

Code of practice for

Design and installation of ceramic fibre furnace linings

UDC 66.043.13:677.523

Confirmed December 2009

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

BSI
Documents

AVA

Document Sharing Hub

Committees responsible for this British Standard

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

- Association of Manufacturers of Domestic Electrical Appliances
- Association of Manufacturers of Mineral Fibre Insulation
- British Ceramic Research Association
- British Steel Industry
- Combustion Engineering Association
- Electricity Supply Industry in England and Wales
- Engineering Equipment and Materials Users' Association
- Institute of Refractories Engineers
- National Coal Board
- Refractories Association of Great Britain
- Coopted member

The following body was also represented in the drafting of the standard:

- Health and Safety Executive

This British Standard, having been prepared under the direction of the Refractory Products Standards Committee, was published under the authority of the Board of BSI and comes into effect on 31 August 1984

© BSI 08-1999

The following BSI references relate to the work on this standard:
Committee reference RPE/9
Draft for comment 82/73301 DC

ISBN 0 580 13890 9

Amendments issued since publication

Amd. No.	Date of issue	Comments
4870	June 1985	
6748	October 1991	Indicated by a sideline in the margin

Contents

	Page
Committees responsible	Inside front cover
Foreword	ii
Section 1. General	
1 Scope	1
2 Definitions	1
Section 2. Design considerations	
3 Design criteria	1
4 Lining systems	2
5 Anchoring systems	3
6 Thermal design for steady conditions	4
7 Thermal design for intermittent heating	5
8 Protection against erosion, abrasion and corrosion	7
Section 3. Design for installation	
9 In situ linings	9
10 Prefabricated modular linings	19
Section 4. Site arrangements	
11 Preparations for installation of ceramic fibre linings	30
Section 5. Installation procedures	
12 Surface preparation, fixing of anchoring and supporting attachments	30
13 In situ linings	32
14 Prefabricated modular linings	34
15 Veneer systems	36
Section 6. Inspection, testing and repair	
16 Inspection and testing	38
17 Repair techniques	38
Section 7. Health and safety considerations	
18 Potential hazards of man-made mineral fibres	39
Appendix A <i>Text deleted</i>	41
Figure 1 — Twist-lock anchor	3
Figure 2 — Threaded anchor	4
Figure 3 — Overlapped joint stud pattern (roof)	10
Figure 4 — Butt joint stud pattern	11
Figure 5 — Shingled joint stud pattern (walls or roof)	12
Figure 6 — Layered blanket linings: typical internal corner detail	12
Figure 7 — Layered blanket linings: alternative internal corner detail	13
Figure 8 — Layered blanket linings: external corners	14
Figure 9 — Door seal (stacked module on board)	15
Figure 10 — Door seal (section through deep door)	15
Figure 11 — Door seal (rebated module)	16
Figure 12 — Door seal (wall to roof)	16
Figure 13 — Side view of furnace showing preferred door movement	17
Figure 14 — Alloy steel box support	17
Figure 15 — Steel angle frame	18
Figure 16 — Burner block construction	18
Figure 17 — Bolted-on vacuum formed burner quarl assembly	19
Figure 18 — Support of typical ceramic fibre quarl in ceramic fibre lining	20

	Page
Figure 19 — Arrangement of lining around quarl of dense refractory material	21
Figure 20 — Lining construction adjacent to burner quarl when dimension $A - B$ is > 20 mm	22
Figure 21 — Typical anchoring system for stacked module (group A)	23
Figure 22 — Typical pleated module (group A)	24
Figure 23 — Typical anchoring system for a furnace construction module (group B)	25
Figure 24 — Typical anchoring system for vacuum formed box type module (group C)	26
Figure 25 — Corner detail of pleated group A module	26
Figure 26 — Corner detail for stacked fibre group A module	27
Figure 27 — Corner junction using box type group C modules	27
Figure 28 — Corner junction using box type group C modules (alternative design)	28
Figure 29 — Corner junction using furnace construction modules (group B)	28
Figure 30 — Door seals for vacuum formed modular construction	29
Figure 31 — Typical stud pattern around a small flue opening	30
Figure 32 — Typical stud pattern around a large flue opening	31
Figure 33 — Typical stud pattern around a burner block	31
Figure 34 — Blanket cutter	33
Figure 35 — Typical wet felt stud patterns (butt joint)	34
Figure 36 — Typical wet felt stud patterns (overlap joints)	35
Figure 37 — Typical junction detail between roof and walls (group C)	36
Figure 38 — Fairing steps in refractory prior to veneering	37
Figure 39 — Method of anchoring stud into refractory	38
Table 1 — Maximum tip temperatures for typical metal anchoring or support components	4
Table 2 — External heat losses and cold face temperatures	6
Publications referred to	Inside back cover

Foreword

This British Standard code of practice has been prepared under the direction of the Refractory Products Standards Committee to recommend good working practice for the design and installation of ceramic fibrous materials which are used as insulating linings for furnace construction.

Good working practice has now developed to the point where its definition is possible but nevertheless new ideas continue to be introduced. The code tries to recognize this and to set out guiding principles on which their acceptability can be judged.

Since design and installation are closely interrelated, it is recommended that designers also make provision for the installation stage. Almost everything that the installer does should at least be considered and very frequently thought out in advance in some detail. This is part of good design.

It is characteristic of many construction materials and systems that limitations to their acceptable use are often hard to define quantitatively; yet somehow the code has to do this. The range of demands on performance and reliability, arising quite objectively from the varying circumstances of operation and maintenance, is significant and the code recognizes this by reference to a “high reliability” level of practice in addition to a level acceptable where the higher cost of the former is not justified.

Some of these factors have relevance to the use of refractory materials other than fibrous and if the present code, as is to be hoped, finds wide acceptance it may also help in the formulation of codes for other areas of refractories technology.

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

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 42, an inside back cover and a back cover.

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

Section 1. General

1 Scope

This code of practice recommends good working practice for the design and installation of insulating linings for furnaces where ceramic fibrous materials comprise the whole or a significant part of the lining. The code is concerned with furnaces generally operating at temperatures of 800 °C and over and mainly with clean conditions; abrasion and slagging, etc are excluded.

NOTE 1 This code is intended to be read in association with BS 7225-3.1.

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

2 Definitions

The definitions given in BS 3446-1 apply, together with the following.

2.1

sprayable ceramic fibre

a system comprising pre-treated bulk fibre blended with a non-corrosive binder system. The system is capable of being applied by means of a spraying device or gun in order to form a monolithic lining which can be applied rapidly

2.2

thermal resistance

the reciprocal of thermal conductance.

Unit: mm² K/W

NOTE For a structure having plane and parallel faces, the thermal resistance is equal to the thickness divided by the thermal conductivity. The usefulness of this quantity is that, when heat passes in succession through two or more components of a structure, the resistances can be added together; the total thus obtained is the thermal resistance of the compound structure.

2.3

layered lining

lining that is composed of several layers of insulating materials

2.4

mastic

a putty-like material containing ceramic fibres and binders which is used for filling voids in cup-locks and other such applications

2.5

composite module

a module which comprises layers of different materials

2.6

pleated blanket module

a construction in which a continuous length of ceramic fibre blanket is pleated in such a way that the fibre orientation is substantially normal to the plane of the lining

2.7

overlapped joint

a single layer of ceramic fibre blanket is applied to overlap the adjacent blanket

2.8

shingled joint

a method of applying double layers of ceramic fibre blanket in such a way that half the width of each layer overlaps half the width of the adjacent layer

2.9

tip temperature

the highest temperature of a metal component in a lining close to the hot face.

Section 2. Design considerations

3 Design criteria

NOTE It is important not only that the design criteria should be understood and agreed but also that there should be a common basis when contractors are tendering.

3.1 Design of furnace linings should be based on the following objectives:

- a) to achieve the required thermal design criteria including agreed thermal resistance, thermal capacity or both;
- b) to ensure that the operating temperatures for each of the component parts of the lining, both metallic and ceramic, will be acceptable in relation to the expected life;
- c) to ensure similarly that the mechanical construction is suitable for the expected duty and life;
- d) to ensure that all significant features of the construction are given appropriate attention, while at the same time not precluding the installation contractor from applying his experience and utilizing improved techniques, etc;
- e) to ensure that the design requirements are fully understood and agreed with the installation contractor before commencement of the work;
- f) to ensure that the design requirements are based on careful consideration of the operating conditions by the purchaser and the design contractor.

3.2 The design may be based on either of the following:

- a) standard design;
- b) high reliability design.

The “standard design” should be used in circumstances where long life without maintenance is not essential, for example, where operation is intermittent and allows opportunity for maintenance at reasonably frequent intervals. The “high reliability design” should be adopted in circumstances where continuous, reliable operation and long life are essential. The aim of designs produced on this basis will be life expectancy, without significant maintenance, for periods of 5 to 10 years or more under the agreed operating conditions. While it is not intended that there should be binding agreement on life expectancy, there should nevertheless be agreement between contractor and purchaser on the basis for decisions that affect the lining life, particularly the choice of design temperature limits for materials.

4 Lining systems

4.1 In situ linings

4.1.1 Layered blanket. This lining may be graded in quality and/or density and is impaled on special steel alloy studs attached to the furnace casing. The lining may also provide for the inclusion of conventional slab or fibrous insulation.

4.1.2 Stacked blanket. This blanket may be secured to the furnace structure by steel alloy rods passed through fibre strips at intervals and supported from the casing or furnace structure by brackets designed for the purpose.

4.1.3 Board with insulation backing. This lining is similar to the layered blanket (see 4.1.1) but with board as the hot face layer.

4.1.4 Protection with alloy mesh. A sheet or mesh of heat-resisting alloy is used to protect ceramic fibre blanket or felt against erosion or abrasion (see 8.2.2).

4.1.5 Veneers. Veneers may be fixed by an adhesive or metal anchorage. Veneering should not be regarded as a high reliability system.

4.1.6 Sprayable lining. This lining may be graded in quality, and may be sprayed on as a full thickness or sprayed onto ceramic fibre or refractory substrates. It may include some form of anchorage.

4.2 Prefabricated modular linings

4.2.1 General. Modules have extended the use of ceramic fibres in furnace linings because of their better resistance to high velocity gases, particulate abrasion and mechanical abuse. This is especially so with the vacuum formed product where a tough outer shell of ceramic fibre protects the internal and backing insulation from contact with the furnace gases.

Vacuum formed fibre has greater resistance to mechanical damage and both vacuum formed and stacked fibres have better resistance than layered blanket to high velocity gases though stacked fibre has a higher thermal conductivity.

4.2.2 Vacuum formed modules. Vacuum formed modules of relatively weak ceramic fibrous material acquire form and strength that gives some resistance to gas erosion, abrasive particles and mechanical abuse. The modules respond well to handling during installation and maintenance.

The modules are generally of hollow form thereby allowing the interior to be filled with graded layers of blanket or other insulants. Filling at site is not recommended. Complete works fabrication should be carried out. Anchors (see clause 5) are generally fabricated from heat-resisting alloy plate.

4.2.3 Stacked modules. These modules are typically about 300 mm square. Backing may be sheet steel or steel mesh which is usually linked with an in-built stud system to allow rapid installation by gun welding. When steel backing is used, this may sometimes form part of the furnace design. The blankets may be attached either by a system of metal anchorages or adhesive; adhesive alone should not be used for high reliability work. These modules are normally installed so that the planes of the blankets in adjacent modules are at 90° to each other to offset the effects of thermal shrinkage.

4.2.4 Composite modules. These modules have a stack-bonded hot face layer of ceramic fibre which is fixed to one or more layers of other suitable backing fibre or insulating slab. The immediate backing layer may be of bonded vermiculite slab, with secondary backing of mineral fibre blanket or calcium silicate slab. The module may also incorporate a final backing plate of steel sheet to form part of the furnace structure.

Anchorage may be by means of serrated alloy studs and alloy locking washers (or cup-locks); alternatively, the modules may be fixed to the furnace casing by means of heat-resisting alloy plates which are secured to studs on the inner surface of the furnace casing.

4.2.5 Pleated blanket modules. These modules are similar to those described in 4.2.3 and use pleated fibre blanket in place of stacked fibre units.

5 Anchoring systems

5.1 General. Metal alloy anchors are normally supplied in sets. A set typically comprises the following:

- a) a stud;
- b) a large diameter (approximately 40 mm) fixing washer;
- c) a mild steel rapid-fix washer for supporting the intermediate layers during installation, particularly on the roof;
- d) one or more nuts for threaded type studs;
- e) a ceramic ferrule which is used to contain the welding melt pool. This ferrule is broken away once the stud has been welded into place.

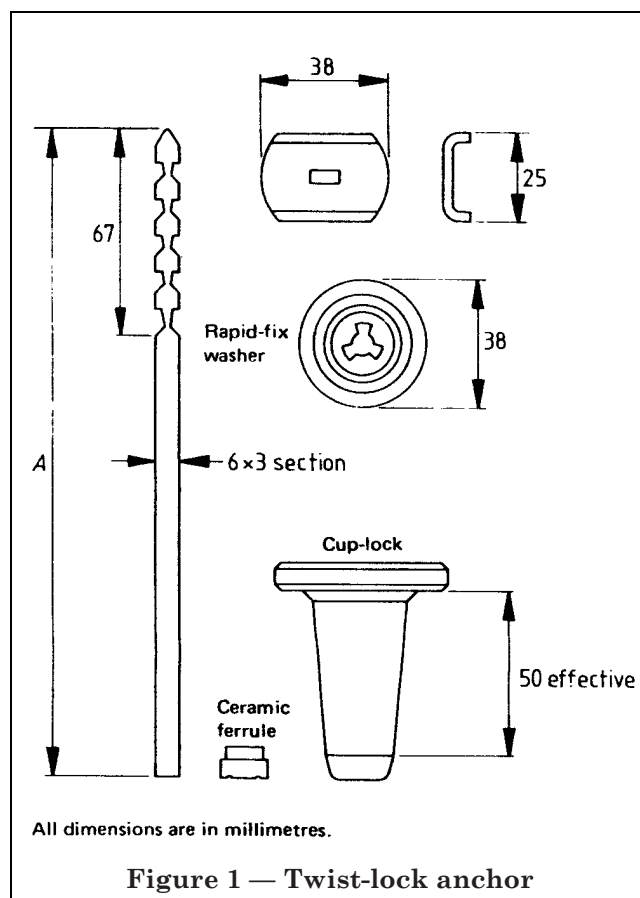
5.2 Twist-lock anchors. The anchor comprises an alloy stud of rectangular cross section (normally 6 mm × 3 mm), suitable for application by gun welding with serrations at approximately 10 mm intervals to give 3 mm square sections locally over a distance of approximately 70 mm from one end (see Figure 1). The remaining length of the stud may be plain or barbed.

5.3 Cup-lock anchors. In cases where the working temperature is beyond that recommended in Table 1 or where the atmosphere is likely to accelerate the corrosion of the metal anchor, a ceramic anchor extension described as a “cup-lock” can be used at the hot face.

Cup-locks (see Figure 1) are available for use in conjunction with either twist-lock or threaded anchors. The cup-lock secures on the twist-lock using a 90° twist action and may be held on to the threaded anchor with a suitable hexagonal nut.

5.4 Threaded anchors. The anchor (see Figure 2) comprises an alloy stud, threaded at one end, suitable for application by the gun welding technique. The stud is of circular cross section and approximately 5 mm in diameter. The threaded portion (*t*) should be:

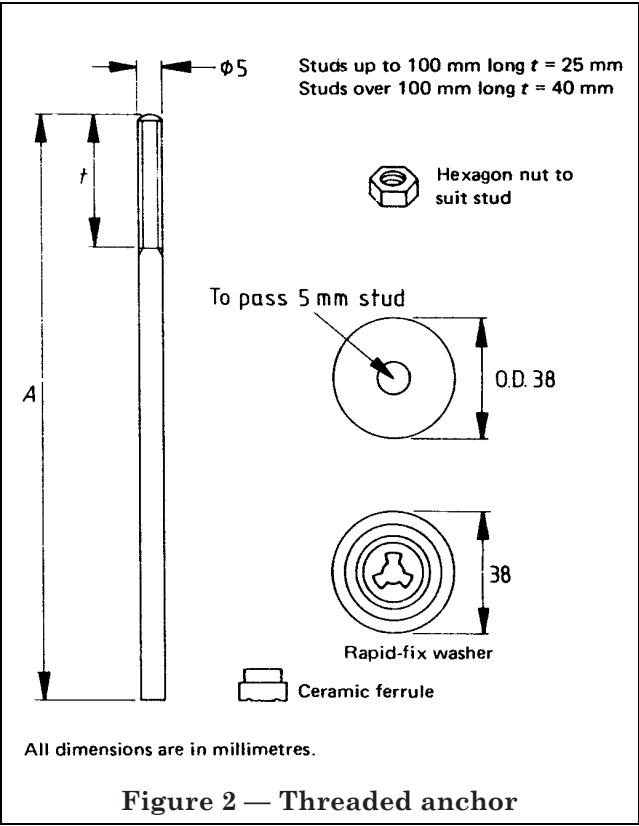
- for stud length (*A*) up to 100 mm:
threaded length 25 mm;
- for stud length (*A*) over 100 mm:
threaded length 40 mm.



5.5 Anchors threaded at both ends. These anchors are very similar to the anchors described in 5.4, except that these are threaded at both ends and supplied with three nuts so that they can be bolted on to the furnace outer casing.

5.6 Temperature of metal components. It is essential that the tip temperature for metal components does not exceed the limits given in Table 1.

Metal components of thick section are cooler than the adjacent refractory because heat is more readily lost to the atmosphere and the temperature may be as much as 200 °C lower than expected from the calculated temperature gradient in the refractory. However, the extent of the difference depends on the effectiveness of the thermal contact with the surrounding refractory and external atmosphere. The magnitude of the allowance should therefore be based on experience. With metal components of thin section, such as would normally be used in fibre constructions, the heat flow through the metal is small and it is therefore unwise to make a large allowance for this “heat drainage” effect.



6 Thermal design for steady conditions

NOTE When considering thermal design, a choice should be made between operation under steady conditions (clause 6) and under intermittent conditions (clause 7).

6.1 General

6.1.1 Where operating conditions are steady, the minimum criteria for design should be:

- a) hot face temperature;
- b) heat loss.

6.1.2 Thermal design should not be based on external surface temperatures alone. Comparisons made on this basis can be extremely misleading because of the sensitivity of external temperature to the assumptions made about heat transfer to the atmosphere. When heat loss is the major consideration, the thermal design should be based on an agreed average value of heat loss over the external surface of the equipment concerned.

6.1.3 Where the design is intended to achieve a defined external temperature, it is essential that the design contractor states the calculated heat loss. Unless otherwise agreed, the value of the external heat transfer coefficient given in Table 2 should be used; these values are based on an ambient temperature of 20 °C in still air and emissivity of 0.8.

6.1.4 The design contractor should state the bulk density, fibre orientation and the assumed values of thermal conductivity taken for the component materials; the appropriate reference temperatures should be included. Allowance should be made for the variation of thermal conductivity with temperature and with the method of test.

6.2 Use of thermal conductivity in design calculations. Since the thermal conductivity of ceramic fibre varies greatly with temperature, in a non-linear way, errors in design calculations can arise when using most published data in the conventional way. These errors, while often small, may sometimes be important.

6.3 Effect of properties of lining materials

6.3.1 General. The thermal conductivity of fibre lining materials is influenced not only by temperature but by a number of other factors such as bulk density, fibre orientation, atmospheric composition and pressure.

Table 1 — Recommended temperature limits

Steel or alloy type	British Standard reference	Maximum temperature	
		Sections ≤ 3 mm	Sections > 3 mm
		°C	°C
Carbon steel	—	450	500
Chromium nickel alloys			
18 % Cr, 8 % Ni	302S31, 304S31 (BS 970-1)	800	900
25 % Cr, 20 % Ni	310S31 (BS 970-1)	1 000	1 100
25 % Cr, 55 % Ni	—	1 200	1 200
15 % Cr, 76 % Ni	NA14 (BS 3072)	1 200	1 200

6.3.2 Bulk density. Within the normal range of available bulk densities, the conductivity usually decreases with increasing density, especially at higher temperatures. Where lining thickness is to be minimized the optimum density to give the required insulation value should normally be chosen, subject to limitations of mechanical stability.

6.3.3 Fibre orientation. Thermal conductivity of stacked fibre, where the heat flow is parallel to the main fibre orientation, is generally higher than thermal conductivity normal to the fibre orientation.

6.3.4 Atmosphere. Hydrogen and helium have high thermal conductivities and allowance for this may be necessary where these gases are present. An approximate estimate of this effect may be made by adding to the thermal conductivity of the fibre in air the difference between the conductivity of the atmosphere concerned and that of air at the appropriate temperature and pressure.

Gases at very high pressure circulate readily in highly porous materials and the insulating effect may be much reduced. Specialist advice should be sought in these cases.

For vacuum application an approximate estimate of the conductivity of the fibre may be made by subtracting the conductivity of air at the appropriate temperature.

6.4 Materials for steady conditions

6.4.1 It is necessary to distinguish between:

- a) the classification temperature;
- b) the maximum acceptable operating temperature for a material under given service conditions for a given life expectancy.

The classification temperature is defined in BS 7225-3.1. However, in the atmosphere and conditions of some industrial applications, any ceramic fibre product may have a lower than expected operating temperature, depending on chemical composition. The maximum operating temperature may then be as much as 200 °C below the classification temperature.

6.4.2 Ceramic fibre exposed to a clean furnace atmosphere as hot face material with the fibre substantially parallel to the hot face should be used at a temperature not higher than 200 °C below the classification temperature and be of bulk density group 128 kg/m³ or greater for a high reliability design and bulk density group 96 kg/m³ for a standard design (see also 6.4.5).

NOTE Bulk density groups are described in BS 7225-3.1.

6.4.3 Ceramic fibre used as a backing layer, or as in 6.4.2 but with the fibres normal to the hot face, should be used at a temperature not higher than 100 °C below the classification temperature. Similarly, fibre used as strip, forming expansion joints between non-fibrous refractory or between modular fibre units, should be used at a temperature not higher than 100 °C below the temperature referred to in 6.4.1 b). The nominal density should normally be between 64 kg/m³ and 96 kg/m³ (uncompressed) but in use the material should be designed to be in compression to half the nominal thickness. If in the form of rope, the fibre should be of similar type and density, the nominal diameter of the rope being twice the width of the expansion joint.

6.4.4 Slab or block insulation of mineral fibre, calcium silicate or similar material should be used at a temperature not higher than 100 °C below the classification temperature when employed as backing for layered blanket or in module manufacture.

6.4.5 Smaller temperature margins than those indicated in 6.4.2, 6.4.3 and 6.4.4 may be acceptable, by agreement, where the life expectancy is less than five years. Acceptable temperatures may usually be judged by reference to experience with equipment operating under similar conditions. The margins should not be less than half of those indicated for the high reliability design.

6.4.6 Where atmospheres are other than clean and oxidizing, further reduction may be necessary in deciding on an acceptable operating temperature.

7 Thermal design for intermittent heating

7.1 General. The factors affecting the design of linings for intermittently operated furnaces are complex and generalized rules are not given in this code. Clause 7 gives guidance on the principles involved but cases involving particular parameters should be examined individually. In furnaces that are used infrequently, higher design heat losses through the lining than those calculated for steady state conditions may be justified.

7.2 Effect of the properties of lining materials

7.2.1 Thermal resistance. The heat loss under steady conditions is controlled by the thermal resistance of the lining. For intermittent conditions, thermal capacity may be the dominant factor.

Table 2 — External heat losses and cold face temperatures

Cold face temperature	Heat transfer coefficient		Heat loss	
	W/(m ² K)		W/m ²	
55	9.99	1.76	350	110
60	10.33	1.82	413	130
65	10.67	1.88	480	152
70	11.02	1.94	550	175
75	11.30	1.99	620	195
80	11.64	2.05	700	220
85	11.92	2.10	775	245
90	12.21	2.15	855	270
95	12.49	2.20	935	295
100	12.83	2.26	1 025	325
105	13.06	2.30	1 110	352
110	13.34	2.35	1 200	380
115	13.63	2.40	1 290	410
120	13.91	2.45	1 390	442
125	14.25	2.51	1 500	475
130	14.48	2.55	1 590	505
135	14.82	2.61	1 700	540
140	15.10	2.66	1 810	575
145	15.39	2.71	1 920	610
150	15.67	2.76	2 040	645
155	15.96	2.81	2 150	680
160	16.24	2.86	2 270	720
165	16.52	2.91	2 400	760
170	16.81	2.96	2 520	800
175	17.15	3.02	2 660	840
180	17.43	3.07	2 790	887
185	17.72	3.12	2 920	930
190	18.00	3.17	3 060	970
195	18.34	3.23	3 210	1 020
200	18.62	3.28	3 350	1 060

NOTE Multiplying the value in W/(m² K) by 0.176 gives the value in Btu/(ft² h °F);
Multiplying the value in W/m² by 0.317 gives the value in Btu/(ft² h).

7.2.2 Thermal capacity. The thermal capacity of the hot face layer has far more effect on the heat storage than that of the backing layers. For intermittent operations the heat storage is less than that in continuous usage.

7.2.3 Thermal diffusivity. For light-weight insulations, this increases rapidly with temperature which makes quantitative calculations very difficult. Generally, fibrous linings reach equilibrium more quickly than do dense materials and the use of the thermal conductivity alone can lead to errors when assessing heat losses.

7.2.4 Lining thickness. Together with thermal conductivity, the thickness determines the thermal resistance. For intermittent operation, the optimum lining thickness may be far less than for continuous conditions, especially when the denser materials are used.

For intermittent applications increasing the thickness of brick linings can lead to an increased heat loss to the walls. With fibre linings, increasing the lining thickness always gives lower heat losses.

The heat stored in linings may reduce the thermal input for heating cycles after the first one. Although in the case of a lining with hot face insulating fire brick more heat is retained between consecutive cycles than in the case of ceramic hot face linings, the higher thermal conductivity of the brick largely offsets the benefits of this greater heat storage and, for some cycles, may be a disadvantage.

7.2.5 Limitations on rates of heating or cooling. The hot face lining material is subject to rapid changes of temperature. Limits on rates of heating and cooling may sometimes be necessary to avoid spalling or cracking of hot face brickwork but they are not necessary with fibrous materials. However furnace construction frequently includes conventional refractories as well as fibre, in which case limitations may be necessary.

7.3 Soaking times. Prolonged soaking times bring the operating procedures closer to continuous conditions and decrease the effects of low thermal mass. This is particularly true for the veneered linings in which a thin layer of fibre covers a dense refractory. Fibre linings reach equilibrium quickly and consequently give more even temperature distribution than brick linings in intermittent operations. This may mean that soaking times can be reduced, especially if their only object is to ensure that the whole of the charge attains a given temperature.

7.4 Furnace charge. The charge in a furnace may limit the rate of heating or cooling either because of its thermal mass or because of limited heat transfer throughout the charge itself. Savings in operation may sometimes be achieved by using a narrower furnace or kiln in order to heat the charge evenly but more quickly.

7.5 Materials for intermittent use. With intermittent operation, interface temperatures are often much lower than those for the steady state. This is especially true with a hot face material of low thermal mass in front of a dense backing material. However, the acceptable maximum temperature should be assumed the same as for steady conditions because the steady state may sometimes be reached.

8 Protection against erosion, abrasion and corrosion

8.1 Gas erosion

8.1.1 General. Untreated ceramic fibre blankets and felts will withstand a continuous velocity of clean gas, calculated at furnace operating temperatures, up to 15 m/s. For gas velocities near to this figure, material of 128 kg/m³ bulk density group is recommended for the hot face. Above this velocity the blanket tends to de-laminate so that the fibres can blow away from the main body of the insulation. Alternative designs are available which can tolerate higher velocities, as described in 8.1.2 to 8.1.4.

8.1.2 Use of wet felt. Wet felt is a ceramic fibre blanket to which has been added a wet inorganic binder. It should be applied in the wet state at a thickness of 6 mm to 10 mm over the exposed surface of the main ceramic fibre insulating material. The wet felt may be allowed to dry naturally (although with some risk that the binder may migrate towards the surface layers) or, preferably, it may be force-dried at temperatures of the order of 60 °C to 80 °C. It will then form a strong light-weight semi-rigid material which can be cut, sawn, or shaped as required. The dried product will tolerate surface velocities of clean gas up to about 35 m/s, calculated at furnace operating temperatures.

8.1.3 Application of surface hardener. A colloidal dispersion of silica is sprayed over the surface of the blanket or felt. This treatment does not seal the surface, which will remain porous, but it provides a sufficiently hard surface to resist velocities of clean gas up to about 25 m/s calculated at furnace operating temperatures. The hardener should be dried as described in 8.1.2. If migration of the silica sol occurs, surface peeling can result. This treatment is of uncertain effectiveness, especially if the depth of penetration is only a few millimetres and it should not be used in high reliability applications.

8.1.4 Use of stacked fibre construction. With this type of lining (see clause 10), the exposed ends of the fibres are substantially perpendicular to the direction of the gas flow. Velocities of clean gas can be tolerated, calculated at furnace operating temperatures, substantially higher than are acceptable for blanket; claims are made for successful use at 60 m/s.

8.2 Mechanical abrasion

8.2.1 General. For severe duty applications, which involve heavy vibration or entrained solid particles in the gas, it may be necessary to protect ceramic fibrous insulation with metal alloy in the form of woven or welded mesh of suitably restricted open area, with expanded or perforated alloy metal or, in extreme cases, with a complete cover of alloy sheet. Careful attention should be exercised in order to avoid heat distortion, e.g. by limiting the size of individual sheets to, for example, 1 m square and by allowing ample facilities for expansion movement at supporting or securing attachments and with adequate overlaps at the edges. With expanded metal, the strands should be orientated in such a way that gases will be deflected away from the fibrous insulating material.

The alloys used should depend on the maximum anticipated service temperature, but generally they are likely to be one of the austenitic stainless steels or a suitable high nickel alloy, as in 8.2.2.

8.2.2 Protection with alloy mesh. As protection against surface abrasion in high temperature environments, where it is necessary to retain flexibility, e.g. from rubbing action at door seals, or from repeated handling of removable portions of insulating material, it is convenient to cover the exposed surface with knitted or woven alloy wire mesh.

The ceramic fibre, in blanket, strip, or rope form, should be of adequate bulk density for the intended application, e.g. 128 kg/m³ bulk density group and the metallic cover should be of appropriate temperature and abrasion resistance for the required service conditions. This cover may be wrapped completely round the fibrous insulating component or it may be secured only as a surface protective cover by means of alloy stud anchors. Metallic knitted fabric is flexible and so will yield readily under impressed forces.

An extensive range of knitted fabrics is available, in various alloys and with various sizes of openings between strands. Typical protective coverings are knitted from alloy wire of diameter 0.15 mm with openings from 3.5 mm to 2.0 mm for fine fabrics, or 0.25 mm diameter with openings from 12 mm to 5 mm for coarser fabrics. Suitable alloys are given in Table 1, but for these fine wire meshes it is recommended that the upper temperature limits in column 2 should be reduced by 100 °C.

Woven wire mesh may be used for large areas of flat surface but it will be difficult to retain this uniformly, because of thermal movement with consequent distortion at elevated temperatures. A typical material would be woven from wire of approximately 0.10 mm diameter, in the alloys described above.

8.3 Corrosion with high-sulphur fuels

8.3.1 When high-sulphur fuels are used the sulphur oxidizes and, with the moisture in the combustion gases, forms acids which will condense on surfaces below the dew-point and will produce severe corrosion. The severity of the corrosion increases with the sulphur content in the fuel and especially with the amount of excess oxygen in the atmosphere which increases the amount of sulphuric acid. The dew-point and the concentration of the acid also vary with these conditions. The most important of these effects is the temperature of the metal surfaces; if it is below the acid dew-point then corrosion will occur and the severity increases to a maximum at around 40 °C below the dew-point. Typically the dew-point may be in the range 120 °C to 140 °C and the concentration of the condensed sulphuric acid in the range 50 % to 80 % V/V.

8.3.2 Ceramic fibres show good resistance to acid corrosion but, whatever the refractory lining, it is difficult to prevent corrosion of steel furnace casings especially where a large variation in ambient temperature or intermittent operation causes a large variation in the casing temperature. Circumstances may permit linings for continuous operation to be designed with casing temperature above the dew-point but this may produce unacceptably high heat loss.

8.3.3 Coatings are marketed, usually based on high-temperature bitumens, which are claimed to provide protection for steel surfaces. The combination of high temperature and strong sulphuric acid is very damaging and the resistance of coatings to these conditions may be very much lower or more short-lived than some of the claims may suggest. When considering the suitability of coatings the technical evidence, from validated experience or extended laboratory testing, should be critically examined. Where coatings are used, good surface preparation and careful application are essential. It may be necessary to accept that corrosion cannot entirely be prevented and choice of plate thickness may then need to incorporate some corrosion allowance.

8.3.4 Partial protection may be obtained by using a layer of aluminium or stainless steel foil in the lining as a barrier to the diffusion of acid vapour. The barrier is a purely mechanical one and the effectiveness depends on continuity; providing this continuity around support studs is difficult and care in installing the foil is necessary. Aluminium foil is cheaper and easier to use but it is essential to ensure that it will not itself fall below the dew-point or rise above the melting point; liquid aluminium may embrittle austenitic steel support components. When the lining design incorporates this foil, the temperature conditions should therefore be checked for the extremes of ambient and operating temperatures.

8.3.5 There may be increased susceptibility to corrosion, where the conditions for it exist, at junctions between mild steel casing plate and austenitic steel studs. Since the lining is supported at these points it is specially important that they are not weakened by corrosion. Traces of chloride ion will always be present and this may give rise to the risk of stress-corrosion cracking in austenitic steel studs.

These risks will be lessened by the tendency for heat leakage along the studs to produce a locally higher temperature which may raise the temperature above the dew-point. Consideration should be given to the use of short mild steel studs in contact with the casing, removing the dissimilar metal junction to a higher-temperature position in the lining where condensation will not occur.

Section 3. Design for installation

9 In situ linings

9.1 General. Some aspects of installation require consideration as part of the design because of their influence on the effectiveness of the completed lining. While improvisation is often necessary in minor detail, it is essential that this be minimized especially where a high reliability design is required. It is essential that details such as joints, roof and wall junctions, corners, burner and door openings and surrounds are considered as part of the design. This code does not seek to inhibit individual solutions to the construction of such features, but to establish minimum standards against which alternatives should be evaluated.

9.2 Layered blanket. The minimum suitable number of layers should be used to reduce installation cost. The use of mineral wool as the backing insulation is normally cheapest, but where the loss of a hot face layer could be hazardous, as in roof lining, it may be safer to use ceramic fibre throughout. Where a combination of mineral wool and ceramic fibre is used, the latter should be in not less than two layers.

For some installations it is convenient to roll out the blanket vertically but horizontal application is preferable when scaffolding makes the alternative difficult.

The direction of gas flow should be considered when deciding the orientation of the joints.

In certain locations that are vulnerable to mechanical damage, such as access doors and openings for tubes or burners, consideration should be given to the possible need for the local use of a dense refractory.

Ceramic fibres have low resistance to erosion by high velocity gas, to abrasive particles and mechanical or physical abuse. In these conditions and depending on their severity, measures available to increase the durability of the lining will range from applying a coating of rigidizer to cladding the hot face of the blanket with high temperature alloy mesh (see **8.2.2**). It is essential that any such treatment is allowed for in the lining design and should not be left for a site decision by the installer.

Hot face layers should be designed with due allowance for the shrinkage of the blanket that takes place during service (see also **13.3.5**).

9.3 Anchoring systems. Several proprietary anchoring systems are used, some based on metallic studs, others based on metal studs with ceramic fittings in which the ceramic component is exposed to the furnace interior. The ceramic components are often hollow and the end of the metal stud that penetrates into the interior of the ceramic component is covered with refractory cement for protection.

The choice of anchoring method used should take into account the temperature of operation and the vulnerability to mechanical damage.

Preference should be given to anchoring methods in which positive interlocking is provided in order to minimize the chance of imperfect fitting or of the anchoring working loose.