headers 300 mm and above in outside diameter and a minimum of 6 mm for headers below 300 mm in outside diameter;
- (b) the requirements of 3.3.2 and 3.3.3;
- (c) the requirements of 3.3.4, 3.3.5 and 3.3.6;
- (d) for those parts of shells drilled for tube expansions, such thickness as is required to provide a parallel belt of tube seat not less than 10 mm wide.

3.3.1.2 Text deleted.

3.3.1.3 All welding of the main seams of boilers constructed in accordance with this standard shall be accounted as having a joint efficiency of 100 %.

3.3.2 Basic calculation

3.3.2.1 Except where the conditions described in 3.3.2.2 apply, the minimum thickness t (in mm) of a cylindrical shell shall be determined by either of the following equations:

$$t = \frac{pD_i}{2f\eta - p} \quad (1)$$

or

$$t = \frac{pD_o}{2f\eta + p} \quad (2)$$

where

- p is the calculation pressure (in N/mm²);
- D_i is the nominal inside diameter of the shell (in mm) (see 3.3.2.3 and 3.3.2.4);
- D_o is the nominal outside diameter of the shell (in mm) (see 3.3.2.3 and 3.3.2.4);

- f is the design stress (in N/mm²) (see 2.2);
- η is the minimum efficiency of longitudinal, diagonal and circumferential ligaments, as determined in 3.3.3.

3.3.2.2 The minimum thickness determined in accordance with 3.3.2.1 shall not be applicable in the following cases.

- (a) For time-independent (non-creep) conditions where the resultant thickness calculated using equation (1) or (2) exceeds one-quarter of the internal diameter. In this case, the thickness shall also be determined from either of the following equations and compared with the thickness determined from equation (1).

$$t = \frac{D_i}{2} \left[\sqrt{\left| \frac{1.5f\eta + p(1 - \eta)}{1.5f\eta - p(1 + \eta)} \right|} - 1 \right] \quad (3a)$$

$$t = \frac{D_o}{2} \left[1 - \sqrt{\left| \frac{1.5f\eta - p(1 + \eta)}{1.5f\eta + p(1 - \eta)} \right|} \right] \quad (3b)$$

The required thickness shall be not less than the greater of the thicknesses determined from equation (1) or (3a), or (2) or (3b).

- (b) For time-dependent (creep) conditions where the resultant thickness exceeds one-half of the internal diameter. In such cases, the method of calculating the thickness shall be subject to agreement between the purchaser and the manufacturer (see 1.5.2.3(d)).

3.3.2.3 Where a shell has tube and wrapper plates of different thicknesses and/or different radii, twice the respective radii shall be used for D_i or D_o in equation (1), (2), (3a) or (3b).

3.3.2.4 Manufacturing tolerances in shell inside or outside diameters shall not be taken into account in calculating shell thickness.

3.3.3 Ligament efficiency

3.3.3.1 Limits of application. Where openings such as tube holes are drilled in a definite pattern, the efficiency of the ligaments shall be determined by the methods given in 3.3.3.2 to 3.3.3.7, provided that the diameter of the largest hole in the group does not exceed that permitted by the following.

- (a) The maximum diameter d (in mm) of any opening designed by this method shall be obtained from the following equation:

$$d = 8.08 \{(1 - K) D_o t\}^{1/3} \quad (4)$$

where

- D_o is the nominal outside diameter of the shell (in mm);
- t is the actual thickness of the shell (in mm);
- K is the factor given by:

$$K = \frac{pD_o}{1.82ft} \quad (\text{but not exceeding } 0.99)$$

where

- p is the calculation pressure (in N/mm²);
- f is the design stress (in N/mm²) (see 2.2).

For elliptical or obround* holes, d shall refer to the mean of the major or minor axes.

(b) No opening designed by this method shall exceed 200 mm diameter.

Openings larger than those permitted in (a) and (b) shall be compensated in accordance with 3.4.

3.3.3.2 Equivalent hole diameter. Where a drum or header is drilled for tube stubs fitted by welding either in line or in staggered formation, the equivalent diameter of the holes d_e (in mm) shall be taken as:

$$d_e = d_a - \frac{A}{t} \quad (5)$$

where

d_a is the actual diameter of the hole (in mm);

t is the thickness of the shell (in mm);

A is the compensating area provided by each tube stub and its welding fillets (in mm²).

The compensating area A shall be measured in a plane through the axis of the tube stub parallel to the longitudinal axis of the drum or header and shall be calculated as follows (see figure 3.3.3.2(a)).

(a) The sectional area of the stub, in excess of that required by equation (31) or (32) for the minimum tube thickness disregarding the minimum thickness given in table 3.7.1.1, from the interior surface of the shell up to a distance b from the outer surface of the shell (see note).

(b) Plus the sectional area of the stub projecting inside the shell within a distance b from the inner surface of the shell.

(c) Plus the sectional area of the welding fillets inside and outside the shell.

For (a) and (b) above

$$b = \sqrt{d_a t_a};$$

where

t_a is the actual thickness of the tube stub (in mm).

NOTE. In the case of a set-on tube stub (see figure 3.3.3.2(b)), the compensation extends from the outer surface of the shell only.

Where the material of the tube stub has an allowable stress lower than that of the shell, the compensating sectional area of the stub shall be multiplied by the ratio:

Design stress of stub at design temperature

Design stress of shell at design temperature

No credit shall be taken for the additional strength of tube stub material having a higher stress value than that of the shell plate.

3.3.3.3 Regular drilling. Where the distance between centres of adjacent tube holes is constant:

$$\eta = \frac{s - d}{s} \quad (6)$$

where

s is the pitch of tube holes (in mm);

d is either the mean effective diameter of the tube holes after allowing for any serrations, counter-boring or recessing, or the equivalent diameter (d_e) after allowing for the compensating effect of the tube stub (in mm) (see 3.3.3.2).

3.3.3.4 Irregular drilling. Where the distance between centres of adjacent tube holes is not constant (see figure 3.3.3.4):

$$\eta = \frac{s_1 + s_2 - 2d}{s_1 + s_2} \quad (7)$$

where

s_1 is the shorter of any two adjacent pitches (in mm);

s_2 is the longer of the two adjacent pitches (in mm);

d is either the mean effective diameter of the tube holes after allowing for any serrations, counter-boring or recessing, or the equivalent diameter (d_e) after allowing for the compensating effect of the tube stub (in mm) (see 3.3.3.2).

When applying equation (7), the double pitch ($s_1 + s_2$) chosen shall be that which makes η a minimum, and in no case shall s_2 be taken as greater than twice s_1 .

3.3.3.5 Diagonal ligaments

3.3.3.5.1 Where bending stresses due to weight are negligible (otherwise refer to 3.3.4) and tube holes are arranged either along a diagonal line with respect to the longitudinal axis as shown in figure 3.3.3.5(1), or in a regular pattern as shown in figure 3.3.3.5(2), the efficiency η to be applied in equation (1) shall be obtained from the series of curves given in figure 3.3.3.5(3) with the ratio b/a as abscissa and the ratio $(2a - d)/2a$ or d/a as parameter;

where

a and b are measured as shown in figures 3.3.3.5(1) and 3.3.3.5(2) on the median line of the plate;

d is either the mean effective diameter of the tube holes after allowing for any serrations, counter-boring or recessing, or the equivalent diameter (d_e) after allowing for the compensating effect of the tube stub (in mm) (see 3.3.3.2).

* An obround opening is, for the purposes of this standard, to be understood as an opening or hole that is neither circular nor elliptical; it is formed by the blending of two radii to give a rounded opening/hole, the major and minor axes of which are different.

NOTE. The data in figure 3.3.3.5(3) are based on the following:

$$\eta = \frac{2}{A + B + \sqrt{(A - B)^2 + 4C^2}}$$

where

$$A = \frac{\cos^2 \alpha + 1}{2 \left(1 - \frac{d \cos \alpha}{a} \right)}$$

$$B = \frac{1}{2} \left(1 - \frac{d \cos \alpha}{a} \right) (\sin^2 \alpha + 1)$$

$$C = \frac{\sin \alpha \cos \alpha}{2 \left(1 - \frac{d \cos \alpha}{a} \right)}$$

$$\cos \alpha = \frac{1}{\sqrt{\left(1 + \frac{b^2}{a^2} \right)}}$$

$$\sin \alpha = \frac{1}{\sqrt{\left(1 + \frac{a^2}{b^2} \right)}}$$

where

α is the angle of centre line of cylinder to centre line of diagonal holes.

3.3.3.5.2 Where there is regular staggered spacing of tube holes as shown in figure 3.3.3.5(4) the smallest value of the efficiency of all the ligament (longitudinal, circumferential and diagonal) shall be obtained from figure 3.3.3.5(5) with

the ratio S_c/S_l as abscissa and the ratio $\frac{S_l - d}{S_l}$ or d/a

as parameter.

where

d is either the mean effective diameter of the tube holes after allowing for any serrations, counter-boring or recessing, or the equivalent diameter (d_e) after allowing for the compensating effect of the tube stub (in mm) (see 3.3.3.2);

S_c is twice the distance (b) between axial rows of holes measured on the median line of the plate (in mm);

S_l is twice the distance (a) between circumferential rows of holes (in mm).

3.3.3.6 Irregular drilling not in a straight line. For holes placed longitudinally along a drum or header which do not come in line, equation (7) in 3.3.3.4 shall apply except that an equivalent longitudinal width of the diagonal ligament shall be used. An equivalent longitudinal width shall be that width which gives, using equation (6), the same efficiency as would be obtained using figure 3.3.3.5(3) for the diagonal ligament in question.

3.3.3.7 Circumferential ligaments

3.3.3.7.1 Where bending stresses due to weight are negligible (otherwise, refer to 3.3.4) the efficiency of ligaments between holes measured on a circumferential line shall not be used to calculate the thickness of a cylindrical shell provided that the efficiency of the circumferential ligaments calculated in accordance with equations (6) and (7) is not less than one-half of that of the longitudinal ligaments.

3.3.3.7.2 Where the circumferential pitch between tube holes measured on the mean of the external and internal drum or header diameters is such that the circumferential ligament efficiency determined by equations (6) and (7) is less than one-half of the ligament efficiency on the longitudinal axis, then η in equations (1) to (3b) shall be taken as twice the circumferential efficiency.

3.3.4 Combined stresses in drum or header shells

3.3.4.1 General. Notwithstanding the thickness of shells calculated in accordance with 3.3.2 and 3.3.3, calculations shall be made to ensure that in no case does the average ligament stress resulting from the combination of stresses arising from internal pressure, the self-weight of the drum or header and its contents, and all externally applied loads, exceed the design stress f (see 2.2) in any line of holes whether longitudinal, circumferential or diagonal.

The average ligament stress in ligaments between holes on a circumferential line shall be the sum of the longitudinal stresses calculated in accordance with 3.3.4.2 and 3.3.4.3. The average ligament stress in ligaments between holes on a diagonal line shall be calculated in accordance with 3.3.4.4.

3.3.4.2 Longitudinal direct pressure stress. The maximum direct longitudinal stress f_d (in N/mm²) due to internal pressure on the drum or header ends shall be calculated as follows:

$$f_d = \frac{p D_i^2}{1.273 A} \quad (8)$$

where

p is the calculation pressure (in N/mm²);

D_i is the nominal inside diameter of the drum or header (in mm);

A is the net cross-sectional area of the drum or header shell plate taken through the tube holes in a plane at right angles to its axis (in mm²).

When a hole in the shell is wholly or partly reinforced by the attaching nozzle the hole size shall be reduced accordingly (see 3.3.3.2).

Nozzles designed in accordance with 3.4 shall be considered as wholly reinforced.

3.3.4.3 Longitudinal bending stress

3.3.4.3.1 The resultant bending moment M_R (in N·mm) at any section shall be the algebraic sum of the resultant bending moments due to the eccentricity of the end pressure M_E and due to externally applied loads M_W , i.e.

$$M_R = M_E + M_W \quad (9)$$

The resultant bending moment M_E (in N·mm) due to eccentricity of end pressure shall be calculated from:

$$M_E = \frac{p D_i^2 e}{1.273} \quad (10)$$

where

p is the calculation pressure (in N/mm²);

D_i is the nominal inside diameter of the drum or header (in mm);

e is the eccentricity of the net cross-section (see figure B.3).

The resultant bending moment M_W (in N·mm) due to externally applied loads shall be calculated by treating the shell as a beam carrying the externally applied loads including its own weight and that of the contents under working conditions. M_W is the bending moment at the section subjected to the greatest bending from this cause.

3.3.4.3.2 The stress due to bending f_b (in N/mm²) shall be calculated as follows:

$$f_b = \frac{M_R Y}{I_A} \quad (11)$$

where

M_R is the resultant bending moment (in N·mm) (see 3.3.4.3.1);

Y is the distance from the neutral axis of the net cross section to the extreme mid point of the shell thickness (in mm);

I_A is the second moment of area of the net cross section through the tube holes taken about its neutral axis (in mm⁴) (see also 3.3.4.3.3).

If a welded nozzle has been designed to compensate fully for the removal of drum material (i.e. when $\eta = 1.0$) the nozzle and its opening shall be assumed to be absent in calculating the longitudinal bending stress. If the nozzle is designed to compensate only for part of the material removed from the drum, the second moment of area of the drum section shall be calculated assuming the size of the hole to be reduced by the amount of compensation provided by the nozzle (see 3.3.3.2).

3.3.4.3.3 In calculating the longitudinal stress in a drum supported on stools or slings and connected to a second drum by a bank of tubes (so arranged as to form substantial struts or ties between the drums), an increase in the value of the second moment of area I_A (in mm⁴) used in 3.3.4.3.2 shall be permitted to take account of the support received from the second drum as follows:

$$I_A = I_b + S I_c$$

where

I_b is the second moment of area of the supported drum (in mm⁴)

I_c is the second moment of area of the second drum (in mm⁴)

S is a factor given by:

$$S = 1 - \frac{a^2}{240} \quad (12)$$

where

a is the angle between the vertical and the line joining the centres of the two drums (in degrees);

where a is equal to or greater than 15.5°, S shall be taken as 0.

In no case shall the actual value of I_A used in equation (11) be taken as more than 1.33 times the second moment of area of the supported drum I_b .

NOTE. In this context, 'bank of tubes' means four or more rows of tubes extending over at least three-quarters of the drum length between supports and pitched longitudinally at not greater than an average pitch of four tube diameters.

3.3.4.4 Evaluation of stresses. Where bending stresses due to weight, externally applied loads and eccentricity of end pressure are not negligible, the stress on ligaments which are on a line which is at an angle α to the longitudinal axis of the drum, as shown in figure 3.3.4.4, shall be evaluated as follows:

Let the circumferential stress on gross area of longitudinal section σ_1 (in N/mm²) be:

$$\sigma_1 = p \frac{(D_i + t)}{2t}$$

where

p is the calculation pressure (in N/mm²);

D_i is the nominal inside diameter of the shell (see 3.3.2.3 and 3.3.2.4) (in mm);

t is the minimum thickness of the shell before allowance for metal wastage (see equation (1)) (in mm).

Let the longitudinal stress on gross area of circumferential section σ_2 (in N/mm²) be:

$$\sigma_2 = \eta_2 (f_d + f_b)$$

where

f_d is the stress due to pressure end load (see equation (8)) (in N/mm²);

f_b is the bending stress due to eccentricity of pressure end load added algebraically to bending stress due to weight loading calculated in accordance with equation (11) taking Y as the distance from the neutral axis of the net cross section to the mid point of the inclined ligament (in N/mm²);

η_2 is the ligament efficiency on a circumferential section at the point where f_d and f_b act.

Where the ligament under consideration is between holes of equal size, the actual ligament efficiency (η_3) on the diagonal line shall be given by:

$$\eta_3 = 1 - \frac{d \cos \alpha}{a}$$

Where holes are of unequal size, the ligament efficiency (η_3) on the diagonal line shall be given by:

$$\eta_3 = 1 - \frac{(d_1 + d_2) \cos \alpha}{2a}$$

where the symbols are as shown on figure 3.3.4.4.

The average direct stress A_1 (in N/mm²) on the ligament shall be given by:

$$A_1 = \frac{1}{\eta_3} \left\{ \frac{\sigma_1 + \sigma_2}{2} + \frac{(\sigma_1 - \sigma_2) \cos 2\alpha}{2} \right\}$$

The average transverse stress B_1 (in N/mm²) on the ligament shall be given by:

$$B_1 = \eta_3 \left\{ \frac{\sigma_1 + \sigma_2}{2} + \frac{(\sigma_1 - \sigma_2) \sin 2\alpha}{2} \right\}$$

The average shear stress C_1 (in N/mm^2) on the ligament shall be given by:

$$C_1 = \frac{(\sigma_1 - \sigma_2) \sin 2\alpha}{2\eta_3}$$

The stress f (in N/mm^2) on the ligament shall be given by:

$$f = \frac{1}{2} \left[A_1 + B_1 + \sqrt{(A_1 - B_1)^2 + 4C_1^2} \right] \quad (13)$$

and this shall not exceed the design stress (see 2.2).

3.3.5 Boiler drum supports

Where large diameter but relatively thin drums are carrying heavy loads on stools or slings, equation (14) shall be used as a guide to assess whether precise calculations are needed to determine local stresses:

$$0.78 \left(\frac{W}{St} \right) \sqrt{\left(\frac{R}{t} \right)} \leq f \quad (14)$$

where

- R is the mean radius of the drum shell (in mm);
- t is the thickness of the drum shell (in mm);
- W is the load on the stool or sling (in N);
- S is the horizontal length of the stool or sling at right angles to axis of the drum but in any case not greater than the chord described by 120° (in mm);
- f is the design stress at the design temperature (in N/mm^2).

Where application of this equation suggests that the design stress is exceeded, reference shall be made to the appropriate methods of analysis given in appendix G of BS 5500 : 1991.

3.3.6 Other stresses in cylindrical shells

In addition to the requirements of 3.3.2 and 3.3.4, which cover general membrane stresses in the shell, and 3.3.5, which covers local stresses at supports, any other local stresses shall also be considered. Local stresses shall not be included when applying 3.3.4. Local stresses at nozzles carrying significant load shall be accounted for as required by 3.4.4.1.

3.4 Openings and branches in cylindrical shells and integral pipes

NOTE. This clause specifies the design rules for openings and branches in cylindrical shells. Recommendations on the forms of connections to be used for branches are given in appendix C, which additionally covers studded and welded sockets.

3.4.1 General

3.4.1.1 The amount of compensation to be provided at an opening for which the ligament efficiency method of 3.3.3 cannot be applied shall be not less than that specified in 3.4.1.2 to 3.4.1.1.

3.4.1.2 Design charts are referred to in 3.4.4.3 that are based on approximate analysis considering internal pressure loading only, but the effects of other loads shall be taken into account.

NOTE 1. The basis on which the design charts (figures 3.4.4(1) to 3.4.4(3)) are founded is outlined in appendix D.

NOTE 2. The effects of loading other than that from internal pressure may be taken into account by the selection of an appropriate value for the factor C (see 3.4.2 and 3.4.4).

Similarly, the effects of attachments and discontinuities in the proximity of the openings shall be taken into account and in no case shall branch connections be less than the thickness specified in 3.4.7. Where material having a lower design stress than that of the shell is taken as compensation, its effective area shall be assumed to be reduced in the ratio of the allowable design stresses at the design temperature, except that in no case shall a material having an allowable stress less than 60 % of the shell material be used. Material having a design stress up to 50 % greater than that for the shell may be used but no credit shall be taken for this in calculating the necessary effective area of such compensation.

All branch connections, nozzles and openings not covered in 3.4.3 shall be designed on the basis of special analysis, experimental evidence, or tests to the satisfaction of the purchaser. The alternative method given in appendix E shall be permitted where experience has shown it to be satisfactory.

NOTE 3. All dimensions exclude any wastage allowances.

3.4.2 Notation

For the purposes of the calculations in 3.4.3 to 3.4.6 the following symbols apply (see also figures 3.4.2(1), 3.4.2(2), 3.4.4(1) to 3.4.4(6), 3.4.4(9) to 3.4.4(11) and 3.4.5(2)):

- A_s , A_n and A_t are cross-sectional areas used in the calculation of compensation for adjacent branches (see figure 3.4.5(2))
- C is a factor applied to T_r/T
- D is the mean diameter of the cylindrical shell
- d is the bore of an opening not provided with a branch, or the mean diameter of a branch; in the case of non-circular openings (see 3.4.4.6).
- d_A is the average value of d for any two adjacent openings being considered
- f_n is the design strength of the rim or forging
- f_s is the design stress of the shell
- g is the arrangement factor from figure 3.4.5(1)
- H is the distance along the shell within which the shell thickening is assumed to contribute to the reinforcement of an opening
- h is the distance along the branch within which branch thickening is assumed to contribute to the reinforcement of an opening

- P is the pitch measured between the centrelines of two openings along mid-thickness of shell
- T is the shell thickness as calculated using either equations in 3.3.2 with $\eta = 1.0$ or equations (31) or (32) in 3.7.1
- T_r is the total thickness of the shell as required throughout 3.4
- T'_r is the modified thickness of the shell (see figures 3.4.4(7) and 3.4.4(8))
- t is the branch thickness as calculated using the branch design stress by the equations for pressure loading only in 3.7.1 for a plain cylinder
- t_r is the total thickness of the branch as required throughout 3.4
- t'_r is the modified thickness of the branch (see figures 3.4.4(7) and 3.4.4(8))
- Y is a factor from figure 3.4.4(2)
- $$\rho = \frac{d}{D} \sqrt{\left(\frac{D}{2T_r}\right)}$$

3.4.3 Application

The rules specified in 3.4.4 to 3.4.9 shall be regarded as valid for the design of circular, elliptical and obround* openings and nozzles (including oblique nozzles) arranged singly or in groups, in cylindrical shells, provided that the mean diameter to thickness ratio of the shell D/T satisfies $D/T \leq 100$ and provided that the following conditions are satisfied.

- Openings and nozzles normal to the shell.* The ratio of the major to minor axes of the opening does not exceed 2.
- Oblique nozzles.* The nozzle is of circular cross section and the angle between the axis of the nozzle and a line normal to the shell surface does not exceed 50° .
- Protruding nozzles.* The mean diameter of the branch does not exceed one-third of the mean diameter of the shell.
- All nozzles.* The nozzle connection is made by fully penetrating welds.

NOTE. This requirement therefore excludes connections similar to those shown in figure C(10) and C(11) and the fillet welded connections shown in figure C(20).

Nozzle connections made with other than fully penetrating welds shall be considered as openings not fitted with branch pieces (see 3.4.4.2), the opening being that formed in the shell before the branch is attached.

NOTE. In cases where the design stress is time-dependent, the requirements of this clause should give adequate margins against creep rupture. However, for parts made from austenitic materials, it may be desirable to check that the end of life deformation is acceptable.

3.4.4 Design of isolated openings and branch connections

3.4.4.1 General. The thickness of shell, T_r , shall be not less than T and the thickness of a branch connection, t_r , shall be not less than t .

Where external loads are negligible, the factor C shall be taken as not more than 1.1.

Where branch or nozzle connections are attached to a piping system designed with due allowance for expansion thrusts, etc. (e.g. complying with the flexibility requirements of BS 806) C shall be taken as not more than 1.0.

Other loadings shall be evaluated in accordance with appendix G of BS 5500 : 1991 and the thickness of shell or branch increased if necessary, such as by selection of a value of C less than 1.0.

For vessels operating in the creep range, $C \leq 1$.

3.4.4.2 Openings not fitted with branches. The value $t_r/T_r = 0$ shall be taken in figure 3.4.4(1) and the factor $C = 1.1$ used to obtain the shell thickness T_r . An iteration shall be performed using a revised value of ρ until the assumed and required values of T_r are equal.

3.4.4.3 Openings fitted with branches. Branch connections shall be permitted to be reinforced by means of an increase in shell thickness or nozzle thickness or by a combination of increases. In some cases, e.g. where external pipework loads are significant, or in order to meet the branch thickness limit specified in 3.4.4.4(c), thickening of the shell may be necessary. This will need to be considered at an early stage in the design process. The following design charts shall apply:

- figure 3.4.4(1), for flush nozzles with $d/D < 0.3$;
- figure 3.4.4(2), for flush nozzles with $d/D > 0.2$;
- figure 3.4.4(3), for protruding nozzles with $d/D < 0.33$.

A value of shell thickness $T_r \geq T$ shall be chosen, and an estimate of the branch thickness $t_r \geq t$ made so that the mean branch diameter d and hence d/D and (where necessary) ρ can be calculated. Using an appropriate value of C from 3.4.4.1, the appropriate design chart shall be entered to give the required value of t_r/T_r (figures 3.4.4(1) and 3.4.4(3)) or Y (figure 3.4.4(2)) from which t_r shall be determined. In the case of flush nozzles in cylindrical vessels where $0.2 < d/D < 0.3$, it is necessary to derive a value t_{r1} from figure 3.4.4(1) and t_{r2} from figure 3.4.4(2) and interpolate so that:

$$t_r = t_{r1} + 10(d/D - 0.2)(t_{r2} - t_{r1})$$

If the value of t_r obtained differs from the estimate a revised value shall be used and the calculation repeated until convergence is achieved. Figures 3.4.4(1), (2) and (3) are provided for ease of application in manual calculations. Definitive thicknesses shall be obtained from the tabulated data in tables 3.4.4(a) and 3.4.4(b). Where it is required to determine t_r/T_r for CT_r/T and ρ values that are not explicitly tabulated, the following procedure shall be used.

- For the nearest listed ρ value below that required, find the nearest tabulated CT_r/T values bounding the exact value above and below. Interpolate linearly to obtain t_r/T_r corresponding to the required value of CT_r/T .
- Similarly obtain t_r/T_r for the exact CT_r/T value for the nearest tabulated ρ value greater than that required.
- Finally interpolate linearly to obtain t_r/T_r for the exact value of ρ .

* See footnote to 3.3.3.1 for an explanation of 'obround'.