Classification and testing of cables under the European Construction Products Regulation (CPR)

1. Introduction

The fire properties of cables used in European Construction are of great importance from a fire safety perspective. The path to new fire tests system for the cable industry has taken time, as shown below :

- Definition of a new set of fire testing method, via an exploratory work financed by the European commission known as the FIPEC program (1996-99) [11],
- Set up a new set of rules related to extend application, via the CEMAC II round robin program (2006-2010) [19],
- Integration of these outputs to the Standardization work of CENELEC TC 20, in connection with CENELEC TC 127, In link with the Mandate M443 [3],
- Publication of a new classification system EN 13501-6 in 2014 [6], for power and communication cables, which has been included in the classification system under the European Construction Product Regulation (CPR),
- Publication by CENELEC TC 20 [7] of a product standard for cables in September 2014, EN 50575 [8], relayed by the Official Journal of the European Union (OJEU) in mid-2015, associated to a two years transitional period,
- From this date, all cable manufacturers who intend to sell cables for use in permanent installations in buildings in Europe must obtain CE-marking for their products.

This process has been triggered by the necessity to adopt an adequate fire safety classification for cables used in construction under the Construction Product Regulation framework [4].

Table 1 : Euroclasses vs fire contribution level (based on Room corner test ISO 9705, 100 kw heat source) [29].

	Level of Fire contribution	Flash over	Time to flash over
A1 class			
A2 class	low	No	
B class	Medium	No	
C class	significant	Yes	> 10 min
D class	High level	Yes	> 2 min
E class	Very high level	Yes	< 2 min

A large part of the workload has been achieved for other construction products by using the EN 13823 (Single Burning item) for linear product and wall/ceiling covering solutions, and for floor covering by using EN ISO 9239-2 (Flooring radiant panel).

Figue1 : EN 13823 test [28].

Figure 2 : EN ISO 9239-2 Flooring radiant panel test [30].

The challenge was to adapt or develop fire tests for cables in line with the new fire parameters such as Heat Release Rate (HRR) and Smoke Production Rate (SPR), measured in dynamic conditions in over ventilated scenario.

We propose to go ahead in the process featured above to explain clearly the key drivers linked to cable fire safety.

2. FIPEC program

The Fire Performance of Electric Cables (FIPEC) [14,15] project is a research project funded by DG XII of the European Commission and co-financed by several European cable manufacturers, materials suppliers, cable users and governmental research bodies.

The FIPEC program was initiated by the European Commission and the goal of the program consists in developing of new measurement techniques for assessing the fire performances of electric cables.

Finally, guidance documents have been drafted and made available to national standardization group and CEN/CENELEC.

This project has been a large program involving several partners:

- IC (Interscience Communication ltdUK) for project management,
- SP (Sweden) for financial management,
- ISSeP (Belgium),
- CESI (Italy).

The FIPEC project has led to the development of different levels of testing ranging from ~~a~~ small-scale, cone calorimeter test procedures developed for cables and materials, to ~~a~~ full-scale-test procedure based on the IEC 60332-3 [19], but utilizing additionally HRR and SPR measurements, and a real scale test.

This program consists of 18 work packages, each of which is being undertaken by several laboratories. These are shown in Table 2.

Table 2 : Work packages of the FIPEC program.

WP	Title
WP 1	Review of European cable installations and planning of real-scale scenarios test series
WP 2	Investigate the effects of variables on a full-scale test
WP 3	Develop small-scale cable test that can determine the essential parameters
WP 4	Develop small-scale material test
WP 5	Construct cables
WP 6	Conduct real-scale fire tests
WP 7	Conduct full-scale standard test
WP 8	Conduct small-scale cable tests
WP 9	Conduct small-scale tests on materials (sheaths and insulations)
WP 10	Validate full-scale standard tests by correlation to real-scale tests in the European scenarios defined in WP 1
WP 11	Correlate the small-scale test results to full-scale standard test results
WP 12	Develop bases for correlation of results of small-scale tests on materials to small-scale test results on cable used in WP 11 to predict full-scale test data
WP 13	Development of mathematical model for the prediction of heat release rate and flame propagation of burning cables in real fires and full-scale tests from the results of small-scale tests on cable specimens
WP 14	Develop a measurement system proposal based on the existing measurement system and the information obtained
WP 15	Prepare guidelines for use in the production of standards
WP 16	Data management
WP 17	Program management
WP 18	Final report

2.1 FIPEC Approach

This program has been set up in the framework of Construction Product Directive in order to develop adequate set of fire tests for cables. Indeed, the current set of tests designed of construction product were not adapted to cable geometry. The idea was to assess the same type of parameters with fire test featuring realistic fire scenario for cables.

The experiments have been carried out at four scales ranging from small material samples to real scale cable installations. The real scale scenario test was considered as a reference scenario.

There was four test-scales ranging from small material samples to real scale test cable installations:

1. Real-scale scenario tests carried out on model electric cable installations,

2. Full-scale standard tests carried out on cable trays (based on IEC 60332-1-3) [21],

3. Small-scale tests on cables carried out in a cone calorimeter,

4. Small-scale tests on materials carried out in a cone calorimeter.

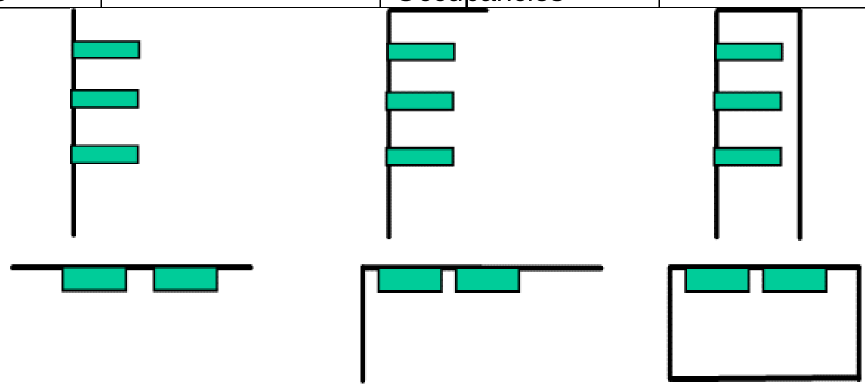
2.1.1 Real scale scenario

Regarding the real scale scenario, the review identified several vertically and horizontally orientated cable installations and several test configurations were selected which were representative of these end use conditions.

Four different configurations have been identified:, semi-closed, closed with ventilation and closed without ventilation. Table 3 illustrates the selected test configurations that can represent scenarios in each of the four studied installation scenarios.

Table 3 : Overview of Horizontal and Vertical Real scale test set-ups [18].

Open	Semi-closed	Closed without ventilation	Closed with ventilation
Power plant Vehicles Tunnels Occupancies	Power plant Tunnel	Power plant Vehicles Tunnels Occupancies	Tunnels Occupancies



In total 22 unique tests were performed, and the work program finally set up featured:

- Four heat source programs (40, 100, 200- and 300-kW combinations),
- Four different categories of cables,
- Eight different set-ups (horizontal and vertical),

- Three different ventilation levels.

2.1.2 Cable selection

Regarding cable selection, the selection was based on four end use applications [17]:

- Power plants,
- Vehicles (trains, ships and aircraft),
- Tunnels,
- Occupancies (e.g. control rooms, underfloor voids, ceiling voids and riser shafts).

Table 4: cable selection for powerplant applications [18].

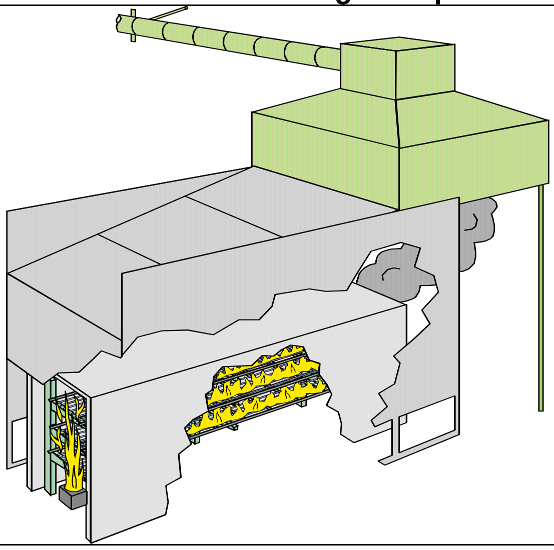
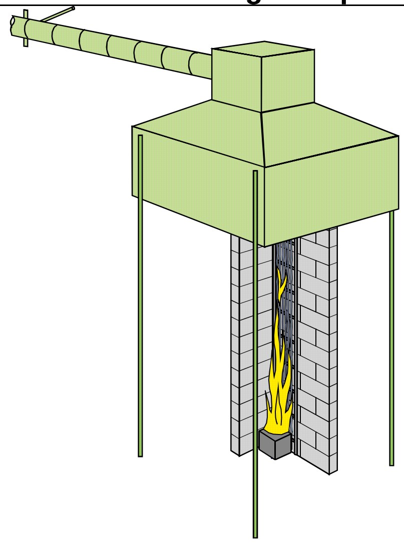
Type of cable	Construction type	Approx. number of cables present	Main orientation
Medium voltage	3×150 mm^2	10	H + V
Low voltage	7×1.5 mm^2	50	H + V
Data cables	12 pairs 0.5 mm^2	100	H + V
Wires	1.5 mm^2	1000-2000	H + V
Optical	Multiple diameter 1 cm	10	H + V

The FIPEC cable test program also included all the different kinds of polymeric matrix, (11 systems from polyvinyl chloride materials to cross-linked polyethylene materials).

2.1.3 Real scale fire tests

The Real-scale fire tests led to the establishment of one horizontal and one vertical configuration for testing ~~the~~ real scale data base cables (Table 5). Both test configurations utilized a stepwise heat source program from 40 to 300 kW.

Table 5 : horizontal and vertical set up real scale fire test, [18]

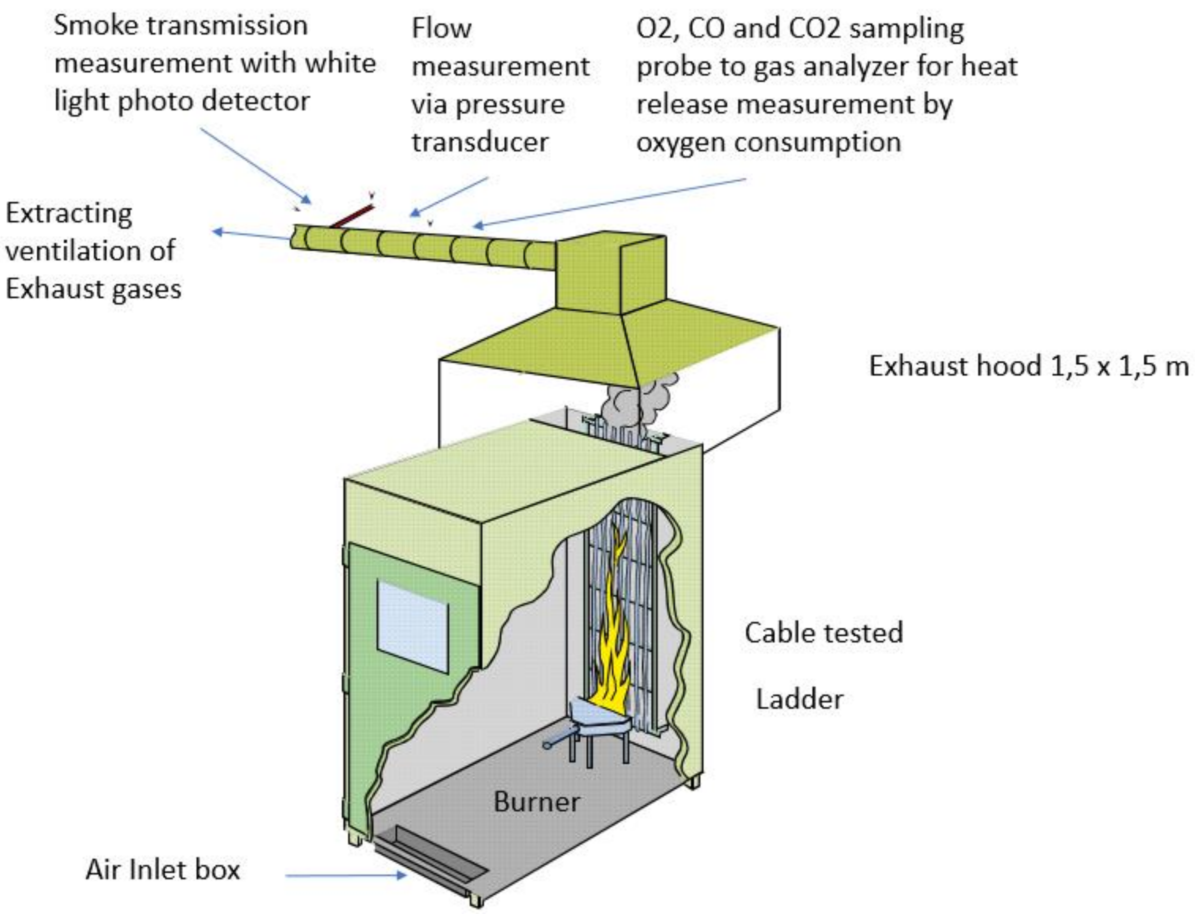
Horizontal testing Set-up	Vertical testing set up
	
Closed configuration	Semi - Closed configuration (corner)
40-100-300 kW sand box burner	40-100-300 kW sand box burner
3 trays with 4 m of cables	1 ladder with 4 m of cables
Mounting with spacing	Mounting with spacing

2.1.4 Full scale fire test

The full-scale fire test, was based on the former IEC 60332-1-3 test and it has been updated with on-line measurement of heat and smoke releases and ignitability. Oxygen consumption calorimetry was used for measuring HRR, and SPR was measured using a dynamical method with photometric system.

Please note that as for other construction product (EN 13023 SBI), the HRR measurement were performed using oxygen consumption technics.

Figure 3 : Modified former IEC 60332-1-3 large scale test [18]



Two different test protocols (fire scenario) have been used for the database tests. These are both based on the IEC 60332-1-3:

Scenario 1

- This scenario corresponded to a 20.5 kW burner and differs from the IEC 60332-1-3 method in two major ways regarding Air flow rate and cable fitting:
  - Air flow in the test chamber is increased from 5000 l/min to 8000 l/min in order to improve the response of the heat release measurement and for increasing the Heat Release Rate measuring range,
  - All cables with a diameter greater than 5 mm are mounted individually with a spacing of one cable diameter between each cable,
  - Cables with a diameter less than 5 mm are mounted in bundles (non-twisted) of 1 cm diameter with a 1 cm distance between each bundle.

Scenario 2

- This second test procedure uses the IEC 60332-1-3 burner with an increased burner output equal to 30 kW. In this case a non-combustible backing board of calcium silicate was mounted on the rear of the cable ladder.

2.1.5 Capability study

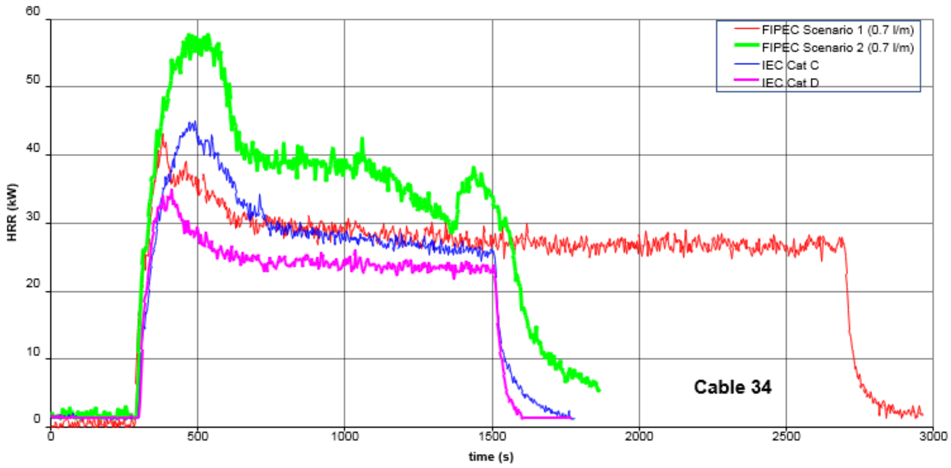
The modified cable test has been confirmed by a complete capability study in order to assess the impact of test variables on cable performance.

Some critical points of these validations are featured below.

At first and more importantly, repeatability and reproducibility were assessed by testing a large number of cables. The reproducibility of HRR was less than 5% - differences between peak heat release rate-and the reproducibility for RSP were in the same magnitude. This results qualified the test method as able to deliver results with a high level of confidence (Figure 4).

Furthermore, the results were comparable with those obtained with the traditional IEC 60332-1-3 series cable test

Figure 4: Comparison with traditional IEC 60332-1-3 series, [18]



A large array of other parameters has been screened to assess the impact on test result deviation:

- loading, bundling, grouping, and spacing of cables on the ladder,
- burner output
- presence of thermal boundaries,
- burner position e.g. angle between burner and cables,
- level of ventilation through the chamber,
- Influence of layers.
- etc.…

The conclusions, fully detailed in the FIPEC Report showed that ():

- Spacing is more severe than non-spacing for larger diameters,

- Spaced bundles are more severe for smaller cables,
- Increasing loading by more layers does not make the test more severe (Figure 6),
- Thermal boundary together with burner increase has most effect to increase severity,
- Angle of the burner does not change significantly the results,
- **Mounting is a dominating factor in the flame spread of cables.**

This confirmed that the variance value linked to the test specimen confection was responsible for 70% of the result dispersion, while systematic error linked to the fire test technology accounted only for 30%.

Figure 5 : Influence of twisted and non-twisted bundles [18]

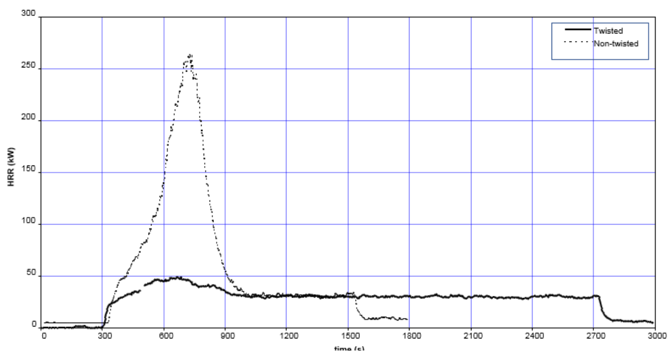
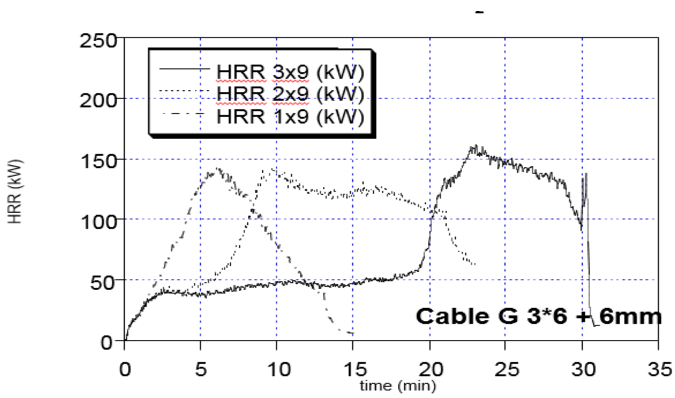


Figure 6 : Influence of layers [18]



2.1.6 Correlation between real and large-scale test

Correlation studies have been finalized between IEC 60332-1-3 - scenario 1 and 2 and vertical and horizontal large-scale tests.

The parameters retained for correlation between fire models encompassed : the flame spread, ignition, peak Heat Release Rate (HRR, Kw/m2), Fire Index of Grow Rate (FIGRA w/s), Total Heat Release (THR, KJ), peak of Smoke production Rate (SPR peak m^2/s), Smoke production Rate (SPR), Smoke Index of Growth rate (SMOGRA m^2/s^2) and Total Smoke Production (TSP, m^2) [Annex I].

The analysis is detailed in the FIPEC report and can be summarized as follows:

- The linear correlation between **IEC 60332-1-3 scenario 1** and vertical real-scale tests is very good for both heat release and smoke parameters. IEC 60332-1-3 scenario 1 and horizontal real-scale tests also have a very relevant linear correlation, which confirms the strong link between the IEC 60332-1-3 tests and real scale scenarios.
- For **IEC 60332-1-3 scenario 2** and vertical real scale tests the linear correlation is relevant for smoke parameters but less relevant for heat release parameters. A part of this explanation stands in the fact that the cables tested in the IEC 60332-1-3 scenario 2 were mostly high-performance cables that did not burn much in scenario 1.

The results of the full-scale modified IEC 60332-1-3 test has been valorized for printing out a classification for the ranking of the fire Developpement and smoke development rates of the cable (Table 6), which has fueled the commission decision of 27 th October 2006 (OJEU 4th of November 2006) as regards to the classification of the reaction to fire performance of construction products [5].

Table 6 :FIPEC proposal Classes of reaction to fire performance for cables [18]

Class	Test method(s)	Classification criteria	Additional classification
A_{ca}	EN ISO 1716	PCS ≤ 2,0 MJ/kg (1) and PCS ≤ 2,0 MJ/kg (2) and	
$B1_{ca}$	FIPEC$_{20}$ Scen 2 (6) *And*	FS ≤ 1.75 m *and* THR_{1200s} ≤ 10 MJ *and* Peak HRR ≤ 20 kW *and* FIGRA ≤ 120 Ws^{-1}	Smoke production (3, 7) and Flaming droplets/particles (4) and Acidity (5)
	EN 50265-2-1	H ≤ 425 mm	
$B2_{ca}$	FIPEC$_{20}$ Scen 1 (6) *And*	FS ≤ 1.5 m; *and* THR_{1200s} ≤ 15 MJ; *and* Peak HRR ≤ 30 kW; *and* FIGRA ≤ 150 Ws^{-1}	Smoke production (3, 8) and Flaming droplets/particles (4) and Acidity (5)
	EN 50265-2-1	H ≤ 425 mm	
C_{ca}	FIPEC$_{20}$ Scen 1 (6) *And*	FS ≤ 2.0 m; *and* THR_{1200s} ≤ 30 MJ; *and* Peak HRR ≤ 60 kW; *and* FIGRA ≤ 300 Ws^{-1}	Smoke production (3, 8) and Flaming droplets/particles (4) and Acidity (5)
	EN 50265-2-1	H ≤ 425 mm	
D_{ca}	FIPEC$_{20}$ Scen 1 (6) *And*	THR_{1200s} ≤ 70 MJ; *and* Peak HRR ≤ 400 kW; *and* FIGRA ≤ 1300 Ws^{-1}	Smoke production (3, 8) and Flaming droplets/particles (4) and Acidity (5)
	EN 50265-2-1	H ≤ 425 mm	
E_{ca}	EN 50265-2-1	H ≤ 425 mm	
F_{ca}	No performance determined		

(1) For the product, excluding metallic materials.
(2) For any external component (i.e. sheath) of the product.
(3) **s1** = TSP_{1200} ≤ 50 m^2 *and* Peak SPR ≤ 0.25 m^2/s
s1a = **s1** and transmittance in accordance with EN 50268-2 ≥ 80%
s1b = **s1** and transmittance in accordance with EN 50268-2 ≥ 60% < 80%
s2 = TSP_{1200} ≤ 300 m^2 *and* Peak SPR ≤ 1.5 m^2/s
s3 = not s1 or s2
(4) For FIPEC$_{20}$ Scenarios 1 and 2: **d0** = No flaming droplets/particles within 1200 s; **d1** = No flaming droplets/ particles persisting longer than 10 s within 1200 s; **d2** = not d0 or d1.
(5) EN 50267-2-3: **a1** = conductivity < 2.5 μS/mm *and* pH > 4.3; **a2** = conductivity < 10 μS/mm *and* pH > 4.3; **a3** = not a1 or a2. No declaration = No Performance Determined.
(6) Air flow into chamber shall be set to 8000 ± 800 l/min.
FIPEC$_{20}$ Scenario 1 = prEN 50399 with mounting and fixing according to Annex 2
FIPEC$_{20}$ Scenario 2 = prEN 50399- with mounting and fixing according to Annex 2
(7) The smoke class declared for class $B1_{ca}$ cables must originate from the FIPEC$_{20}$ Scen 2 test.
(8) The smoke class declared for class $B2_{ca}$, C_{ca}, D_{ca} cables must originate from the FIPEC$_{20}$ Scen 1 test.

Symbols used: PCS – gross calorific potential; FS – flame spread (damaged length); THR – total heat release; HRR – heat release rate; FIGRA – fire growth rate; TSP – total smoke production; SPR – smoke production rate; H – flame spread.

As a conclusion, FIPEC project also formalized all the standard proposals related to modified IEC 60332-1-3 series, which became the EN 50399 cable test. It has been considered as the essential technical brick towards fire classification of cables at the European level.

3 Construction Product Regulation (CPR) framework

The Construction Product Regulation (CPR) [4] has been set up to facilitate the free circulation of construction products in the EU, removing trade barriers eventually created by technical specification. This is achieved by providing a unique base of technical standards offering uniform assessment methods for the performance of construction products throughout the European Economic Area.

Construction product regulation is applicable to all construction products put in a permanent manner in a building. For cables, those concerned are intended to be used for the supply of electricity and communications permanently installed in buildings and other civil engineering works. CPR became mandatory for cable since the 1st of July 2017.

The process towards harmonized standards for cable has been a long road and is summarized below

Table 7: Milestones overview.

OJEU (Official Journal of the European Union) 11th of February 89	Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products
OJEU 4th of November 2006	2006/751/EC: Commission Decision of 27 October 2006 amending Decision 2000/147/EC implementing Council Directive 89/106/EEC as regards the classification of the reaction-to-fire performance of construction products This decision pointed out a distinct fire classification for cables, and set up instruction for cable fitting and mounting – all data fueled by the FIPEC program
OJEU 4 th of April 2011	Regulation No. 305/2011[1] (Construction Products Regulation, or CPR) of the European Parliament and of the European Council is a regulation of 9 March 2011 that lays down harmonized conditions for the marketing of construction products and replaces Construction Products Directive (89/106/EEC). Application deadline 1st of July 2013
18 th of May 2009	M/443 Mandate from Commission to CEN and CENELEC concerning the execution of standardization work for harmonized standards on power, control and communication cables related to supply of electricity, communications and Fire detection and alarm
10th of June 2016	**Harmonized standard EN 50575**, amended in 2016 03 25 related to Power, control and communication cables. Cables for general applications in construction works subject to reaction to fire requirements Mandatory for cable since the 1st of July 2017

CPR applied to cable is organized around 2 series of technical standards

Reference standards

- Harmonized standard hEN 50575 which details the content of the essential requirement and features (in the Annex Z) the Essential Requirements, the Assessment and Verification of constancy of Performance (AVCP) and the labelling description [8],
- CLC/TS 50576 [9] for extended applications, completed by some Guidance from the Group of Notified Bodies for the Construction Products Directive 89/106/EEC (SH02).

The reference standards use technical standards, included those related to fire test methods:

- **EN 13501-6 [6]**, which details the fire classification and refers to fire test methods below:
  - EN ISO 1716 [2]: determination of the gross calorific value,
  - EN 60332-1-2 [10] (ex EN 50265-2-1): Test for flame spread on vertically mounted single cable,
  - EN 50399 (ex IEC 60332-3): Test for flame spread of vertically mounted bunched wires or cables, issued from FIPEC program,

- EN 61034-1 and 2 [24]: Smoke opacity measurement in a 27 m^3 smoke box on horizontally mounted bunched wires or cable,
- EN 60754-2 [25]: Test on gases evolved during combustion of materials from cables in the tubular furnace. Determination of acidity (by pH measurement) and conductivity.

1 EN 13 501-6

The EN 13501-6 [6] turns over the interpretation of test results into Euroclasses applicable to cable, and completes the array, especially the EN 13 501-1 [23] dealing with reaction to fire of with linings, floorings, and linear system (pipe insulation etc…).

The classification is based on heat release and flame spread, smoke production, burning droplets, and acidity.

EN 13501-6 describes different levels of reaction to fire considering the heat release, the smoke opacity and the smoke corrosivity

Regarding rate of heat release and flame spread classes, seven classes of cables are defined: Aca, $B1_{ca}$, $B2_{ca}$, C_{ca}, D_{ca}, E_{ca} and F_{ca}. These classes combines the test results issued form EN ISO 1716 [2] (Class A_{ca}), EN 60332-1-2 [10] and EN 50399 [10] & EN 60332-1-2 [10] (Classes $B1_{ca}$, $B2_{ca}$, C_{ca}, D_{ca}, E_{ca}).

The performances of the different heat release and flame spread classes can approximately be described below.

Table 8 : EN 13501-6 overview.

		Test required		
Class	Level of Fire contribution	EN ISO 1716	EN 60332-1-2	EN 50399
A_{ca}	No contribution	X		
$B1_{ca}$	low		X	X
$B2_{ca}$	Medium		X	X
C_{ca}	significant		X	X
D_{ca}	High level		X	X
E_{ca}	Very high level			X
F_{ca}	No performance determined			

Regarding dripping of flaming droplets, 3 classes are considered d1, d2 and d3 and are issued from the results of the EN 50399 test.

Regarding rate of smoke production [27],

- 3 classes are defined s1, s2, s3 and are issued for the results of rhe EN 50399 test. The measurement is made in dynamic conditions and under over ventilated fire scenario,
- Two complementary smoke classes are considered - s1a and s1b-. This complementary classes are linked to the test results from EN 61034-2 test, corresponding to cumulative values measured in an under ventilating fire scenario.

Table 9 : smoke classes for cable.

Smoke classes	s1	s1a	s1b	s2	s3
EN 50399	$TSP_{1200} \leq 50$ m^2 Peak SPR ≤ 0.25 m^2/s	$TSP_{1200} \leq 50$ m^2 Peak SPR ≤ 0.25 m^2/s	$TSP_{1200} \leq 50$ m^2 Peak SPR ≤ 0.25 m^2/s	$TSP_{1200} \leq 300$ m^2 Peak SPR ≤ 1.5 m^2/s	Nor s1 or s2
EN 61034-2		**Transmittance in accordance with EN 61034-2 ≥ 80%**	**Transmittance in accordance with EN 61034-2 ≥ 60% < 80%**		

Regarding smoke corrosivity, 3 classes are defined: a1, a2, a3 and are issued from the results of the EN 60754-2 test.

The classification system from EN 13501-6 is summarized in Table 10 below.

Table 10 : Reaction to fire classes for electric cables.

Class	Test method(s)	Classification criteria	Additional classification
A_{ca}	EN ISO 1716	PCS ≤ 2,0 MJ/kg (1)	
$B1_{ca}$	EN 50399 (30 kW flame source) *And*	FS ≤ 1.75 m *and* $THR_{1200s} \leq 10$ MJ *and* Peak HRR ≤ 20 kW *and* FIGRA ≤ 120 Ws^{-1}	Smoke production (2,5) and Flaming droplets/particles (3) and Acidity (4)
	EN 60332-1-2	H ≤ 425 mm	
$B2_{ca}$	EN 50399 (20,5 kW flame source) *And*	FS ≤ 1.5 m; *and* $THR_{1200s} \leq 15$ MJ; *and* Peak HRR ≤ 30 kW; *and* FIGRA ≤ 150 Ws^{-1}	Smoke production (2,5) and Flaming droplets/particles (3) and Acidity (4)
	EN 60332-1-2	H ≤ 425 mm	
C_{ca}	EN 50399 (20,5 kW flame source) *And*	FS ≤ 2.0 m; *and* $THR_{1200s} \leq 30$ MJ; *and* Peak HRR ≤ 60 kW; *and* FIGRA ≤ 300 Ws^{-1}	Smoke production (2,6) and Flaming droplets/particles (3) and Acidity (4)
	EN 60332-1-2	H ≤ 425 mm	
D_{ca}	EN 50399 (20,5 kW flame source) *And*	$THR_{1200s} \leq 70$ MJ; *and* Peak HRR ≤ 400 kW; *and* FIGRA ≤ 1300 Ws^{-1}	Smoke production (2,6) and Flaming droplets/particles (3) and Acidity (4)
	EN 60332-1-2	H ≤ 425 mm	
E_{ca}	EN 60332-1-2	H ≤ 425 mm	
F_{ca}	No performance determined		

(1) For the product as a whole, excluding metallic materials, and for any external component (i.e. sheath) of the product.
(2) **s1** = $TSP_{1200} \leq 50$ m^2 *and* Peak SPR ≤ 0.25 m^2/s
s1a = **s1** and transmittance in accordance with EN 61034-2 ≥ 80%
s1b = **s1** and transmittance in accordance with EN 61034-2 ≥ 60% < 80%
s2 = $TSP_{1200} \leq 300$ m^2 *and* Peak SPR ≤ 1.5 m^2/s
s3 = not s1 or s2
(3) **d0** = No flaming droplets/particles within 1200 s; **d1** = No flaming droplets/ particles persisting longer than 10 s within 1200 s; **d2** = not d0 or d1.
(4) EN 60754-2: **a1** = conductivity < 2.5 μS/mm *and* pH > 4.3; **a2** = conductivity < 10 μS/mm *and* pH > 4.3; **a3** = not a1 or a2. No declaration = No Performance Determined.
(5) The smoke class declared for class $B1_{ca}$ cables must originate from the test according to EN 50399 (20,5 kW Flame source).
(6) The smoke class declared for class $B2_{ca}$, C_{ca}, D_{ca} cables must originate from to test according EN 50399 (30 kW Flame source).
Symbols used: PCS – gross calorific potential; FS – flame spread (damaged length); THR – total heat release; HRR – heat release rate; FIGRA – fire growth rate; TSP – total smoke production; SPR – smoke production rate; H – flame spread.

As indicated, EN 50399 becomes a central test in Euroclasses classification because it combines heat release measurement (classes $B1_{ca}$, $B2_{ca}$, C_{ca}, D_{ca}), smoke transmission measurement (s1, s2, s3) and flaming droplet assessment (d0, d1, d2).

2 EN ISO 1716

This standard characterizes the potential maximum value of heat release when a product is completely burned in an over ventilated fire. The calorific potential of a material is measured in a bomb calorimeter.

This test is used to assess the polymeric part of electric cables and each individual layer needs to be assessed. Before testing the matrix must be finely grounded with a cryogenic grinder.

The sample is placed in a calorimetric bomb under high oxygen pressure and under pure oxygen atmosphere.

The test is used for *Class A_{ca}.* level which corresponds to the highest performance products that practically cannot burn, i.e. ceramic products,

Figure 7 : ISO 1716 apparatus (courtesy form CREPIM)

3.1 EN 60332-1-2

This test is used to assess the vertical flame propagation of a single insulated wire or cable with a 1 kW pre-mixed flame.

The cable specimen (600 +/- 25 mm length) is attacked by a Bunsen burner 175 mm flame with 40 mm inner blue cone.

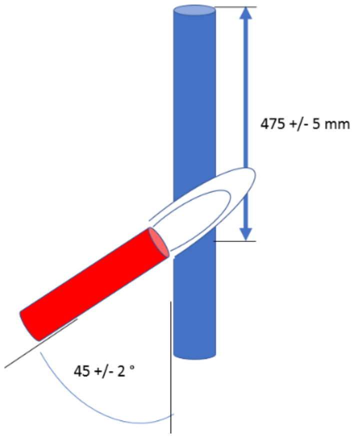
The flame shall be applied continuously for a time period linked to the diameter. At the end of the specified test duration, the burner shall be removed, and the flame of the burner extinguished.

Table 11 – Time for flame application

Overall diameter of test piece (mm)	Flame application time (s)
D<25	60 ± 2
25 < D ≤50	120 ± 2
50 < D ≤75	240 ± 2
D>75	480 ± 2

The wire or cable shall pass the test, if the distance between the lower edge of the top support and the onset of charring is greater than 50 mm.

Figure 8 : EN 60332-1-2 principle (courtesy from CREPIM)

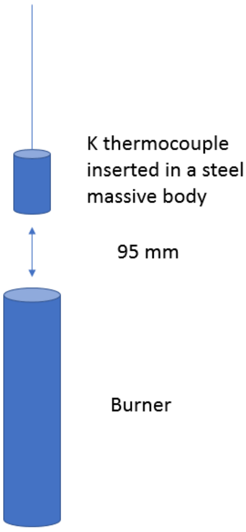


The onset of char / changing state area is determined by assessing the surface state change. Where the surface changes from a resilient to a brittle ("crumble effect") surface indicates the onset of charring. Any trace of soot is to be ignored. Softening or any deformation of the non-metallic is also to be ignored.

The Critical point in this test stands in the burner output calibration, which must be carried out according to EN 60695-11-2 [11]. The burner output is controlled with the system pictured in Figure 9 : burner calibration according to EN 60695-11-2 [11].

After flame stabilization, and verification of the burner alignment, the time measured to pass from 100 to 700 °C shall correspond to 46 +/- 6 s. The calibration must be repeated 3 times per set, and must be done regularly to secure the burner capability.

Figure 9 : burner calibration according to EN 60695-11-2 [11]



This test is not adequate for low section cables and optical cables, which must be tested according to EN 60332-1-3 [33]. In this case the dripping of flaming particles is assessed with a filter paper put below the burner (Cellulosic based, 80 +/- 15 g/m^2, harsh yield ≤0,1%), stabilized before test at 23 +/- 2°C and 50 +/- 5% Relative humidity. .

3 EN 50399

This test is an evolution of the former IEC 60332-1-3 [21] test and has been adapted during FIPEC program to characterize the reaction to fire of cable in the framework of the CPR. The test measures the vertical spread of flame on cables positioned vertically, with an ignition source positioned below.

Some measuring techniques have been added, including heat release and smoke production measurements. Compared with existing test methods described in the former IEC 60332-3, they enable a more comprehensive assessment system, which is both more precise and sensitive, and enables a wider range of fire performance levels.

The test chamber is 1 m wide, 2 m deep and 4 m high. Test rack is placed vertically into the chamber with the cables facing the burner.

Figure 10 : EN 50399 principle

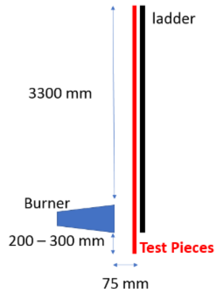


Table reviews the key differences between both test methods. EN 50399 has been fitted to correspond to the Construction Product Regulation (CPR) requirement regarding Euroclass.

Table 12 : EN 50399 comparison vs former CEI 60332-1-3

	EN 50399	CEI 60332-3
Flowrate	8000 +/- 400 l/min, less than 10% of variation during the test	5000 +/- 500 l/min 10% of variation during the test
Test duration	20 min	20 min or 40 min depending of the cable category
Sample length	3,5 m, vertical	3,5 m vertical
Sample conditioning	16 h @ 20 +/- 10 °C	16h @ 20 +/- 10 °C
Sample details	Non jointed cable mounted on the front of the standard ladder Number of cables depending of the cable's diameter	Jointed (cables ≤ 35 mm2) and non-jointed (cables > 35 mm2) mounted on the front of the standard ladder Number of cables depending other the volume of non-metallic material par meter of ladder Category A: 7 l/m Category B: 3,5 l/m Category C: 1,5 l/m Category D: 0,5 l/m This value is calculated considering the density of non-metallic material, determined according to the EN 60811-13
Burner	95% min Propane, gas burner One burner used at 2 scenarios 20,5 kW for Euroclass B2ca, Dca 30 kW for Euroclass B1ca, cable associated with calcium silicate board (11 mm thickness, 870 +/- 50 kg/m^3)	Gas burner One or two burners depending of the cable section (more or less than 35 mm2)
Parameters registered	**Heat release rate** based on oxygen consumption technic THR 1200 s MJ (Total Heat release) HRR peak kW (Heat release rate – peak) FIGRA w/s (Fire Index of Growth rate) **Smoke production rate** based on white or laser light photometric measurement TSP 1200 s m^2 (Total smoke production) SPR peak m^2/s (Smoke production rate – peak) **Flaming droplets** and particles persisting longer than 10 s	Vertical spread of flame
Criteria	Euroclasses calculation details in the 206/751/CE document of the Official journal of the European Communities	Maximum height of the charred portion does not exceed 2,5 m above the bottom edge of the burner

Figure 11 : EN 50399 apparatus (courtesy from Nexans)

While and after test

<u>The mounting phase is critical</u> because it clearly influences a large part of the test results and controls the upstream convective flow of heat. The mounting procedure is described below in Table 13 and the number of cables is linked to their diameter. Please

note that cable mounting implies a space between each test piece.

Table 13 : Mounting of the test sample

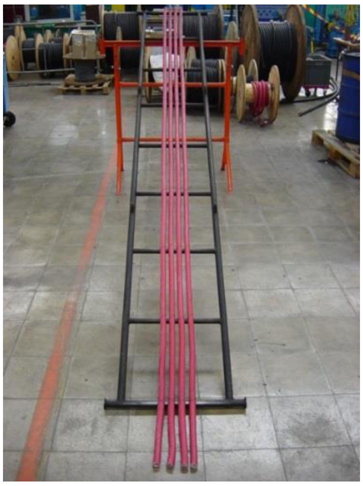
	Number of 3,5 m long test piece per test	**Spacing between test pieces**	**Mounting details**
d ≤ 20 mm	Test piece = cable $N = \text{int}\left(\frac{300+20}{dc+20}\right)$	20 mm spacing between cables	The test sample shall be mounted on the front of the standard ladder. The first test piece or bundle of test pieces shall be positioned in the center of the ladder. Further test pieces shall be added on either side so that the whole array of test pieces is centered on the ladder. Each test piece or bundle of test pieces shall be attached individually to each rung of the ladder by means of a metal wire using crossed wire method of fixing shown in Figure 13 : crossed wire method for fixing cable. For cables up to and including 50 mm diameter, wire between 0,5 mm and up to and including 1,0 mm in diameter shall be used. For cables above 50 mm diameter, wire between 1,0 mm and 1,5 mm in diameter shall be used. The lower part of each test piece of test pieces shall extend between 200 mm and 300 mm under the lower edge of the burner face,
5 < d ≤ 20 mm	Test piece = cable $N = \text{int}\left(\frac{300+dc}{2dc}\right)$	One cable diameter spacing between cables	
d ≤ 5 mm	15 Test pieces Each test pieces corresponding **to a 10 mm diameter bundles.** Each bundle containing n cables $n = int\left(\frac{100}{d^2c}\right)$ For bundles, apply a metal wire around the bundle at each rung position.	10 mm spacing between non-twisted bundles.	

d_c is the measured diameter of the cable (in mm and rounded to the nearest mm

int: the integer part of the result

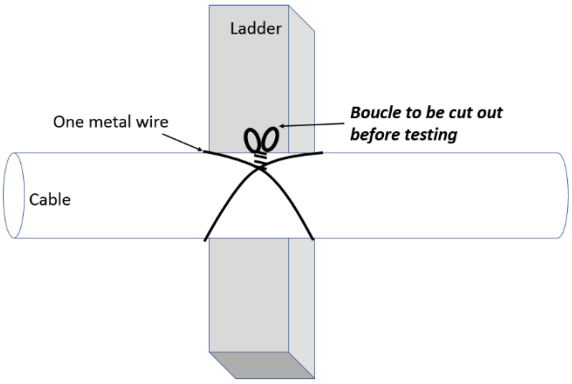
The parallelism of the cables must be controlled during mounting and on the final test specimen before testing. Calibrated spacers use is recommended to check out the global geometry of the specimen and the space between cables.

Figure 12 : Test pieces fitted on the ladder (courtesy form Nexans)



The conditioning of cable at room temperature before mounting get them mechanically relaxed and easier to fit – less curbing. It is recommended to set the cables under mechanical tension to get parallel straight line of cables.

Figure 13 : crossed wire method for fixing cable



Regarding HRR measurement, the apparatus is regularly calibrated with reference gases (Propane @ 20,5, 30- and 50-kw burner outputs) and methanol, to cross check the calibration data. The difference between correction factor linked to each gas shall be less than 10%.

Regarding SPR measurement, the apparatus is regularly calibrated with 99% purity heptane tested in a tray, and the -TSP divided by mass of heptane- ratio shall be within the range 110 +/- 25 m^2/1000 g.

At last, linearity, sensibility and drift of oxygen measurement devices and photometric system is controlled before each tests series.

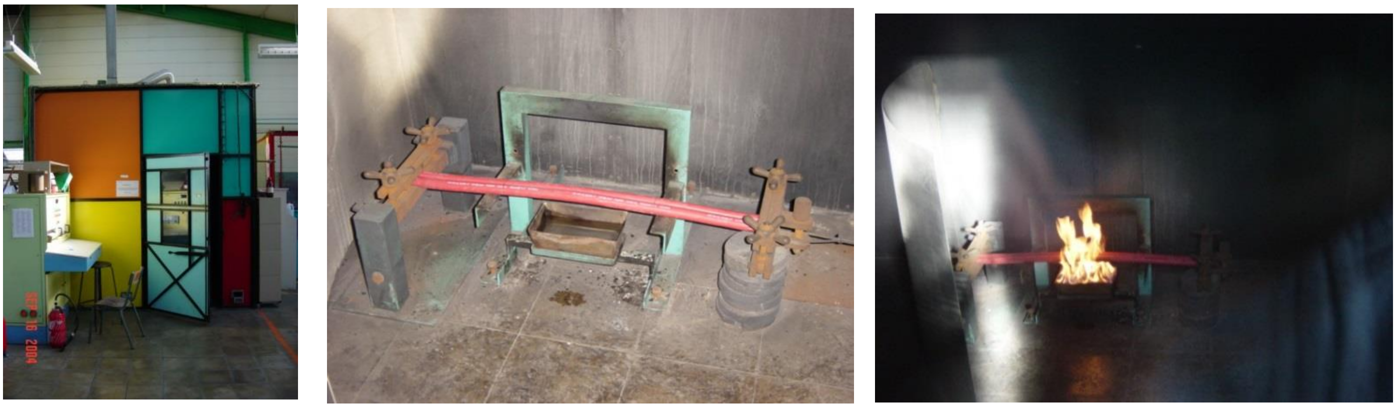
2 EN ISO 61 034-1 (apparatus) and -2 (Test procedure)

Historically this test is a key test for cable industry to assess the smoke release. The cable is placed above a tray containing standardized fuel (Ethanol 90 % / Methanol 4 % / water 6 %) in a 27 m^3 (3 x 3 x 3 m) chamber. This chamber is equipped with a halogen photometric system, with a 3 m path length.

The smoke released by the cable stressed by the below fire is measured in terms of light attenuation, and the result delivered is the transmittance (%). The chamber is equipped with a 10-15 m^3/min ventilator to homogenize the smoke density.

Figure 14 : EN ISO 61034-1 apparatus (courtesy from Nexans).

Before test During test (phase on)



The number of cables tested depends of the cable diameter and the specimens must be bundled at 300 mm in front of each end. The test pieces are positioned in horizontal position and centered above the tray, and the distance between the bottom exposed face of the sample and the bottom of the tray have is set up at 150 mm ± 5 mm.

Table 14: number of cables per test piece

Length of cable = 1 m Diameter of the cable, mm	Number of cables per test piece
D < 40	1
20 <D ≤ 40	2
10 <D ≤ 20	3
5 < D ≤ 10	N_1= 54/D mm N_1: number of cable sections
1< D ≤5	N_2= 45/3D mm N_2: number of bundles confectioned from seven test pieces of cable sections twisted together

The test is considered as over if there is no decrease in light transmittance for 5 min after the fire source has extinguished, or when the test duration reaches 40 min.

The linearity of the photometric system must be verified regularly, and the tension applied on the halogen light shall be stabilized at 12 V for all the test duration, to get a stable nominal luminous flux from 2000 to 3000 lm.

The response of the chamber must be checked regularly with two reference mixtures of alcohol/toluene at 2 different contents of toluene (4 and 10%). The acceptance criteria are based on TSP: from ,8 to 1,2 m^2 for 4% toluene mix and 0,18 to 0,26 m^2 for 10% toluene mix.

Compared with the EN 50399 test method, this test is corresponding to an under ventilated fire, and the transmission measurement corresponds to a cumulative value.

Table 15 : fire scenario comparison.

EN 50399	**EN ISO 61034-1 & 2**
Overventilated fire model	Under ventilated fire model
Dynamic measurement	Cumulative measurement
20, 5 and 30 kw/m^2 fire model	Less than 20 k<m^2 fire model

This test is used to fuel the s1a (final transmittance ≥ 80%) and s1b (final transmittance ≥ 60%) categories of the Euroclass.

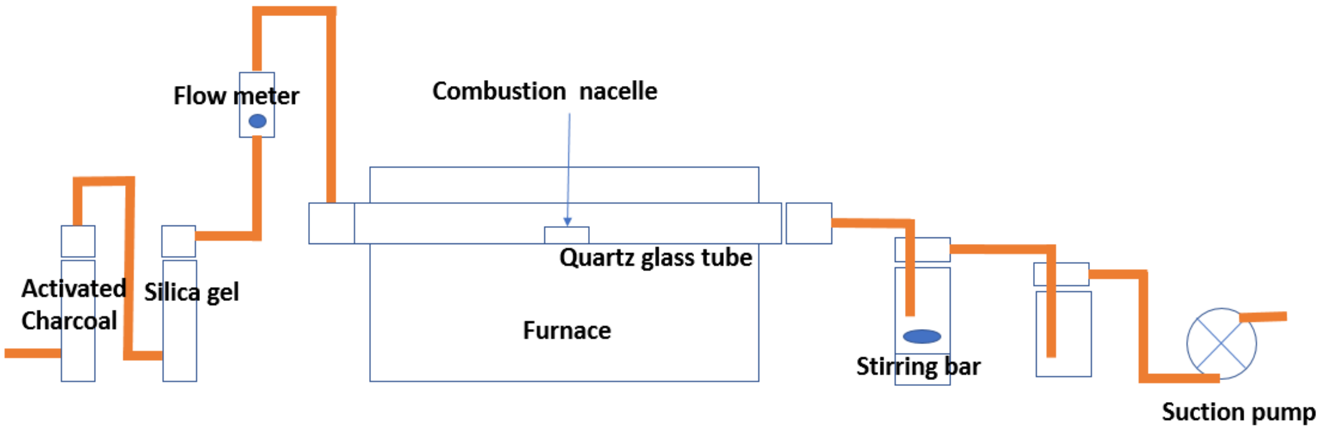
3 EN 60754-2

This standard details corresponds to the determination of the degree of acidity of gases, which consists in two parameters: pH value and conductivity.

This standard provides a method for determining the acidity (by pH measurement) and conductivity of an aqueous solution of gases evolved during the combustion of materials.

The material under test shall be heated in a stream of dry air and generally an ambient air sucked system is used. The flow rate of air introduced into the quartz tube has to be adjusted according to the actual internal cross-sectional area of the tube, such that the speed of air flowing across the sample is approximately 20 ml/mm2/h, means around 40 l/ h for a 50 mm internal diameter quartz tube. The heating system is adjusted such that the temperature at the designated position for the boat is not less than 935 °C and not more than 965 °C.

Figure 15 : EN 60 754-2 Method 3: Ambient suck air system by means of suction pump



The combustion procedure is done for 30 min in the furnace, under air flow conditions.

Three test specimens for the general method, or two for the simplified method, each consisting of (1 000 ±5) mg of the material to be tested, are be prepared.

The evolved gases shall be trapped by bubbling through wash bottles filled with distilled or demineralized water. The acidity of the resulting solution is assessed by determination of its pH value. The conductivity of the solution is also determined using a conductometer electrode apparatus.

Each test specimen shall be taken from a sample representative of the final material, which means that each individual constitutive non-metallic part of the cable must be tested. Each test specimen shall be cut into several smaller pieces. and the final value of pH and conductimetry is pondered by the weight contribution of each sub part.

This test is used for determining the categories a1, a2 and a3 of the Euroclasses

- **a1** = conductivity < 2.5 µS/mm *and* pH > 4.3;
- **a2** = conductivity < 10 µS/mm *and* pH > 4.3;
- **a3** = not a1 or a2.

This test does not determine whether a material is zero halogen or not.

Annex I: Measuring heat release rate (HRR) by oxygen consumption technique, and smoke density

I Measure of the heat release rate (HRR) by oxygen consumption technique

THE HRR from a fire is the most important single parameter for fire characterization. The HRR is a measure of fire intensity or fire powerfulness. It is, however, only during the last 25 years that this parameter could be measured in a fire situation.

Hugget explained the principle of the measurement of the HRR. Indeed, he showed that HRR from a fire involving conventional organic fuel or material is 13.1 kJ per gram of oxygen consumed, with an accuracy of +/- 5% or better. *[26].*

An incomplete combustion or ~~and~~ a variation of the nature of the fuel only has a minor effect on the results.

I-1 BURNING OF METHANE

The combustion of methane can be described as follows:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \qquad \textbf{Equation 1}$$

The net heat of combustion Δ Hc, is 50 kJ per gram of methane burnt (reaction considered at 25°C~~, and~~ water evolves to ~~is~~ vapor).

The molecular masses of the molecules are:

- M(CH4) = 16 g/mole
- M(O2) = 32 g/mole

Thus E = 50 x 16/64 = 12.5 kJ/g O_2 for this reaction

E is the heat released per gram of oxygen consumed by burning methane and can be written as:

$$E = \frac{\Delta Hc}{r_0} \qquad \textbf{Equation 2}$$

$_0 = m_{O2}/m_{fuel}$ or oxygen mass to fuel mass ratio.

The value of E from a fire involving conventional organic fuel or material is 13.1 kJ per gram of oxygen consumed, with an accuracy of +/- 5% or better (Table I-1: E for typical synthetic polymers).

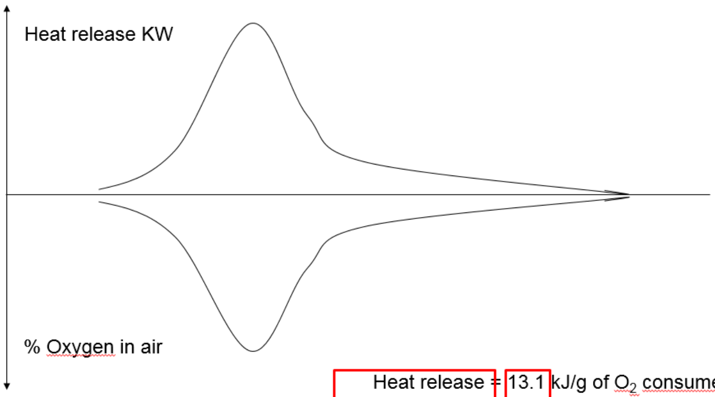
Table I-1: E for typical synthetic polymers.

Fuel	**E, kJ/g O_2**
Polyethylene	12.65
Polypropylene	12.66
Polyisobutylene	12.77
Polybutadiene	13.14
Polystyrene	12.97
Polyvinylchloride	12.84
Polyvinylidene chloride	13.61
Polyvinylidene fluoride	13.32
Polymethylmethacrylate	12.98
Polyacrylonitrile	13.61
Polyethylene Terephthalate	13.21
Polycarbonate	13.12
Cellulose triacetate	13.23
Nylon-6,6	12.67
Isobutene polysulfone	12.59
Average	**13.02**

This fact is the underlying principle for oxygen consumption calorimetry and allows the measurement of HRR from fires.

As show below in Figure I-1, there is a perfect symmetry between oxygen consumption during fire due to carbon oxidation, and HRR evolution.

Figure I-1 : Heat release measurement by oxygen consumption.



Heat release = 13.1 kJ/g of O_2 consumed

$$\dot{q} = E \times 1.1 \times C\sqrt{\frac{\Delta P}{T}} \times \frac{X^{0}_{O2} - X_{O2}}{\alpha - 1.5 X_{O2}}$$

The HRR ($\dot{q}$) can be expressed as

$$\dot{q} = E\,(m^{0}_{02} - \dot{m}_{02}) \qquad \text{Equation 3}$$

$\dot{q}$: HRR (kJ/s),

m^{0}_{O2} : mass flow of oxygen contends in incoming air,

$\dot{m}_{O2}$: mass flow of oxygen contends in the exhaust combustion gas.

In the oxygen analyzer, the percentage or molar fraction of oxygen in the gas.

Thus

$$X_{O2} = \frac{\dfrac{\dot{m}_{O2}}{M_{O2}}}{\dfrac{\dot{m}_{O2}}{M_{O2}} + \dfrac{\dot{m}_{N2}}{M_{N2}}} \qquad \text{Equation 4}$$

Consequently

$$m^{0}_{02} - \dot{m}_{02} = \dot{m}_{N2} \times \frac{M_{O2}}{M_{N2}} \times \frac{X^{0}_{O2} - X_{O2}}{(1 - X_{O2}) \cdot (1 - X^{0}_{O2})} \qquad \text{Equation 5}$$

X^{0}_{O2} : fraction of oxygen in incoming air

X_{O2} : fraction of oxygen contends in the exhaust combustion gas

$\dot{m}_{N2}$: mass flow of nitrogen (kg/s),

M_{O2} : molecular weight of oxygen (≈ 32 g/mol),

M_{N2} : molecular weight of nitrogen (≈ 28 g/mol).

We must consider the following relation:

$$\frac{\dot{m}_a}{M_a} = \frac{\dot{m}_{N2}}{M_{N2}} + \frac{m^{0}_{O2}}{M_{02}} \qquad \text{Equation 6}$$

That leads to

$$\dot{q} = \dot{m}_a \times E \times \frac{M_{O2}}{M_a} \times \frac{(X^{0}_{O2} - X_{O2})}{(1 - X_{O2})} \times (1 - X^{0}_{H2O}) \qquad \text{Equation 7}$$

X^{0}_{H2O} : Fraction of water in incoming air

The missing parameter is now the exhaust flow rate $\dot{m}_e$. Because due to dilution linked to combustion reaction and stoichiometry evolution, the incoming flow rate of air $\dot{m}_e$ is not equal to the exhaust flow rate. $\dot{m}_a$.

I-2 DETERMINATION OF THE MASS FLOW RATE ($\dot{m}_a$)

Considering burning of methane under nitrogen:

$$CH_4 + 2O_2 + 7.52N_2 \rightarrow CO_2 + 2H_2O + 7.52\ N_2$$ **Equation 8**

Incoming gas molecules: 9.52

Outcoming gas molecules: 10.52

The incoming volume of gas that completely has reacted has expanded by 10.52/9.52 = 1.105. The expansion factor is called (α). In the test set-up, only a fraction of the incoming air is fully depleted of its oxygen.

$$\dot{m}_e = \dot{m}_a - \Phi\dot{m}_a + \alpha\,\Phi\,\dot{m}_a$$ **Equation 9**

$\dot{m}_e$ is the rate of mass flow of outcoming gas of combustion

$\dot{m}_a$ is the rate of mass flow of exhaust air

The oxygen depletion factor (Φ) is

$$\phi = \frac{m^0_{O2} - \dot{m}_{02}}{m^0_{O2}} = \frac{X^0_{O2} - X_{O2}}{(1 - X_{O2})X^0_{O2}}.$$ **Equation 10)**

The waste pipe of exhaust fumes is equipped with a venturi tube, two thermocouples and pressure pick-ups. This device determines the mass flow ($\dot{m}_e$) of exhaust combustion gas applying the Bernouilli law:

$$\dot{m}_e = C \cdot \sqrt{\frac{\Delta p}{T}}$$ **Equation 11**

ΔP : difference in pressure (Pa),

C: Commissioning factor -constant of calibration (S.I),

T: temperature of gases in the device (K).

Substituting $\dot{m}_e$ for $\dot{m}_a$ in the HRR equation, we get:

$$\dot{q} = E \times 1.1 \times C\sqrt{\frac{\Delta P}{T}} \times \frac{X_{O2}^{0} - X_{O2}}{\alpha - 1.5X_{O2}}$$ ***Equation 12***

C is a proportionality constant. X_{O2}^{0} and X_{O2} are oxygen analyzer readings of incoming and exhaust gas respectively.

To limit the deviation linked to fast flashing materials and to smooth the response, HRR data are generally calculated over a 30 s running average.

This equation is available in all standards dealing with oxygen consumption calorimetry such as Cone Calorimeter standard -ISO 5660-1 [19], EN 50399 and EN 13823.

As explained in the EN 50399 Annex E, the C value (Commissioning factor) results from the aggregation of different parameters. The first one is the factor kc linked to the flow profile in the pipe -averaging of the velocity profile in the section of the exhaust duct, which is modified by correction factors issued for Propane calibration (20,5, 30 & 50 kw) and Methanol calibration

EN 50399 show up in Table I-2 an example of commissioning factor calculation

Table I-2 : example of commissioning factor calculation.

Type of calibration	**Correction factor**	**Average**	**C factor**
Kc Factor from flow profile			0,90
Propane 20,5 kW	1,03	1,013	
Propane 30 kW	1,025		
Propane 50 kW	0,985		
Methanol (4 liters)	1,06	1,06	
Final correction factor		1,037	
Commissioning C			0,93

The deviation between the Factor from flow profile Kc and the final value of the Commissioning factor C must be less than 10%

I-3 SMOKE OPACITY

The measurement is associated with the oxygen consumption technique because it can easily be set up on the same flow rate. The measurement is realized under dynamic and flow through methods.

The transmittance is the ratio of transmitted light intensity through smoke to incident light intensity, under specified conditions. It is dimensionless and is usually expressed as a percentage.

The quantity which is being measured is the extinction coefficient according to the Beer-Lambert law

$$I = I_0 e^{-kL}$$ ***Equation 13***

I: intensity of a light beam after passing through smoke

I_0: initial intensity of the light beam

k: extinction coefficient

L: path length through the environment with extinction coefficient k

Because of the nature of the flow-through system, the extinction coefficient will have to be related to the volume flow rate.

I-3.1 Smoke opacity measurement applied to EN 50399

SPR (Smoke Production Rate) calculation is based on the formula below

$$SPR = k \times Q_v$$ ***Equation 14***

K: [m^{-1}]

Qv: [m^3s^{-1}]

SPR:[m^2s^{-1}]

TSP (Total smoke production) calculation is based on the formula below

$$TSP = SPR \times t$$ ***Equation 15***

t: time [s]

TSP [m^2]

According to EN 50399, the apparatus is regularly calibrated with 99% purity heptane tested in a tray, and the ratio TSP divided by mass of heptane shall be within the range 110 +/- 25 m^2/1000 g.

I-3.2 Smoke opacity measurement applied to EN 61034-1 & 2

The optical density is defined by the equation :

$$D = \ln 10 \frac{I_0}{I}$$ ***Equation 16***

D: measured optical density

Optical density D is given for a specific path length

$$D0 = \frac{1}{L} \ln 10 \frac{I_0}{I}$$ ***Equation 17***

D0: optical density corresponding to the path length L

L: path length m

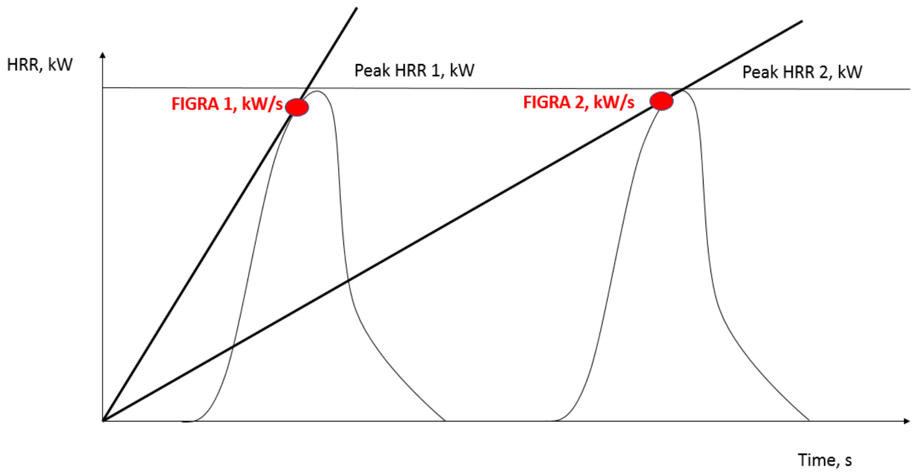
I-4 Calculation of FIGRA and SMOGRA index

HRR is a key indicator to assess fire powerfulness: the higher the peak of HRR, the higher the heat emitted in the environment, and so the spread of flame.

However, this approach points out some limit linked to the occurring time of the HRR peak. As shown below in Figures I-2 and I-3, both systems tested under building fire scenario are characterized by an equivalent value of HRR peak, the only difference stands in the occurring time.

The product n°2 has a far lower impact of flame spread because the HRR peak occurs later.

Figure I-2 : HRR peak occurrence of 2 systems.



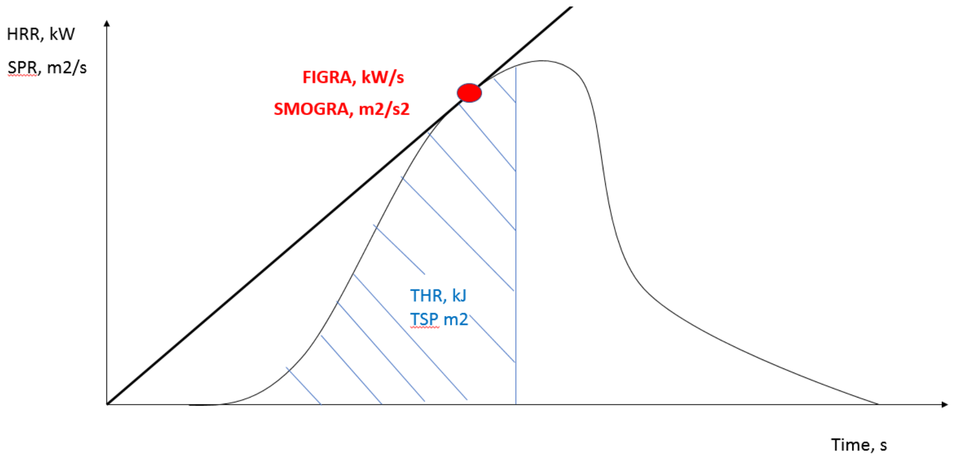
This demonstrates that HRR peak is not considered alone as a reliable parameter to assess the real fire risk of a material/system, because it does not integrate the occurrence time.

The index FIGRA (Fire Index of Growth Rate) and SMOGRA (SMOke index of GRowth rAte) have been introduced to combined HRR peak and occurrence time.

Mathematically FIGRA and SMOGRA index are obtained by operating on HRR and RSP values with a second derivative, which corresponds to an acceleration. FIGRA corresponds to the maximum value of the function that divides HRR by elapsed test time.

FIGRA and SMOGRA represents finally the maximum rate of acceleration for HRR and SRR.

Figure I-3 : FIGRA and SMOGRA calculation.



Bibliographic references

1. *Commission decision of 27 th october 2006 (OJEU 4 th of November 2006), amending Decision 2000/147/EC implementing Council Directive 89/106/EC as regards the classification of the reaction to fire performance of construction products*
2. *EN ISO 1716:2018 Reaction to fire tests for products. Determination of the gross heat of combustion (calorific value)*
3. *M/443 Mandate from Commission to CEN and CENELEC concerning the execution of standardization work for harmonized standards on power, control and communication cables related to supply of electricity, communications and Fire detection and alarm, 18 th of May 2009*
4. *Regulation No. 305/2011[1] (Construction Products Regulation, or CPR) of the European Parliament and of the European Council is a regulation of 9 March 2011 that lays down harmonized conditions for the marketing of construction products and replaces Construction Products Directive (89/106/EEC), OJEU 4 th of April 2011*
5. *2006/751/EC: Commission Decision of 27 October 2006 amending Decision 2000/147/EC implementing Council Directive 89/106/EEC as regards the classification of the reaction-to-fire performance of construction products, OJEU 4th of November 2006*
6. *EN 13501-6:2014. Fire classification of construction products and building elements - Part 6: Classification using data from reaction to fire tests on electric cables*
7. *European Committee for Electro-technical Standardization, Technical Committee 20*
8. *EN 50575. Power, control and communication cables - Cables for general applications in construction works subject to reaction to fire requirements*
9. *CLC/TS 50576: Electric cables - Extended application of test results*
10. *EN 50399: Common test methods for cables under fire conditions - Heat release and smoke production measurement on cables during flame spread test - Test apparatus, procedures, results*
11. *EN 60332-1-2. Tests on electric and optical fibre cables under fire conditions - Part 1-2: Test for vertical flame propagation for a single insulated wire or cable - Procedure for 1 kW pre-mixed flame*
12. *EN 60695-11-2: Fire hazard testing - Part 11-2: Test flames - 1 kW nominal pre-mixed flame - Apparatus, confirmatory test arrangement and guidance*
13. *FIPEC Final Report on the Europeans Commission SMT Programme SMT4-CT96-2059, 410pp, ISBN 0 9532312 5 9, London 2000.*
14. *A review of the FIPEC project, P. van Hees, U. Vercellotti, H. Breulet and S. Grayson, Fire and Materials Conference 1999, San Antonio USA.*
15. *An overview of the real scale tests in the FIPEC project (Fire Performance of Electrical Cables), Interflam 1999.*
16. *Mathematical modelling of fire development in cable installation, P. Van Hees and J. Axelsson, A. M. Green and S. J. Grayson, Fire and Materials Journal, Volume 25 nr 4, pp169-178. Wiley Publications.*
17. *Assessing the fire performance of electric cables, P. van Hees, J. Axelsson, U Vercellotti, H Breulet, A. Green and S. Grayson, FR 2000 conference, London UK.*
18. *The FIPEC REPORT : FIRE PERFORMANCE OF ELECTRIC CABLES S. J. Grayson Interscience Communications Ltd, UK, P. Van Hees SP, Sweden, A. M. Green Fire Testing Technology Ltd, UK, H. Breulet ISSeP, Belgium and U. Vercellotti, CESI, Italy, Interscience Communication, ISBN: 0 953 2312 5 9, September 2000*
19. *CEMAC CE marking fo cable, SP Techical Institute of Sweden, SP Report 2010:27, ISBN 978-91-86319-65-6, ISSN 0284-5172, Boras 2010*

20. *ISO 5660-1: Reaction-to-fire tests -- Heat release, smoke production and mass loss rate -- Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement)*

21. *CEI 60332-3:2000+ A1:2008, Test on electric cable under fire conditions. Test on bunched wires or cables. This standard has been replaced in 2000 by a series of international standards: IEC 60332-3-10 Apparatus, -21 Cat A F/R, -22 Cat A, -23 Cat B, -24 Cat C, -25 Cat D*

22. *Extended field of application (EXAP) for reaction-to-fire Euro-classification of optical fibre cables Richard Johansson, Johan Post, Michael Försth, SP Technical Research Institute of Sweden, SP Report 2015:32, ISBN 978-91-88001-61-0, ISSN 0284-5172, Borås 2015*

23. *EN 13501-1: Fire classification of construction products and building elements. Classification using data from reaction to fire tests*

24. *EN 61034-1 & 2: Measurement of smoke density of cables burning under defined conditions*

25. *EN 60754-2: Test on gases evolved during combustion of materials from cables. Determination of acidity (by pH measurement) and conductivity*

26. *Babrauskas, V., Ten Years of Heat Release Research with the Cone Calorimeter, pp. III-1 to III-8 in Heat Release and Fire Hazard, Vol. I, Y. Hasemi, ed., Building Research Institute, Tsukuba, Japan (1993).]*

27. *Smoke and Safety in case fo fire, Frank Gyppaz, Nexans Research Center- Lyon France. Nexans Brochure of septembre 13*

28. *EN 13823+A1 January 2015 - Reaction to fire tests for building products - Building products excluding floorings exposed to the thermal attack by a single burning item*

29. *ISO 9705-1:2016 - Reaction to fire tests -- Room corner test for wall and ceiling lining products -- Part 1: Test method for a small room configuration*

30. *EN ISO 9239-2:2002 Reaction to fire tests for floorings -- Part 2: Determination of flame spread at a heat flux level of 25 kW/m2*

31. *EN 50265-2-1 (superseded) -Common test methods for cables under fire conditions - Test for resistance to vertical flame propagation for a single insulated conductor or cable - Part 2-1: procedures - 1 kW pre-mixed flame –*

32. *EN 50268-2 (superseded) – Common test methods for cables under fire conditions. Measurement of smoke density of cable burning under defined conditions. Part 2: Procedure.*

33. *EN 60332-1-3: Tests on electric and optical fiber cables under fire conditions - Test for vertical flame propagation for a single insulated wire or cable - Procedure for determination of flaming droplets/particles*