TECHNICAL REPORT

ISO/TR 15655

Second edition
2020-02

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

This document is a preview generated by EVS

Reference number
ISO/TR 15655:2020(E)

© ISO 2020

This document is a preview generated by EVS



COPYRIGHT PROTECTED DOCUMENT

© ISO 2020

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

 © ISO 2020 – All rights reserved

Contents

Page

Foreword ..... **vi**
Introduction ..... **vii**
1 Scope **1**
2 Normative references **1**
3 Terms and definitions **1**
4 Tests for thermal properties at elevated temperatures **1**
4.1 Metals 1
4.1.1 General 1
4.1.2 Specific heat 1
4.1.3 Thermal conductivity 2
4.1.4 Thermal diffusivity 2
4.1.5 Thermal strain (expansion and contraction) 3
4.1.6 Emissivity 3
4.2 Concrete 4
4.2.1 General 4
4.2.2 Specific heat 4
4.2.3 Thermal conductivity 4
4.2.4 Thermal diffusivity 5
4.2.5 Thermal strain (expansion and contraction) 5
4.2.6 Density 6
4.2.7 Emissivity 6
4.2.8 Spalling 7
4.2.9 Expansion/shrinkage 7
4.2.10 Moisture 7
4.3 Masonry 7
4.3.1 Specific heat 7
4.3.2 Thermal conductivity 8
4.3.3 Thermal diffusivity 9
4.3.4 Thermal strain (expansion and contraction) 9
4.3.5 Density 10
4.3.6 Emissivity 10
4.3.7 Spalling 10
4.3.8 Expansion/shrinkage 11
4.3.9 Moisture content 11
4.4 Wood 11
4.4.1 General 11
4.4.2 Specific heat 11
4.4.3 Thermal conductivity 12
4.4.4 Thermal diffusivity 12
4.4.5 Density 13
4.4.6 Charring rate 13
4.4.7 Emissivity 14
4.4.8 Moisture 14
4.5 Plastics, fibre reinforcement, organic and inorganic materials 14
4.5.1 General 14
4.5.2 Specific heat 15
4.5.3 Thermal conductivity 15
4.5.4 Thermal diffusivity 16
4.5.5 Thermal strain (expansion and contraction) 16
4.5.6 Density 16
4.5.7 Emissivity 17
4.6 Adhesives 17
4.6.1 General 17

This document is a preview generated by EVS

© ISO 2020 – All rights reserved

4.6.2 Specific heat ... 17
4.6.3 Thermal conductivity ... 18
4.6.4 Thermal diffusivity ... 18
4.6.5 Thermal strain (expansion and contraction) ... 18
4.6.6 Density ... 18
4.6.7 Emissivity ... 19

5 Tests for mechanical properties at elevated temperatures ... 19
5.1 Metals ... 19
5.1.1 General ... 19
5.1.2 Elastic modulus ... 19
5.1.3 Creep ... 20
5.1.4 Stress relaxation ... 20
5.1.5 Bauschinger effect ... 21
5.1.6 Stress–strain (steady state) ... 21
5.1.7 Stress–strain (transient state) ... 21
5.1.8 Ultimate strength (tension) ... 22
5.1.9 Ultimate strength (compression) ... 22
5.1.10 Joints — Bolts (ultimate capacity: shear, slip and tension under steady state and transient heating) ... 23
5.1.11 Joints — Bolts (stress–strain under transient heating) ... 23
5.1.12 Joints — Welds (ultimate capacity: steady state and transient heating) ... 24
5.1.13 Joints — Welds (stress–strain under transient heating) ... 24
5.2 Concrete ... 25
5.2.1 General ... 25
5.2.2 Elastic modulus (compression) ... 25
5.2.3 Transient creep (under compression) ... 25
5.2.4 Stress relaxation ... 26
5.2.5 Stress–strain (steady state) ... 26
5.2.6 Stress–strain (transient) ... 26
5.2.7 Ultimate strength (compression) ... 26
5.2.8 Ultimate strength (tension) ... 27
5.3 Masonry ... 27
5.3.1 General ... 27
5.3.2 Elastic modulus ... 27
5.3.3 Shear modulus ... 28
5.3.4 Modulus of rupture ... 28
5.3.5 Creep (in compression) ... 28
5.3.6 Stress–strain (steady state) ... 29
5.3.7 Stress–strain (transient state) ... 29
5.3.8 Ultimate strength in compression ... 30
5.3.9 Ultimate strength in shear ... 30
5.3.10 Bond/frictional strength ... 30
5.3.11 Bending/flexure strength ... 30
5.4 Wood ... 31
5.4.1 General ... 31
5.4.2 Elastic modulus ... 31
5.4.3 Creep ... 31
5.4.4 Ultimate strength in compression ... 31
5.4.5 Ultimate strength in shear ... 32
5.4.6 Ultimate strength in tension ... 32
5.4.7 Adhesive strength (tensile shear) ... 32
5.4.8 Adhesive strength (delamination) ... 33
5.4.9 Bending strength ... 33
5.4.10 Joints (mechanical fixings) ... 33
5.5 Plastics, fibre reinforcement, organic and inorganic materials ... 34
5.5.1 General ... 34
5.5.2 Elastic modulus ... 34
5.5.3 Shear modulus ... 34

This document is a preview generated by EVS

 © ISO 2020 – All rights reserved

5.5.4 Poisson's ratio 34
5.5.5 Flexural creep 35
5.5.6 Tensile creep 35
5.5.7 Stress–strain (steady state heating) 35
5.5.8 Stress–strain (transient heating) 35
5.5.9 Ultimate strength (compression) 36
5.5.10 Ultimate strength (shear) 36
5.5.11 Ultimate tension 36
5.6 Adhesives 36
5.6.1 General 36
5.6.2 Elastic modulus in compression 37
5.6.3 Modulus of elasticity 37
5.6.4 Creep (tension and compression) 37
5.6.5 Ultimate strength (compression) 37
5.6.6 Ultimate strength (shear) 37
5.6.7 Ultimate strength (tension) 38
5.6.8 Bond strength (slant shear) 38
5.6.9 Bond strength (tensile lap-shear) 38
5.6.10 Bond strength (shear) 38
5.6.11 Bond strength (direct tension) 39
5.6.12 Bending strength 39
5.6.13 Flexural strength 39
Bibliography **40**

This document is a preview generated by EVS

© ISO 2020 – All rights reserved

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.

This document is a preview generated by EVS

© ISO 2020 – All rights reserved

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.

This document is a preview generated by EVS

© ISO 2020 – All rights reserved

— 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.

This document is a preview generated by EVS

© ISO 2020 – All rights reserved

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.

This document is a preview generated by EVS

© ISO 2020 – All rights reserved

This document is a preview generated by EVS

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

This document is a preview generated by EVS

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).

© ISO 2020 – All rights reserved