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Reaction to fire tests — Measurement of material properties using a fire propagation apparatus

Essais de réaction au feu — Mesurage des propriétés des matériaux au moyen d'un appareillage de propagation du feu

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Foreword

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

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

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

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

ISO 12136 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Fire initiation and growth*.

Introduction

This International Standard contains four separate test methods[3][4][5][12], which are conducted using a fire propagation apparatus (FPA). The ignition, combustion and pyrolysis test methods involve the use of horizontal specimens subjected to a controlled, external radiant heat flux, which can be set from 0 kW/m^2 to 65 kW/m^2. The fire propagation test method involves the use of vertical specimens subjected to ignition near the base of the specimen from an external radiant heat flux and a pilot flame. The combustion, pyrolysis and fire propagation test methods can be performed using an inlet air supply that is either normal air or other gaseous mixtures, such as air with added nitrogen, 100 % nitrogen or air enriched with up to 40 % oxygen.

The ignition test method is used to determine the time required for ignition, t_{ign}, of horizontal specimens by a pilot flame as a function of the magnitude of a constant, externally applied radiant heat flux. Measurements also are made of time required until initial fuel vaporization. The surface of these specimens is coated with a thin layer of black paint to ensure complete absorption of the radiant heat flux from the infrared heating system (note that the coating does not itself undergo sustained flaming).

The combustion test method is used to determine the chemical and convective heat release rates, and smoke generation rate when the horizontal test specimen is exposed to an external radiant heat flux.

The pyrolysis test method with a flow of 100 % nitrogen and no ignition can be used to measure the mass loss rate as a function of externally applied radiant heat flux for a horizontal specimen. From these measurements, the heat of gasification of the material can be determined.

The fire propagation test method using 40 % oxygen is used to determine the chemical heat release rate of a burning, vertical specimen during upward fire propagation and burning initiated by a heat flux near the base of the specimen. Chemical heat release rate is derived from the release rates of carbon dioxide and carbon monoxide. Observations also are made of the flame height on the vertical specimen during fire propagation. As discussed in B.5 and B.6, the use of enhanced oxygen in small-scale fire tests can better simulate the flame heat flux occurring in large-scale fires[16][18][19][20][21]. Correlation has been developed between the results from small-scale tests with 40 % oxygen and the results from large-scale tests for a class of materials (see B.6).

Distinguishing features of the FPA include:

— tungsten-quartz external, isolated heaters to provide a radiant flux of up to 65 kW/m^2 to the test specimen, which remains constant whether the surface regresses or expands;

— provision for combustion or upward fire propagation in prescribed flows of normal air, air enriched with up to 40 % oxygen, air oxygen vitiated, pure nitrogen or mixtures of gaseous suppression agents with the preceding air mixtures;

— the capability of measuring heat release rates and exhaust product flows generated during upward fire propagation on a vertical test specimen 0,305 m high.

The original FPA uses a vertical exhaust duct configuration[6], which requires laboratories to have available a sufficient ceiling height to accommodate all the system components. Also, the original FPA has the gas sampling and analysis system completely separate from the main apparatus. To reduce this ceiling height constraint and to allow for a more compact arrangement, a horizontal exhaust configuration has been developed as shown in Figures 1 and 2. The FPA with horizontal duct provides equivalent results to those measured using the FPA with vertical duct, as described in Annex C.

The FPA is used to evaluate the flammability of materials and products. It is also designed to obtain the transient response of such materials and products to prescribed heat fluxes in specified inert or oxidizing environments and to obtain laboratory measurements of generation rates of fire products (CO_2, CO, and, if desired, gaseous hydrocarbons) for use in fire safety engineering.

Ignition of the specimen is by means of a pilot flame at a prescribed location with respect to the specimen surface [described in 11.1 e)].

The Fire Propagation test of vertical specimens is not suitable for materials that, on heating, melt sufficiently to form a liquid pool.

This International Standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this International Standard to establish appropriate health and safety practices and to determine the applicability of regulatory limitations prior to use. For specific hazard statements, see Clause 7.

This International Standard specifies small-scale test methods for determining the performance of materials when exposed to fire, which are based on decades of research published in the fire science literature. Parts of this International Standard are based on information contained in ASTM E2058 and NFPA 287.

The following test methods, capable of being performed separately and independently, are included:

1) Ignition test, to determine t_{ign} for a horizontal specimen;

2) Combustion test, to determine Q_{chem}, Q_c, $\dot{m}$, ΔH_{eff}, and Y_s from burning of a horizontal specimen;

3) Pyrolysis test, to determine $\dot{m}$ and ΔH_g; and,

4) Fire propagation test, to determine Q_{chem} from burning of a vertical specimen.

Reaction to fire tests — Measurement of material properties using a fire propagation apparatus

1 Scope

This International Standard determines and quantifies the flammability characteristics of materials, in relation to their propensity to support fire propagation, by means of a fire propagation apparatus (FPA). Material flammability characteristics that are quantified in this International Standard include time to ignition, chemical and convective heat release rates, mass loss rate, effective heat of combustion, heat of gasification and smoke yield. These properties can be used for fire safety engineering and for fire modelling.

2 Normative references

The following referenced documents are indispensable for the application 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.

ISO 13943, *Fire safety — Vocabulary*

ISO 14934-3, *Fire tests — Calibration and use of heat flux meters — Part 3: Secondary calibration method*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and the following apply.

3.1
essentially flat surface
surface whose irregularity from a plane does not exceed ±1 mm

3.2
flashing
existence of flame on or over the surface of the specimen for periods of less than 1 s

3.3
ignition
sustained flaming on or over the surface of the specimen for periods of over 10 s

3.4
fire propagation
increase in the exposed surface area of the specimen that is actively involved in flaming combustion

3.5
smoke yield
mass of smoke particulates generated per unit mass of fuel vaporized

4 Symbols

A	Exposed surface area of specimen	m^2
A_d	Cross sectional area of test section duct	m^2
c_p	Specific heat of air at constant pressure	kJ/kg K
D	Optical density per unit length	m^{-1}
$\dot{D}_{O_2}$	Consumption rate of O_2	kg/s
$\dot{G}_{co}$	Mass flow rate of CO in test section duct	kg/s
$\dot{G}_{co_2}$	Mass flow rate of CO_2 in test section duct	kg/s
$\dot{G}_j$	Mass flow rate of compound j in test section duct	kg/s
ΔH_{co}	Heat of complete combustion per unit mass of CO	kJ/kg
ΔH_{eff}	Effective heat of combustion	kJ/kg
ΔH_g	Heat of gasification	kJ/kg
ΔH_T	Net heat of complete combustion per unit mass of fuel vaporized	kJ/kg
K	Flow coefficient of averaging Pitot tube [duct gas velocity/$(2\,\Delta P_m / \rho)^{1/2}$]	–
k_{co_2}	Stoichiometric CO_2 to fuel mass ratio, for conversion of all fuel carbon to CO_2	–
k_{co}	Stoichiometric CO to fuel mass ratio, for conversion of all fuel carbon to CO	–
k_{O_2}	Stoichiometric ratio of mass of oxygen consumed to mass of fuel burned	–
L	Optical path length	m
M_{loss}	Total mass loss in combustion test method	k
M_s	Total smoke generation in combustion test method	kg
$\dot{m}$	Mass loss rate of test specimen	kg/s
$\dot{m}_s$	Mass generation rate of smoke	kg/s
$\dot{m}_d$	Mass flow rate of gaseous mixture in test section duct	kg/s
P_{atm}	Atmospheric pressure	Pa
ΔP_m	Pressure differential across averaging Pitot tube in test section duct	Pa
Q	Cumulative heat released during combustion test method	kJ

$\dot{Q}_{chem}$	Chemical heat release rate	kW
$\dot{Q}_c$	Convective heat release rate	kW
T_a	Gas temperature in test section duct before ignition	K
T_d	Gas temperature in test section duct	K
t	Time	s
t_{ign}	Ignition time	s
$\dot{v}$	Total volumetric flow rate in test section duct	m3/s
W	Width of a flat specimen or the circumference of a cable specimen	m
Y_s	Smoke yield	–
X_{co_2}	Mole fraction of carbon dioxide in test section duct	–
X_{co}	Mole fraction of carbon monoxide in test section duct	–
ρ	Gas density in test section duct	kg/m^3

5 Principle

The four test methods given in this International Standard are based on measurements of time to observed ignition, mass loss rate, heat release rate and smoke generation rate. The test methods are performed using a laboratory calorimeter known as fire propagation apparatus whereby the heat source is isolated from the test specimen. The test methods are intended to produce flammability property measurements that will characterize fire behaviour during reference-scale fire tests.

The ignition, combustion or fire propagation test methods, or a combination thereof, have been performed with materials and products containing a wide range of polymer compositions and structures, as described in B.7.

The unique feature of the fire propagation test method is that it produces laboratory measurements of the chemical heat release rate during upward fire propagation and burning (from a material's own flame after initiation by an external radiant flux) on a vertical test specimen in normal air, oxygen-enriched air, or in oxygen-vitiated air.

These test methods are intended for evaluation of specific flammability characteristics of materials. Materials to be analysed consist of specimens from an end-use product or the various components used in the end-use product. Results from the test methods provide input to flame spread and fire growth models, risk analysis studies, building and product designs and materials research and development.

This International Standard can be used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products or assemblies under actual fire conditions. The sample size and amount should not exceed the measurement capacity of the apparatus. A sample that is explosive in nature should not be tested in the apparatus.

6 Apparatus

6.1 General

6.1.1 Dimensions

Where dimensions are stated in the text or in figures, they shall be followed within a tolerance of ±0,5 % typical and ±1 % maximum. An exception is the case of components which are intended to fit together, where the joint tolerance shall be appropriate for a sliding fit.

6.1.2 Components

The apparatus (see photograph and schematic in Figures 1 and 2 respectively, and exploded view in Figure 3) shall consist of the following components:

a) an infrared heating system;

b) a load cell system;

c) an ignition pilot flame and timer;

d) a product gas analysis system;

e) a laser smoke measuring system;

f) a combustion air distribution system;

g) a water-cooled shield;

h) an exhaust system;

i) measuring section instruments;

j) calibration instruments;

k) a digital data acquisition system.

6.2 Infrared (IR) heating system

The IR heating system[1)] shall consist of four 240 mm long, 81 mm high and 81 mm wide heaters (see different views in Figures 1 to 3) and a power controller.

Each of the four IR heaters shall contain six tungsten filament tubular quartz lamps (each 500 watts) in a compact reflector body that produces up to 510 kW/m^2 of radiant flux in front of the quartz window that covers the lamps. The reflector body is water cooled and the lamp chamber, between the quartz window and reflector, is air cooled for prolonged life. The emitter of each lamp is a 127 mm long tungsten filament in an argon atmosphere enclosed in a 9,5 mm outer diameter (o.d.) clear quartz tube. The emitter operates at approximately 2 205 °C (4 000 °F) at rated voltage, with a spectral energy peak at 1,15 µm. Wavelength greater than about 3,6 µm is absorbed by the quartz bulb envelope and heater front window, which are air cooled.

1) Hi-Temp 5208-05 high density infrared heaters with model 500T3/CL/HT lamps and 664 SCR power controller; or Hi-Temp 5209-05 with QIH240-1000R12 lamps and 3629B power controller, supplied by Research, Inc., http://www.researchinc.com, are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.

6.3 Load cell system

The load cell system, shown in Figures 2 and 3, shall consist of a load cell with a suitable load cell signal conditioning load cell controller, which shall have:

a) an accuracy of 0,1 g and a measuring range of 0 g to1 000 g; a 6,35 mm diameter stainless steel shaft, at least 330 mm long, resting on the load cell support point;

b) a 100 mm diameter, 1,5 mm thick aluminium load platform connected to the upper end of the stainless steel shaft by a collar;

c) two low friction, ball-bushing bearings that guide the shaft as it passes through the top and bottom, respectively, of the air distribution chamber.

The stainless steel shaft shall incorporate, at the lower end, a threaded adjustment rod to compensate for horizontal test specimens of different thicknesses.

6.4 Ignition pilot flame

The ignition pilot shall consist of an ethylene/air (60/40 by volume) flame adjusted for a 10 mm length. The pilot flame is anchored at the 50 mm long, horizontal end of a stainless steel tube with an outer diameter of 6,35 mm and an inner diameter of 4,70 mm. In the horizontal tube section, use a four-hole ceramic insert to produce a stable flame and prevent flashback. The pilot flame tube shall be able to be rotated and elevated to position the horizontal flame at specified locations near the specimen [described in 11.1 e)], as shown in Figures 2 and 3.

6.5 Ignition timer

The device for measuring time to sustained flaming shall be capable of recording elapsed time to the nearest 0,1 s and have an accuracy of better than 1 s/h.

6.6 Gas analysis system

6.6.1 Gas sampling

The gas analysis system shall consist of a gas sampling system and gas analysis instruments. The gas sampling arrangement is shown in Figure 4. This arrangement consists of:

a) a sampling probe in the test section duct;

b) primary and secondary plastic filters (5 µm pore size) to prevent entry of soot;

c) a condenser operating at temperatures in the range −5 °C to 0 °C to remove liquids;

d) a tube containing an indicating desiccant (10 to 20 mesh) to remove most of the remaining moisture;

e) a filter to prevent soot from entering the analysers, if not already removed;

f) a sampling pump that transports the flow through the sampling line, system flow meters, needle valves and manifolds to direct the flow to individual analysers (CO, CO_2, O_2, and hydrocarbon gas).

The sampling probe, made of stainless steel tubing (6,35 mm o.d.) with 14 holes, inserted through a test section port, shall be positioned such that the open end of the tube is at the centre of the test section. The sampling probe is connected to a tee fitting that allows either sample or calibration gas to flow to the analyser, and the excess to waste.

6.6.2 Carbon dioxide/carbon monoxide analysers

The carbon dioxide analyser shall enable measurements from 0 % to 1,5 vol % (15 000 µl/l) and the carbon monoxide analyser shall enable measurements from 0 % to 0,05 vol % (500 µl/l) levels. Drift shall be not more than ±1 % of full scale over a 24 h period. Precision shall be 1 % of full-scale and the 10 % to 90 % of full-scale response time shall be 10 s or less (typically 5 s for the ranges specified). The time delay of the system shall not exceed 25 s (measured from sampling probe to the analyser, as shown in Figure 4).

6.6.3 Inlet air oxygen analyser

This analyser shall have a 10 % to 90 % of full-scale response time of 10 s or less, an accuracy of 0,05 % of full-scale, a noise and drift of not more than ±0,005 vol % (50 µl/l) O_2 over a 30 min period and a 0 % to 100 % range. The time delay of the system shall not exceed 25 s (measured from the sampling probe to the analyser, as shown in Figure 4).

6.6.4 Optional product analysers for the combustion test

An additional oxygen analyser can be used to measure the depletion of oxygen in the combustion products. This analyser should have the same specifications as the inlet air analyser but should have a concentration range of 19 % to 21 %. A hydrocarbon gas analyser employing the flame ionization method of detection can be used to determine the total gaseous hydrocarbon concentration. This analyser should have a 10 % to 90 % of full-scale response time of 1 s or less and multiple ranges to permit measurements from a full-scale of 0,001 vol % (10 µl/l) methane equivalent to 0,1 vol % (1 000 µl/l). The time delay of the system shall not exceed 25 s (measured from the sampling probe to the analyser, as shown in Figure 4).

6.7 Combustion air distribution system

6.7.1 General

This system shall consist of an air distribution chamber, shown in Figure 5, and air supply pipes, shown in Figures 6 and 7.

6.7.2 Air distribution chamber

This aluminium chamber, shown in Figure 5, shall contain eight discharge tubes arranged in a circle, the inside diameter of which shall be 165 mm. Each tube shall be aluminium and built to distribute inlet gases (air, O_2, N_2, etc.) to three sets of screens (stainless steel woven wire cloth of 10, 20, and 30 mesh from bottom to top, respectively), for producing a uniform air flow. Inlet air flows downward through the eight discharge tubes, disperses on the bottom plate, then rises through the mesh screens towards the aluminium support cylinder.

6.7.3 Air supply pipes

These pipes shall consist of an aluminium cylinder, shown in Figures 3 and 6, extending from the air distribution chamber up to the load platform. This cylinder shall contain a step (see Figures 6 and 7) to support a quartz pipe (165,0 ± 5,0 mm inner diameter and 3,0 ± 0,5 mm thickness). Above the load platform elevation, the quartz pipe (see Figures 6 and 7) shall supply oxidant to the specimen flame while enabling radiant energy from the IR heating system to reach the specimen surface. The aluminium support cylinder shall be rigidly attached to the distribution chamber; the quartz pipe shall be removable.

6.8 Water-cooled shield

To prevent the specimen from being exposed to the IR heaters during the 1 min heater stabilization period, there shall be a shield (see Figure 8) consisting of two aluminium cylinders welded together with an inlet and outlet for water circulation. An electrically-actuated, pneumatic piston shall raise the shield to cover the specimen during test preparation and shall lower the shield within 1 s to expose the specimen at the start of a test.

6.9 Exhaust system

The exhaust system (see Figure 3) shall consist of the following main components:

a) an intake funnel;

b) a mixing section;

c) a measuring section;

d) duct flanges;

e) a high temperature blower fan to draw gases through the intake funnel, mixing section and measurement section at flow rates from 0,1 m^3/s to 0,25 m^3/s.

The intake funnel, mixing section and measurement section shall be coated internally with fluorinated ethylene propylene (FEP) resin enamel and finish layers over a suitable primer to form a three layer coating that shall withstand temperatures of at least 200 °C.

6.10 Measuring section instruments

6.10.1 Measuring section thermocouple probe

A thermocouple probe, inserted through a measuring section port, shall be positioned such that the exposed, type K measurement bead is at the centre of the measuring section, at the axial position of the gas sampling port. Fabricate the thermocouple probe of wire no larger than 0,254 mm ± 0,5 % diameter for measurement of gas temperature with a time response [in the specified exhaust flow, see 11.2 h)] of no more than 1 s and an accuracy of 1,0 °C.

6.10.2 Averaging Pitot probe and pressure transducer

An averaging Pitot probe, inserted through a measuring section port downstream of the thermocouple port, shall measure the mass flow rate of the gas stream using at least four sets of flow sensing openings. One set of flow sensing openings shall be facing upstream and the second set shall be facing downstream. The flow sensing openings shall be designed for compatibility with the measuring section diameter. Measure the differential pressure generated by the probe with an electronic pressure transducer (electronic manometer).

NOTE The measured differential pressure is proportional to the square of the flow rate. Experience has shown that the averaging Pitot probe in this application is reliable (not susceptible to plugging), while minimizing pressure losses in the exhaust system.

6.11 Heat flux gauge

For calibration of the IR heating system, use a Gardon-type, or equivalent, total heat-flux gauge which has a nominal range of 0 kW/m^2 to 100 kW/m^2 and a flat, 6 mm to 8 mm diameter sensing surface coated with a durable, flat-black finish. The body of the gauge shall be cooled by water above the dew point of the gauge environment. The gauge shall be rugged and maintain an accuracy of within ±9 % (in accordance with ISO 14934-3) and repeatability within 0,5 % between calibrations. Check the calibration of the heat-flux gauge monthly through the use of a black-body oven calibration facility that compares the gauge response to that of an optical pyrometer. Alternatively, compare the gauge output to that of a reference standard.

6.12 Digital data acquisition system

Digitally record the output from the CO, CO_2, hydrocarbon gas, O_2 combustion and O_2 inlet air analysers, the load cell, the measuring section duct thermocouple, and the electronic pressure transducer at 1 s intervals. Time shift the data for the gas concentrations to account for delays within the gas sampling lines and respective instrument response times. The data collection system shall be accurate to within ±1 °C for temperature measurement and ±0,01 % of full-scale instrument output for all other channels. The system shall