
Reaction to fire tests — Spread of flame —

Part 1:

Guidance on flame spread

Essais de réaction au feu — Propagation du feu —

Partie 1: Guide sur la propagation de la flamme

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Foreword

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

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 5658-1, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Reaction to fire*.

ISO 5658 consists of the following parts, under the general title *Reaction to fire tests — Spread of flame*:

- *Part 1: Guidance on flame spread* (Technical Report)
<https://standards.iteh.ai/catalog/standards/sist/38a090c9-6936-4ad8-b25b-3882d0aa3740/iso-tr-5658-1-1997>
- *Part 2: Lateral spread on building products in vertical configuration*
- *Part 3: Lateral ignition of and flame spread on building products in vertical configuration (LIFT) method* (Technical Report)
- *Part 4: Intermediate-scale spread of flame with vertically oriented specimens*

Annex A of this Technical Report is for information only.

Introduction

The rate and extent of flame spread are important properties to be characterized when evaluating the reaction-to-fire hazards of construction products. Historically, there have been many approaches taken to the measurement of flame spread and most of these have evolved with little fundamental justification. This Technical Report describes different modes of flame spread and proposes some theoretical principles to assist with the relevant application of the data obtained from flame spread tests.

Many flame spread tests measure the rate and extent of the flame front as the flame moves over the surface of large-area, flat products such as linings on walls, ceilings and floors. Usually the orientation of the test specimen is related to the end-use application (for example, exposed face upwards for floor-coverings). This requirement for end-use relevance is satisfied by ISO 5658-2 and ISO/TR 5658-3 when wall-linings are to be evaluated.

Flame spread over construction products is related to the fire scenario. ISO/TC 92/SC 1 have concentrated on development of tests to simulate flame spread in rooms and along corridors. Other important scenarios where flame spread data are required are facades (both front and behind), shafts, stairs and roofs; much of the theoretical guidance given in this Technical Report may be applied to these scenarios even though ISO test procedures may not yet be available.

Flame spread can also occur over non-planar products (e.g. pipes) and within assemblies (e.g. along joints or inside air-gaps). Whilst this Technical Report concentrates on the theory pertinent to flat products, some of the theory outlined may be applied to improve the understanding of these more complex situations (see clause 8, flame spread within assemblies).

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Flame spread initiated by removal of flaming drops or debris is not treated in this Technical Report. Empirically derived tests for these secondary flame spread phenomena are available (see ref. [34]).

NOTE — Flame spread can be reduced and sometimes eliminated due to melting and dripping; these effects are also not treated in this Technical Report.

Reaction to fire tests — Spread of flame —

Part 1:

Guidance on flame spread

1 Scope

This Technical Report provides guidance on flame spread tests for construction products. It describes the principles of flame spread and classifies different flame spread mechanisms.

The results of small-scale flame spread tests (e.g. ISO 5658-2 [31], ISO/TR 5658-3 [32] and ISO 9239-1 [35]) and large-scale tests (e.g. ISO 9705 [13]) may be used as components in a total hazard analysis of a specified fire scenario. The theoretical basis of these tests is explained so that relevant conclusions or derivations may be made from the test results.

2 Principles of flame spread

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Flammability of room surfaces is a major concern of all building regulations. The primary room surfaces in question are any combustible linings used on the walls or ceilings, along with floor coverings. To understand the role of bench-scale tests in assessing this hazard, the dominant fire effects must be placed in context.

The ceiling can show a very rapid fire spread and a high contribution to hazard. Recent research suggests that the least combustible materials should be allocated to the ceiling in order to minimize fire hazard. There is not universal agreement on this point, however, and some studies conclude the opposite (see reference [25]). For almost any fire scenario, flame spread along the ceiling is wind-aided, that is, the air-flow and the flame spread are both in the same direction.

For common fire scenarios, flame spread on walls will be upward, that is wind-aided, in the vicinity of the fire source. In other parts of the walls, flame spread will be downward, that is opposed-flow, since entrained air is moving upwards, opposite to the direction of flame motion. Much of the wall can, however, be directly ignited by submersion into the layer of hot gases forming below the ceiling. This ignition does not involve a flame spread process at all, but it is directly accelerated by ceiling flammability.

Flame spread on floors is generally ignorable within a room since it is very limited until quite late in a fire. Flame spread on floors in corridors, however, can be of major concern. This flame spread is usually caused by a room fire impinging on the adjacent corridor and igniting the flooring. There will usually be some prevailing air flow direction within a corridor. Flame spread can then proceed either in the wind-aided direction, or as opposed flow. Commonly, flame spread in both directions can occur simultaneously on corridor flooring materials.

In principle, two different bench-scale test methods would be required to represent the two fundamentally different flame spread processes of wind-aided spread and opposed-flow spread. The flame spread rates are not similar in these two processes. Wind-aided spread tends to be much more rapid since a large amount of virgin combustible can be the flame tip, whereas in the opposite direction the heating of the material is limited to a very small heating zone. Research studies have shown, however, that a test solely dedicated to examining wind-aided spread is not necessary [26].

Theory and experiments both reveal that wind-aided flame spread can be directly predicted once the heat release rate and the ignitability behaviour of the specimen is established. These would be done in bench-scale by the use of the ISO 5660 method for heat release rate and either ISO 5660 or ISO 5657 for ignitability.

Flame spread for the opposed-flow configuration also requires information about the flame flux and the flame heating distance for that geometry [27]. In the context of ISO bench-scale test methods, this is the role for the ISO 5658 test. Thus, while there are two flame spread modes of concern and while the wind-aided spread is often of dominant concern, there is seen to be a need only for one lateral bench-scale flame spread ISO test, and this test is devoted solely to the opposed-flow mode.

3 Characteristics of flame spread modes

3.1 General

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In this clause, the characteristics of different flame spread modes are described and summarized in Table 1. For each of the modes, the dominant heat transfer mechanisms are identified. The various modes are distinguished by two criteria: orientation of the fuel surface and direction of the main flow of gases relative to that of flame spread. Only flat fuel surfaces are considered. It is furthermore assumed that the fuel slab is located in a normal gravity environment, i.e., special cases such as flame spread under microgravity conditions (spaceships) are not considered. The analysis is for thick fuels, or else thin fuels in combination with a backing board. Cases where burning may be on two sides simultaneously (e.g. upward flame spread over curtains) are not explicitly included.

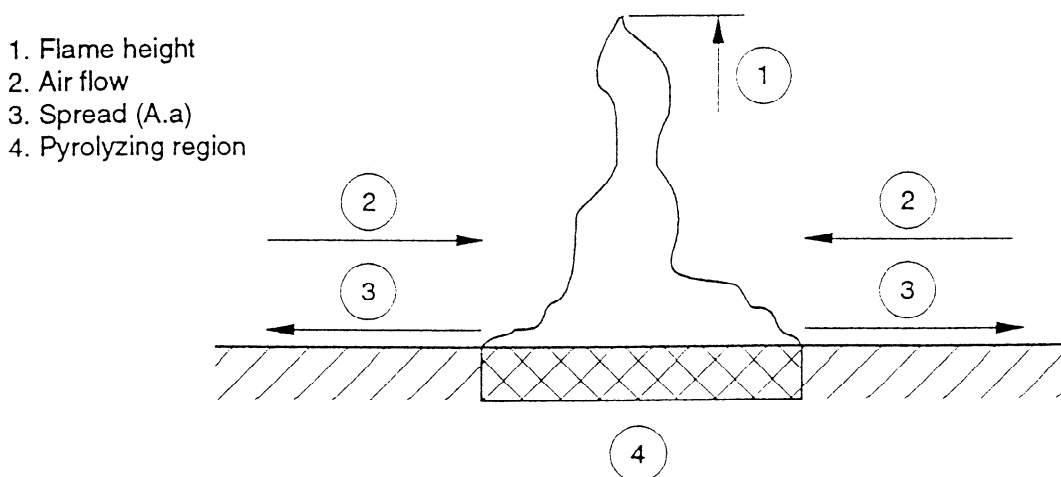


Figure 1 - Flame spread mode A.a (3.1 (a))

Table 1 — Modes of flame spread

Mode reference	Application	Type of flame spread
Aa	Flooring; Horizontal	Opposed-flow
Ab	Flooring; Horizontal	Opposed-flow
Ac	Flooring; Horizontal	Wind-aided
Ba	Walls; Vertical	Wind-aided
Bb	Walls; Vertical	Opposed-flow
Bc	Walls; Vertical	Opposed-flow
Ca	Ceilings; Horizontal	Wind-aided

3.2 Horizontal facing upward

a) Flame spread over a horizontal surface away from a burning area is illustrated in figure 1. The burning area has the characteristics of a pool fire. The air flow rate entrained into the flame is assumed to be reasonably uniform around the perimeter of the fire. Flame spread is against the direction of the entrained air flow, and is therefore of the opposed-flow type. The heat transfer to the non-burning fuel is primarily flame radiation. Only locally, close to the pyrolysis front, is gas phase conduction between the flame foot and the virgin fuel the dominant mode of heat transfer. If the entrained air flow rate is not uniform around the perimeter, the flame tilts in the direction of the dominant flow. As a result, the far field flame radiation to the unburnt fuel is no longer symmetrical. Objects blocking the flow and ventilation openings providing fresh air may have a pronounced effect on the flow field close to the fire.

b) This configuration is identical to that in 3.1 a), except that there is now a forced air flow because of which the flame tilts over in the direction of the flow. This mode is illustrated in figure 2. On the upstream side of the pool fire, flames spread against the air flow. However, the view factor between the flame and the non-burning fuel on this side is now very small. Consequently, the far field flame radiation becomes negligible and the gas phase conduction near the pyrolysis front is the only dominant method of heat transfer. In fact, significant flame heating is only over a very small region near the pyrolysis front (a few mm). Therefore, the spread rate is very slow and opposed-flow flame spread is commonly referred to as creeping spread. For many fuels the heat transfer is insufficient to maintain the spread, at least in absence of external heating (such as in 3.1 a). A criterion for creeping spread will be discussed below.

1. Air flow
2. Spread (A.b)
3. Spread (A.c)
4. Pyrolyzing region

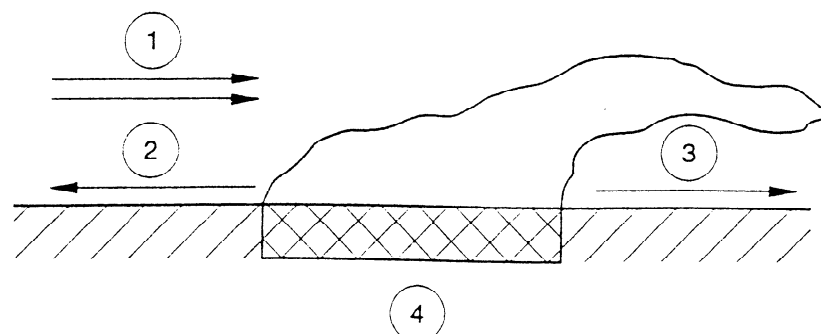


Figure 2 - Flame spread modes A.b and A.c (3.1 b and 3.1 c)

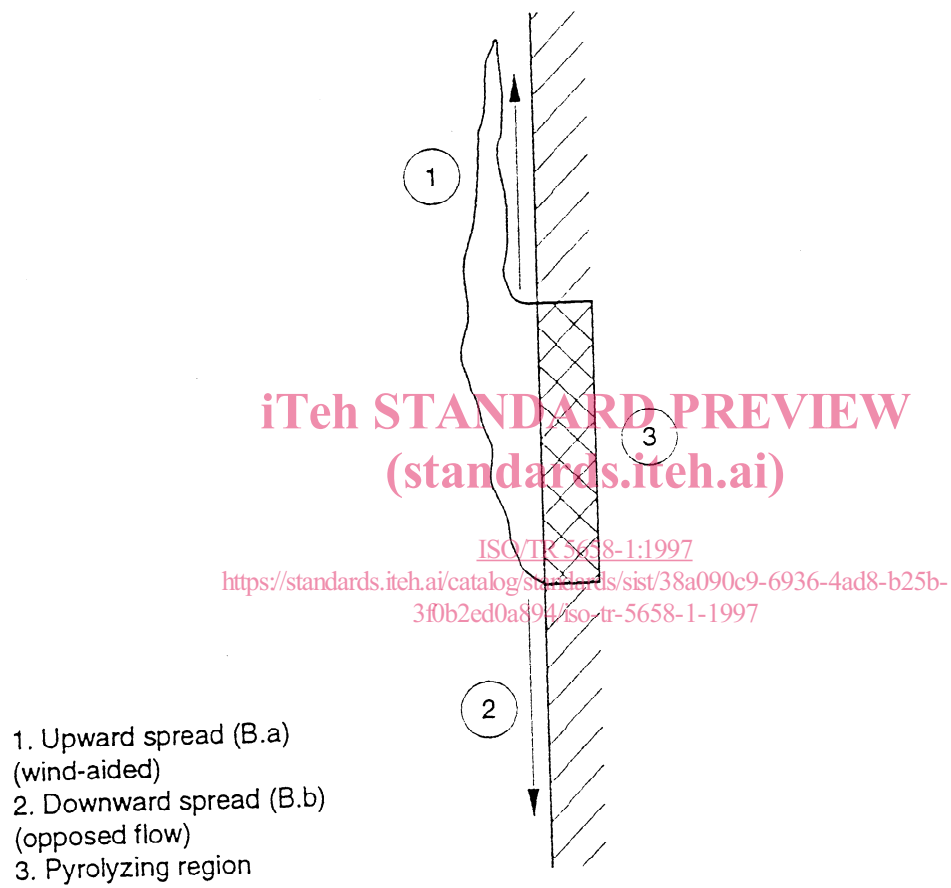


Figure 3 - Flame spread modes B.a and B.b (3.2 a and 3.2 b)

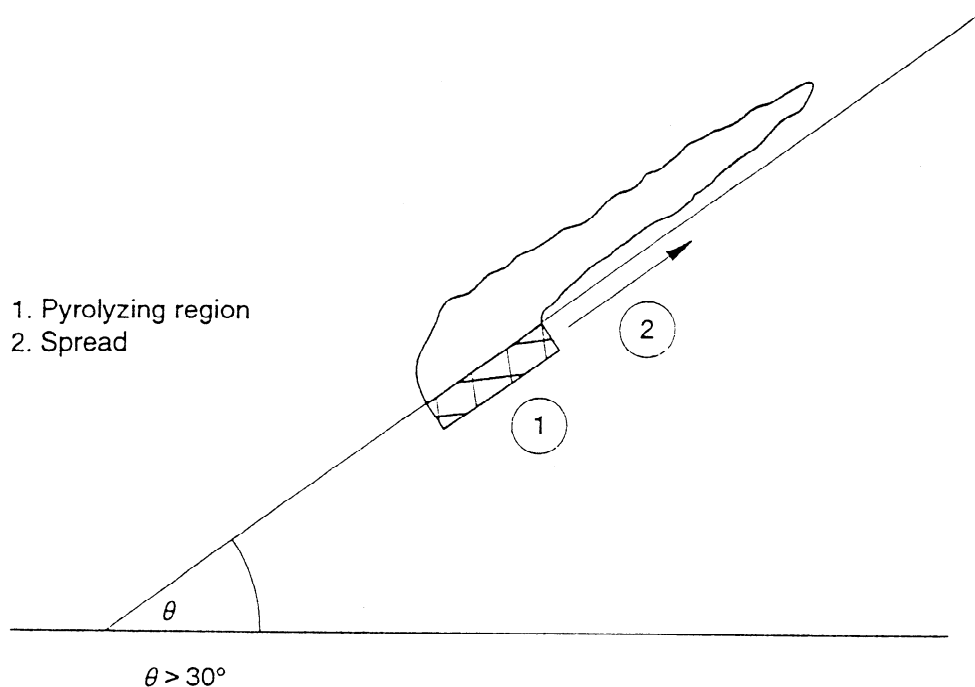


Figure 3a - Flame spread up an inclined plane

c) This mode is illustrated at the downstream side of the flame in figure 2. The fuel area between the pyrolysis front and the flame tip is covered by flames. The heat transfer to this area is primarily by flame radiation and convection. This is a typical example of wind-aided flame spread. There is still gas phase heat conduction near the pyrolysis front, but this mechanism is rather insignificant. Due to the increased view factor, flame radiation in the region between the pyrolysis front and the flame tip is much greater than in mode 3.1a), at least when flames are luminous.

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3.3 Vertical or inclined

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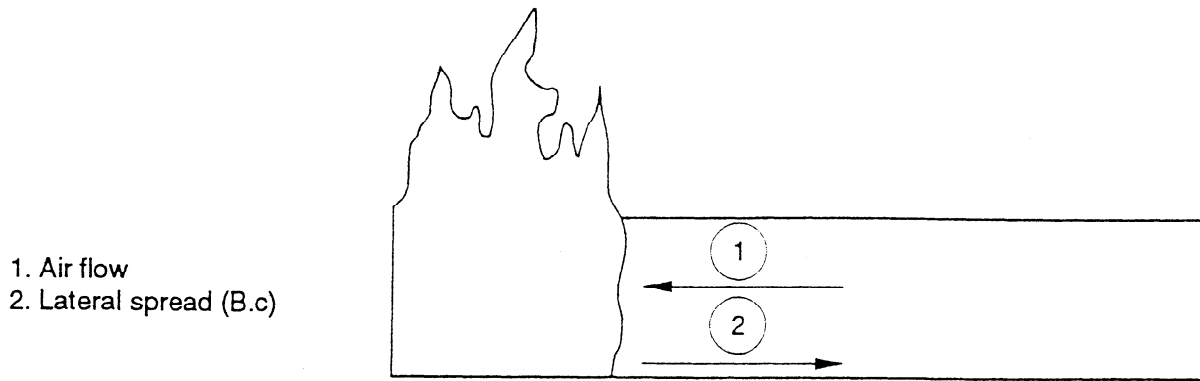
a) Perhaps the most important flame spread mechanism is that of upward spread over vertical surfaces. This mode is illustrated in figure 3 and is very similar to that of 3.1c). The main difference is that flames cover part of the non-burning fuel ahead of the pyrolysis front due to buoyancy. Wind-aided spread is important because it is by far the fastest flame spread mechanism. Consequently, many bench and intermediate-scale tests used for regulatory purposes evaluate the wind-aided flame spread propensity of a material as a measure of its hazard in fire, for example the ASTM E84 Tunnel Test [3] and the DIN 4102 [2] test.

b) Downward spread from a wall flame is also shown in figure 3. It is a form of opposed flow or creeping spread analogous to 3.1b).

c) Lateral spread is illustrated in figure 4. Heat transfer to the non-burning fuel is primarily gas phase conduction near the pyrolysis front. Consequently this mode is similar to that of 3.1b) and 3.2b).

d) The important flame spread mechanisms over an inclined plane are dependent upon the angle of inclination of a surface and the extent of the pyrolyzing region in relation to the width of the combustible surface. For surfaces inclined at angles in excess of around 30°, flame spread can be represented as illustrated in figure 3a. The flames from the burning fuel are in contact with the fuel surface ahead of the pyrolyzing region, producing substantial radiative and convective heat transfer to the fuel. The substantial flame lean is due to the fluid

dynamics of the air entrainment process and results in a mode of flame spread similar to that of upward spread over vertical surfaces, as shown in figure 3. This flame spread process is evaluated in the NT Fire 007 test [41]. This effect is also described in 7.2.5 in relation to sloping corridors. For angles of inclination up to 30 °, the modes of flame spread are represented by combinations of figures 1 (A.a./3.1a) and 2 (A.c./3.1c).



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Figure 4 - Flame spread mode B.c (4.2 c)
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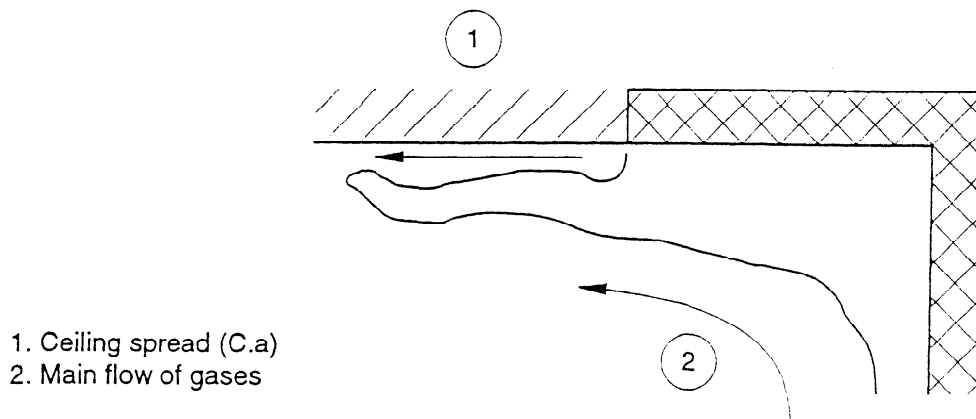


Figure 5 - Flame spread mode C.a (3.3)

3.4 Horizontal facing downward

Ceiling spread is shown in figure 5; a similar mechanism applies to the underside of wide ventilation ducts. Buoyancy and the main flow of gases result in a wind-aided type of spread similar to 3.1c) and 3.2a).

4 History of surface spread of flame tests

Different spread of flame tests have been developed in several countries and for different applications.

These tests are different concerning specimen size, specimen orientation (sometimes depending from the type of application a material is designed for), heat and ignition source applied to the specimen as well as criteria for acceptance.

Table 2 shows the most important “spread of flame tests” used all over the world.

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Table 2 — National spread of flame tests

Test	Specimen Orientation	Direction of Flame Spread	Specimen Size (mm)	Heat flux Density fromto (kW/m ²)	Ignition source	Criteria	Principal countries of use
ASTM E 162 [5]	Inclined (face down)	Downward	150 × 460		Horizontal gas flame, applied to upper end	Flame spread Heat evolved Smoke	USA
ASTM E 648 [4]	Horizontal (face up)	Horizontal	250 × 1050	11.....1	Horizontal gas flame, applied to the hot end	Critical flux for spread	USA, Germany
BS 476-7 [1]	Vertical	Lateral	885 × 265	33.....5	Vertical gas flame, applied to the hot end	Extent and velocity of spread after 1,5 min and 10 min.	GB, Belgium
NEN 3883 [6]	Vertical	Lateral	1000 × 230	37.....0	Vertical gas flame, applied to the hot end	Flame spread after 1,5 and 10 minutes	Netherlands
CSE/RF3/77 [7]	Vertical (wall position) Horiz. (floor position) Horiz. (ceiling position)	Lateral Horizontal Horizontal	800 × 155	16.....0 30.....1 12.....0	Vertical gas flame, applied to the hot end	Critical flux for spread of flame	Italy
NFP 92-506 [8]	Vertical	Lateral	400 × 95		Gas flame, applied to the hot end Vertical gas flame, applied to the hot end	Velocity and extent of spread	France
DIN 4102-15 [2]	Vertical (4 opposed specimens)	Vertical	190 × 1000	30.....0 + influence of opposed burning material	Gas flame at lower end of specimen (pilot and radiation)	Flame spread after 10 minutes	Germany
IMO Resolution A 653 (16) (a) ASTM E 1317-90 [10]	Vertical	Lateral	155 × 800	50.....15	Vertical gas flame, applied to the hot end	Heat for sustained burning (HSB) Critical flux at extinguishment (CIE)	For ships in different countries
ASTM E84 [3]	Horizontal (face down)	Horizontal	510 × 7320	35.....0	Horizontal gas flame, applied to one end of specimen, with heat output of 5,3 MJ/min.	Flame spread Smoke	USA, Canada
NT Fire 002 [39]	Vertical	Vertical	800 × 300	35.....0	Gas flame, applied to lower end of specimen	Ignitability Flame spread	Scandinavia, Austria