TECHNICAL REPORT

ISO/TR 15655

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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

Reference number
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Contents

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

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

This second edition cancels and replaces the first edition (ISO/TR 15655:2003), which has been technically revised.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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 (all parts)[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 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 document 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 document to reflect possible future changes in design and advances in materials technology.

In the past, the behaviour of jointing systems in fire has received limited interest yet their behaviour is fundamental to the performance of composite elements and structural frames. This document also addresses jointing systems under individual materials, e.g. 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.

The objectives of this document 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 document 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.

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]	—	—

L laboratory test method

S standard test method

— property not required

[a] Laboratory or standard test method is available 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	—

L laboratory test method

S standard test method

X no elevated temperature test method available

— property not required

[a] Laboratory or standard test method is available 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.

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

— ISO/TR 15656;

— ISO/TR 15657;

— ISO/TR 15658.

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);

— ISO/TR 12470 (all parts);

— ISO/TR 12471.

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

1 Scope

This document 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.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Tests for thermal properties at elevated temperatures

4.1 Metals

4.1.1 General

In this Clause 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.

4.1.2 Specific heat

4.1.2.1 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 (DSC).

4.1.2.2 Laboratory test methods or procedures under development

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

— The DSC 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.

4.1.3 Thermal conductivity

4.1.3.1 National or International Standards

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

4.1.3.2 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.

4.1.4 Thermal diffusivity

4.1.4.1 National or International Standards

No standards have been identified.

4.1.4.2 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.

4.1.5 Thermal strain (expansion and contraction)

4.1.5.1 National or International Standards

The national standards JIS A 1325[21] and JIS Z 2285[127] are used at Japan Testing Centre for Construction Materials at temperatures T = 0 °C to 900 °C.

4.1.5.2 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 exists 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.

4.1.6 Emissivity

4.1.6.1 National or International Standards

For non metals reference should be made to ISO 8990[15] for the calibrated and guarded hot box. The national standard JSI A 1423 is used for tests at ambient temperature at Japan Testing Centre for Construction Materials and General Building Research Corporation of Japan.

4.1.6.2 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.

4.2 Concrete

4.2.1 General

During heating, concrete undergoes both chemical and physical changes, e.g. loss of moisture, dehydration, de-carbonization, quartz conversion. 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.

4.2.2 Specific heat

4.2.2.1 National or International standard

The 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.

4.2.2.2 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 100 °C;

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

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

4.2.3 Thermal conductivity

4.2.3.1 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 R2616[20].

4.2.3.2 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 CRTR method for measuring diffusivity, which is carried out under transient heating conditions. Furthermore, this technique is questionable and warrants further investigation.

4.2.4 Thermal diffusivity

4.2.4.1 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].has been identified for steady state heating conditions: 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.

4.2.4.2 Laboratory test methods or procedures under development

The TPS 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 TPS 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.

4.2.5 Thermal strain (expansion and contraction)

4.2.5.1 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.