TECHNICAL REPORT

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Fire resistance — Tests for thermo-physical and mechanical properties of structural materials at elevated temperatures for fire engineering design

Résistance au feu — Essais des propriétés thermophysiques et mécaniques des matériaux aux températures élevées pour la conception de l'ingénierie contre l'incendie

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 15655 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 2, *Fire containment*.

ISO/TR 15655 is one of a series of documents developed by ISO/TC 92 that provide guidance on important aspects of calculation methods for fire resistance of structures. The others in this series are currently in preparation and include:

— ISO/TS 15656, *Fire resistance — Guide for evaluating the capability of calculation models for structural fire behaviour*

— ISO/TS 15657, *Fire resistance — Guidelines on computational structural fire design*

— ISO/TS 15658, *Fire resistance — Guidelines for full scale structural fire tests*

Other related documents developed by ISO/TC 92/SC 2 that also provide data and information for the determination of fire resistance include:

— ISO 834 (all parts), *Fire-resistance tests — Elements of building construction*

— ISO/TR 10158, *Principles and rationale underlying calculation methods in relation to fire resistance of structural elements*

— ISO/TR 12470, *Fire-resistance tests — Guidance on the application and extension of results*

— ISO/TR 12471[1)], *Computational structural fire design — State of the art and the need for further development of calculation models and for fire tests for determination of input material data required*

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1) In preparation.

Introduction

Fire engineering has developed to the stage whereby detailed calculation procedures are now being carried out to establish the behaviour of structural elements and frames under the action of fire. These cover standard fire resistance furnace tests such as ISO 834[1] as well as natural/real fires, in which performance based criteria covering stability, integrity and insulation may need to be determined.

As fire engineering is advanced through the development of design codes and standards, there is an increasing need to provide as inputs to the numerical calculations, the thermal and mechanical properties of construction materials at elevated temperatures. In addition, as part of the process in applying rules for the interpolation and extension of fire resistance test results, specific data on material properties is often required to conduct assessments on variations in construction other than those tested.

It is important therefore, that information on the behaviour of structural materials at elevated temperatures is available to the fire engineer and confidence is provided in its use as a result of being determined using established and accepted laboratory techniques and test standards. Since it is also possible to determine the properties of materials under a variety of experimental conditions, those adopted should reflect the heating and loading conditions that may be experienced in either real fires or standard fire resistance tests.

The objectives of this Technical Report relate to test methods for determining the thermal and mechanical properties of construction materials for use in fire engineering design and has therefore been prepared to:

— Identify the existence of national or International Standards that provide suitable test methods for determining the thermal and mechanical properties at elevated temperatures of materials used in load bearing construction.

— Identify whether the test methods are based upon steady state or transient heating conditions and provide information on the limits of experimental conditions. For steady state tests, comment where possible, on the sensitivity of the parameter to the heating conditions and/or the suitability of the method being adopted for transient tests.

— Identify through the scientific literature, experimental techniques that have been used to determine a material property, which may be adopted by a standards body as a basis for further development into a full test standard. However, it should be noted that it is not the intention of this Technical Report to provide a definitive list of references but sources of information are given as an aid to initially reviewing some of the work conducted in a particular field of research.

— Comment on the limitations of developing a test method for a particular thermal or mechanical property in which it may be more appropriate to measure a combination of properties.

— Identify/prioritize the need for test methods that will have an immediate benefit in providing data for fire engineering calculations.

Currently, there is an active technical group of leading experts working in the field of developing test methods for concrete members. This work is being conducted within International Union of Testing and Research Laboratories for Materials and Structures, RILEM TC 129-MHT, under the convenorship of Professor Schneider. In this Technical Report, reference is made to test methods being currently developed which are applicable to concrete structures exposed to fire. In some cases, the test methods being developed could be applied to the testing of masonry products.

Fire resistance — Tests for thermo-physical and mechanical properties of structural materials at elevated temperatures for fire engineering design

1 Scope

This Technical Report identifies test methods already in existence and provides guidance on those that need to be developed to characterize the thermo-physical and mechanical properties of structural materials at elevated temperatures for use in fire safety engineering calculations.

It is applicable to materials used in load-bearing construction in which structural and thermal calculations might be required to assess the performance of elements or systems exposed to either standard fire tests, real or design fire heating conditions.

It is recognized that the elevated temperature properties of materials can be determined under a variety of conditions. Since fire is a relatively short transient process lasting from a few minutes to several hours, ideally, the properties determined should reflect the transient thermal and loading conditions as well as the duration of heating that may be experienced in practice. However, it is also recognized that some properties are relatively insensitive to the transient conditions and therefore, alternative steady state test methods may be appropriate. Some properties are sensitive to orientation effects, for example timber, and these should be considered with respect to how the tests are conducted.

In cases where materials undergo either a chemical or a physical reaction during the heating process, it might be impossible to determine an individual property. This Technical Report gives guidance in selecting a test method to determine an effective value representing a combination of properties. It is also recognized that a test specimen may be comprised of a small construction such as that used in the testing of masonry. This often involves building a mini assembly to form a pyramid in order to represent the true behaviour.

Apart from the traditional construction materials such as metals, concrete, masonry and wood, the use of plastics and fibre reinforcement is becoming more common. Therefore these materials have also been included in this Technical Report to reflect possible future changes in design and advances in materials technology.

In the past, the behaviour of jointing systems in fire has only received a little interest yet their behaviour is fundamental to the performance of composite elements and structural frames. This Technical Report also addresses jointing systems under individual materials, for example welds for steel, glues for timber. However, in many cases, the end use of an adhesive is not clear or it covers a range of applications. For this reason a separate category for adhesives is included.

For some materials, it has not been possible to identify an existing standard or laboratory procedure for conducting tests at elevated temperatures under either steady state or transient heating conditions. In these cases, standards for conducting tests at ambient temperature are identified. These may be considered to form the basis for development into a test method suitable at elevated temperatures.

Based upon current fire design methodologies and those that are beginning to receive attention, Table 1 and Table 2 summarize the requirements and availability of test methods for measuring the thermal and mechanical properties considered to have an immediate priority.

NOTE For composite concrete and steel structures the material properties required are addressed under each individual material.

Table 1 —Summary of test methods available for measuring the thermo-physical properties at elevated temperatures

Thermal property	Material					
	Metals	Concrete	Masonry	Wood	Plastics, fibre reinforcement, organic and inorganic	Adhesives
Specific heat	L[a]	L[a], S[a]	S[a], L[b]	L[b]	S[a], L[b]	S[a], L[b]
Thermal conductivity	L[b]	L[b], S[b]	L[b], S[b]	L[a], S[b]	L[b], S[b]	L[b]
Thermal diffusivity	L[a]	L[a], S[b]	L[a], S[b]	L[a]	L[a], S[b]	L[a]
Linear expansion	L[a]	L[a], S[b]	L[a], S[b]	—	S[a]	S[a]
Linear contraction	L[a]	L[a], S[b]	L[a], S[b]	—	S[a]	S[a]
Density	—	S[a]	S[a]	L[a]	S[a]	L[a], S[a]
Charring rate	—	—	—	L[a], S[a]	—	—
Emissivity	L[a]	L[a], S[a]	L[a], S[a]	S[a]	S[a]	S[a]
Spalling	—	L[a], S[b]	L[a], S[a]	—	—	—
Shrinkage	—	S[a]	S[a]	—	—	—
Moisture	—	S[a]	S[a]	L[a]	—	—
Others	—	—	—	—	—	—

L Laboratory test method

S Standard test method

— Property not required

[a] Laboratory or standard test method available suitable for fire engineering but may still require further development.

[b] Laboratory or standard test method may be suitable for elevated temperature testing but requires further development into a transient test to be suitable for fire engineering.

Table 2 —Summary of test methods available for measuring the mechanical properties at elevated temperatures

Mechanical property		Material					
		Metals	Concrete	Masonry	Wood	Plastics, fibre reinforcement, organic and inorganic	Adhesives
Elastic modulus		L[a]	L[a], S[a]	L[a]	L[a]	X	X
Shear modulus		—	—	X	—	X	—
Modulus of rupture		—	—	S[b]	—	—	—
Poissons ratio		—	L[a]	—	L[a]	X	—
Creep		S[a]	L[a]	L[a], S[b]	L[a]	X	X
Stress relaxation		L[a], S[a]	L[a]	—	—	—	—
Bauschinger effect		X	—	—	—	—	—
Stress/strain	Steady state	S[a]	L[a]	L[a]	—	X	—
	Transient state	L[a]	L[a]	L[a]	—	X	—
Ultimate strength	Compression	X	L[a]	L[a]	L[b]	X	X
	Shear	—	—	X	L[b]	X	X
	Tension	L[a], S[a]	L[a]	—	L[b]	X	X
Adhesive strength	Shear	—	—	—	L[b]	—	S[b]
	Tension	—	—	—	L[b]	—	S[b]
	Delamination	—	—	—	X	—	—
Bending/flexure strength		—	—	X	X	—	S[b]
Joints (in general)		L[a]	—	X	X	X	—
Others		—	—	—	—	—	—

L Laboratory test method
S Standard test method
X No elevated temperature test method available
— Property not required

[a] Laboratory or standard test method available suitable for fire engineering but may still require further development.

[b] Laboratory or standard test method may be suitable for elevated temperature testing but requires further development into a transient test to be suitable for fire engineering.

2 Tests for thermal properties at elevated temperatures

2.1 Metals

2.1.1 General

In this section metals that may be used as structural components include aluminium alloys, mild and micro-alloyed steels and stainless steels. Under fire conditions, the heating rates of interest will generally fall within the range 1 °C/min to 50 °C/min. The extremes represent situations from heavily protected steelwork such as reinforcement encased within several inches of concrete cover to fully exposed members.

It is recommended that test methods for thermal properties should be capable of evaluating steels at temperatures up to 1 200 °C, and aluminium up to 600 °C.

2.1.2 Specific heat

2.1.2.1 National or International Standards

There is no standard identified specifically for metals although reference should be made to ISO 11357-1[3] for using the differential scanning calorimeter.

2.1.2.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out by the following:

- The differential scanning calorimeter has been used under transient heating conditions for heating rates up to 10 °C/min for aluminium and steel. However, for steel it is not particularly suitable for temperatures greater than the transformation temperature (approximately 720 °C).

- The potential drop calorimeter/spot methods have been carried out on steel at temperatures up to 1 300 °C. Pallister[4] [5] has reported a test procedure in which specimens are heated at rates of up to 10 °C/min, momentarily stabilized and then subjected to a controlled electrical pulse. The resulting change in temperature is accurately measured. The test method is also used to measure specific heat during cooling. Although the test method was developed for steel, the technique can in principle, be applied to aluminium.

- A similar electrical adiabatic technique is reported by Awberry[6] in which measurements on steel samples are taken continuously as they are heated at a rate of 3 °C/min.

A more detailed review of the specific heat data for steels and the measuring techniques are presented in a paper by Preston[7].

Although no test standard has been identified, techniques for measuring the specific heat of metals have been established for several years and could readily form the basis of a standard.

2.1.3 Thermal conductivity

2.1.3.1 National or International Standards

See ISO 8301[8] and ISO 8302[9].

2.1.3.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out by the following:

- Powell[10] describes a method for measuring thermal conductivity under transient heating conditions for steel using a heating rate of 3 °C/min to 4 °C/min. The technique involves measuring the electrical resistivity at elevated temperatures during continuous heating up to 1 300 °C.

- Measurements of thermal conductivity during continuous (transient) longitudinal and radial heat flow have been described in Reference [11] of the Bibliography. Tests have been conducted on steel for temperatures up to 1 000 °C. As before, the methods rely on measuring changes in electrical resistance for establishing thermal conductivity.

2.1.4 Thermal diffusivity

2.1.4.1 National or International Standards

No standards have been identified.

2.1.4.2 Laboratory test methods or procedures under development

A new method for measuring thermal conductivity and diffusivity that is similar in principle to the hot wire, has been developed by Gustaffsson[12]. This is referred to as the transient plane source (TPS) technique.

The experimental procedure has been described in papers by Grauers and Persson[13] and Log and Gustaffsson[14]. A thin layer of electrically conducting material (nickel) which acts as both a heat source and a temperature-measuring device is sandwiched between two samples of the material. The assembly is heated in a conventional furnace to the desired temperature and stabilized to avoid any thermal gradients before the electrical pulse is triggered. The temperature rise of the metal strip, which is measured by its change in resistivity, depends upon the rate heat is conducted into the material.

Success has been reported in applying the technique for measuring the thermal conductivity and diffusivity for several materials including stainless steel and aluminium. However, no information has been found to demonstrate that it has been used in metals and alloys at elevated temperatures. For other materials, it has been used successfully at temperatures up to 1 000 K. Currently the test method has only been developed for steady state heating conditions. Although the authors state that the technique could be combined with the constant rate of temperature rise (CRTR) method for measuring diffusivity, which is carried out under transient heating conditions, this is questionable. However, the advantage of the technique is that from a single test, values for the combined effect of more than one parameter are obtained.

2.1.5 Thermal strain (expansion and contraction)

2.1.5.1 National or International Standards

No standards have been identified.

2.1.5.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out by the following:

— British Steel Swinden Technology, UK;

— National Physical Laboratory, UK;

— Welding Institute, UK.

Although no test standards could be identified, commercial equipment exist that rely on being able to accurately measure both expansion and contraction as part of studying metallurgical transformation processes in metals and alloys. These are generally referred to as “dilatometer” tests in which heating rates in excess of 100 °C/s can be accurately controlled from ambient temperature up to the melting point. Specimens are generally heated by electrical induction or resistance heating often through the specimen itself, and are capable of replicating heating cycles used in fire resistance tests and natural fires. For carbon steel there is a heating rate dependence through the magnetic transformation temperature (approximately 740 °C).

The laboratory procedures could be readily developed into a standard.

2.1.6 Emissivity

2.1.6.1 National or International Standards

No standard identified specifically for metals but reference should be made to ISO 8990[15] for calibrated and guarded hot box.

2.1.6.2 Laboratory test methods or procedures under development

“Black box” calibration methods are widely used in many laboratories.

It is recommended to use steady state methods for measuring emissivity.

2.2 Concrete

2.2.1 General

During heating, concrete undergoes both chemical and physical changes such as loss of moisture, dehydration, de-carbonization, quartz conversion, etc. These effects can have a significant influence on the thermal and mechanical performance of structural elements at elevated temperatures. For the majority of test methods carried out to determine the thermal and mechanical properties, it is preferable that these are conducted under transient heating conditions.

Since concrete is a poor conductor of heat, in order to reflect the majority of fire conditions, it is recommended that tests be carried out at heating rates within the range of 0,5 °C/min to 10 °C/min with an upper limit of 1 000 °C.

2.2.2 Specific heat

2.2.2.1 National or International standard

The differential scanning calorimeter (DSC), ISO 11357-1[3], has been successfully applied to evaluating concrete under transient heating conditions but is limited in its application to temperatures up to around 500 °C.

2.2.2.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out by the following:

— Japan Testing Centre for Construction Materials, T = 20 °C to 150 °C;

— General Building Research Corporation of Japan, T = 20 °C to 90 °C;

— Swedish National Testing Research Institute, transient test method is used.

2.2.3 Thermal conductivity

2.2.3.1 National or International Standards

The following national standards have been found which could be adopted or are already in place for testing concrete. Each method is based upon steady state heating conditions:

a) BS 1902-5.5[16];

b) BS 1902-5.6[17];

c) BS 1902-5.8[18];

d) JIS A1412[19] used at:

   1) Japan Testing Centre for Construction Materials (small scale tests);

   2) General Building Research Corporation of Japan (small scale tests);

e) ISO 8301[8];

f) ISO 8302[9];

g) JIS R2618[20].

2.2.3.2 Laboratory test methods or procedures under development

A new method for measuring thermal conductivity and diffusivity that is similar in principle to the hot wire, has been developed by Gustaffsson[12]. This is referred to as the transient plane source (TPS) technique.

The experimental procedure has been described in papers by Grauers and Persson[13] and Log and Gustaffsson[14]. A thin layer of electrically conducting material (nickel) which acts as both a heat source and a temperature-measuring device, is sandwiched between two samples of the material. The assembly is heated in a conventional furnace to the desired temperature and stabilized to avoid any thermal gradients before the electrical pulse is triggered. The temperature rise of the metal strip, which is measured by its change in resistivity, depends upon the rate heat is conducted into the material.

Success has been reported in applying the technique for measuring the thermal conductivity and diffusivity for several materials including concrete at temperatures up to 1 000 K. Currently the test method has only been developed for steady state heating conditions. However, the authors state that the technique could be combined with the constant rate of temperature rise (CRTR) method for measuring diffusivity, which is carried out under transient heating conditions. Furthermore, this technique is questionable and warrants further investigation.

2.2.4 Thermal diffusivity

2.2.4.1 National or International Standards

The following standards have been identified for steady state heating conditions:

a) JIS A1325[21] is used at:

   1) Japan Testing Centre for Construction Materials;

   2) General Building Research Corporation of Japan, T = 20 °C to 90 °C.

b) ENV 1159-2[22]. This standard was originally developed for evaluating ceramic matrix composites with continuous reinforcement. It involves a laser flash experimental procedure that is carried out under steady state heating conditions at temperatures up to 2 800 K.

2.2.4.2 Laboratory test methods or procedures under development

The transient plane source test method described in 2.2.2.2 can also be used to determine thermal diffusivity. However, the technique needs to be further developed in conjunction with the constant rate temperature rise method for transient heating conditions.

Measuring the diffusivity of concrete using the transient plane source technique avoids the necessity of requiring the specific heat to be determined for calculating heat transfer characteristics. In this respect, more accurate information may be obtained particularly where physical and chemical changes affect mass transport properties.

Laboratory test methods or procedures under development are being carried by the Swedish National Testing and Research Institute.

2.2.5 Thermal strain (expansion and contraction)

2.2.5.1 National or International Standards

BS 1902-5[23], describes a steady state method for refractory based materials for temperatures up to 1 100 °C, which may be considered for adoption for concrete. However, since concrete undergoes both thermal and physical changes during heating, it is preferable that a transient test method be eventually developed.

2.2.5.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are as follows:

- A laboratory test method (steady state) is used at the Japan Testing Centre for Construction Materials.
- Within RILEM TC 129-MHT[2] a transient test method has been developed which enables axial thermal strain to be measured over the temperature range of 20 °C to 1 000 °C and above. The procedure is briefly described as follows:

  Specimens are heated slowly between 0,5 °C/min and 2,0 °C/min to a specific surface temperature and held for a period of 1 h. Thermal expansion is recorded as a function between the average surface and core temperatures. The test method also allows contraction of concrete during cooling to be measured. This involves a similar procedure described for expansion but under reverse heating conditions.

  In this test, a distinction is made between specimens referred to as "drying" and "non-drying" concrete. Non-drying concrete condition exists when moisture is prevented from escaping during the test. For structural elements in the fire state, this condition may occur in large member sizes when the distance to the surface is greater than 200 mm. "Drying" concrete allows the moisture to freely escape. For the latter, where it is not possible to separate the effects of moisture and therefore the thermal strain measured is regarded as the total thermal strain for the specimen.

It is also recognized for some types of low expansion concrete, shrinkage due to the loss in moisture and dehydration effects may result in net contraction during the heating phase.

Although a national standard currently exists for measuring contraction and expansion, due to changes in chemical and physical properties during heating, it is preferable that a procedure be available for transient heating conditions. In this respect, it is recommended the procedures given in RILEM TC 129-MHT[2] be the basis for developing a standard.

2.2.6 Density

2.2.6.1 General

It is recommended to use a steady state method to measure density.

2.2.6.2 National or International Standards

EN 678[24] describes a test method for the determination of the dry density of autoclaved aerated concrete that may be considered for adoption for concrete.

2.2.6.3 Laboratory test methods or procedures under development

No standards have been identified.

2.2.7 Emissivity

2.2.7.1 National or International Standards

The following standards have been identified.

a) JIS A 1423[25] is used by:

   1) Japan Testing Centre for Construction Materials;

   2) General Building Research Corporation of Japan.

b) See also ISO 8990[15] for the calibrated and guarded hot box.

It is recommended to use steady state methods for measuring emissivity.

2.2.7.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are standard “black box” methods.

2.2.8 Spalling

2.2.8.1 National or International Standards

BS 1902-5.11[26], developed for refractory materials, may be considered for adoption.

2.2.8.2 Laboratory test methods and procedures under development

Laboratory test methods or procedures under development are being carried out at the following:

— Japan Testing Centre for Construction Materials;

— General Building Research Corporation of Japan;

— VTT building technology, Finland.

See also References [27] and [28] in the Bibliography.

2.2.9 Expansion/shrinkage

2.2.9.1 National or International Standards

EN 680[29] describes a test method for the determination of the drying shrinkage of autoclaved aerated concrete that is appropriate for *in situ* concrete.

2.2.9.2 Laboratory test methods or procedures under development

No test methods or procedures under development have been identified.

2.2.10 Moisture

2.2.10.1 National or International Standards

EN 1353[30], describes a test method for pre-fabricated autoclaved aerated concrete that is appropriate for concrete and is used by:

a) Japan Testing Centre for Construction Materials (small scale tests);

b) General Building Research Corporation of Japan.

2.2.10.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

2.3 Masonry

2.3.1 Specific heat

2.3.1.1 National or International Standards

ISO 11357-1[3] describes the use of the differential scanning calorimeter (DSC) under transient heating conditions.

2.3.1.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out at the following:

— Japan Testing Centre for Construction Materials, T = 20 °C to 150 °C;

— General Building Research Corporation of Japan, T = 20 °C to 90 °C;

— Swedish National Research Institute.

2.3.2 Thermal conductivity

2.3.2.1 National or International Standards

The following national standards have been found which may be considered for adoption, or are already in place for testing masonry. Each method is based upon steady state heating conditions:

a) BS 1902-5.5[16];

b) BS 1902-5.6[17];

c) BS 1902-5.8[18];

d) JIS A1412[19] is used at:

   1) Japan Testing Centre for Construction Materials;

   2) General Building Research Corporation of Japan;

e) ASTM C201-47[31];

f) EN 993-14[32];

g) ISO 8894-1[33];

h) EN 993-14[34];

i) ISO 8301[8];

j) ISO 8302[9];

k) JIS R2618[20].

2.3.2.2 Laboratory test methods or procedures under development

A new method for measuring thermal conductivity and diffusivity that is similar in principle to the hot wire, has been developed by Gustafsson[12]. This is referred to as the transient plane source (TPS) technique.

The experimental procedure has been described in papers by Grauers and Persson[13] and Log and Gustafsson[14]. A thin layer of electrically conducting material (nickel) which, acts as both a heat source and a temperature-measuring device, is sandwiched between two samples of the material. The assembly is heated in a conventional furnace to the desired temperature and stabilized to avoid any thermal gradients before the electrical pulse is triggered. The temperature rise of the metal strip, which is measured by its change in resistivity, depends upon the rate heat is conducted into the material.

Success has been reported in applying the technique for measuring the thermal conductivity and diffusivity for several materials including concrete at temperatures up to 1 000 °C. Currently the test method has only been developed for steady state heating conditions. However, the authors state that the technique could be combined with the constant rate of temperature rise (CRTR) method for measuring diffusivity, which is carried out under transient heating conditions. However, this technique is questionable and requires further investigation.

Laboratory test methods or procedures under development are being carried out at the following:

— Swedish National Testing and Research Institute;

— British Steel Technical.

2.3.3 Thermal diffusivity

2.3.3.1 National or International Standards

The following standards have been identified for steady state heating conditions:

a) JIS A1412[19], which is used at:

   1) Japan Testing Centre for Construction Materials;

   2) General Building Research Corporation of Japan, T = 20 °C to 200 °C;

b) ENV 1159-2[22]. This standard was originally developed for ceramic matrix composites with continuous reinforcements. It involves a laser flash experimental procedure that is carried out under steady state heating conditions at temperatures up to 2 800 K.

2.3.3.2 Laboratory test methods or procedures under development

The transient plane source test method described in 2.3.2.2, can also be used to determine thermal diffusivity. However, the technique needs to be further developed in conjunction with the constant rate temperature rise method for transient heating conditions.

Measuring the diffusivity of masonry using this technique avoids the necessity of requiring the specific heat to be determined for calculating heat transfer characteristics. In this respect, more accurate information may be obtained particularly where physical and chemical changes affect mass transport properties.

Laboratory test methods or procedures under development are being carried by the Swedish National Testing and Research Institute.

2.3.4 Thermal strain (expansion and contraction)

2.3.4.1 National or International Standards

The following standards have been identified:

a) BS 1902-5.14[35], describes a steady state method for refractory based materials for temperatures up to 1 100 °C. The technique is based upon the split column method which could be adopted for masonry.

However, since masonry undergoes both thermal and physical changes during heating, it is preferable that a transient test method be employed.

b) JIS A1325[21] is used at Japan Institute Testing Centre for Construction Materials.

2.3.4.2 Laboratory test methods or procedures under development

Under RILEM TC129-MHT[2], a transient test method has been developed for concrete which enables axial thermal strain to be measured over the temperature range of 20 °C to 1 000 °C and above. With further work, the method may be developed for evaluating masonry under transient heating conditions. The procedure is briefly described as follows:

a) Specimens are heated slowly between 0,5 °C/min and 2,0 °C/min to a specific surface temperature and held for a period of 1 h. During this time, thermal expansion is measured as heat is conducted from the surface to the specimen core. Thermal expansion is recorded as a function between the average surface and core temperatures. The test method also allows contraction during cooling to be measured. This involves a similar procedure described for expansion but under reverse heating conditions.

b) In the test, a distinction is made between “drying” and “non-drying” specimens. The non-drying condition exists when moisture is prevented from escaping during the test. In the fire condition this may occur in large member sizes when the distance to the surface is greater than 200 mm. “Drying” condition allows the moisture to freely escape. For the latter, where it is not possible to separate the effects of moisture the strain measured is regarded as the total thermal strain for the specimen. For some masonry products, the influence of moisture on the thermal properties may not be as severe as for concrete.

It is also recognized for some types of low expansion materials, shrinkage due to the loss in moisture and dehydration effects may result in net contraction during the heating phase.

Although a national standard currently exists for measuring contraction and expansion, due to changes in chemical and physical properties during heating, it is preferable a procedure is available for transient heating conditions. In this respect, it is recommended that the procedures developed in RILEM[2] described above which have been developed for concrete could in principle, be applied to masonry products. These may be considered to provide the basis for developing a standard. However, as with concrete, the temperature range would need to be extended to a surface temperature of 1 000 °C.

2.3.5 Density

2.3.5.1 National or International Standards

EN 678[24] describes a method for measuring the dry density of autoclaved aerated concrete that may be considered for use with other masonry products. Reference should also be made to EN 772-10[36] and EN 772-13[37] for suitable test methods to be considered.

2.3.5.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

2.3.6 Emissivity

2.3.6.1 National or International Standards

The following standards have been identified:

a) JIS A1423[25], which is used by:

— Japan Testing Centre for Construction Materials.

— General Building Research Corporation of Japan.

b) See also ISO 8990[15] for steady state methods describing the use of the calibrated and guarded hot box.

It is recommended to use steady state methods for measuring emissivity.

2.3.6.2 Laboratory test methods or procedures under development

Standard “black box” methods are laboratory test methods or procedures under development.

2.3.7 Spalling

2.3.7.1 National or International Standards

BS 1902-5.11[26], developed for refractory materials, may be considered for adoption.

2.3.7.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out by the following:

- Japan Testing Centre for Construction Materials;
- General Building Research Corporation of Japan;
- VTT Building Technology, Finland.

See also References [27] and [28] in the Bibliography for concrete that may be possible to adopt for masonry products.

2.3.8 Expansion/shrinkage

2.3.8.1 National or International Standards

EN 680[29] describes a test method for the determination of the drying shrinkage of autoclaved aerated concrete. Reference should also be made to BS 6073:1981[38].

2.3.8.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

2.3.9 Moisture content

2.3.9.1 National or International Standards

EN 1353[30] describes a test method for pre-fabricated autoclaved aerated concrete that could be adopted for other masonry products.

2.3.9.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

2.4 Wood

2.4.1 General

During heating, the thermal properties are affected by both chemical and physical changes and therefore transient test methods are generally preferred for determining the majority of properties. This penalizes a number of steady state procedures since they rely upon achieving steady state conditions over a considerable time before the measurements are made. A review of the various test methods for thermal properties is presented in a report prepared under RILEM TC 74 THT. Reference should also be made to a major review by Tenwolde *et al*[39] on the thermal properties of wood.

In general, it is recommended that transient tests be carried out using heating rates between 1 °C/min and 10 °C/min with maximum surface temperatures of 1 000 °C.

2.4.2 Specific heat

2.4.2.1 National or International Standards

No standards have been identified.

2.4.2.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out by the following:

— Building Research Institute, Prague. Samples are heated in an oven and placed within a non-adiabatic calibrated calorimeter[40].

— Japan testing Centre for Construction Materials. Properties are determined up to 150 °C.

— General Building Research Corporation of Japan. Properties are determined up to 200 °C.

2.4.3 Thermal conductivity

2.4.3.1 General

Apart from grain orientation, the thermal conductivity of wood is a function of its oven dry density, moisture content and temperature. For charred wood only the oven, dry density and temperature are important. References in the literature refer to deriving the thermal conductivity of wood for both wet and dry conditions and are discussed in a review paper by Janssens[41]. The methods employed should be considered in addition to the test methods given in 2.4.3.3.

2.4.3.2 National or International Standards

JIS A1412[19] is used at:

a) Japan testing Centre for Construction Materials;

b) General Building Research Corporation of Japan.

2.4.3.3 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried by the following:

— Building Research Institute, Prague. Transient test method is used in which samples are built into the wall of an oven with temperature rise through the specimens recorded during heating.

— Reference [41] in the Bibliography describes work carried out in measuring the thermal conductivity of both wood and char at temperatures up to 800 °C.

2.4.4 Thermal diffusivity

2.4.4.1 National or International Standards

No standards have been identified.

2.4.4.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried at the following:

- Japan Testing Centre for Construction Materials.
- General Building Research Corporation of Japan. Tests are carried out at temperatures up to 200 °C.
- Technical University of Prague/Building Research Institute, Prague have conducted transient tests to measure the diffusivity at temperatures up to 300 °C.

2.4.5 Density

2.4.5.1 National or International Standards

No standards have been identified.

2.4.5.2 Laboratory methods or procedures under development

Mass loss determinations and measurements of dimensional changes are carried out on oven-dry wood samples after heating to temperatures up to 600 °C[42].

2.4.6 Charring rate

2.4.6.1 National or International Standard

See ASTM E119[43].

2.4.6.2 Laboratory methods or procedures under development

Laboratory test methods or procedures under development are being carried as follows:

a) samples of wood exposed to standard fire test heating conditions in accordance with ASTM E119[43];

b) Japan Testing Centre for Construction Materials;

c) General Building Research Corporation of Japan;

d) Fire research station have carried tests to measure charring rates using long pulses of low irradiance from a gas fired furnace operating at 870 °C[45] [46];

e) NRDL carried out similar test procedure to d) using short pulses of high irradiances[47];

f) White and Tran[48] [49] have reported on tests carried out using the standard ASTM E906[50] heat release calorimeter in which specimen blocks were exposed to a constant heat flux. Thermocouples were placed within the specimens and the depth of the char was regarded as the point at which the temperature attained 300 °C;

g) at the Technical University of Braunschweig studies based upon the standard heating curve have been conducted[51].

There are extensive references covering the determination of charring rates for different wood species, varying grain orientations, solid and laminated timber samples as well as exposure to different types of heating conditions. However, a review by Janssens[41] highlighted the problem of providing predictions when there is a considerable scatter in the data reported in the literature. In his paper, he proposes that ASTM E119[43] (ISO 834)[1] standard fire be adopted as the exposure condition from which measurements of the charring rates are made.

While this approach provides suitable data for the standard fire test condition, it should also be recognized that for the real fire condition, a wide range of exposure conditions will prevail. It is therefore recommended that in addition to the standard fire, charring rate determinations should be carried out for several standardized constant heat flux sources representing a range of fire conditions that may be experienced in practice.

2.4.7 Emissivity

2.4.7.1 National or International Standards

The following standards have been identified:

a) Tests are carried out in accordance with JIS A1423[25] at:

— Japan Testing Centre for Construction Materials;

— General Building Construction of Japan.

b) See also ISO 8990[15] for steady state methods using the calibrated and guarded hot box.

It is recommended to use steady state methods for measuring emissivity.

2.4.7.2 Laboratory methods or procedures under development

No laboratory test methods or procedures under development have been identified.

2.4.8 Moisture

2.4.8.1 National or International Standards

No standards have been identified.

2.4.8.2 Laboratory test methods or procedures under development

Mass loss determinations and measurements of dimensional changes are carried out on oven-dry wood samples after heating to temperatures up to 600 °C[42].

2.5 Plastics, fibre reinforcement, organic and inorganic materials

2.5.1 General

The use of plastic materials, fibre reinforcement and organic and inorganic materials for structural support is receiving greater interest. However, since the type of material can vary enormously, specific guidance on heating rates, maximum temperatures and whether transient test methods are necessary, cannot at this stage be given. However, in the absence of any other information on exposure conditions, the following is recommended for developing suitable test methods:

a) maximum test temperature = 1 000 °C or decomposition temperature whichever is lower;

b) heating rates for transient tests: within the range of 0,5 °C/min to 25 °C/min;

c) steady state tests are acceptable if there are no time dependent chemical or physical changes involving adiabatic reactions.

Unless otherwise stated the following test methods are conducted under steady state heating conditions.

2.5.2 Specific heat

2.5.2.1 National or International Standards

The following standards have been identified:

a) ISO 11357-1[3], describes the use of the differential scanning calorimeter (DSC) for measuring plastics under transient heating conditions. Two methods are described:

   1) power-compensation DSC;

   2) heat-flux DSC.

b) ENV 1159-3[52], describes two methods for ceramic based composites:

   1) drop calorimeter, for temperatures up to 2 250 K;

   2) differential scanning calorimeter, for temperatures up to 1 900 K.

It is recommended that decomposition temperatures not be exceeded.

2.5.2.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out as follows:

— Japan Testing Centre for Construction Materials, used at temperatures up to 150 °C;

— General Building Research Corporation of Japan, used at temperatures up to 200 °C.

2.5.3 Thermal conductivity

2.5.3.1 National or International Standards

JIS A1412[19] is used at:

a) Japan Testing Centre for Construction Materials;

b) General Building Research Corporation of Japan.

2.5.3.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out as follows:

— UK National Physical Laboratory for testing plastics.

— A method for measuring thermal conductivity and diffusivity that is similar in principle to the hot wire, has been developed by Gustaffsson[12]. This is referred to as the transient plane source (TPS) technique.

  The experimental procedure has been described in papers by Grauers and Persson[13] and Log and Gustaffsson[14]. A thin layer of electrically conducting material (nickel) which acts as both a heat source and a temperature-measuring device is sandwiched between two samples of the material. The assembly is heated in a conventional furnace to the desired temperature and stabilized to avoid any thermal gradients before the electrical pulse is triggered. The temperature rise of the metal strip, which is measured by its change in resistivity, depends upon the rate heat is conducted into the material.

  Success has been reported in applying the technique for measuring the thermal conductivity and diffusivity for several materials including plastic sheet. Currently the test method has only been developed for steady state heating conditions. However, although the authors the state that the technique could be combined with the constant rate of temperature rise (CRTR) method for measuring diffusivity under transient heating conditions, this is questionable and needs to be re-examined.

2.5.4 Thermal diffusivity

2.5.4.1 National or International Standards

ENV 1159-2[22] was originally developed for ceramic matrix composites with continuous reinforcements. It involves a laser flash experimental procedure that is carried out under steady state heating conditions at temperatures up to 2 800°K. However, it requires the material to be chemically and physically stable during the measurement.

2.5.4.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out as follows:

— The transient plane source test method described in 2.5.3.2, can also be used to determine thermal diffusivity of plastic sheet. However, the technique needs to be further developed in conjunction with the constant rate temperature rise method for transient heating conditions.

  Measuring the diffusivity of plastic sheet using this technique avoids the necessity of requiring the specific heat to be determined for calculating heat transfer characteristics. In this respect, more accurate information may be obtained particularly where physical and chemical changes affect mass transport properties.

— Sweden National Testing and Research Institute.

— Japan Testing Centre for Construction Materials.

— General Building Research Corporation of Japan.

2.5.5 Thermal strain (expansion and contraction)

2.5.5.1 National or International Standards

The following standards have been identified:

a) BS 6319-12[53], is used for measuring resin and polymer cements;

b) ASTM D 696[54], for plastics;

c) ENV 1159-1[55], for measuring composites up to 2 300 K;

d) ISO 11359-2[56], for measuring plastics.

2.5.5.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

2.5.6 Density

2.5.6.1 National or International Standards

ISO 1183[57] has been identified for measuring the density of plastics.

2.5.6.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

2.5.7 Emissivity

2.5.7.1 National or International Standards

The following standards have been identified:

a) JIS A1423[25] is used at:

   1) Japan Testing Centre for Construction Materials;

   2) General Building Research Corporation of Japan.

b) See also ISO 8990[15] for the calibrated and guarded hot box.

2.5.7.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

It is recommended to use appropriate steady state test methods.

2.6 Adhesives

2.6.1 General

Adhesives may be used in a variety of materials under widely different applications, e.g. joints for the assembly of structural members or providing additional strengthening of existing members.

For adhesives used in joints, it can be assumed that since the mass of material is generally greater than the actual member itself, the rates of heating and maximum temperatures at which tests are conducted are limited to the exposure conditions appropriate to those for the member itself.

As with plastics, in the absence of specific information on exposure conditions, the following is recommended:

a) maximum test temperature = 1 000 °C or decomposition temperature whichever is lower;

b) heating rates for transient tests are within the range of 0,5 °C/min to 25 °C/min.

Unless stated otherwise all the test methods described below are conducted under steady state heating conditions.

2.6.2 Specific heat

2.6.2.1 National or International Standards

ISO 11357-1[3], describes the use of the differential scanning calorimeter (DSC) for measuring plastics under transient heating conditions. This could be adopted for measurements on adhesives and binders. Two methods are described:

a) power-compensation DSC;

b) heat-flux DSC.

It is recommended that decomposition temperatures not be exceeded.

2.6.2.2 Laboratory test methods

Laboratory test methods or procedures under development are being carried out by the following:

- Japan Testing Centre for Construction Materials, tests for temperatures up to 150 °C;
- General Building Research Corporation of Japan, tests for temperatures up to 200 °C.

2.6.3 Thermal conductivity

2.6.3.1 National or International Standards

JIS A1412[19] is used at:

- Japan Testing Centre for Construction Materials;
- General Building Research Corporation of Japan.

2.6.3.2 Laboratory test methods or procedures under development

Although not stated, the hot-wire method described in 2.2.3.2 may be suitable for bulk specimens.

2.6.4 Thermal diffusivity

2.6.4.1 National or International Standards

No standards have been identified.

2.6.4.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out by the following:

- Japan Testing Centre for Construction Materials;
- General Building Research Corporation of Japan, tests at temperatures up to 200 °C;
- Although not stated, the hot wire method described in 2.2.3.2 may be suitable for bulk specimens.

2.6.5 Thermal strain (expansion and contraction)

2.6.5.1 National or International Standards

The following standards have been identified:

a) BS 6319-12[53], can be used on bulk resins;

b) JIS A1325[21], used at the Japan Testing Centre for Construction Materials;

c) ASTM D 696[54], used for testing plastics can be adopted on bulk specimens;

d) ISO 11359-2[56], can be used on bulk specimens.

2.6.5.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

2.6.6 Density

2.6.6.1 National or International Standards

The following standards have been identified:

a) BS 6319-5[58], which provides two methods for resin based mortars;

b) ISO 1183[57], which can be used on bulk specimens.

2.6.6.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried by the following:

— Japan Testing Centre for Construction Materials;

— General Building Research Corporation of Japan.

2.6.7 Emissivity

2.6.7.1 National or International Standards

The following standards have been identified:

a) JIS A1423[25], is used by:

   — Japan Testing Centre for Construction Materials;

   — General Building Research Corporation of Japan.

b) See also ISO 8990[15] for the calibrated and guarded hot box, which could be applied to bulk specimens.

2.6.7.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3 Tests for mechanical properties at elevated temperatures

3.1 Metals

3.1.1 General

The mechanical (strength) properties of metals generally decrease at elevated temperatures and are well below 5 % of their ambient temperature at values representing 0,7 to 0,8 of their melting point. For practical use in fire engineering design of load bearing members, test methods at elevated temperatures need not exceed 1 000 °C for steels and 500 °C for aluminium alloys. A review of some of the test methods for mechanical behaviour is given in Reference [59] in the Bibliography.

3.1.2 Elastic modulus

3.1.2.1 General

The elastic modulus of metals at elevated temperatures can be determined using several methods. One of the most common approaches is to determine values from stress/strain curves derived from tensile tests carried out at elevated temperatures using standards such as EN 10002-5[60]. However, while values of the elastic modulus can be determined, the elastic portion is often curvilinear and therefore a range of values can be obtained. More importantly, extensometry used for tensile tests does not have the requisite level of accuracy for elastic modulus determination.

The following methods are preferred. Although these are based upon steady state heating conditions, the influence of heating rate is generally small and therefore it is not necessary for transient test methods to be developed.

3.1.2.2 National or International Standards

No standards have been identified.

3.1.2.3 Laboratory methods or procedures under development

Laboratory test methods or procedures under development are being carried out as follows:

— Static methods for elastic moduli can be determined by flexing a “mini” beam either under four-point loading or as a cantilever. Deflections are measured by using optical lever systems in which the accuracy of measurement is considered to be within 1 % [61] [62].

— There are two main types of dynamic methods:

  1) Specimens in the form of a bar are set into vibration to their fundamental frequency. From the frequency, mass and dimensions of the bar Young's modulus is determined[63] [64] [65].

  2) Ultrasonic frequencies are sent along a bar in which the transit times of the ultrasonic waves are measured[66] [67].

  Both methods are carried out under steady state heating for temperatures up to 1 000 °C.

3.1.3 Creep

3.1.3.1 General

In the past, data used in structural design for the fire limit state has often been derived from a combination of results obtained from conventional tensile tests and creep tests both conducted under steady state heating conditions. Although properties derived from transient tests are preferred, the use of creep results with tensile tests is still practised. There is therefore a need to have agreed standards for the steady state tests.

3.1.3.2 National or International Standards

The following standards have been identified:

a) BS 3500-3[68];

b) ISO 9994[69];

c) ISO 204[70].

3.1.3.3 Laboratory test methods or procedures under development

At the Tokyo Institute of Technology a similar method (see Reference [71] in the Bibliography) to the standards given above for temperatures up to 600 °C is under development.

3.1.4 Stress relaxation

3.1.4.1 National or International Standards

In BS 3500-6[72], a steady state test method is described.

3.1.4.2 Laboratory test methods or procedures under development

Tests have been carried out at the Tokyo Institute of Technology using the method given in Reference [73] in the Bibliography on structural steel at temperatures between 400 °C and 600 °C.

During the cooling stages of a fire, structural elements try to contract thermally. If this is prevented, high stress levels are created resulting in considerable forces being generated, usually at the connections. This often manifests itself as localized fractures. In order to analyse these effects, it is necessary to have an understanding of strain hardening during cooling as well as any associated creep behaviour. A test method is therefore needed in which specimen strain is held at a constant level during cooling from temperatures up to 1 000 °C during which time changes in stress are measured.

3.1.5 Bauschinger effect

3.1.5.1 General

The Bauschinger effect is a hysteresis phenomenon that occurs in metals during strain reversal. It manifests itself in structures during load redistribution that takes place between members within a framework.

3.1.5.2 National or International Standards

No standards have been identified.

3.1.5.3 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified which are suitable for single stage stress reversal.

3.1.6 Stress–strain (steady state)

3.1.6.1 General

Tensile tests under steady state heating are carried out to derive stress–strain relationships at various temperatures. Loading is generally applied under a constant strain rate/crosshead speed. In order to use the data for the transient condition of a fire, it is normal to add to the plastic strain, a contribution due to creep effects, see 3.1.3.

There are several disadvantages with this type of test compared to the transient method. For example, the heating conditions are not replicated and the material properties can metallurgically change during heating to the test temperature prior to the tests. However, since work reported in the literature has shown correlation between numerical models using steady state results and actual performance, this type of test is included.

3.1.6.2 National or International Standards

EN 10002-5[60] has been identified.

3.1.6.3 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.1.7 Stress–strain (transient state)

3.1.7.1 National or International standard

No standards have been identified but some aspects of EN 10002-5[60] have been adopted, see 3.1.7.2.

3.1.7.2 Laboratory test methods or procedures under development

Tests carried out under transient heating conditions normally involve applying a constant stress to a specimen at ambient temperature and then monitoring strain as the specimen is heated at a fixed rate[74] [75] [76].

The design of the specimens and methods of fitting instrumentation are often identical to those used in conventional steady state tests at elevated temperatures as described in EN 10002-5[60]. However, it has been found to be necessary to improve upon the existing hot tensile test methods by:

a) use of extensometers with increased accuracy and resolution;

b) better contacts between the thermocouples and specimens;

c) use of specimens with extended parallel lengths to minimize the effects of the gripping arrangements on longitudinal temperature profiles;

d) adjustments to the surface temperature measurements are necessary to reflect “bulk” specimen temperatures.

The stress levels applied extend beyond those that may be used in practice and generally fall within the range of 0,05 times to 1,3 times the value of the ambient temperature yield or 0,2 % proof stress. Heating can be provided by direct and indirect resistance furnaces, induction heating as well as by halogen lamps. The heating rates adopted are usually in the range of 2,5 °C/min to 50 °C/min and reflect those that may be experienced by unprotected and heavily protected members in both standard tests and real fires. There is an influence of heating rate on aluminium and steel which results in an apparent improvement in strength with increasing heating rates. For steel, this effect is small and is ignored in engineering design codes. Tests carried out under slow heating conditions provide slightly conservative behaviour when applied to more severe fire scenarios.

The advantage of this type of test to the steady state method is that all the microstructural changes that a load-bearing member will experience in reality, are replicated in the transient test.

From the resulting strain temperature curves derived for each loading condition, the data is manipulated to derive conventional stress–strain relationships as described in 3.1.6, as well as strength reduction values for specific limits of critical strain.

Laboratory test procedures have been carried out at:

— British Steel Swinden Technology Centre, UK;

— BHP Steel, Australia;

— University of Helsinki, Finland.

3.1.8 Ultimate strength (tension)

3.1.8.1 National or International Standards

The following standards have been identified for:

a) steady state heating conditions, refer to EN 10002-5[60];

b) transient heating conditions for which no standards have been identified.

3.1.8.2 Laboratory test methods or procedures under development

British Steel Swinden Technology Centre. Data from the transient test described in 3.1.7.2 can be manipulated providing the limits of strain adopted in the tests are sufficiently great.

3.1.9 Ultimate strength (compression)

3.1.9.1 National or International Standards

No standards have been identified.

3.1.9.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.1.10 Joints — bolts (ultimate capacity: shear, slip and tension under steady state and transient heating)

3.1.10.1 General

Bolts are one of the main components used in joining members to form structural frames. In general, data is required primarily on the ultimate capacity and to a lesser extent on stress–strain behaviour. For high strength friction grip bolts data on “slip” behaviour is also important.

In order to evaluate the behaviour of steel bolts in joints as full components it is often necessary to carry out tests within bulky couplings. This creates practical difficulties in achieving heating rates under transient heating conditions of much greater than 10 °C/min. However, since the apparent strength of metals increase as the rate of heating increases, the results obtained under slow heating conditions would tend to be slightly conservative. It is recommended that tests be carried out at a heating rates up to 10 °C/min for maximum temperatures of 800 °C.

For aluminium bolts, heating rates up to 25 °C/min are practical with a maximum temperature of 500 °C.

3.1.10.2 National or International Standards

No standards have been identified.

3.1.10.3 Laboratory test methods or procedures under development

Test methods have been developed at British Steel Swinden Technology Centre for evaluating steel bolts used in structural connections. These are carried out in tension or double shear under steady state[77], or transient heating conditions using a heating rate of 5 °C/min. Similar work under steady state heating conditions is reported in work described in Reference [78] in the Bibliography.

Measurement of the slip loads of high strength friction grip bolts at elevated temperatures is important in moment resisting connections and has been described in References [79] and [80] in the Bibliography. Tests have been carried out on both painted and unpainted surfaces under steady state heating conditions at temperatures up to 500 °C. The procedures described could readily be developed for conducting tests under transient heating conditions.

3.1.11 Joints — bolts (stress–strain under transient heating)

3.1.11.1 National or International Standards

No standards have been specifically identified but relevant parts of EN 10002-5[60] can be adopted.

3.1.11.2 Laboratory test methods or procedures under development

These have been developed at British Steel Swinden Technology Centre. The stress–strain behaviour for bolts can be obtained using exactly the same methods described in 3.1.7, in which samples machined from individual bolts are used. Since the heating rates at connections during fire are generally lower than the individual members, the heating rates employed during transient tests need only be taken up to 25 °C/min. It is recommended that the maximum temperatures be limited to 500 °C and 1 000 °C for aluminium and steel respectively. Tests carried out at slower heating rates provide slightly conservative results.

3.1.12 Joints — welds (ultimate capacity: steady state and transient heating)

3.1.12.1 General

Welds are widely used in the fabrication of members and frequently in some countries also in the construction of steel frames. For welded assemblies tests to measure the ultimate capacity of fillet welds can be carried out under both steady state and transient heating conditions. For the latter, due to the bulk of steel being heated it is difficult on a practical level to achieve specimen-heating rates greater than 10 °C/min in steel. However, research has shown that slow heating rates tend to provide slightly conservative results. It is therefore recommended to adopt heating rates up to 10 °C/min for maximum temperatures of 1 000 °C.

For aluminium, heating rates up to 25 °C/min for maximum temperatures of 500 °C should be adopted.

3.1.12.2 National or International Standards

The following standards have been identified:

a) Samples machined from butt welds can be tested according to the steady state method described in EN 10002-5[60].

b) For fillet weld assemblies, no standard could be identified.

3.1.12.3 Laboratory test methods or procedures under development

Test procedures exist at British Steel Swinden Technology Centre in which cruciform shapes are fabricated from plate using fillet welds of different throat sizes. These are subjected to tensile tests which are taken to failure to determine the ultimate capacity of the joint. The tests can be carried out under steady state or transient heating conditions at rates up to 5 °C/min with maximum temperatures of 1 000 °C. It has been found that for slow rates of heating, differences in results obtained in the plastic range at high strains, between transient and steady state heating conditions are small.

3.1.13 Joints — welds (stress–strain under transient heating)

3.1.13.1 General

Since the heating rates at connections during fire are generally lower than the individual members, the heating rates employed during transient tests need only be taken up to a maximum of 25 °C/min. There is a small heating rate dependence on the properties obtained with the slower heating rates providing slightly conservative results. It is recommended that the maximum temperatures be limited to 500 °C and 1 000 °C for aluminium and steel respectively.

3.1.13.2 National or International standard

No standards have been specifically identified but relevant parts of the EN 10002-5[60] can be adopted.

3.1.13.3 Laboratory test methods or procedures under development

British Steel Swinden Technology Centre has carried out transient tests described in 3.1.7 to determine the strength reduction values for the fire limit state. Specimens were prepared from multi-pass butt-welded joints in 12 mm and 25 mm plate of steel grades 275 and 355. MMA, SAW and GMAW welding techniques were evaluated using different welding consumables. The transient tests were carried out at a heating rate of 10 °C/min with initial applied stress levels of between 0,1 and 1,0 of the ambient temperature yield strength or 0,2 % proof stress.

3.2 Concrete

3.2.1 General

During heating, concrete undergoes both chemical and physical changes and therefore for the fire condition it is usually necessary to be able to describe the properties under transient heating conditions. In the development of new test procedures, heating rates should be within the range of 0,5 °C/min to 10 °C/min unless specifically stated otherwise with maximum surface temperatures during heating of 1 000 °C.

3.2.2 Elastic modulus (compression)

3.2.2.1 National or International Standards

No standards have been identified for transient heating conditions.

For steady state heating conditions, the following standards have been identified. Although these are ambient temperature tests, they could be developed for tests at elevated temperatures.

a) BS 1881-121[81] is a static test method.

b) BS 1881-209[82] is a dynamic test method.

c) EN 1352[83] is used for lightweight concrete.

d) ISO 6784[84].

3.2.2.2 Laboratory methods or procedures under development

Currently in RILEM TC 129 MHT, a procedure is being developed for the fire condition.

3.2.3 Transient creep (under compression)

3.2.3.1 National or International Standards

No standards have been identified.

3.2.3.2 Laboratory test methods or procedures under development

Currently, a procedure is being developed within RILEM TC129 MHT[85] for testing over the range 20 °C to 750 °C and above under transient heating conditions.

For drying concrete (i.e. moisture is lost during the heating process), the total strain, S_{total}, is given by the relationship:

$$S_{\text{total}} = S_{\text{thermal}} + S_{\text{movement}} + S_{\text{non-elastic}} + S_{\text{elastic}}$$

where

$S_{thermal}$ is the thermal strain;

$S_{movement}$ is the movement strain;

$S_{non\text{-}elastic}$ is the non-elastic strain;

$S_{elastic}$ is elastic strain.

Transient creep is therefore determined after subtracting strains due to elastic deformation, thermal expansion and shrinkage as a result of loss in moisture. However, it is stated in the test method that it is not possible to separate the effects of moisture loss and therefore, measurements of creep strain include the moisture component.

In the case of non-drying concrete (moisture is prevented from escaping) the total strain measured does not include moisture shrinkage effects.

The test method involves heating the sample under a constant load at a rate of up to 4 °C/min to specific temperatures measured on the surface. The surface temperature is then held constant while the core temperatures are monitored. During this time, the change in specimen length is recorded. Transient creep is therefore determined as a function of the average temperature between the specimen surface and core.

It is recommended that the procedures described form the basis for developing a standard in which the temperature measured at the surface is increased to 1 000 °C.

3.2.4 Stress relaxation

3.2.4.1 National or International Standards

No standards have been identified for transient heating conditions.

3.2.4.2 Laboratory test methods or procedures under development

A test procedure is currently under development within RILEM TC 129 MHT.

3.2.5 Stress–strain (steady state)

Steady state test data for the fire condition can be used with a creep component added. Although it is generally preferable to adopt data based upon transient heating conditions.

3.2.5.1 National or International Standards

No standards have been identified.

3.2.5.2 Laboratory test methods or procedures under development

A test method is being developed within RILEM TC129 MHT.

3.2.6 Stress–strain (transient)

3.2.6.1 National or International standard

No standards have been identified.

3.2.6.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified. However, by numerical manipulation of the results from transient creep tests under compression described in 3.2.3.2, stress–strain relationships at elevated temperatures can be derived.

3.2.7 Ultimate strength (compression)

3.2.7.1 National or International Standards

No standards have been identified for transient heating conditions.

3.2.7.2 Laboratory test methods or procedures under development

Within RILEM TC 129 MHT[86], a draft test method has been published. This method gives procedures for establishing the compressive strength of concrete under different conditions and includes the following:

a) compressive strength at elevated temperatures and after cooling back to ambient temperature in which loads are applied during the complete fire exposure;

b) compressive strength at elevated temperatures and after returning to ambient with no load applied during the heating process.

In each case, concrete is evaluated in two conditions:

— “drying concrete” whereby moisture is allowed to freely escape during the test;

— “non-drying concrete” in which moisture does not escape and can be applied to specimens with a cross-section greater than 400 mm or moisture is physically prevented from escaping.

Specimens are heated at rates up to 4 °C/min as determined by the surface temperature.

3.2.8 Ultimate strength (tension)

3.2.8.1 National or International Standards

No standards have been identified for transient heating conditions.

3.2.8.2 Laboratory test methods or procedures under development

A test method is being developed within RILEM TC 129 MHT.

3.3 Masonry

3.3.1 General

During heating, many masonry products undergo chemical and physical changes in a similar manner to concrete. However, in some cases the effects are less noticeable on the materials properties being measured. Therefore, while it is recommended that properties determined under transient heating conditions are preferred, in cases where these do not currently exist, results from steady state tests may provide adequate information for design calculations.

It is proposed however, that where a test method has already been established for evaluating the properties of concrete under transient heating conditions, this may be considered as a basis for developing a test method for masonry products.

In the testing of masonry products, it is often customary to construct a mini assembly, for example a pyramid to determine representative properties rather a single component.

3.3.2 Elastic modulus

3.3.2.1 National or International Standards

No standards have been identified for transient heating conditions.

For steady state heating conditions, the following have been identified. Although these are ambient temperature tests they may be considered for developing tests at elevated temperatures.

a) BS 1881-121[81] is a static test method.

b) BS 1881-209[82] is a dynamic test method.

c) EN 1352[83] is used for lightweight concrete.

d) ISO 6784[84].

3.3.2.2 Laboratory test methods or procedures under development

No laboratory methods or procedures have been specifically identified although the test methods being developed in RILEM TC129 MHT for concrete may be considered.

3.3.3 Shear modulus

3.3.3.1 National or International Standards

No standards have been identified.

3.3.3.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.3.4 Modulus of rupture

3.3.4.1 National or International Standards

The following standards have been identified:

a) BS 1902-4.5[87] is used for measuring dense and insulating products under steady state conditions may be considered for masonry.

b) ISO 5013[88] is technically similar to BS 1902-4.5[87].

3.3.4.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.3.5 Creep (in compression)

3.3.5.1 National or International Standards

The following standards have been identified:

a) BS 1902-4.5[87], is used for evaluating refractory products under steady state heating conditions;

b) EN 993- 9[89], is used for evaluating refractory products under steady state heating conditions;

c) ISO 3187[90], is technically equivalent to EN 993-9[89];

d) EN 1355 [91], is used for evaluating autoclaved aerated concrete under steady state heating conditions.

3.3.5.2 Laboratory test methods or procedures under development

Currently, a procedure is being developed within RILEM TC 129 MHT[85] for testing concrete over the range 20 °C to 750 °C or higher under transient heating conditions. This test method could form the basis for developing a suitable method for masonry. The test for concrete is briefly described as follows.

For drying concrete (i.e. moisture is lost during the heating process), the total strain, S_{total}, during transient creep is given by the relationship:

$$S_{\text{total}} = S_{\text{thermal}} + S_{\text{movement/shrinkage}} + S_{\text{non-elastic}} + S_{\text{elastic}}$$

where

S_{thermal}	is the thermal strain;
$S_{\text{movement/shrinkage}}$	is the movement strain;
$S_{\text{non-elastic}}$	is the non-elastic strain;
S_{elastic}	is elastic strain.

Transient creep is therefore determined after subtracting strains due to elastic deformation, thermal expansion and movement/shrinkage as a result of loss in moisture. However, it is not possible to separate the effect of moisture loss and therefore the creep strain includes the moisture component.

In the case of non-drying concrete (moisture is prevented from escaping), the total strain measured does not include moisture shrinkage effects.

The test method involves heating the sample under a constant load at a rate of up to 4 °C/min to specific temperatures measured on the surface. The surface temperature is then held constant while the core temperatures are monitored. During this period, the change in specimen length is recorded. Transient creep is therefore determined as a function of the average temperature between the specimen surface and core.

It is recommended the procedures described for evaluating concrete could form the basis of developing into a standard for masonry products in which the temperature measured at the surface is increased to 1 000 °C.

3.3.6 Stress–strain (steady state)

3.3.6.1 National or International Standards

No standards have been identified.

3.3.6.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified. A test method for concrete is being developed within RILEM TC 129 MHT. This procedure may be considered for adaptation to masonry products.

3.3.7 Stress–strain (transient state)

3.3.7.1 National or International Standards

No standards have been identified.

3.3.7.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified. However, by numerical manipulation of the results from transient creep tests under compression described in 3.3.5.2 stress–strain relationships at elevated temperatures can be derived.

3.3.8 Ultimate strength in compression

3.3.8.1 National or International Standards

No standards have been identified.

3.3.8.2 Test methods or procedures under development

Within RILEM TC129 MHT[86] a draft test method has been published. This paper describes procedures for establishing the compressive strength of concrete under different conditions and includes the following:

a) compressive strength at elevated temperatures and after cooling back to ambient temperature in which loads are applied during the complete fire exposure;

b) compressive strength at elevated temperatures and after returning to ambient with no load applied during the heating process.

In each case, concrete is evaluated in two conditions:

— “drying concrete” whereby moisture is allowed to freely escape during the test;

— “non-drying concrete” in which moisture does not escape and can be applied to specimens with a cross-section greater than 400 mm or is physically prevented from escaping.

Specimens are heated at rates up to 4 °C/min as determined by the surface temperature.

It is suggested this procedure be considered for adoption in testing masonry products.

3.3.9 Ultimate strength in shear

3.3.9.1 National or International Standards

No standards have been identified.

3.3.9.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.3.10 Bond/frictional strength

3.3.10.1 National or International Standards

No standards have been identified.

3.3.10.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.3.11 Bending/flexure strength

3.3.11.1 National or International Standards

EN 1351[92] provides a method using a prism for measuring the flexure (tensile) strength of autoclaved aerated concrete. This method is designed only for testing at ambient temperature.

3.3.11.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.4 Wood

3.4.1 General

The mechanical properties of wood at elevated temperatures are dependent upon both chemical and physical changes and therefore transient test methods are preferred. Ideally, tests should be conducted under the heating conditions similar to the exposure conditions of a standard fire resistance test, and/or a constant heat flux which is comparable to a real fire. However, most of the test methods available are based upon steady state heating conditions. Considerable further work is required to develop transient heating methods.

Reference should be made to a technical report prepared under RILEM[93].

3.4.2 Elastic modulus

3.4.2.1 National or International Standards

No standards have been identified at elevated temperatures but EN 310[94] could be developed for ambient temperature tests.

3.4.2.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out by the following:

a) Tests are carried out at VTT Building Technology, Finland, under steady state heating conditions in which specimens are heated in a kiln, removed and tested for about 1 min. The temperature range covered is from 20 °C to 200 °C.

b) Measurement of the elastic modulus has been reported in Reference [95] in the Bibliography in which tests have been carried out on wood parallel to the grain at temperatures up to 200 °C. Wood having moisture contents of 0 % and 12 % were evaluated.

3.4.3 Creep

3.4.3.1 National or International Standards

No standards have been identified.

3.4.3.2 Laboratory test methods or procedures under development

Tests are being carried out at VTT Building Technology, Finland, under steady state heating conditions on specimens sampled perpendicular to the grain. A distinction is made between transient drying and constant wet conditions. In each case, specimens are heated in a kiln and subjected to a constant load over a period between 3 h and 24 h. The temperature range covered is from 20 °C to 125 °C.

3.4.4 Ultimate strength in compression

3.4.4.1 National or International standards

No standards have been identified.

3.4.4.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out by the following:

a) Tests are carried out at VTT Building Technology, Finland, under steady state heating conditions in which specimens are heated in a kiln, removed and tested within about 1 min. The temperature range covered is from 20 °C to 200 °C.

b) Reference [96] in the Bibliography describes tests carried out to determine the compressive strength at various temperatures ranging up to 200 °C.

3.4.5 Ultimate strength in shear

3.4.5.1 National or International Standards

No standards have been identified.

3.4.5.2 Laboratory test methods or procedures under development

Tests are being carried out at VTT Building Technology, Finland, under steady state heating conditions in which specimens are heated in a kiln, removed and tested within about 1 min. The temperature range covered is from 20 °C to 200 °C.

3.4.6 Ultimate strength in tension

3.4.6.1 National or International Standards

No standards have been identified.

3.4.6.2 Laboratory test methods or procedures under development

Laboratory test methods or procedures under development are being carried out as follows:

a) at VTT Building Technology, Finland, under steady state heating conditions in which specimens are heated in a kiln, removed and tested within about 1 min. The temperature range covered is from 20 °C to 200 °C.

b) Reference [96] in the Bibliography describes tests carried out to determine the tensile strength at various temperatures ranging up to 200 °C.

3.4.7 Adhesive strength (tensile shear)

3.4.7.1 National or International Standards

EN 302-1[97] which may be considered being adopted for elevated temperatures.

3.4.7.2 Laboratory test methods or procedures under development

Tests are being carried out at VTT Building Technology, Finland, under steady state heating conditions in which shear specimens are heated in a kiln, removed and tested within about 1 min. The temperature range covered is from 20 °C to 200 °C.

3.4.8 Adhesive strength (delamination)

3.4.8.1 National or International Standards

EN 302-2[98] could be adopted for elevated temperature tests for determining the delamination resistance of load-bearing timber structures.

3.4.8.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.4.9 Bending strength

3.4.9.1 National or International Standards

EN 310[94] describes a test method for testing wood based panels in bending which could be considered for elevated temperature transient heating conditions.

3.4.9.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.4.10 Joints (mechanical fixings)

3.4.10.1 National or International Standards

The following standards have been identified:

a) BS 6948[99], which is for ambient temperature tests;

b) ISO 8969[100], which is similar to BS 6948[99], also for ambient temperature testing;

c) EN 26891[101], which describes general principles for evaluating joints with mechanical fasteners;

d) ISO 6891[102], which is identical to EN 26891[101].

3.4.10.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.5 Plastics, fibre reinforcement, organic and inorganic materials

3.5.1 General

The use of these types of materials in load-bearing members in buildings and structures is currently limited to a few specific applications. Since these may or may not undergo chemical and/or physical changes at elevated temperatures, which in turn, may have some or negligible influence on the properties in the temperature regime of interest, references to test methods carried out either under steady state and transient heating conditions are provided. In cases where there is an absence of any test method being available at elevated temperatures, reference to standards are provided, which have already been adopted for testing conducted under ambient temperature conditions. At a later date, these could then form the basis for developing a suitable method for determining the relevant properties for the fire conditions.

3.5.2 Elastic modulus

3.5.2.1 National or International Standards

No elevated temperature test has been identified.

The following standards have been identified:

a) BS 2782-3:Method 320A-F[103], describes a method for ambient temperature tests on plastic sheet and different types of injection moulding plastics.

b) ISO 527[104] is technically similar to BS 2782-3:Method 320A-F[103].

3.5.2.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.5.3 Shear modulus

3.5.3.1 National or International standard

No standards have been identified.

3.5.3.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.5.4 Poisson's ratio

3.5.4.1 National or International standards

No standards have been identified.

3.5.4.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.5.5 Flexural creep

3.5.5.1 National or International Standards

ISO 899-2[105] describes a test method for measurements on plastics at ambient temperature under three-point loading.

3.5.5.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.5.6 Tensile creep

3.5.6.1 National or International Standards

The following standards have been identified:

a) BS 2782-3:Method 324A[106], which describes a method for plastics at ambient temperature;

b) ISO 899-1[107], which is technically the same as BS 2782-3:Method 324A[106].

3.5.6.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.5.7 Stress–strain (steady state heating)

3.5.7.1 National or International Standards

The following standards have been identified:

a) ISO 527-4[108] describes a method for measuring the tensile properties of isotropic and orthotropic fibre-reinforced plastic composites at ambient temperature.

b) ISO 527-5[109] describes a test method for measuring the tensile properties of unidirectional fibre-reinforced plastic composites at ambient temperature.

3.5.7.2 Laboratory test methods or procedures under development

None identified however, test methods may be considered using the procedures described for steel specimens (EN 10002-5)[60].

3.5.8 Stress–strain (transient heating)

3.5.8.1 National or International Standards

No standards have been identified.

3.5.8.2 Laboratory test methods or procedures under development

No standards have been identified. However, transient test methods may be considered using the procedures described for steel specimens in 3.1.7.2.

3.5.9 Ultimate strength (compression)

3.5.9.1 National or International Standards

The following standards have been identified:

a) ISO 604[110] describes a test method for plastics at ambient temperature;

b) JIS K 7191-1[111], JIS K 7191-2[112] and JIS K 7191-3[113] describe a test method to determine the ultimate temperature for plastics under compressive loading.

3.5.9.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.5.10 Ultimate strength (shear)

3.5.10.1 National or International Standards

No standards have been identified.

3.5.10.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.5.11 Ultimate tension

3.5.11.1 National or International Standards

No standards have been identified.

3.5.11.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6 Adhesives

3.6.1 General

A review of the available tests methods has indicated that while there is a wide range of tests for determining the mechanical properties under ambient temperature conditions, there appears to be an extreme lack of suitable test methods at elevated temperatures and none of these involve transient heating conditions. However, the following standards have been identified in which the test methods may form the basis for developing into a suitable standard for testing under elevated temperature transient heating conditions.

It is recommended that should test methods be developed, the heating rates and the range of temperatures over which the tests are conducted be governed by the requirements of the parent material for which the adhesive or binder is used. In the absence of specific information on exposure conditions the following is recommended:

a) maximum test temperature = 1 000 °C or decomposition temperature whichever is the lower;

b) heating rates for transient tests are within the range 0,5 °C/min to 25 °C/min.

Unless otherwise stated, the following tests are currently carried out at ambient temperature.

3.6.2 Elastic modulus in compression

3.6.2.1 National or International Standards

BS 6319-6[114] describes a test method for resin based mortars and concrete in which specimens in the form of rectangular prisms are used.

3.6.2.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.3 Modulus of elasticity

3.6.3.1 National or International Standards

BS 6319-3[115] describes a test method for polymer and polymer/cement based mortars in which specimens in the form of rectangular prisms are used.

3.6.3.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.4 Creep (tension and compression)

3.6.4.1 National or International Standards

BS 6319-11[116] describes a test method for polymer and polymer/cement mortars to provide comparative data on materials which may be used in situations where creep is likely to be important.

3.6.4.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.5 Ultimate strength (compression)

3.6.5.1 National or International Standards

BS 6319-2[117] sets out the test method for evaluating resin based mortars and cements in the form of cubes.

3.6.5.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.6 Ultimate strength (shear)

3.6.6.1 National or International Standards

No standards have been identified.

3.6.6.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.7 Ultimate strength (tension)

3.6.7.1 National or International Standards

BS 6319-7[118] describes a test method for resin-based mortars and concretes which are cast in the form of dumb-bell-shaped specimens.

3.6.7.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.8 Bond strength (slant shear)

3.6.8.1 National or International Standards

BS 6319-4[119] describes a method for resin-bonded prisms which are used to represent various constructions.

3.6.8.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.9 Bond strength (tensile lap-shear)

3.6.9.1 National or International Standards

The following standards have been identified:

a) EN 1465[120], which specifies a method for rigid-to-rigid-bonded assemblies;

b) ISO 4587[121], which is technically similar to EN 1465[120].

3.6.9.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.10 Bond strength (shear)

3.6.10.1 National or International Standards

The following standards have been identified:

a) BS 3544[122] describes a test method for tests polyvinyl acetate adhesives for wood using double lab joints under three-point loading in shear.

b) ASTM D 2295[123] describes a test method for metal-to-metal adhesives at elevated temperatures.

3.6.10.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.11 Bond strength (direct tension)

3.6.11.1 National or International Standards

The following standards have been identified:

a) EN 26922[124], which gives a test method for butt joints in pure tension and the procedure appropriate to all types of adhesives and can be carried out at elevated temperatures under steady state heating conditions.

b) ISO 6922[125], which is identical to EN 26922[124].

3.6.11.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.12 Bending strength

3.6.12.1 National or International Standards

BS 6319-10[126] describes a method for determining the temperature of deflection under a bending or heat distortion temperature, for resin-based mortars and concretes. Specimens are cast as rectangular prisms.

3.6.12.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

3.6.13 Flexural strength

3.6.13.1 National or International Standards

BS 6319-3[115] describes a test for measuring resin compositions.

3.6.13.2 Laboratory test methods or procedures under development

No laboratory test methods or procedures under development have been identified.

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