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Plastics — Guidance on the assessment of the fire characteristics and fire performance of fibre-reinforced polymer composites

Plastiques — Lignes directrices pour l'évaluation des caractéristiques au feu et des performances au feu de polymères composites renforcés de fibres

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Foreword

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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 25762 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 4, *Burning behaviour*.

Introduction

The information given in this International Standard is in accordance with the principles recommended in ISO 10840 which was established to develop a general policy and philosophy for the development and use of fire tests for plastics.

Fibre-reinforced polymer (FRP) composites are produced in a wide variety of chemical and physical forms, some of which cause difficulties for fire laboratories since the specimens required for some tests are not representative of the FRP composite in its end-use configuration.

This International Standard identifies those tests which can be used for determining the fire characteristics of various FRP composites and provides guidance on how to assess the fire performance of FRP composites in different applications. Since FRP composites can be used as lightweight construction materials, the experience of users in transport applications has been valuable in the preparation of this International Standard. Test data from methods that are specified by regulators of marine and rail products have been provided to exemplify the fire performance of some FRP composites.

Plastics — Guidance on the assessment of the fire characteristics and fire performance of fibre-reinforced polymer composites

1 Scope

This International Standard gives guidelines for the assessment of the fire characteristics and fire performance of fibre-reinforced polymer (FRP) composites, particularly in structural applications in buildings and transport.

It is applicable to FRP composites prepared from thermosetting or thermoplastic resins and reinforced with inorganic fibres greater than 7,5 mm in length.

This International Standard gives guidelines on:

— the applicability of product types (e.g. sheets, laminates, profiled sections and some sandwich constructions) to end-use performance;

— the test methods and performance criteria for different physical forms of FRP test specimen.

NOTE 1 FRP composites vary widely in their physical form (e.g. in thickness, density and shape).

NOTE 2 FRP composites can also be assembled products containing other materials (such as metals or inorganic non-fibrous fillers) and as systems containing air-gaps, joints and fixing attachments.

NOTE 3 Handling and storage recommendations for the fire safety management of FRP composites are given in Annex C. In addition, some guidance on how to tackle fires involving FRP composites is provided in Annex D.

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 472, *Plastics — Vocabulary*

ISO 13943, *Fire safety — Vocabulary*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms, definitions and abbreviated terms given in ISO 13943 and ISO 472 and the following apply.

3.1 General

3.1.1
fibre-reinforced polymer composite
polymer matrix composite consisting of thermosetting resin or thermoplastic materials and fibres of greater than 7,5 mm in length prior to processing

NOTE Plastics compositions containing fibres of 7,5 mm or less in length are treated as plastics.

3.1.2
load-bearing capacity
R
ability of an element to maintain its structural stability despite exposure to fire on one or more faces for a period of time

3.1.3
integrity
E
ability of an element with a separating function to withstand fire exposure on one side only without the transmission of fire to the non-fire side as a result of the passage of significant quantities of flames or hot gases from the fire to the non-fire side thereby causing ignition either of the unexposed surface or of any material adjacent to that surface

NOTE This may include the ability of an element to withstand delamination (the layers of the material separating from each other) when under load and exposed to fire.

3.1.4
insulating capacity
I
ability of an element to withstand fire exposure on one side only without significant transfer of heat from the exposed to the unexposed side

3.1.5
product
material, composite or assembly about which information is required

3.1.6
composite
structured combination of two or more discrete materials, with one of the materials (the matrix) forming a continuous phase

NOTE 1 The structure of a composite can be made up of one or more layers.

NOTE 2 For the purposes of this International Standard, at least one of the materials is a plastic or an organic-based polymer.

3.1.7
ARHE(t_n)
average rate of heat emission at time t
integrated heat emission from time 0 to time t, divided by t

NOTE It is expressed in kW/m^2 for cone calorimeter results (see ISO 5660-1).

3.1.8
MARHE
maximum average rate of heat emission
maximum value of ARHE from $t = 0$ to $t = t_{end}$

NOTE It is usually expressed in kW/m^2.

3.1.9
FIGRA index
fire growth rate index
maximum value of the quotient of the rate of heat release from the specimen and the length of time it occurs

NOTE It is usually expressed in W/s. Further details concerning its derivation are given in EN 13823.

3.1.10
SMOGRA index
smoke growth rate index
maximum value of the quotient of the rate of smoke production by the specimen and the length of time it occurs

NOTE It is usually expressed in m^2/s^2. Further details concerning its derivation are given in EN 13823.

3.1.11
resistance to radiation
W
ability of a product/construction element to withstand fire exposure on one side only, thus reducing the probability of the transmission of fire as a result of significant radiated heat either passing through the product/element to adjacent materials or being radiated from its unexposed surface to adjacent materials

NOTE 1 The product/element might also need to protect people in the vicinity. A product/element which satisfies the insulating-capacity criterion, I, is also deemed to satisfy the W requirement for the same period.

NOTE 2 Failure of integrity under the “cracks or openings in excess of given dimensions” criterion or the “sustained flaming on the unexposed side” criterion (see 5.2.1) automatically means failure under the resistance to radiation criterion.

3.1.12
TSP_{600s}
total smoke production from the specimen in the first 600 s of exposure to the burner flames

3.2 Types of material

3.2.1
thermosetting material
material capable of being changed into a substantially infusible and insoluble product when cured by heat or by other means, such as radiation and catalysts

NOTE 1 These materials are resins and include polymers such as polyesters, epoxides, acrylics, urethanes and phenolics.

NOTE 2 The resins may incorporate non-fibrous fillers, flame-retardants, pigments and stabilizers.

3.2.2
thermoplastic material
polymeric material that becomes soft and plastic when heated

NOTE 1 These polymers include polypropylene (PP), polyetheretherketone (PEEK) and polyethersulfone (PES).

NOTE 2 The polymers can incorporate non-fibrous fillers, flame-retardants, pigments and stabilizers.

3.2.3
reinforcing fibre
fibrous material added to a matrix resin or polymer in order essentially to improve its mechanical properties

NOTE These materials include glass, carbon, aramid, thermoplastic fibres (such as polypropylene, polyamide and polyester) and natural fibres (such as cellulose and wood).

4 Fibre reinforcement

4.1 Form

The reinforcement can be in the form of unidirectional rovings or yarns, fabrics, chopped strands (individual or in mats), fully aligned layers or knits, braids or continuous-filament mats.

NOTE The type of fibre and its form should be described in all test reports on the FRP composite.

4.2 Fibre content

The fibre content in the composite can be as low as 10 % by volume and as high as 75 % by volume.

4.3 Core materials

These can include:

a) honeycomb structures (aluminium, aramid, paper, polypropylene or phenolic-resin-impregnated fibreglass);

b) plywood;

c) foam (cellulose acetate, polystyrene, polyurethane, phenolic or PVC);

d) balsa wood.

4.4 Production methods

FRP composites can be produced by a variety of processes as described in the various parts of ISO 1268, for example:

a) pultrusion;

b) wet lay-up (by hand or spray application);

c) filament winding;

d) compression moulding;

e) moulding using prepregs;

f) resin transfer moulding;

g) vacuum infusion;

h) continuous lamination.

Some FRP composites have gel-coats on their surfaces. The gel-coat might be similar to the unreinforced resin but, in many cases, a different resin is used.

FRP composites are often used as skins in sandwich constructions in combination with plastic foams or honeycomb core material. When FRP composite products are manufactured or installed, the fire laboratory performing a test or assessment should record details of the composition and assembly of the test specimen that are typical of the end-use application of the product. These details could include the types of joint or fixing attachment, air-gaps, edge coverings, skins or facings and metal inserts or reinforcements.

5 Fire characteristics

5.1 Reaction to fire

5.1.1 General

More than one fire test should be performed to characterize adequately the reaction-to-fire properties of FRP composites.

NOTE Reaction-to-fire test results on some typical FRP composites are shown in Annex B. These data back up the recommendations given in 5.1.1 to 5.1.7.

5.1.2 Combustibility

When tested in accordance with ISO 1182, all grades, types and densities of FRP composite are usually classified as combustible due to the contribution of their polymer content.

5.1.3 Ignitability

Under certain conditions of heat, orientation and ventilation, a naked flame can ignite FRP composites. Care should be taken to avoid contact with naked-flame sources when handling and storing these composites before and during installation.

The ignitability of FRP composites can be tested using the standard ignition sources described in ISO 10093, which include flaming, radiant heat and electrical sources. These sources can be used in standard fire tests (see ISO 10840) or in *ad hoc* tests, some of which might provide information on the ignitability of the FRP composites under end-use conditions.

5.1.4 Rate of heat release

The rate of heat release of FRP composites should be determined by the following standard tests:

a) For small test specimens, ISO 5660-1 or ISO 13927 should be used.

b) For intermediate-scale test specimens, the guidance in ISO 15791-1 should be followed. Tests such as ISO 21367 or EN 13823 could be used.

c) For large test specimens, either ISO 9705 and ISO/TR 9705-2 or ISO 24473 should be used.

NOTE Additional information on rate of heat release measurements is given in Annex A.

5.1.5 Flame spread

ISO/TS 5658-1 should be referred to for guidance on the appropriateness of a flame spread test (especially concerning the nature of the ignition source, the orientation of the test specimen and the ventilation conditions in the vicinity of the test specimen). Lateral flame spread across a vertically oriented specimen can be determined in accordance with ISO 5658-2, and flame spread over horizontally mounted floorings can be determined in accordance with ISO 9239-1.

NOTE 1 The extent and rate of flame spread depend largely on the ignitability of, and rate of heat release from, a combustible product.

NOTE 2 Since the fire performance of products, including flame spread, is to a great extent dependent on the composition of the product (such as the type of substrate), including any fixings or mountings relevant to the end-use application, standard small-scale tests are not always appropriate for the evaluation of FRP composites. Large-scale test methods, which more appropriately reflect end-use conditions for composites in structural applications, are briefly discussed in 6.4.

5.1.6 Smoke

Burning some FRP composites can generate dense, black smoke. When assessing potential smoke emission from FRP composites in a building or other enclosure under fire conditions, essential factors that should be considered include the possible extent of flame spread over the surface of the composite, the ventilation conditions and the rate of decomposition of the resin.

Smoke density can be measured in a dynamic test involving a well-ventilated fire (such as that described in ISO 5660-2) or in a test carried out in a chamber in which the smoke accumulates (such as that in ISO 5659-2).

NOTE Prediction of the precise smoke-producing potential of FRP composites is difficult because of the wide range of combustion conditions likely to be met within an actual fire. Generalized conclusions from small-scale tests have been substantiated by evidence from fire incidents. The density of the smoke produced increases with increasing temperature and with the intensity of the heat flux incident on the material. In a smouldering fire, where decomposition occurs in oxygen-deficient conditions, small grey spherical particles predominate and the specific optical-density values can be lower than for flaming conditions.

5.1.7 Toxicity

ISO Technical Committee TC 92/SC 3 guidelines, as given in ISO 16312-1, ISO 16312-2, ISO 13571 and ISO 19706, should be followed in the assessment of the likely toxic hazard of a defined scenario.

NOTE When organic materials such as wood, paper or plastics are burned, hot gases and smoke are evolved. All combustion gases produced can prove fatal in a short time if inhaled in sufficient concentration. However, the toxicity hazard in a fire arises through many factors, including the rate of fire growth and the ambient ventilation conditions, as well as the inherent toxicity of the combustion products, and this philosophy is embodied in the ISO/TC 92/SC 3 guidelines.

A stepwise approach should usually be taken, including such factors as risk of ignition, rate of fire growth, flame spread, smoke-producing potential, location and mobility of occupants and fire protection measures. An estimation of the risk (that is, the likelihood of that hazard occurring) should also be made.

Some small-scale tests can be used to determine the composition of fire effluents from burning FRP composites. For example, ISO 5659-2 could be used as a fire model with gas analysis performed using Fourier transform infrared spectroscopy or another method (such as ion chromatography). From the results, a toxicity index can be derived for up to 10 common fire gases.

5.2 Structural performance

5.2.1 General

A very important regulatory requirement in buildings and other enclosures (such as ships and trains) is the need to ensure that fires are, wherever possible, confined to the compartment of fire origin. The required structural performance is usually assessed by fire resistance tests on elements of the building structure. Various levels of thermal action can be used to simulate different fire scenarios. Probably the most widely used is the standard temperature/time curve, which serves as a simulation for a fully developed fire (see ISO 834-1). Other test fires used in certain situations include the smouldering fire, the semi-natural fire, the hydrocarbon fire and the external fire (such as exposure to fire emerging from a window of a building or from a free-burning external fire).

Resistance-to-fire performance characteristics which should be assessed include load-bearing capacity, R, integrity, E, and insulating capacity, I (see 3.1.2 to 3.1.4). Other characteristics which might be specified under certain conditions for some elements are resistance to radiation, W (see 3.1.11), mechanical aspects, self-closing ability and smoke leakage.

The assessment of integrity should generally be made on the basis of the following three criteria:

a) cracks or openings in excess of given dimensions;

b) ignition of a cotton pad;

c) sustained flaming on the unexposed side.

The integrity should be determined by all three criteria during the test. The cotton pad should be applied until it ignites and, once it has ignited, it should be withdrawn and the test continued until all three criteria have been exceeded. The times taken to reach the failure point for each aspect of integrity should be recorded.

If composites are used as a sandwich structure with a thin fibre-reinforced resin laminate attached over a core material (for example, for cabin interiors of passenger aircraft, transport vehicles or ships), the whole assembly should be tested in an appropriate fire test.

NOTE 1 Engineering theory shows that the flexural stiffness of any panel is proportional to the cube of its thickness. The purpose of a core in a composite laminate is therefore to increase the stiffness of the laminate by effectively thickening it with a low-density core material. This can provide a dramatic increase in stiffness for very little additional mass. Thus a sandwich panel comprising FRP skins bonded to one or both sides of a suitable core material can be as little as 20 mm thick and up to 200 mm thick.

NOTE 2 Core materials can be composed of any of a large number of lightweight materials (see 4.3)

5.2.2 Walls and ceilings

The efficiency of joints and fixing attachments, especially in the case of lightweight assemblies and mechanically fixed facings, is important in determining the overall fire resistance of an element. The joints should be proven by testing, and the construction of the assembly or facing should not deviate from that of the test specimen in order to ensure that the required levels of fire resistance are achieved.

The reaction-to-fire performance of an element, including its fixing attachments, can also be affected by its structure. If the product is a wall or ceiling lining, the reaction-to-fire performance can be assessed by a room test, such as that in ISO 9705, in which the product is installed for the test as far as possible in its end-use condition. When testing FRP composite panels, the test specimen should be fixed to a steel framework.

5.2.3 Floors

For floors, other than those of the lowest storey of a building, fire resistance should be determined by constructing the floor so that it resembles as closely as possible the end-use assembly. For example, floors in aircraft can be composed of FRP skins with thick, low-density cores (such as aramid honeycomb compositions).

In some transport applications (such as railway vehicles), the fire source can be under the floor and could be an electrical cabinet containing a high-power supply or a traction transformer (or a reactor filled with insulation fluid). These floors should be tested in accordance with ISO 834-1 or EN 1364-2, which are appropriate to a non-load-bearing element. The requirements should be defined from under the floor to the top of the floor covering.

5.2.4 Structural integrity of fibre-reinforced composites on exposure to fire

Structural-integrity evaluation is an important requirement for FRP composites used for structural applications. Since not many standard fire test methods are available, many researchers modify mechanical tests to meet their needs. This area of research is being actively addressed in building and transport applications.

Determination of failure criteria is difficult for some FRP composites. When the resin contained in some FRP composites has fully burnt, the residual structure is effectively a fibre curtain. If the reinforcement is a glass fibre mat (random or woven), the further input of heat can cause local melting of the glass fibre, and this can result in a growing hole that is sufficient to cause the composite to fail the integrity specification of ISO 834-1.

6 Fire test methods

6.1 Assessment of fire hazard

The design, construction and conditions of use of an FRP composite should be analysed to define the individual factors likely to affect significantly the response to fire of the product. Certain parameters can then be measured using recognized techniques. Other parameters should be identified and investigated individually.

6.2 Fire tests for determining performance requirements

For control purposes involving building and transport products, standard fire tests are specified for the assessment of specific reaction-to-fire and structural fire-resistance characteristics. In addition, they are performed to determine whether given construction elements, wall linings or ceiling linings satisfy a minimum level of performance for use in a given situation or occupancy.

NOTE Attention is drawn to the fact that there can be legal or statutory requirements for assessing the fire risk of FRP composites.

Standard fire tests cannot, in isolation, measure the fire hazard (although they can assist in its assessment and control) and satisfactory results in these tests cannot alone guarantee fire safety since such tests cover only one of a number of factors that need to be taken into account.

Precise simulation of all fire conditions to which a product is likely to be exposed in practice would be desirable, but this is impracticable and the experimental procedure uses only standardized exposure conditions. The results of such standard tests are directly applicable in practice only when an FRP composite product is exposed to fire conditions identical to those used in the test.

The concept of standard testing assumes that a range of FRP composite products will generally give the same performance ranking under all combustion conditions. However, if there are significant changes in parameters such as thickness, density or fibre content across a range of composite products, differences in performance classification can occur. The fire performance of a new FRP composite product is often predicted by analogy with the performance in practice of a well-known product of similar ranking in the test.

6.3 Applicability of standard fire test methods to FRP composites

Standard tests are typically carried out on small-size specimens supported often in non-typical orientations by means other than those used in practice. This is particularly true of lining materials. Thus the test specimen can be exposed to forces considerably different from those acting on it in an actual building or transport vehicle, and the physical performance of the composite can be impossible to predict. In such cases, an indicative non-standard fire test might be needed to provide a basis on which to judge the applicability and validity of the information from standard tests.

Many of the well-established fire test procedures used for building products were originally devised for cellulosic products. Difficulties can be experienced in conducting standard fire tests because of the widely varying physical nature of the FRP composites available, and a proper rating might not be obtainable.

NOTE It is known that some types of FRP composite can decompose explosively when exposed to heat. For example, some types of phenolic resin produce moisture during the cure process, which becomes trapped in the structure of the laminate. When exposed to heat, this expands and can result in explosive delamination. This normally simply results in small-bubble delamination. However, particularly in some small test specimens, it can cause the laminate to come apart entirely, which can cause a safety hazard. For example, this type of delamination has been known to damage the ISO 5660-1 cone calorimeter apparatus by throwing the retainer frame off the specimen holder. Where this is likely, appropriate precautions should be taken, such as securing the retainer frame to the specimen holder with screws or bolts.

6.4 Large-scale tests

Recognizing that small-scale tests cannot adequately assess more complex building constructions, a number of methods have been developed by ISO/TC 92 so that a composite or an assembly can be tested in its installed state in a way that is more closely related to the end-use applications. These methods include ISO 9705 (full-scale room test for surface products), ISO 13784-1 and ISO 13784-2 (large- and small-room tests for sandwich panels) and ISO 13785-2 (large-scale test for façades). Large-scale tests, carried out in isolation, can only be relied on to give information applicable to the severity of the fire conditions selected and to the size and constructional design of the components involved.

If representative fire performance is to be achieved, the construction of full-size test specimens (that is, structural elements of the fibre-reinforced composite and assemblies of such elements) requires careful design of jointing systems, consideration of edge effects and (where appropriate) of air-gaps, and realistic simulation of the method used in practice for supporting any protective facings.

Extrapolation of test results to other large-scale fire scenarios or to other composites and assemblies is extremely difficult, and this practice should be avoided whenever possible.

6.5 Standard fire tests for conformity purposes

The reaction-to-fire tests that should be used for quality control of plastics products and FRP composites for many conformity purposes are specified in ISO 10840 and ISO 15791-1. Most tests are intended to assess the response of a material, product or structure to one or more aspects of fire.

When testing structural elements or other elements used in construction, test specimens should comprise a representative section of the entire construction, including all relevant design features, such as fastenings. Structural test specimens should ideally be either full size or, for compliance with standard fire resistance tests, at least 3 m × 3 m or 4 m × 3 m for vertical and horizontal dividing elements, respectively.

NOTE 1 The ISO 834 series provides procedures for large-scale fire resistance testing of some FRP composites.

Intermediate-scale fire resistance tests are performed on, typically, 1 m × 1 m test specimens. The period for which a construction element continues to perform the function for which it was designed, as determined by conformity with specified criteria for load-bearing capacity, integrity and insulating capacity, defines the fire resistance of the composite under test.

NOTE 2 An intermediate-scale fire resistance test for FRP composites, ISO 30021-2, is currently under development.

Annex A
(informative)

Heat release measurements on FRP composites

A.1 General

The gross calorific value of materials influences fire severity in terms of fire duration. The rate of heat release is of major importance for fire growth and is very dependent on the combustion conditions, especially the heat flux incident on the exposed surface and the ventilation.

The rate of heat release directly influences many of the other reactions to fire, such as smoke and toxic-gas production. The ability to measure accurately the heat released from items such as wall linings is viewed as essential to fire protection engineering.

The extent and rate of heat release is limited primarily by ventilation. Complete combustion of FRP composites is unlikely to occur, so their gross calorific value is rarely released.

Until about 1990, it was not easy to determine the rate of heat release from fires, and calculations were made from heats of combustion. Measurement of oxygen consumption in fires now makes it possible to determine the rate of heat release more directly, regardless of how complete the degree of combustion is.

A.2 Test methods and results

The cone calorimeter used in ISO 5660-1 is an instrument designed to measure the heat released from burning materials. Specimens tested with the cone calorimeter can be subject to various levels of incident heat flux and so it is possible to model different stages of a developing fire. This modelling has been shown to correlate well with results from some large-scale fire tests, such as ISO 9705 (which simulates a fire which starts in a corner of a small room) and ISO 24473.

Often when an FRP composite is tested in the cone calorimeter, it proves difficult to ignite at low incident heat fluxes. At higher heat fluxes, ignition takes place. As the heat flux at the test specimen surface is increased, the value of the peak heat release rate (HRR) from the material also increases. The use of flame-retardants in the FRP composite causes a decrease in the value of the peak HRR (see Table A.1).

Table A.1 — Rate of heat release measured by ISO 5660-1 for standard and flame-retardant grades of glass-fibre-reinforced polyester composites when exposed to an incident heat flux of 50 kW/m^2

Description of product	Parameter	
	Mean peak HRR kW/m^2	MARHE kW/m^2
Polyester GRP with no added flame retardant	390	232
Polyester GRP with added flame retardant	195	94

The heat released from larger-scale specimens of FRP composites can be determined in tests such as those described in ISO 21367, EN 13823, ISO 24473, ISO 14696 and ISO 9705.

A.3 Calculation of ARHE

The ARHE can be calculated as follows:

When the rate of heat emission data comprises pairs of data points with the first data point as ($t_1, \dot{q}_1$), where t is the time and $\dot{q}$ is the rate of heat emission, the ARHE can be calculated (assuming a trapezoidal area) from the equation

$$\mathrm{ARHE}(t_n) = \frac{\sum_{2}^{n}(t_n - t_{n-1}) \times \frac{\dot{q}_n + \dot{q}_{n-1}}{2}}{t_n - t_{n-1}}$$

Generally, $t_1 = 0$ and $q_1 = 0$, or at least t can be rescaled to meet this condition, in which case the expression above can be further simplified. The heat emission for each time element, h_n, is calculated assuming a scan rate of 2 s (the first heat element is obtained from data points 1 and 2 and assigned to data point 2 as h_2), i.e.

$$h_n = (t_n - t_{n-1}) \times \frac{\dot{q}_n + \dot{q}_{n-1}}{2}$$

Summing these elements from $n = 2$ to $n = n$ and dividing by the interval from t_1 to t_n gives

$$\mathrm{ARHE}(t_n) = \frac{\sum_{2}^{n} h_n}{t_n - t_1}$$

Annex B
(informative)

Typical results given for glass-fibre-reinforced polymer composites by ISO and EN fire test methods

B.1 General

Eight laboratories in the UK and France obtained the results given in this annex during the PYROMMS project involving fire tests on composites for construction and transport applications over the period 2002 to 2004. Three laboratories conducted each test method (except ISO 21367) using the standard test conditions so that the variability of the test data could be assessed across a range of fire conditions.

Tests using ISO 21367 were conducted by only one laboratory. The results of these ISO 21367 intermediate-scale reaction-to-fire tests are included in this annex to allow comparison with the other standard test methods carried out in this project.

B.2 Description of products tested

The seven glass-fibre-reinforced polymer (GRP) composites tested in the PYROMMS project were all products manufactured for specific structural applications, and they were tested under conditions that represented their end-uses. Details of the products tested are given in Table B.1.

NOTE Additional details on how FRP composites should be prepared as test specimens are given in Annex E. The method used to manufacture any given laminate or panel or sandwich can affect the performance of that product in a fire.

Table B.1 — Description of glass-fibre-reinforced polymer composite products tested

Composite		End-use application	Thickness mm	Resin content [a] % by mass	Volume fraction [a] of glass fibres
Ref.	Description				
A	Non-flame-retarded polyester GRP	Wire-reinforced roof glazing panel; 12,5-mm-square grid pattern	5,0	68	0,16
B	Flame-retarded polyester GRP	Profiled roof-light panel	1,4	56	0,26
C	Modified acrylic GRP	Pultruded electric-cable U-channel conduit	4,0	34	0,45
D	Phenolic GRP prepreg sandwich panel with aramid honeycomb core	Aircraft interior furnishings and partitions	10,2	38	0,41
E	Phenolic GRP sheet	Cladding for buildings and transport	3,0	34	0,47
F	Vinyl ester GRP sheet	Skin for sandwich panels in superstructures of ships, typically used with 40-mm-thick balsa wood core	4,0	29	0,50
G	Polypropylene GRP sheet	Automotive panels such as boot (trunk) covers	2,5	43	0,37

[a] These values are derived from laboratory test data on the glass-fibre-reinforced polymer composite products.

B.3 Test results

Mean values of the results for each test performed by three laboratories are presented in Tables B.2 to B.7.

This test data confirms that variability is associated with parameters such as time to ignition, which is dependent on the test conditions, and peak heat release rate (HRR), which is dependent on the test apparatus and data recording.

Table B.2 — Fire growth with some typical glass-fibre-reinforced polymer composites

Ref.	Product description	Thickness mm	ISO 11925-2 small-flame test		EN 13823 single burning item (SBI) test	
			Flame height mm	Flaming droplets/ particles [a]	FIGRA index W/s	Total heat release, THR_{600s} MJ
A	Non-flame-retarded polyester GRP Roof glazing panel	5,0	203	None	1 707	111,8
B	Flame-retarded polyester GRP Profiled roof-light panel	1,4	81	None	927	12
C	Modified acrylic GRP Pultruded U-channel cable conduit	4,0	22	None	58	4,3
D	Phenolic GRP/honeycomb sandwich Aircraft interior panel	10,2	94	None	58	0,7
E	Phenolic GRP sheet Cladding panel	3,0	18	None	17	1,2
F	Vinyl ester GRP sheet Skin for marine sandwich panel (SBI test specimen included 50 kg/m^3 mineral fibre 20 mm thick)	4,0	127	None	624	56,2
G	Polypropylene GRP Automotive panel	2,5	263	Flaming	3 686	81,8

[a] In the ISO 11925-2 test, flaming droplets/particles were determined by ignition or not of a filter paper below the test specimen.

Table B.3 — Results for smoke production and flaming droplets/particles with some typical glass-fibre-reinforced polymer composites

Ref.	Product description	Thickness mm	EN 13823 single burning item (SBI) test		
			SMOGRA index m^2/s^2	TSP_{600s} m^2	Flaming droplets/particles [a]
A	Non-flame-retarded polyester GRP Roof glazing panel	5,0	497	3 588	None
B	Flame-retarded polyester GRP Profiled roof-light panel	1,4	533	395	None
C	Modified acrylic GRP Pultruded U-channel cable conduit	4,0	5	60	None
D	Phenolic GRP/honeycomb sandwich Aircraft interior panel	10,2	65	69	None
E	Phenolic GRP sheet Cladding panel	3,0	3	45	None
F	Vinyl ester GRP sheet Skin for marine sandwich panel (SBI test specimen included 50 kg/m^3 mineral fibre 20 mm thick)	4,0	176	1 525	None
G	Polypropylene GRP Automotive panel	2,5	124	366	Flaming

[a] In the SBI test, flaming droplets/particles were reported if they persisted for ⩾ 10 s on the floor of the test apparatus.

Table B.4 — Flame spread results for some typical glass-fibre-reinforced polymer composites

Ref.	Product description	ISO 5658-2 Lateral spread of flame in vertical configuration with 50 kW/m^2 exposure		ISO 11925-2 Vertical flame spread with bottom edge attack from small flame
		Critical flux at extinction, CFE kW/m^2	Average heat for sustained burning, Q_{sb} MJ/m^2	Flame height mm
A	Non-flame-retarded polyester GRP Roof glazing panel (5 mm thick)	2,29	2,50	203
B	Flame-retarded polyester GRP Profiled roof-light panel (1,4 mm thick)	16,71	1,72	81
C	Modified acrylic GRP Pultruded U-channel cable conduit (4 mm thick)	35,16	10,77	22
D	Phenolic GRP/honeycomb sandwich Aircraft interior panel (10,2 mm thick)	38,07	1,80	94
E	Phenolic GRP sheet Cladding panel (3 mm thick)	35,79	14,42	18
F	Vinyl ester GRP sheet Skin for marine sandwich panel (4 mm thick)	9,04	4,06	127
G	Polypropylene GRP Automotive panel (2,5 mm thick)	2,25	1,69	263

Table B.5 — Heat release rate results for some typical glass-fibre-reinforced polymer composites

Ref.	Product description	ISO 5660-1 Cone calorimeter in horizontal configuration with 50 kW/m^2 exposure		ISO 21367	EN 13823 single burning item (SBI) test
		HRR_{max} kW/m^2	MARHE kW/m^2	FIGRA index W/s	$FIGRA_{0,2MJ}$ index W/s
A	Non-flame-retarded polyester GRP Roof glazing panel (5 mm thick)	390	232,2	84,1	1 707
B	Flame-retarded polyester GRP Profiled roof-light panel (1,4 mm thick)	195	94,2	49,2	927
C	Modified acrylic GRP Pultruded U-channel cable conduit (4 mm thick)	158	48,5	8,2	58
D	Phenolic GRP/honeycomb sandwich Aircraft interior panel (10,2 mm thick)	114	40,4	69	58
E	Phenolic GRP sheet Cladding panel (3 mm thick)	153	45,3	68	17
F	Vinyl ester GRP sheet Skin for marine sandwich panel (4 mm thick) (SBI test specimen included 50 kg/m^3 mineral fibre 20 mm thick)	330	179,2	53,6	624
G	Polypropylene GRP Automotive panel (2,5 mm thick)	439	274,0	181,3	3 686

Table B.6 — Total heat release results for some typical glass-fibre-reinforced polymer composites

Ref.	Product description	ISO 5660-1 Total heat release, $Q_{A,total}$ MJ/m^2	ISO 21367 Total heat release, THR$_{600s}$ MJ	EN 13823 Total heat release, THR$_{600s}$ MJ
A	Non-flame-retarded polyester GRP Roof glazing panel (5 mm thick)	136	5,12	111,8
B	Flame-retarded polyester GRP Profiled roof-light panel (1,4 mm thick)	23	0,59	12
C	Modified acrylic GRP Pultruded U-channel cable conduit (4 mm thick)	47	0,53	4,3
D	Phenolic GRP/honeycomb sandwich Aircraft interior panel (10,2 mm thick)	31	0,13	0,7
E	Phenolic GRP sheet Cladding panel (3 mm thick)	58	0,70	1,2
F	Vinyl ester GRP sheet Skin for marine sandwich panel (4 mm thick) (SBI test specimen included 50 kg/m^3 mineral fibre 20 mm thick)	60	3,19	56,2
G	Polypropylene GRP Automotive panel (2,5 mm thick)	72	11,61	81,8

Table B.7 — Smoke parameters representing the total amount of smoke produced by the test specimen for some typical glass-fibre-reinforced polymer composites

Ref.	Product description	ISO 5659-2 (50 kW/m^2, no pilot flame) Maximum specific optical density, $D_{S,max}$	ISO 5660-2 (50 kW/m^2) Total smoke production, S_A m^2/m^2	ISO 21367 Total smoke production, TSP_{600s} m^2	EN 13823 Total smoke production, TSP_{600s} m^2
A	Non-flame-retarded polyester GRP Roof glazing panel (5 mm thick)	792	5 708	103,1	3 588
B	Flame-retarded polyester GRP Profiled roof-light panel (1,4 mm thick)	634	1 603	60,9	395
C	Modified acrylic GRP Pultruded U-channel cable conduit (4 mm thick)	344	491	5,7	60
D	Phenolic GRP/honeycomb sandwich Aircraft interior panel (10,2 mm thick)	238	643	13,0	69
E	Phenolic GRP sheet Cladding panel (3 mm thick)	59	442	1,4	45
F	Vinyl ester GRP sheet Skin for marine sandwich panel (4 mm thick) (SBI test specimen included 50 kg/m^3 mineral fibre 20 mm thick)	792	2 425	86,5	1 525
G	Polypropylene GRP Automotive panel (2,5 mm thick)	459	1 111	41,2	366

B.4 Intermediate-scale fire resistance tests

The results of intermediate-scale fire resistance tests carried out on the same composites (except that, in these tests, composite F was a sandwich panel) are presented in Table B.8. These tests were conducted on 1 m × 1 m specimens prepared in accordance with the principles outlined in Annex E and exposed to the ISO 834-1 temperature/time curve.

Table B.8 — Results of intermediate-scale fire resistance tests on some typical glass-fibre-reinforced polymer composites

Ref.	Product description	Insulation failure time minutes	Integrity failure time minutes
A	Non-flame-retarded polyester GRP Roof glazing panel (5 mm thick)	12	60
B	Flame-retarded polyester GRP Profiled roof-light panel (1,4 mm thick)	2	60
C	Modified acrylic GRP Pultruded U-channel cable conduit (4 mm thick)	4	> 240
D	Phenolic GRP/honeycomb sandwich Aircraft interior panel (10,2 mm thick)	6	109
E	Phenolic GRP sheet Cladding panel (3 mm thick)	4	35
F	Vinyl ester GRP/balsa wood/vinyl ester GRP marine sandwich panel (facings 4 mm thick, core 40 mm thick)	69	240
G	Polypropylene GRP Automotive panel (2,5 mm thick)	4	5,5

NOTE 1 The fact that composite B was a profiled sheet, with extra stiffening provided by the corrugations, enhanced its integrity performance.

NOTE 2 Composite E exhibited multiple delaminations caused possibly by the explosive expansion of moisture trapped in the laminate from the curing process. This might be the explanation for its poor relative integrity performance in these fire resistance tests.

Annex C
(informative)

Recommendations for the handling and storage of fibre-reinforced polymer composites

C.1 General

FRP composites should be stored away from flammable materials (such as paints and solvents), and storage and working areas should be kept free from rubbish that could spread a fire or ignite spontaneously.

All staff should be made aware that FRP composites are combustible, and safety procedures should be established and adhered to before work that requires flames or burning is started. Fire extinguishers should always be to hand when work that requires flames or burning is carried out.

Smoking should be prohibited in the storage and processing areas and “No smoking” notices should be prominently displayed.

C.2 Warehouses

Stockpiles should not be covered. Storage should be in a level situation (not on ramps) and at ground level. Where storage on upper floors is unavoidable, raised thresholds should be provided in doorways and low walls (bunds) fitted at the edges of floors where there are no upright structural elements and around the ends of staircases. These low bund-walls should be of fire-resistant and liquid-tight construction. Tightly packed sand bags may be used instead of low walls in some locations.

In multistorey occupied buildings, stockpiles should not be sited below any occupied floor in order to minimize the hazard in the event of fire, as the time taken to evacuate such buildings is likely to be longer than for single-storey buildings and there is a risk of smoke and fire spreading rapidly to the upper floor. Where storage on floors below occupied floors is unavoidable, an automatic fire-detection system linked to the fire alarm should be installed, together with an automatic sprinkler system.

Stockpiles should be kept in areas separated from production processes by fire-resistant partitioning. The siting of stockpiles should be such that permanently marked accessways can be maintained to and from the stockpiles and such that the stockpiles do not impair any sprinkler system.

Automatic sprinkler systems are recommended for all buildings in which large quantities of FRP composites are stored. The system should be installed and designed in accordance with the relevant requirements of fire insurers. Systems should be maintained and tested regularly.

C.3 Fabrication

Fabrication and construction work should be carried out at a sufficient distance from the main FRP composite storage areas to prevent fire spreading to a storage area.

Smoking should be prohibited when handling FRP composites.

When welding or burning adjacent to FRP composites, sparks and molten metal should be prevented from falling onto the composites by protecting them with a suitable non-combustible sheet.

When each welding or burning job is complete, the surrounding area should be inspected to make certain that nothing is burning or smouldering. Before finishing for the day, each worker should carefully inspect all places where burning has been carried out. A second inspection should be made one hour after work has finished for the day. Fire extinguishers and/or hose reels should be available at an easily recognizable fire point and close at hand when welding or burning adjacent to FRP composites.

C.4 Building and civil-engineering sites

Stockpiles of FRP composites should be limited to no more than 60 m^3 in size. If a bigger volume needs to be stored, it should be divided into two or more stockpiles that are at least 20 m apart.

FRP composite products should be stored in a fenced compound or in a building that can be secured and locked. Recommendations for warehouses should be followed where practicable.

Annex D
(informative)

Procedure in the event of fire involving fibre-reinforced polymer composites

With some resins, a fire involving the resin can spread very quickly. If there is an outbreak of fire, the fire brigade should be summoned immediately and the area evacuated by all personnel except those fighting the fire. A small fire should be tackled at once using water, CO_2 or dry-powder extinguishers. Dense smoke can be given off, creating a hazard for firefighters. If the fire is not brought quickly under control, any personnel who are remaining in the building or storage area to fight the fire (or, if it is a transport vehicle which is on fire, near the vehicle) should be evacuated promptly. Since it does not generally present any particular danger to the environment, the water used to fight fires involving FRP composites can be disposed of in the usual way, without any special treatment, via municipal sewage installations.

The following points identify the steps for cleaning a building or transport vehicle after a fire:

— vacuum cleaning of surfaces to remove dust and soot;

— grit-blasting of porous surfaces;

— wet cleaning (if required to supplement the above procedures).

Residues from a wet-cleaning process should be incinerated at temperatures recommended for the resin or thermoplastic used to produce the FRP composite. These temperatures would normally be greater than 900 °C.

Annex E
(informative)

Mounting and fixing of test specimens of fibre-reinforced polymer composites

E.1 General

This guidance provides basic rules, which are generally valid, for the mounting and fixing of FRP composite products in reaction-to-fire test standards. These mounting and fixing rules will ensure that the reaction-to-fire test results are representative of the product behaviour, in one or more end-use applications, when exposed to a fire in the relevant fire scenario.

FRP composites should be tested and classified in relation to their end-use application, and the mounting and fixing instructions given in Clause E.2 serve that purpose. The FRP product, as put on the market, should be submitted to the tests to obtain classifications that are relevant to the end-use. Mounting and fixing options might apply and may define the field of application of the classification. Generic products should be tested and classified in a consistent manner.

E.2 Mounting and fixing of test specimens

E.2.1 Options for mounting and fixing

Two options should be considered:

a) standardized mounting and fixing to cover a group of, or possibly all, end-use applications;

b) mounting and fixing that is representative of a specific end-use application.

E.2.2 Standardized mounting and fixing

Standardized mounting and fixing should be defined in a specification, respecting the general rules laid down in the supporting fire standards, to enlarge the field of application of a test result. For all standardized mounting and fixing specifications, the field of application of the specification should be defined, using the principle that the performance in the standardized mounting is equal to or lower than the performance in the end-use applications covered.

E.2.3 End-use testing

If no standardized mounting and fixing arrangements are specified, all end-use applications should be tested. If, however, standardized mounting and fixing arrangements are specified, testing can be limited to a few, or even one, end-use application.

In the fire tests, the product should be tested so that, as far as possible, the classification relates to its performance in its end-use application. FRP composite products should be tested as such. If underlying layers can be exposed in the end-use application, the ignitability test should be carried out on the edge of the test specimens in order to assess the ignitability of the underlying layers. For products that are covered by another surface product in the end-use application, the thermal attack in the test should be on the surface product of the assembly of products that is tested.

If the end-use application is known, the product should be tested accordingly or using standardized mounting and fixing. Products can be tested using a specific mounting and fixing arrangement recommended by the manufacturer of the product. The applicability of the resulting classification will, however, be limited to the end-use applications represented by the mounting and fixing arrangement used.

E.2.4 Product parameters

The following product and end-use application parameters, and their variability, should be taken into account:

- thickness;
- density;
- colour;
- surface coating;
- composition of product;
- geometry and structure, e.g. shape, number of layers and composition of layers;
- substrate;
- method of fixing;
- joints, type and position;
- air-gaps;
- edges;
- product orientation;
- exposure to thermal attack.

Parameters may be neglected if it can be demonstrated that they have no effect on the fire performance or if they are not relevant to the product(s) under consideration.

E.3 Influence of mounting and fixing arrangements in intermediate-scale fire tests

The method of fixing should be specified in any mounting and fixing arrangement used. It should consist of at least the composition, type, size, position and number of fixing attachments. If mechanical fixing attachments are used, care should be taken that they do not interfere with the flame application or with potential flame spread.

NOTE 1 These guidelines apply to intermediate-scale reaction-to-fire tests, such as the EN 13823 single burning item (SBI) test, and to fire resistance tests, such as that in ISO 834-1.

NOTE 2 The mountings and fixing attachments can influence the test result. Important parameters for these are composition, type, size, position and number. If an adhesive is used, the type and amount of adhesive, the method of application (full area, dots or waves) and the curing conditions are important. An adhesive can fail (and the product can become partly or fully detached from its support) or contribute to the fire.

NOTE 3 Warping of the test specimen in the specimen holder can change the distance from the burner and thus affect the exposure during the test. The clamping technique used can be critical for thin products. The specimen holder can have a “heat sink” effect or the screws in the frame can impede flame spread in the case of multilayer products with flame spread on a vertical edge.

E.4 Mounting and fixing procedures used for the test specimens of composites A to G described in Annex B

E.4.1 EN 13823 (SBI) tests

E.4.1.1 General

The SBI test was performed in a modified procedure with equal wall sections 0,5 m wide × 1,5 m high assembled from the sample. The extra area of the long wall was completed with 12,5 mm calcium silicate board. The butt joint between the test specimen and the calcium silicate board was covered (on the exposed side) with an aluminium strip (1,45 m long × 50 mm wide × 3 mm thick) stitched at 400 mm separations to both wall sections. Test specimens were prepared in accordance with the guidelines on mounting and fixing given in CEN/TS 15447.

E.4.1.2 Product A

This non-flame-retardant polyester GRP roof glazing panel contained wire-matrix reinforcement. It was substantially flat with a slight crinkle pattern on the external (upper) face. The interior (lower) face was smooth and this was exposed to the fire source in all tests.

The product was tested free-standing with the maximum air-gap in the SBI apparatus. The corner joint was reinforced with 1-mm-thick steel flashing 20 mm wide. The product was fixed on a steel mounting frame with 200 mm separations horizontally and 400 mm separations vertically. No joints were required on the walls of the test specimen.

E.4.1.3 Product B

This flame-retarded polyester GRP profiled roof-light panel had an external face with a polyester weathering film embedded into the composite and a pattern of slightly raised parallel ridges at distances of 25 mm across its surface. The internal face was smooth and this was exposed to the fire source in all tests.

The product was tested free-standing with the maximum air-gap in the SBI apparatus. The corner joint was reinforced with 1-mm-thick steel flashing 20 mm wide. The product was fixed on a steel mounting frame with 200 mm separations horizontally and 400 mm separations vertically. No joints were required on the walls of the test specimen.

E.4.1.4 Product C

This modified acrylic GRP pultruded U-channel is used as a conduit for electric cables. The sample supplied was 4 mm thick, 150 mm wide and 50 mm deep. To ensure good contact between adjacent profiles during installation, 5 mm was cut off the ends of the U-channel. The exposed face was the back face of the U-channel.

Channel sections were mounted vertically and the side walls of the channel were fixed mechanically using bolts, nuts and washers with a layer of ceramic wool (20 mm wide × 3 mm thick) between adjacent side-walls at 500 mm separations. Calcium silicate backing board was pressed against the back edges of the sidewalls of the U-channel.

E.4.1.5 Product D

This sandwich panel for aircraft interior furnishing had an overall thickness of 10,2 mm. The skins were made of woven-glass-reinforced phenolic prepreg and were bonded symmetrically to an aramid honeycomb core. The exposed face in a fire could be either side of the product when installed in its end-use application.

Panels were mounted vertically in the free-standing mode with the maximum air-gap in the SBI apparatus.

The vertical joint at the corner of the SBI specimen was made by cutting through one facing and bending and folding to create a clean radius edge (as specified by the manufacturer).

E.4.1.6 Product E

This glass-fibre-reinforced phenolic sheet was mounted vertically as a cladding panel in the free-standing mode with the maximum air-gap in the SBI apparatus. No joints were required on the walls of the test specimen.

E.4.1.7 Product F

This glass-fibre-reinforced vinyl ester sheet is used in superstructure applications on ships where it is often fixed as a skin over a low-density core such as 40-mm-thick balsa wood. In the SBI test, a standard Euroclass A2 rock fibre slab of 50 kg/m^3 density and 20 mm thickness was used in an assembly, with the rock fibre and GRP sheet mounted over calcium silicate board. No joints were required on the walls of the test specimen.

E.4.1.8 Product G

This glass-fibre-reinforced polypropylene sheet is used in automotive applications. The product was tested free-standing with the maximum air-gap in the SBI apparatus. The corner joint was reinforced with 1-mm-thick steel flashing 20 mm wide. The product was fixed on a steel mounting frame with 200 mm separations horizontally and 400 mm separations vertically. No joints were required on the walls of the test specimen.

E.4.2 Fire resistance tests

The fire resistance tests were conducted in accordance with the principles of ISO 834-1 using 1 m × 1 m test specimens mounted vertically on an intermediate-scale wall furnace. Five thermocouples were used to control the furnace temperature. Ceramic wool (20 mm wide, 3 mm thick) was used on all edges of the test specimen.

When testing product B, the centre thermocouple was fixed in a trough of the profiled GRP sheet. The other four thermocouples were fixed on peaks of the profiled sheet.

When testing product C, U-channel sections were mounted vertically and the side walls of the channel were fixed mechanically using bolts, nuts and washers with a layer of ceramic wool (20 mm wide × 3 mm thick) between adjacent side-walls at 300 mm separations. The exposed face was the back surface of the U-channel section.

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