BS EN 60695-1-21:2016

BSI Standards Publication

Fire hazard testing

Part 1-21: Guidance for assessing the fire hazard of electrotechnical products — Ignitability — Summary and relevance of test methods

bsi.

National foreword

This British Standard is the UK implementation of EN 60695-1-21:2016. It is identical to IEC 60695-1-21:2016. It supersedes PD IEC/TR 60695-1-21:2008 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/89, Fire hazard testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Compliance with a British Standard cannot confer immunity from legal obligations.

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EUROPEAN STANDARD

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Fire hazard testing - Part 1-21: Guidance for assessing the fire hazard of electrotechnical products - Ignitability - Summary and relevance of test methods (IEC 60695-1-21:2016)

Essais relatifs aux risques du feu - Partie 1-21: Lignes directrices pour l'évaluation des risques du feu des produits électrotechniques - Allumabilité - Résumé et pertinence des méthodes d'essais (IEC 60695-1-21:2016)

Prüfungen zur Beurteilung der Brandgefahr - Teil 1-21: Anleitung zur Beurteilung der Brandgefahr von elektrotechnischen Erzeugnissen - Entzündbarkeit - Zusammenfassung und Bedeutung der Prüfverfahren (IEC 60695-1-21:2016)

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

European foreword

The text of document 89/1336/FDIS, future edition 1 of IEC 60695-1-21, prepared by IEC/TC 89 "Fire hazard testing" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60695-1-21:2016.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-07-12
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2019-10-12

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Endorsement notice

The text of the International Standard IEC 60695-1-21:2016 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

ISO 11357 (Series)	NOTE	Harmonized as EN ISO 11357 (Series).
ISO 4589-1:1996	NOTE	Harmonized as EN ISO 4589-1:1999.
ISO 4589-2:1996	NOTE	Harmonized as EN ISO 4589-2:1999.
ISO 4589-3:1996	NOTE	Harmonized as EN ISO 4589-3:1999.

Annex ZA
(normative)
Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60695-1-20	-	Fire hazard testing - Part 1-20: Guidance for assessing the fire hazard of electrotechnical products - Ignitability - General guidance	EN 60695-1-20	-
IEC 60695-1-30	-	Fire hazard testing -- Part 1-30: Guidance for assessing the fire hazard of electrotechnical products - Preselection testing process - General guidelines	EN 60695-1-30	-
IEC 60695-4	2012	Fire hazard testing -- Part 4: Terminology concerning fire tests for electrotechnical products	EN 60695-4	2012
IEC Guide 104	-	The preparation of safety publications and the use of basic safety publications and group safety publications	-	-
ISO 13943	2008	Fire safety - Vocabulary	EN ISO 13943	2010
ISO/IEC Guide 51	-	Safety aspects - Guidelines for their inclusion in standards	-	-

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIRE HAZARD TESTING –

Part 1-21: Guidance for assessing the fire hazard of electrotechnical products – Ignitability – Summary and relevance of test methods

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60695-1-21 has been prepared by IEC technical committee 89: Fire hazard testing.

The text of this standard is based on the following documents:

FDIS	Report on voting
89/1336/FDIS	89/1339/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

It has the status of a basic safety publication in accordance with IEC Guide 104 and ISO/IEC Guide 51.

This first edition of IEC 60695-1-21 cancels and replaces the first edition of IEC TR 60695-1-21 published in 2008. It constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Change from a TR to an international standard;

b) Modified Introduction;

c) Modified Scope;

d) Updated normative references;

e) Updated terms and definitions;

f) Updates and new text in Clause 4;

g) Addition of text concerning ASTM D 3638;

h) Updates to Annex A;

i) Updates to the bibliography.

A list of all the parts in the IEC 60695 series, under the general title *Fire hazard testing*, can be found on the IEC website.

The IEC 60695-1 series, under the general title *Fire hazard testing*, consists of the following parts:

Part 1-10: Guidance for assessing the fire hazard of electrotechnical products – General guidelines

Part 1-11: Guidance for assessing the fire hazard of electrotechnical products – Fire hazard assessment

Part 1-12: Guidance for assessing the fire hazard of electrotechnical products – Fire safety engineering

Part 1-20: Guidance for assessing the fire hazard of electrotechnical products – Ignitability – General guidance

Part 1-21: Guidance for assessing the fire hazard of electrotechnical products – Ignitability – Summary and relevance of test methods

Part 1-30: Guidance for assessing the fire hazard of electrotechnical products – Preselection testing procedures – General guidelines

Part 1-40: Guidance for assessing the fire hazard of electrotechnical products – Insulating liquids

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Fires are responsible for creating hazards to life and property as a result of the generation of heat (thermal hazard), and also as a result of the production of toxic effluent, corrosive effluent and smoke (non-thermal hazard). Fires start with ignition and then can grow, leading in some cases to flash-over and a fully developed fire. Ignition resistance is therefore one of the most important parameters of a material to be considered in the assessment of fire hazard. If there is no ignition, there is no fire.

For most materials (other than metals and some other elements), ignition occurs in the gas phase. Ignition occurs when combustible vapour, mixed with air, reaches a high enough temperature for exothermic oxidation reactions to rapidly propagate. The ease of ignition is a function of the chemical nature of the vapour, the fuel/air ratio and the temperature.

In the case of liquids, the combustible vapour is produced by vaporization of the liquid, and the vaporization process is dependent on the temperature and chemical composition of the liquid.

In the case of solids, the combustible vapour is produced by pyrolysis when the temperature of the solid is sufficiently high. The vaporization process is dependent on the temperature and chemical composition of the solid, and also on the thickness, density, specific heat, and thermal conductivity of the solid.

The ease of ignition of a test specimen depends on many variables. Factors that need to be considered for the assessment of ignitability are:

a) the geometry of the test specimen, including thickness and the presence of edges, corners or joints;
b) the surface orientation;
c) the rate and direction of air flow;
d) the nature and position of the ignition source;
e) the magnitude and position of any external heat flux; and
f) whether the combustible material is a solid or a liquid.

In the design of an electrotechnical product the risk of fire and the potential hazards associated with fire need to be considered. In this respect the objective of component, circuit and equipment design, as well as the choice of materials, is to reduce the risk of fire to a tolerable level even in the event of reasonably foreseeable (mis)use, malfunction or failure.

Fires involving electrotechnical products can also be initiated from external non-electrical sources. Considerations of this nature are dealt with in an overall fire hazard assessment.

The aim of the IEC 60695 series of standards is to save lives and property by reducing the number of fires or reducing the consequences of the fire. This can be accomplished by:

- trying to prevent ignition caused by an electrically energised component part and, in the event of ignition, to confine any resulting fire within the bounds of the enclosure of the electrotechnical product.
- trying to minimise flame spread beyond the product's enclosure and to minimise the harmful effects of fire effluents including heat, smoke, and toxic or corrosive combustion products.

For these reasons there are many tests used to evaluate the ignitability of electrotechnical products and of the materials used in their construction. This part of IEC 60695 describes ignitability test methods in common use to assess electrotechnical products, or materials used in electrotechnical products. It also includes test methods in which, by design, ignitability is a significant quantifiable characteristic. It forms part of the IEC 60695-1 series, which gives guidance to product committees wishing to incorporate fire hazard test methods in product standards.

FIRE HAZARD TESTING –

Part 1-21: Guidance for assessing the fire hazard of electrotechnical products – Ignitability – Summary and relevance of test methods

1 Scope

This part of IEC 60695 provides a summary of test methods that are used to determine the ignitability of electrotechnical products or materials from which they are formed. It also includes test methods in which, by design, ignitability is a significant quantifiable characteristic.

It represents the current state of the art of the test methods and, where available, includes special observations on their relevance and use. The list of test methods is not to be considered exhaustive, and test methods which were not developed by the IEC are not to be considered as endorsed by the IEC unless this is specifically stated.

This basic safety publication is intended for use by technical committees in the preparation of standards in accordance with the principles laid down in IEC Guide 104 and ISO/IEC Guide 51.

One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60695-1-20, *Fire hazard testing – Part 1-20: Guidance for assessing the fire hazard of electrotechnical products – Ignitability – General guidance*

IEC 60695-1-30, *Fire hazard testing – Part 1-30: Guidance for assessing the fire hazard of electrotechnical products – Use of preselection testing procedures*

IEC 60695-4:2012, *Fire hazard testing – Part 4: Terminology concerning fire tests for electrotechnical products*

IEC Guide 104, *The preparation of safety publications and the use of basic safety publications and group safety publications*

ISO/IEC Guide 51, *Safety aspects – Guidelines for their inclusion in standards*

ISO 13943:2008*, Fire safety – Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943:2008 and IEC 60695-4:2012 (some of which are reproduced below) and the following apply.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
combustion
exothermic reaction of a substance with an oxidizing agent

Note 1 to entry: Combustion generally emits fire effluent accompanied by **flame**s (3.10) and/or glowing.

[SOURCE: ISO 13943:2008, 4.46]

3.2
end product
product that is ready for use without modification

Note 1 to entry: An end product can be a component of another end product.

[SOURCE: IEC 60695-4:2012, 3.2.7]

3.3
fire
⟨general⟩ process of **combustion** (3.1) characterized by the emission of heat and fire effluent and usually accompanied by smoke, **flame** (3.10), glowing or a combination thereof

Note 1 to entry: In the English language the term “fire” is used to designate three concepts, two of which, **fire** (3.4) and **fire** (3.5), relate to specific types of self-supporting combustion with different meanings and two of them are designated using two different terms in both French and German.

[SOURCE: ISO 13943:2008, 4.96]

3.4
fire
⟨controlled⟩ self-supporting **combustion** (3.1) that has been deliberately arranged to provide useful effects and is limited in its extent in time and space

[SOURCE: ISO 13943:2008, 4.97]

3.5
fire
⟨uncontrolled⟩ self-supporting **combustion** (3.1) that has not been deliberately arranged to provide useful effects and is not limited in its extent in time and space

[SOURCE: ISO 13943:2008, 4.98]

3.6
fire hazard
physical object or condition with a potential for an undesirable consequence from **fire** (3.3)

[SOURCE: ISO 13943:2008, 4.112]

3.7
fire point
minimum temperature at which a material ignites and continues to burn for a specified time after a standardized small **flame** (3.10) has been applied to its surface under specified conditions

cf. **flash point** (3.15)

Note 1 to entry: In some countries the term "fire point" has an additional meaning: a location where fire fighting equipment is sited, which may also comprise a fire-alarm call point and fire instruction notices.

Note 2 to entry: The typical units are degrees Celsius (°C).

[SOURCE: ISO 13943:2008, 4.119]

3.8
fire retardant, noun
substance added or a treatment applied to a material in order to delay **ignition** (3.19) or to reduce the rate of combustion (3.1)

cf. **flame retardant** (3.11)

Note 1 to entry: The use of (a) fire retardant(s) does not necessarily suppress **fire** (3.3) or terminate **combustion (3.1)**.

[SOURCE: ISO 13943:2008, 4.123]

3.9
fire scenario
qualitative description of the course of a **fire** (3.5) with respect to time, identifying key events that characterise the studied fire and differentiate it from other possible fires

Note 1 to entry: It typically defines the **ignition** (3.19) and fire growth processes, the **fully developed fire** (3.16) stage, the fire decay stage, and the environment and systems that impact on the course of the fire.

[SOURCE: ISO 13943:2008, 4.129]

3.10
flame, noun
zone in which there is rapid, self-sustaining, sub-sonic propagation of **combustion** (3.1) in a gaseous medium, usually with emission of light

[SOURCE: ISO 13943:2008, 4.133, modified (addition of “zone in which there is”)]

3.11
flame retardant, noun
substance added, or a treatment applied, to a material in order to suppress or delay the appearance of a **flame** (3.10) and/or reduce the flame spread rate

cf. **fire retardant** (3.8)

Note 1 to entry: The use of (a) flame retardant(s) does not necessarily suppress **fire** (3.3) or terminate **combustion** (3.1).

[SOURCE: ISO 13943:2008, 4.139]

3.12
flaming combustion
combustion (3.1) in the gaseous phase, usually with emission of light

[SOURCE: ISO 13943:2008, 4.148]

3.13
flash-ignition temperature
FIT
minimum temperature at which, under specified test conditions, sufficient flammable gases are emitted to ignite momentarily on application of a pilot **flame** (3.10)

[SOURCE: ISO 871:2006, 3.1]

3.14
flash-over
⟨stage of fire⟩ transition to a state of total surface involvement in a **fire** (3.3) of combustible materials within an enclosure

[SOURCE: ISO 13943:2008, 4.157]

3.15
flash point (°C)
minimum temperature to which it is necessary to heat a material or a product for the vapours emitted to ignite momentarily in the presence of **flame** (3.10), under specified test conditions

Note 1 to entry: The typical units are degrees Celsius (°C).

[SOURCE: ISO 13943:2008, 4.154]

3.16
fully developed fire
state of total involvement of combustible materials in a **fire** (3.5)

[SOURCE: ISO 13943:2008, 4.164]

3.17
glowing combustion
combustion (3.1) of a material in the solid phase without **flame** (3.10) but with emission of light from the combustion zone

[SOURCE: ISO 13943:2008, 4.169]

3.18
ignitability
ease of ignition
measure of the ease with which a test specimen can be ignited, under specified conditions

[SOURCE: ISO 13943:2008, 4.182]

3.19
ignition
sustained ignition (deprecated)
⟨general⟩ initiation of **combustion** (3.1)

[SOURCE: ISO 13943:2008, 4.187]

3.20
ignition
sustained ignition (deprecated)
⟨flaming combustion⟩ initiation of sustained **flame** (3.10)

[SOURCE: ISO 13943:2008, 4.188]

3.21
ignition source
source of energy that initiates **combustion** (3.1)

[SOURCE: ISO 13943:2008, 4.189]

3.22
lower flammability limit
LFL
minimum concentration of fuel vapour in air below which propagation of a **flame** (3.10) does not occur in the presence of an **ignition source** (3.21)

Note 1 to entry: The concentration is usually expressed as a volume fraction at a defined temperature and pressure, and expressed as a percentage.

[SOURCE: ISO 13943:2008, 4.216]

3.23
minimum ignition temperature
ignition point
minimum temperature at which sustained **combustion** (3.1) can be initiated under specified test conditions

Note 1 to entry: The minimum ignition temperature implies the application of a thermal stress for an infinite length of time.

Note 2 to entry: The typical units are degrees Celsius (°C).

[SOURCE: ISO 13943:2008, 4.231]

3.24
spontaneous-ignition temperature
SIT
minimum temperature at which **ignition** (3.19) is obtained by heating, under specified test conditions, in the absence of any additional **flame** (3.10) **ignition source** (3.21)

[SOURCE: ISO 871, 3.2]

3.25
thermal inertia
product of thermal conductivity, density and specific heat capacity

EXAMPLES The thermal inertia of steel is $2,3 \times 10^8$ $J^2 \cdot s^{-1} \cdot m^{-4} \cdot K^{-2}$. The thermal inertia of polystyrene foam is $1,4 \times 10^3$ $J^2 \cdot s^{-1} \cdot m^{-4} \cdot K^{-2}$.

Note 1 to entry: When a material is exposed to a heat flux, the rate of increase of surface temperature depends strongly on the value of the thermal inertia of the material. The surface temperature of a material with a low thermal inertia rises relatively quickly when it is heated, and vice versa.

Note 2 to entry: The typical units are joules squared per second per metre to the fourth power per Kelvin squared ($J^2 \cdot s^{-1} \cdot m^{-4} \cdot K^{-2}$).

[SOURCE: ISO 13943:2008, 4.326]

3.26
tracking
arc tracking
⟨electrotechnical⟩ progressive formation of conducting paths that are produced on the surface and/or within a solid insulating material, due to the combined effects of electric stress and electrolytic contamination

[SOURCE: ISO 13943:2008, 4.342]

3.27
upper flammability limit
UFL
maximum concentration of fuel vapour in air above which propagation of a **flame** (3.10) will not occur in the presence of an **ignition source** (3.21)

Note 1 to entry: The concentration is usually expressed as a volume fraction at a defined temperature and pressure, and expressed as a percentage.

[SOURCE: ISO 13943:2008, 4.349]

4 Summary of published test methods

4.1 General

This summary cannot be used in place of published standards which are the only valid reference documents. It represents the current state of the art of the test methods and, where available, includes special observations on their relevance and use. The list of test methods is not to be considered exhaustive, and test methods which were not developed by the IEC are not to be considered as endorsed by the IEC unless this is specifically stated. General guidance on ignitability is given in IEC 60695-1-20.

Some test methods are material tests and some are end product tests. Table A.1 lists the test methods described below and distinguishes between material tests and end product tests.

In cases where fire tests are not yet specified, and need to be developed or altered for the special purpose of an IEC technical committee, this shall be done in liaison with IEC Technical Committee 89.

The test method(s) selected shall be relevant to the fire scenario of concern.

NOTE 1 Not all the following test methods are specifically ignition or ignitability tests, but some tests have been included because ignition data are, or can be, measured.

NOTE 2 Where no repeatability and reproducibility data are known to be available, information may be available from the author/publisher of the relevant test method.

4.2 Tests using heated air or electrical heating

4.2.1 Determination of ignition temperature using a hot-air furnace, ISO 871

4.2.1.1 Purpose and principle

ISO 871 specifies a laboratory method for determining the flash-ignition temperature and spontaneous-ignition temperature of plastics using a hot-air furnace.

A specimen of the material is heated in a hot-air ignition furnace using various temperatures within the heated chamber, and the flash-ignition temperature is determined with a small pilot flame directed at the opening in the top of the furnace to ignite evolved gases. The spontaneous-ignition temperature is determined in the same manner as the flash-ignition temperature, but without the ignition flame.

4.2.1.2 Test specimen

Materials supplied in any form, including composites, may be used. A 3 g sample is used if the density is greater than 100 $kg\cdot m^{-3}$. For cellular materials having a density less than 100 $kg\cdot m^{-3}$, any outer skin is removed and a block of dimensions 20 mm × 20 mm × 50 mm is cut.

4.2.1.3 Test method

An air velocity of 25 $mm\cdot s^{-1}$ is set and an initial test temperature is chosen. At the end of 10 min the temperature is lowered or raised by 50 °C, depending on whether ignition has or has not occurred and a fresh sample is tested. When the range within which the ignition temperature lies has been determined, tests are begun 10 °C below the highest temperature within this range and continued by dropping the temperature in 10 °C steps until the temperature is reached at which there is no ignition during a 10 min period. The ignition temperature is recorded as the lowest test temperature at which ignition is observed.

4.2.1.4 Repeatability and reproducibility

Data are available in Annex A of ISO 871:2006.

4.2.1.5 Relevance of test data

Tests made under the conditions of this method can be of considerable value in comparing the relative ignition characteristics of different materials. Values obtained represent the lowest ambient air temperature that will cause ignition of the material under the conditions of this test. Test values are expected to rank materials according to ignition susceptibility under actual use conditions.

4.2.2 Differential scanning calorimetry (DSC), ISO 11357 [1][1]

4.2.2.1 Introduction

Differential scanning calorimetry (DSC) is one of a number of thermal methods of analysis which are not used to directly measure ignition, but which are used to measure a number of properties which affect ignitability and which can be used in fire safety engineering studies and in fire modelling.

NOTE Other useful techniques include thermogravimetric analysis (TGA), differential thermal analysis (DTA), thermomechanical analysis (TMA), dynamic mechanical thermal analysis (DMTA), and pyrolysis gas chromatography [2], [3].

4.2.2.2 Purpose and principle

ISO 11357 consists of seven parts, and describes methods using DSC to measure the following properties of polymeric materials such as thermoplastics and thermosetting plastics, including moulded materials and composite materials:

- Glass transition temperature
- Temperature and enthalpy of melting and crystallization
- Specific heat capacity
- Polymerization temperatures and/or times and polymerization kinetics
- Oxidation induction time
- Crystallization kinetics

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1 Numbers in square brackets refer to the bibliography.

The DSC method involves the measurement of the difference between the heat flow into a test specimen and that into a reference specimen as a function of temperature and/or time, while the test specimen and the reference specimen are subjected to a controlled temperature programme under a specified atmosphere.

4.2.2.3 Test specimen

Test specimens may be liquid or solid. The optimum test specimen mass varies depending on what parameter is being studied, but will typically be in the range 5 mg to 50 mg. The test specimen is placed in a sample pan which, if required, is sealed with a lid. The reference specimen is usually an identical empty sample pan.

4.2.2.4 Test method

The instrument is first calibrated, then the sample pans are inserted and the instrument is programmed to carry out the desired thermal cycle. Control operations and data analysis are according to the manufacturer’s instructions.

4.2.2.5 Repeatability and reproducibility

Data are given in annexes to the various parts of ISO 11357.

4.2.2.6 Relevance of test data

DSC enables the measurement of two important parameters which are needed in fire models of ignition. These are: a) specific heat capacity as a function of temperature, and b) the heat of gasification.

4.3 Tests using radiant heat

4.3.1 Heat release rate – Cone calorimeter method, ISO 5660-1 [4]

4.3.1.1 Purpose and principle

ISO 5660-1 specifies a method for assessing the heat release rate, smoke production rate and mass loss rate of a test specimen exposed in the horizontal orientation to a controlled level of irradiance in the presence of a spark ignition source. The irradiance is within the range of 0 kW × m^{-2} to 100 kW × m^{-2}. The heat release rate is determined by measurement of the oxygen consumption derived from the oxygen concentration and the flow rate in the combustion product stream. The time to ignition (sustained flaming) is also measured in the test. The test specimen is mounted on a load cell so that the mass is measured during the test.

The test method is based on the observation that, generally, the net heat of combustion is proportional to the amount of oxygen required for combustion. The relationship is that approximately 13,1 kJ of heat are released per gram of oxygen consumed.

4.3.1.2 Test specimen

The test specimen is square (100 mm × 100 mm) and not more than 50 mm thick. It is wrapped in aluminium foil so that the bottom and sides are covered and the top surface is exposed. The wrapped test specimen is placed in a retainer frame. A substrate is used if appropriate.

4.3.1.3 Test method

The apparatus is first calibrated, and then the exhaust flow and irradiance levels are set. The test specimen is placed in position under a radiation shield, and then the test is started when the shield is removed and the spark igniter is inserted and powered.

Data are collected for typically 32 min after sustained flaming has occurred. Three specimens are tested.

4.3.1.4 Repeatability and reproducibility

Data are available in Annex B of ISO 5660-1:2015.

4.3.1.5 Relevance of test data

Heat release rate is one of the most important variables in determining the hazard from a fire. In a typical fire, many items composed of many surfaces contribute to the development of a fire, thus making its evaluation quite complex. A determination must first be made of when each separate surface will ignite, if at all, and this bench scale test gives this information.

The size of the fire from any items already burning must be determined in order to calculate its contribution to the external irradiance on nearby items. Flame spread over each surface must also be evaluated. The heat release rate from the whole surface is then determined knowing the heat release rate per unit area for a given irradiance, as a function of time, as evaluated using this bench scale test. The total fire output then involves a summation over all surfaces for all materials.

Ignition time data as a function of irradiance can also be used to calculate useful ignition related parameters such as the thermal inertia of materials.

4.3.2 Heat release of insulating liquids, IEC TS 60695-8-3[2] [5]

4.3.2.1 Purpose and principle

This technical specification specifies test methods for determining the heat release and smoke production from insulating liquids of electrotechnical products when exposed to a defined heat flux. The technical specification may also be applicable to other liquid specimens.

The principle of the method is the same as that described in 4.2.1.1. In addition a laser, shining through the exhaust effluent, is used to measure smoke production, as described in ISO 5660-1.

4.3.2.2 Test specimen

For preliminary tests 20 cm^3 of liquid are used. 50 cm^3 of liquid are used for the main tests. The liquid is placed in a square, stainless steel sample holder which is 100 mm × 100 mm and 15 mm deep.

4.3.2.3 Test method

The apparatus is calibrated in accordance with ISO 5660-1 and preliminary tests are carried out to find the minimum heat flux (critical ignition flux) at which the test specimen ignites in less than 1 200 s. The main tests are then carried out at this critical ignition flux. Data analysis is in accordance with ISO 5660-1.

4.3.2.4 Repeatability and reproducibility

No data are currently available.

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2 Withdrawn in 2015.

4.3.2.5 Relevance of test data

From this test it is possible to obtain a quantitative assessment of the relative ease, or difficulty, of the ignition of liquids used for electrotechnical purposes. Quantitative heat release and smoke production data are also obtained. All these data can be used in fire safety engineering studies including fire hazard assessments.

4.3.3 Standard test method for determining material ignition and flame spread properties, ASTM E 1321 [6]

4.3.3.1 Purpose and principle

ASTM E 1321 determines material properties related to piloted ignition of a vertically oriented sample under a constant and uniform heat flux and to lateral flame spread on a vertical surface due to an externally applied radiant-heat flux.

4.3.3.2 Test specimen

Test specimens are tested in the form of intended use. For the ignition test, specimens are 155 mm × 155 mm. For the flame spread test, specimens are 800 mm × 155 mm. For both tests, materials and composites of normal thickness 50 mm or less are tested using their full thickness. The test method is restricted to thermally thick test specimens (i.e. when the exposed surface has ignited, the back surface will not have become significantly heated above the ambient temperature).

4.3.3.3 Test method

The test method consists of two procedures; one to measure ignition and one to measure lateral flame spread. Vertically mounted specimens are exposed to the heat from a vertical air/gas fuelled radiant-heat energy source inclined at 15° to the test specimen.

For the ignition test, a test specimen is exposed to a heat flux of 30 $kW{\cdot}m^{-2}$ and the time of ignition, if it occurs within 20 min, is noted. The test is repeated until a minimum flux for ignition, with a tolerance of ± 2 $kW{\cdot}m^{-2}$, has been obtained. Tests are then repeated at higher heat fluxes (using increments of about 10 $kW{\cdot}m^{-2}$), until an ignition time / heat flux profile has been determined for heat fluxes between the minimum heat flux for ignition and 65 $kW{\cdot}m^{-2}$. The data are correlated with defined theories of ignition for the derivation of material flammability properties.

For the flame spread test, a test specimen is exposed to a graduated heat flux that is approximately 5 $kW{\cdot}m^{-2}$ higher at the hotter end than the minimum heat flux necessary for ignition; this heat flux being determined from the ignition test. The test specimen is preheated to thermal equilibrium; the preheat time also being determined from the ignition test. After ignition, the flame front progression along the horizontal length of the test specimen is tracked as a function of time. The data are correlated with defined theories of ignition and flame spread for the derivation of material flammability properties.

4.3.3.4 Repeatability and reproducibility

No data are currently available.

4.3.3.5 Relevance of test data

The results of this test method provide a minimum surface flux and temperature necessary for ignition and for lateral spread, an effective material thermal inertia value, and a flame-heating parameter pertinent to lateral flame spread. The results are potentially useful to predict the time to ignition and the velocity of lateral flame spread on a vertical surface under a specified external flux without forced lateral airflow. Data can be used in fire growth models.

4.3.4 Determination of the characteristic heat flux for ignition from a non-contacting flame source, IEC TS 60695-11-11 [7]

4.3.4.1 Purpose and principle

IEC TS 60695-11-11 describes a test method used to obtain the ignition characteristic heat flux (ICHF) of electrotechnical products, sub-assemblies and materials. The heat flux originates from a non-contacting flame. The test method measures ignition time as a function of incident heat flux.

4.3.4.2 Test specimen

Test specimens are cut from a representative sample of the material taken from an end-product. Where this is not possible, the test specimen is produced using the same fabrication process and the same thickness as would be normally used to make a part of a product. The size of each test specimen is 75 mm ± 1 mm long by 75 mm ± 1 mm wide for both end-product testing and materials testing. Preferred thicknesses are 0,75 mm ± 0,1 mm, 1,5 mm ± 0,1 mm and 3,0 mm ± 0,2 mm.

4.3.4.3 Test method

The first step is to use a heat flux meter to determine the incident heat fluxes generated at several different distances vertically above the flame. These are in the range 30 $kW \cdot m^{-2}$ to 75 $kW \cdot m^{-2}$.

Tests are then carried out on test specimens at heat flux levels which are a multiple of 5 $kW \cdot m^{-2}$ and which are in the range 30 $kW \cdot m^{-2}$ to 75 $kW \cdot m^{-2}$, such that one of the heat fluxes is the highest at which the average ignition time is greater than 120 s.

For the purposes of this test method, ignition of the test specimen is considered to be a sustained and continuous flaming combustion for at least 5 s.

4.3.4.4 Repeatability and reproducibility

Inter-laboratory trials (round-robin tests) have been conducted and the results will be included in the next edition of IEC TS 60695-11-11.

4.3.4.5 Relevance of test data

This test method simulates the fire behaviour of products, assemblies and materials in those cases where a flame source exists close to, but does not make contact with these items. An example is a candle flame near an electrotechnical product.

It has been found that this test method is useful to investigate the possibility of ignition of an electrotechnical product which is exposed to a heat flux from an energy source that does not impinge directly on the product.

4.4 Oxygen index tests

4.4.1 Oxygen index – Ambient temperature test, ISO 4589-2 [8]

4.4.1.1 Purpose and principle

ISO 4589-2 is used to determine the minimum volume fraction of oxygen, in a mixture with nitrogen that will support combustion of small vertical test specimens under specified test conditions. The results, reported as percentages, are defined as oxygen index values.

4.4.1.2 Test specimen

For moulded materials the test specimen dimensions are 80 mm to 150 mm in length, 10 mm in width and 4 mm in thickness. The dimensions for other materials are detailed in Table 2 of ISO 4589-2:1996.

4.4.1.3 Test method

A small test specimen is supported vertically in a mixture of oxygen and nitrogen flowing upwards through a transparent chimney. The upper end of the specimen is ignited and the subsequent burning behaviour of the specimen is observed to compare the period for which burning continues, or the length of specimen burnt, with specified limits for such burning. By testing a series of specimens in different oxygen concentrations, the minimum oxygen concentration is estimated for the required burning behaviour.

4.4.1.4 Repeatability and reproducibility

Data are given in 9.4 and Annex D of ISO 4589-2:1996.

4.4.1.5 Relevance of test data

The oxygen index (OI) test at ambient temperature was first described by Fenimore and Martin [9] in 1966. The first use of the method in standards was ASTM Standard Test Method D 2863:1970 and it has since been published in a wide range of national and international standards. It was published as ISO 4589 in 1984 and has now been revised as ISO 4589-2. The OI test at elevated temperatures is described in ISO 4589-3 [10] (see 4.4.2).

In the period since ASTM D 2863 became a standard, a considerable number of papers have been published about this test. An example is the review by Weil, Hirschler, et al. [11] relating to correlations with other fire tests and to the test’s relevance to real fires. The conclusion of this review was that results do not correlate well with any other fire test or with the behaviour of real fires.

The guidance document, ISO 4589-1 [12] states:

“The test is used for the quality control of materials, particularly to check the incorporation of flame retardants in the material under test, and for research and development. This test, in isolation, is insufficient to evaluate the burning behaviour and should not be used for regulations relating to safety control and consumer protection.”

It also states, referring to both ISO 4589-2 and ISO 4589-3:

“It is essential that these small-scale laboratory tests be regarded as material tests only. They are primarily for assistance in development, monitoring consistency and/or pre-selection of materials and **are not for use as the sole means of assessing the potential fire hazard of a material in use.**”

4.4.2 Oxygen index – Elevated temperature test, ISO 4589-3 [10]

4.4.2.1 Purpose and principle

ISO 4589-3 is used to determine the minimum volume fraction of oxygen, in a mixture with nitrogen that will support combustion of small vertical test specimens under specified test conditions over a range of temperatures typically between 25 °C and 150 °C. The results, reported as percentages, are defined as oxygen index values at the test temperature, which is typical of the practical temperature that a plastic material may experience in an overheated service situation.

The standard also includes a method for determining the temperature at which the oxygen index of small vertical test specimens in air is 20,9 under specified test conditions. The result is defined as the flammability temperature (FT) and the method is limited to the determination of results less than 400 °C.

4.4.2.2 Test specimen

For moulded materials the test specimen dimensions are 80 mm to 150 mm in length, 10 mm in width and 4 mm in thickness. The dimensions for other materials are detailed in Table 2 of ISO 4589-2:1996.

4.4.2.3 Test method

A small test specimen is supported vertically in a mixture of oxygen and nitrogen flowing upwards through a transparent double-walled chimney. The chimney is provided with a heating element suitable for use, in conjunction with a pre-heater for heating the incoming gas mixture, to maintain the test atmosphere within the inner tube in the vicinity of the test specimen at the desired test temperature. The upper end of the specimen is ignited and the subsequent burning behaviour of the specimen is observed to compare the period for which burning continues, or the length of specimen burnt, with specified limits for such burning. By testing a series of specimens in different oxygen concentrations, the minimum oxygen concentration is estimated for the required burning behaviour at the selected test temperature.

An alternative procedure is given in Annex A of ISO 4589-3:1996 for the measurement of the flammability temperature (FT). In this procedure air flows upwards through the chimney at a selected test temperature and the burning behaviour of the test specimen is noted. A subsequent test is then carried out at a higher or lower temperature, depending on the previously observed burning behaviour. This procedure is repeated until the FT is established, to within an increment of 5 °C, as the lowest temperature at which the test specimen exceeds at least one of the test criteria.

4.4.2.4 Repeatability and reproducibility

No repeatability data are currently available. Annex B of ISO 4589-3:1996 summarises interlaboratory results of a correlation exercise conducted in the UK in 1986 to assess the effect of different types of specimen support, from which reproducibility data may be calculated. Eight laboratories participated in this exercise.

4.4.2.5 Relevance of test data

See 4.4.1.5.

The flammability temperature test identifies a pass/fail criterion at a specified temperature and is widely used for demonstrating satisfactory behaviour at a limiting temperature. This method is only suitable for testing well-characterized grades of materials. However, great caution should be exercised when testing unknown compounds in which apparently satisfactory behaviour is observed at temperatures above the flammability temperature. It is possible for flammable volatiles to be swept from the chimney during the conditioning period prior to the attempted ignition, rendering the tested material less flammable than the virgin material.

Conversely, some flame-retarded materials may be mis-represented by this test. If the flame retardant works by releasing gas phase combustion inhibitors (e.g. water vapour, carbon dioxide, and antimony halides/oxyhalides) during pyrolysis of the material, then such inhibitors may be swept from the chimney during the conditioning period prior to the attempted ignition, rendering the tested material more flammable than the virgin material.

4.5 Glowing/hot-wire based test methods

4.5.1 Glow wire tests, IEC 60695-2-11 [14], IEC 60695-2-12 [15] and IEC 60695-2-13 [16]

4.5.1.1 Glow-wire flammability test for end-products, IEC 60695-2-11 [14]

4.5.1.1.1 Purpose and principle

The glow-wire is a specified loop of resistance wire, which is electrically heated to a specified temperature. The test apparatus is described in IEC 60695-2-10 [13].

The purpose of IEC 60695-2-11 is to ensure that, under defined conditions, the glow-wire does not cause ignition of parts, and that a part, if ignited, has a limited duration of burning without spreading fire by flames or by burning or glowing particles falling from the test specimen.

4.5.1.1.2 Test specimens

The test specimen should be a complete end-product chosen so that the conditions of the test will not be significantly different from those occurring in normal use.

If the test cannot be made on a complete end-product, it is acceptable to:

a) cut a piece containing the part under examination from it, or
b) cut an aperture in the complete end-product to allow the glow-wire access, or
c) remove the part under examination in its entirety and test it separately.

4.5.1.1.3 Test method

The tip of the heated glow-wire is brought into contact with a test specimen for a specific period of time and a range of observations and measurements are made, depending upon the particular test procedure.

The tip of the glow-wire is applied horizontally to the part of the test specimen which is likely to be subjected to thermal stresses in normal use.

4.5.1.1.4 Repeatability and reproducibility

No data are known to be available.

4.5.1.1.5 Relevance of test data

This test identifies a pass/fail criterion at a temperature specified by the relevant product committee. The main use of the test by electrotechnical committees is to ensure the suitability of insulating materials in contact with live parts or electrical connections that might overheat due to a fault. The aim is to ensure that possible ignition of the insulating material does not cause a fire to spread from the product.

Overheating of the electrical connection may cause ignition in the product but, on removal of the fault current, an insulating material which has passed the test would be expected to self-extinguish. Therefore, although the product may have been rendered unusable, flame spread is unlikely to have occurred and so the user and other property will not have been put at risk from fire.

This test has been used for many years as an alternative/replacement for IEC 60695-2-3, *Bad connection test,* which was withdrawn in 2003.

As well as checking the integrity of the supporting insulating material, during the test, the operator also records whether flaming or molten droplets fall onto a specified surface below. In a large product this would be assessed by placing below the test specimen a sample of the material that would, in normal use, be subjected to the droplets. If this layer was not damaged and contained the molten material then this would be considered satisfactory. When there is no surface to trap the droplets, and they were likely to escape from the product (for example onto a flammable surface) then a standard sheet of wrapping tissue on a wooden board is used.

The operator also records whether or not the material ignites. Some product committees note that ignition has occurred and then assume a standardized zone above the area of the live part or electrical connection to carry out further tests. This is known as consequential testing and it may be carried out using the needle flame test (see 4.6.1).

4.5.1.2 Glow-wire flammability index (GWFI) test method for materials, IEC 60695-2-12 [15]

4.5.1.2.1 Purpose and principle

The glow-wire is a specified loop of resistance wire, which is electrically heated to a specified temperature. The test apparatus is described in IEC 60695-2-10 [13].

The purpose of IEC 60695-2-12 is to determine the glow-wire flammability index (GWFI) of solid electrical insulating materials and other solid materials. The GWFI is the highest temperature at which three test specimens comply with the specified conditions.

4.5.1.2.2 Test specimens

The dimensions of the test specimens are ≥ 60 mm × ≥ 60 mm × a preferred value of thickness. They can be manufactured by compression moulding, injection moulding or casting, or cut from sheets or parts of end-products.

4.5.1.2.3 Test method

The tip of the heated glow-wire is brought into contact with the vertically mounted test specimen for a specific period of time and a range of observations and measurements is made, dependent upon the particular test procedure.

By repeated tests with different test temperatures of the glow-wire, using a new test specimen each time, the GWFI of the material under test is established.

4.5.1.2.4 Repeatability and reproducibility

No data are known to be available.

4.5.1.2.5 Relevance of test data

This test is a materials test carried out on a series of standard test specimens. The data obtained can then be used in a preselection process to judge the ability of materials to meet the requirements of IEC 60695-2-11, the glow-wire flammability test method for end products. The test method is not valid for determining the flammability, fire behaviour, or fire hazard of complete items of equipment, since the dimensions of the insulating systems or combustible parts, the design and heat transfer to adjacent metallic or non-metallic parts, etc., greatly influence the flammability of the materials used therein.

As an outcome of conducting a fire hazard assessment, an appropriate series of preselection flammability and ignition tests may permit reduced end product testing (see IEC 60695-1-30).

4.5.1.3 Glow-wire ignition temperature (GWIT) test method for materials, IEC 60695-2-13 [16]

4.5.1.3.1 Purpose and principle

The glow-wire is a specified loop of resistance wire, which is electrically heated to a specified temperature. The test apparatus is described in IEC 60695-2-10 [13].

The purpose of IEC 60695-2-13 is to determine the glow-wire ignitability index (GWIT) of solid electrical insulating materials and other solid materials. The GWIT is the minimum temperature at which ignition will take place.

4.5.1.3.2 Test specimens

The dimensions of the test specimens are ≥ 60 mm × ≥ 60 mm × a preferred value of thickness. They can be manufactured by compression moulding, injection moulding or casting, or cut from sheets or parts of end-products.

4.5.1.3.3 Test method

The tip of the heated glow-wire is brought into contact with the vertically mounted test specimen for a specific period of time and a range of observations and measurements made, dependent upon the particular test procedure.

By repeated tests with different test temperatures of the glow-wire, using a new test specimen each time, the GWIT of the material under test is established.

4.5.1.3.4 Repeatability and reproducibility

No data are known to be available.

4.5.1.3.5 Relevance of test data

This test is a materials test carried out on a series of standard test specimens. The data obtained can then be used in a preselection process to judge the ability of materials to meet the requirements of IEC 60695-2-11, the glow-wire flammability test method for end products. The test method is not valid for determining the ignitability, fire behaviour, or fire hazard of complete items of equipment, since the dimensions of the insulating systems or combustible parts, the design and heat transfer to adjacent metallic or non-metallic parts, etc., greatly influence the flammability of the materials used therein.

As an outcome of conducting a fire hazard assessment, an appropriate series of preselection flammability and ignition tests may permit reduced end product testing (see IEC 60695-1-30).

4.5.2 Hot wire coil ignitability test, IEC 60695-2-20[3] and ASTM D 3874 [17]

4.5.2.1 Purpose and principle

This test method is intended, in a preliminary fashion, to differentiate materials with respect to their resistance to ignition caused by their proximity to electrically heated wires and other heat sources. Under certain normal (as well as abnormal) operations of electrical equipment, insulating materials may be in close proximity of a heated electrical source such as a motor, a conductor in an overcurrent state, or resistive heating source. If the intensity and/or duration of the exposure to these sources is severe, the insulating material may ignite.

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3 Withdrawn in 2007.

4.5.2.2 Test specimen

The test specimen consists of a bar specimen measuring 125 mm ± 5 mm by 13,0 mm ± 0,5 mm at the thickness to be evaluated.

4.5.2.3 Test method

In this test method, the test specimen, with the center portion wrapped with a coil of heater wire, is supported horizontally at both ends. The circuit is then energized by applying a fixed power density to the heater wire, which rapidly heats up. The behaviour of the test specimen is observed until one of the following happens: a) the material under test ignites, b) the material under test melts, or c) 120 s of exposure have elapsed without the occurrence of ignition or melting. The time to ignition and the time to melt-through, as applicable, are recorded.

4.5.2.4 Repeatability and reproducibility

There are currently no published data available. ASTM D 3874 states:

"It is likely that, when care is taken to adhere to this test method, the average determined will fall within plus or minus 15 % of the value obtained by an interlaboratory evaluation."

However, the IEC test was withdrawn in 2007 because of unsatisfactory repeatability and reproducibility.

4.5.2.5 Relevance of test data

This test method is used for preselection of materials, for quality control and product evaluation. The resultant data have been used for determining the suitability of polymeric materials intended for use in electrical equipment when in direct contact or within 0,8 mm of possible ignition sources.

4.6 Flame tests

4.6.1 Needle flame test, IEC 60695-11-5 [18]

4.6.1.1 Purpose and principle

The needle flame test, IEC 60695-11-5, simulates the effect of a small flame which may result from fault conditions, in order to assess the fire hazard.

4.6.1.2 Test specimen

The test specimen is a complete equipment, sub-assembly or component.

4.6.1.3 Test method

A 12 mm high butane test flame is applied to that part of the test specimen most likely to be affected by flames for a specified duration. A specified layer is placed underneath the test specimen to evaluate the possibility of spread of fire. During and after the application of the test flame the test specimen is observed for glowing, dripping particles and ignition.

4.6.1.4 Repeatability and reproducibility

No data are known to be available.

4.6.1.5 Relevance of test data

The needle flame test is used to check the suitability of materials that may be affected by flames from insulating materials supporting live parts under conditions of an overheated electrical connection. It can also be used to check materials that may require consequential testing (see 4.5.1.1.5).

In some cases a part that would normally be required to meet IEC 60695-2-11 may have dimensions incompatible with the glow wire test apparatus. Should this situation occur, product committees may use the needle flame test IEC 60695-11-5.

4.6.2 50 W horizontal and vertical flame test methods, IEC 60695-11-10 [19]; 500 W flame test methods, IEC 60695-11-20 [20]

4.6.2.1 Purpose and principle

IEC 60695-11-10 is a test method using a 50 W flame. IEC 60695-11-20 is a test method using a 500 W flame.

These test methods refer to solid electrical insulating materials and are intended to serve as a preliminary indication of their behaviour when exposed to a flame ignition source. The results make it possible to check the constancy of the characteristics of a material and provide an indication of the progress in the development of insulating materials and a relative comparison and classification of various materials.

4.6.2.2 Test specimen

In both test methods the test specimen is 125 mm long, 13 mm wide, and up to 13 mm thick.

4.6.2.3 Test method

These tests involve applying a flame ignition source to a horizontal or vertical test specimen and measuring the burned length or surface spread of flame rate.

NOTE The apparatus for producing the 50 W flame is described in IEC 60695-11-4 [21]. The apparatus for producing the 500 W flame is described in IEC 60695-11-3 [22].

4.6.2.4 Repeatability and reproducibility

Data are available in IEC 60695-11-10:2013, Annexes A and B, and IEC 60695-11-20:2015, Annex A.

4.6.2.5 Relevance of test data

This test is a materials test carried out on a series of standard test specimens. The data obtained can then be used in a preselection process to judge the ability of materials to meet the many flammability requirements for end products. The test method is not valid for determining the flammability, fire behaviour, or fire hazard of complete items of equipment, since the dimensions of the insulating systems or combustible parts, the design and heat transfer to adjacent metallic or non-metallic parts, etc., greatly influence the flammability of the materials used therein.

As an outcome of conducting a fire hazard assessment, an appropriate series of preselection flammability and ignition tests may permit reduced end product testing (see IEC 60695-1-30).

4.6.3 1 kW nominal pre-mixed flame, IEC 60695-11-2 [23]

4.6.3.1 Purpose and principle

IEC 60695-11-2 provides detailed requirements for the production of a 1 kW nominal, propane based pre-mixed type test flame.

4.6.3.2 Test specimen

The test flame can be used to test electrotechnical equipment, sub-assemblies and components and solid electrical insulating materials or other combustible materials. Test specimen details are described in the relevant standards that use this test flame.

4.6.3.3 Test method

Examples of appropriate test arrangements are given in Annex B of IEC 60695-11-2:2013. Numerous tests use this flame ignition source. For details the relevant test method should be consulted.

When used for testing equipment, unless otherwise stated in the relevant specification, the recommended distance from the top of the burner tube to the point on the surface of the test specimen is approximately 100 mm and the burner is fixed in position during the test.

When used for testing strips of materials, where the operator may move the flame during the test to follow the distorting or burning test specimen, the tip of the blue cone in the flame should be as close as possible without touching the test specimen.

4.6.3.4 Confirmation of the test flame

Confirmation of the test flame is carried out by measuring the time taken for a defined copper block to increase in temperature by a defined amount.

4.6.3.5 Relevance of test data

This 1 kW, high intensity, pre-mixed test flame is very widely used to simulate the reaction to fire of end-products, components and materials to the direct impingement of a flame ignition source.

4.6.4 Vertical and 60° tests for aircraft components, FAR 25 [25]

4.6.4.1 Purpose and principle

The requirements for electrical system components are given in FAR 25.869 (a). It states that insulation on electrical wires and electric cable installed in any area of an aeroplane fuselage shall be self-extinguishing when tested in accordance with a 60° Bunsen burner test described in Part I, Appendix F of FAR 25.

The requirements for materials and parts used in the crew and passenger compartments are given in FAR 25.853. It states that electrical conduit shall be self-extinguishing when tested in accordance with a vertical Bunsen burner test described in Part I, Appendix F of FAR 25.

4.6.4.2 Test specimen

The test specimen for the vertical Bunsen burner test is at least 50 mm wide and 305 mm long, unless the actual size used in the airline is smaller. The test specimen thickness is no thicker than the minimum thickness qualified for use in an airline.

The test specimen for the 60° Bunsen burner test is a length of wire or cable. The gauge is the same as that used in the airline.

4.6.4.3 Test method

These tests involve applying an ignition source to a 60° or vertical test specimen. The flame time, burned length, and flaming time of drippings, if any, are then measured or noted.

Electrical conduits are submitted to a 12 s application of flame. Wire and cable products are submitted to a 30 s application of flame.

4.6.4.4 Repeatability and reproducibility

No data are known to be available.

4.6.4.5 Relevance of test data

These test methods are used for the preselection of materials, quality control and product evaluation for electrical wires, electrical cables and electrical conduit used in the aviation industry.

4.7 Tests using an electrical arc

4.7.1 Tracking index tests, IEC 60112 [26], ASTM D 3638 [27]

4.7.1.1 Purpose and principle

Both IEC 60112 and ASTM D 3638 specify the method of test for the determination of the comparative tracking index (CTI) of solid insulating materials on pieces taken from parts of equipment and on plaques of material using alternating voltages. IEC 60112 also specifies the method of test for the determination of the proof tracking index (PTI). The standards also provide for the determination of erosion when required. For an overview of the main differences between IEC 60112 and ASTM D 3638, see Table 1.

4.7.1.2 Test specimen

For the IEC 60112 test method the test specimen should be flat, at least 3 mm thick, and have an area sufficient to ensure that during the test no liquid flows over the edges of the test specimen. The recommended minimum size is 20 mm × 20 mm.

For ASTM D 3638 a minimum thickness of 2,5 mm is to be used. In case thinner samples are used, these plaques have to be stacked to the minimum thickness specified in both test standards.

4.7.1.3 Test method

The upper surface of the test specimen is supported in an approximately horizontal plane and subjected to an electrical stress via two platinum electrodes, 4 mm apart, using an a.c. voltage of between 100 V and 600 V. The surface between the electrodes is subjected to a succession of drops of electrolyte either until an over-current device operates, or until ignition and a persistent flame occurs, or until the test period has elapsed.

The individual tests are of short duration (less than 1 h) with up to 50 or 100 drops of about 20 mg of electrolyte falling at 30 s intervals. The number of drops needed to cause failure usually increases with decreasing applied voltage and, below a critical value, tracking ceases to occur.

During the test, the specimen may also erode or soften, thereby allowing the electrodes to penetrate it. If required, erosion is measured. If a hole is formed, this is reported.

Table 1 lists the main differences between IEC 60112 and ASTM D 3638.

Table 1 – Main differences between IEC 60112 and ASTM D 3638

Parameter	IEC 60112	ASTM D 3638
Specimen thickness	≥ 3 mm	≥ 2,5 mm
Electrolyte: Ammonium chloride (aq.)	Solution A (CTI and PTI) (395 ± 5) Ω·cm	(CTI) (385 ± 5) Ω·cm
Electrolyte: Ammonium chloride and alkyl naphthalene sulphonate (aq.) NOTE more aggressive	Solution B (CTI-M) (200 ± 5) Ω·cm	Not applicable
Length of the electrodes	≥ 12 mm	≥ 20 mm
Evaluation of test results for CTI	The maximum voltage that does not cause ignition or tracking (conduction) with solution A. a) 5 test specimens withstand 50 drops without failure, and b) 5 test specimens withstand 100 drops at 25 V lower Result reported e.g. as: “CTI 300”. If the voltage, at which 100 drops can be applied without failure, is lower than the CTI – 25 V, then that voltage is written in parentheses along with the CTI value. Example: “CTI 300 (250)”.	The voltage which will cause failure by tracking (conduction) when the number of drops of contaminant required to cause failure is equal to 50. Ignition of the specimen is not a failure criterion. The test is done on 5 specimens. The average number of drops/voltage relation is plotted on a graph. The CTI voltage is read from the graph where 50 drops cause failure.
Evaluation of test results for CTI-M	The same as for CTI, but with solution B.	Not applicable
Evaluation of test results for PTI	The same as for CTI part a). It is used as a pass or fail test at a voltage specified in an end product specification.	Not applicable

4.7.1.4 Repeatability and reproducibility

For IEC 60112 data are reported in IEC TR 62062:2002 [28].

4.7.1.5 Relevance of test data

The test discriminates between materials with relatively poor resistance to tracking, and those with moderate or good resistance, for use in equipment which can be used under moist conditions.

The test is not a good indicator of a material’s ability to resist ignition from an arcing source as a primary failure mode. The method is set up to create accelerated conditions for the evaluation of tracking as a primary failure mode. However, these conditions do not accurately reflect conditions under which an arc ignition would occur in the field. While ignition of the specimen often occurs during this test, it is a secondary event to the developing (or completed) carbon track.

NOTE More severe tests of longer duration are required for the assessment of performance of materials for outdoor use, utilizing higher voltages and larger test specimens – see the inclined plane test, IEC 60587 [29].

4.7.2 High-Current Arc Ignition (HAI), UL 746A – Sec. 32 [30]

4.7.2.1 Purpose and principle

UL 746A – Sec. 32 was developed to differentiate between solid insulating materials with regard to resistance to ignition from arcing electrical sources. Under certain normal, as well as abnormal, operations of electrical equipment, insulating materials may be in the proximity of a source of arcing. If the intensity and/or duration of the arcing are severe, the insulating material may ignite.

4.7.2.2 Test specimen

The test specimen consists of a bar sample measuring 125 mm ± 5 mm by 13,0 mm ± 0,5 mm at the thickness to be evaluated.

4.7.2.3 Test method

Two electrodes, one a copper rod and the other a stainless steel rod, both at 45 º to the horizontal, are brought into contact on the surface of the test specimen. The stainless steel electrode is capable of being removed to a distance that will break an arc and then brought back into contact to reinitiate the arc in a cyclic motion along its 45º axis. At the initiation of the test, a 32,5 A circuit (power factor 0,5) is energized and the movable electrode is cycled at a rate of 40 arcs per minute until a flame is detected (or the specimen sustains 200 arcs without ignition). The test may also be run with the initial electrode contact 1,6 mm or 3,2 mm above the surface.

4.7.2.4 Repeatability and reproducibility

There are no currently published data available. However, it is recognized that the following factors often contribute to a broad deviation in measured data;

a) the occurrence of variable arc profiles due to asynchronous timing of AC frequency and arc initiation,
b) deterioration of electrode tips during the test cycle, and
c) lack of precise control of the moveable electrode.

A revised method that addresses these issues (and others) is currently under development in the United States.

4.7.2.5 Relevance of test data

These test methods are used for the preselection of materials, for quality control and product evaluation. The resulting data have been used for determining the suitability of polymeric materials intended for use in electrical equipment when in direct contact, within 0,8 mm of non-arcing sources (such as single conductors or bus-bars), or within 12,7 mm of arcing sources (such as parts of opposite polarity).

4.7.3 High-voltage arc resistance to ignition (HVAR), UL 746A – Sec. 33 [31]

4.7.3.1 Purpose and principle

UL746A – Sec. 33 is used to differentiate between solid insulating materials with regard to resistance to ignition or the formation of a visible carbonized conducting path over the surface of the material when subjected to high voltage, low current arcing such as during the malfunction of certain high voltage power supplies in electrical equipment.

4.7.3.2 Test specimen

The test specimen consists of a bar sample measuring 125 mm ± 5 mm by 13,0 mm ± 0,5 mm at the thickness to be evaluated. The test specimens are preconditioned for a minimum of 40 h at 23 ºC ± 2 ºC and at 50 % ± 5 % relative humidity.

4.7.3.3 Test method

Two electrodes, both at 45º to the horizontal, are placed 4,0 mm ± 0,1 mm apart on the surface of the test specimen. At the initiation of the test, an initial circuit of 5,2 kV with a current limiter of 2,36 mA is utilized to create a continuous arc between the electrodes. The test is continued for 5 min or until ignition occurs, or a hole forms in the test specimen.

4.7.3.4 Repeatability and reproducibility

No data are currently available.

4.7.3.5 Relevance of test data

These test methods are used for the preselection of materials, for quality control and product evaluation. The resulting data have been found useful for determining the suitability of polymeric materials intended for use in electrical equipment when in direct contact or close proximity (0,8 mm to non-arcing or 12,7 mm to arcing) to uninsulated live parts.

Annex A
(informative)

Applicability of test methods

A.1 Applicability of test methods

Table A.1 lists the test methods described in Clause 4 and distinguishes between material tests and end-product tests.

Table A.1 – Applicability of test methods *(1 of 2)*

Subclause	Test method	Material test	End-product test	Comments
4.2.1	Hot-air furnace ISO 871	✓	×	This measures the flash-ignition temperature and spontaneous-ignition temperature of plastics
4.2.2	Differential scanning calorimetry ISO 11357	✓	×	This measures a number of properties which affect ignitability
4.3.1	Cone calorimeter method ISO 5660-1	✓	If the geometry is appropriate	This is predominantly a heat release rate test, but time to ignition is measured
4.3.2	Heat release of insulating liquids IEC 60695-8-3	✓	✓	This is a test for insulating liquids. It is predominantly a heat release rate test, but time to ignition is measured
4.3.3	Material ignition and flame spread test ASTM E 1321	✓	✓	This is used mainly to assess interior building materials
4.3.4	ICHF from a flame source IEC/TS 60695-11-11	✓	✓	This test measures ignition time as a function of the heat flux from a non-contacting flame
4.4.1	Oxygen index – Ambient temperature test ISO 4589-2	✓	×	This test is based on whether burning is sustained after ignition. Oxygen volume fraction is a variable
4.4.2	Oxygen index – Elevated temperature test ISO 4589-3	✓	×	This test is based on whether burning in air is sustained after ignition. Temperature is a variable
4.5.1.1	Glow-wire flammability test for end-products IEC 60695-2-11	×	✓	The ignition source is a hot wire applied for 30 s

Table A.1 *(2 of 2)*

Subclause	Test method	Material test	End-product test	Comments
4.5.1.2	Glow-wire flammability test for materials IEC 60695-2-12	✓	×	The ignition source is a hot wire applied for 30 s. The glow-wire flammability index (GWFI) is determined
4.5.1.3	Glow-wire ignitability test for materials IEC 60695-2-13	✓	×	The ignition source is a hot wire applied for 30 s. The glow-wire ignitability index (GWIT) is determined
4.5.2	Hot wire coil ignitability test ASTM D3874 [IEC 60695-2-20, withdrawn]	✓	×	The ignition source is a hot wire coiled round the test specimen. Heating is applied for up to 120 s. The IEC test method, IEC 60695-2-20, was withdrawn because of poor repeatability and reproducibility.
4.6.1	Needle flame test IEC 60695-11-5	✓	✓	The ignition source is a small diffusion flame
4.6.2	50 W Horizontal and vertical flame test methods IEC 60695-11-10	✓	×	The ignition source is a 50 W pre-mixed flame
	500 W flame test methods IEC 60695-11-20	✓	×	The ignition source is a 500 W pre-mixed flame
4.6.3	1 kW nominal pre-mixed flame IEC 60695-11-2	✓	✓	The ignition source is a 1 kW pre-mixed flame
4.6.4	Vertical and 60° tests for aircraft components FAR 25 – Part I – Appendix F	×	✓	This is a test for aerospace electrical wires and cables
4.7.1	Proof and comparative tracking indices of solid insulating materials IEC 60112	✓(CTI)[a]	✓(PTI)[b]	Ignition which causes persistent flaming (burning for more than 2 s) is a failure criterion in this test
	Standard test method for comparative tracking index of electrical insulating materials ASTM D 3638	✓	×	Flame ignition shall be reported.
4.7.2	High-current arc ignition (HAI) test UL 746A – Sec. 32	✓	×	This is used to evaluate polymeric insulating materials
4.7.3	High-voltage arc ignition (HVAR) test UL 746A – Sec. 33	✓	×	This is used to evaluate polymeric insulating materials

[a] CTI = Comparative tracking index

[b] PTI = Proof tracking index

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[30] UL 746A – Sec. 32, *Standard for Polymeric Materials – Short Term Property Evaluations – Sec. 43: High-current arc ignition test*

[31] UL 746A – Sec. 33, *Standard for Polymeric Materials – Short Term Property Evaluations – Sec. 44: High-voltage arc ignition test*

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