Beyond Standards, FIRE

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If among essential requirements, fire safety has its place in the European Construction Products Regulation, experience and tools developed by fire engineering experts go beyond the normative framework to simulate, analyze and investigate fires of all kinds.

1. Introduction

Jicable 2011 dedicates an important place to studies on cables fire behaviour, session B3 is planning several conferences on this subject. Such an interest shows the will of the French industrials to make progress knowledge on this so complex science of fire, and on the part cables can play during a fire.

In France, the work done with the main principals for years allowed to develop cables with specific fire behaviour characteristics contributing to improve safety of persons and goods.

As an example we can mention the French metropolitan company (RATP), running one of the densest railroad networks, and using for more than 30 years cables especially developed to insure travellers safety, EDF as well has been using for many years in its power stations cables with fire performances adapted to its safety requirements. Finally, the aerospace, aircraft and naval industries took their parts on this subject. What about building, construction?

We can remind that in a car we drive with 1.2 km of cables, high speed trains are running with 100 km of cables, boats navigate with 2 500 km of cables, planes fly with 650 km of cables, and finally that in some buildings...
more than 100 kg of cables can be found per one square meter.

The Construction Products Directive, recently amended as a Regulation, includes cables as construction products.

It thus allows to establish a fire performance classification for cables. The work carried out to get this classification needed several years working in partnership with industrials and test laboratories. This article gives a short overview of all resulting tests and standards.

To allow fire safety decision-makers to have so complete as possible information, and to take into account the European texts into the French regulation, a set of tests showing cables behaviour during a fire was carried out in association with the French Central Laboratory of Police Prefecture (LCPP).

Two types of cables were tested, standard cables and low fire hazard cables, energy and data transmission. All tests carried out highlighted the technical advantages of low fire hazard cables. Adapted to building requirements, these cables allow to obtain a behaviour improving persons and rescue teams safety, especially by giving more safety on the escape routes. Their main advantages are the non propagation of fire and a non irritating clear smoke emission, two prominent criteria in the first minutes of a fire development.

Preparatory tests before real fire tests were realized on the constituent materials of cables by Laboratoire Central de la Préfecture de Police (LCPP) in its laboratory. Cable testing in a real fire took place in December 2010 on the training centre site of the Service Départemental d’Incendie et de Secours de Seine et Marne (SDIS 77) (Fire and Rescue Service of Seine and Marne).

SDIS 77 put at disposal on its training centre site of Gurcy Le Chatel the installations allowing to realize real fires, and tests on cables were supervised by specialized trainers of SDIS 77.

Finally, to strengthen what was learnt from real size tests, a modeling of the cables fire development according to some parameters followed during tests was done by the LCPP fire engineering service.

### 2. Fire behaviour normative tests for cables

Energy cables as well as telecommunication cables are considered as construction products and are now concerned by the European Construction Products Directive (CPD) [1]. The unified European system describing a classification of products in term of reaction to fire performance should be formally applied to cables very soon in European Union countries [2]. The decision of the European Commission published on October 26th 2006 describes the reaction to fire performance levels called Euroclasses [3]. The main Euroclasses are expressed from Aca for non combustible products to Fca for products with no performance (table 1). In addition to these classes, additional Subclasses are described to define ability of smoke production, of generating flaming droplets/particles, and combustion product acidity. The normative Euroclasses do not describe any specific criteria on toxicity of effluents as used in investigation done by LCPP.

#### 2.1. Cables, construction products - (Table 1)

<table>
<thead>
<tr>
<th>Class</th>
<th>Test methods</th>
<th>Classification criteria</th>
<th>Additional classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_0</td>
<td>EN ISO 1716</td>
<td>PCS ≤ 2.0 MJ/kg</td>
<td>Smoke production</td>
</tr>
<tr>
<td></td>
<td>EN 50399</td>
<td>FS ≤ 1.75 m</td>
<td></td>
</tr>
<tr>
<td>B1_ea</td>
<td>20.5 kw burner</td>
<td>THR&lt;sub&gt;1200&lt;/sub&gt; ≤10 MJ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EN 60332-1-2</td>
<td>H ≤ 425 mm</td>
<td></td>
</tr>
<tr>
<td>B2_ea</td>
<td>20.5 kw burner</td>
<td>THR&lt;sub&gt;1200&lt;/sub&gt; ≤15 MJ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EN 60332-1-2</td>
<td>H ≤ 425 mm</td>
<td></td>
</tr>
<tr>
<td>C_a</td>
<td>EN 50399</td>
<td>FS ≤ 2.0 M</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.5 kw burner</td>
<td>THR&lt;sub&gt;1200&lt;/sub&gt; ≤30 MJ</td>
<td>Smoke production</td>
</tr>
<tr>
<td></td>
<td>EN 60332-1-2</td>
<td>H ≤ 425 mm</td>
<td></td>
</tr>
<tr>
<td>D_a</td>
<td>EN 50399</td>
<td>THR&lt;sub&gt;1200&lt;/sub&gt; ≤70 MJ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.5 kw burner</td>
<td>Peak HRR ≤ 400 kW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EN 60332-1-2</td>
<td>H ≤ 425 mm</td>
<td></td>
</tr>
<tr>
<td>E_a</td>
<td>EN 60332-1-2</td>
<td>H ≤ 425 mm</td>
<td></td>
</tr>
<tr>
<td>F_a</td>
<td>EN 60332-1-2</td>
<td>No performance determined</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Classification of reaction to fire performance.

**PCS: Gross heat of combustion**

**FS:** Flame Spread (the extent of flame spread is determined as the extent of damage measured by the onset of char, as measured in the EN 50399 test)

**THR<sub>1200</sub>** : Total heat release (integrated value of the heat release rate over 1200s)

**Peak HRR: Peak of Heat Release Rate** (Maximum of thermal energy released per unit time by an item during combustion under specified conditions)

**FIGRA:** Fire growth rate index (highest value of the quotient between HRR and time)

H is the Flame Spread (distance from the point of application of the test flame to the upper onset of charring of the sample, as measured in the EN 60332-1-2 test)

The construction of the Euroclass table is based on the development of a new bench scale fire test, especially adapted to cables. It discriminates enough the reaction to fire performances to rank the cables in 6 classes, by keeping a close relationship with the fire tests applied to the other construction products concerned by the CPD.
2.1.1. **Principal classifications.**

2.1.1.1. **Classification of non combustible products.** (figure 1)

In analogy with the other construction products, the measurement of the gross heat of combustion according to the EN ISO 1716 [4] standard is used to classify cables in the Euroclass A<sub>ca</sub>.

2.1.1.2. **Classification of combustible products (Euroclasses B1 to E)**

2.1.1.2.1. **A classification based on heat release.**

The Research project FIPEC [5], initiated by the European Commission, led to the description of a reaction to fire scenario based on vertical propagation and heat release measurements and correlated with large scale tests. The new standard EN50399 [6] describes precisely this fire test procedure. It comes from the FIPEC project completed by the standardization work of CENELEC TC20 in close link with the European cable industry and third party laboratories. The 3.5 m cable pieces are fixed on a vertical ladder placed in a ventilated cabin (figure 2). A gas burner fed by a mixture of propane/air and placed horizontally provides a 20.5 or 30 kW flame at the base- ment of the test sample. The mounting of the cable pieces (number, spacing between cable pieces or bundles) is defined in function of the cable overall diameter.
A metallic hood placed on the top of the cabin (figure 2) collects the combustion effluents through an exhaust duct. The duct is equipped with a sampling line allowing the measurement of oxygen consumption to calculate the heat release during fire. In addition, a smoke opacity measurement system is installed on the pipe.

The cable performance is evaluated after 20 minutes flame application. The test described in EN 50399 allows the determination of the vertical fire spread (FS) together with the heat release (figure 3) and the smoke production (figure 4). The criteria of each Euroclass are calculated from these measurements: Peak of heat release rate (peak HRR), Total Heat Release (THR), Fire Growth Rate index (FIGRA).

EN50399 differs from the other vertical ladder propagation tests like EN/IEC 60332-3 [7] by several points:
• The ventilation of the cabin is much higher
• Cables or cable bundles are systematically spaced from each other.
• The mounting is defined according to the cable diameter but not to the volume of non-metallic material
• The instrumentation provides dynamic heat release and smoke data which are very useful for fire engineering and simulation [8].

Even if the dimensions of the cabin and the test sample orientation are specific to cables, EN 50399 provides data similar to the ones obtained with the SBI chamber [9] and used for the classification of other construction products concerned by the European Directive [10].

2.1.2. Additional classifications

2.1.2.1. Flaming droplets and particles: d0, d1 & d2

Material separating from the cable during a fire and continuing to flame for a minimum period can cause the propagation of fire to other parts or other products in the building. These flaming droplets and particles can be visualized in the EN 50399 cabin to determine the additional Euroclasses d0, d1 and d2 (table 2).

2.1.2.2. Smoke production: s1a, s1b, s2, s3

As previously mentioned, smoke production during the vertical propagation can be measured by the EN 50399 installation (figure 7). The optical density of smoke is measured either by a white light system or a laser light system installed in the extraction duct. The additional classifications s1, s2 and s3 are defined by 2 criteria based on the total smoke release (TRP) and the peak of smoke production rate (Peak SPR) (table 3).

The additional Euroclass s1 describing low smoke production cables is divided into 2 classes: s1a and s1b. These classes are defined by the measurement of smoke density released in a specific non ventilated 27m³ cubic cabin described in EN 61034-2 [11]. Cable pieces are burnt above a tray containing a flaming alcoholic solution. The smoke density is measured for a maximal period of 40 minutes through the percentage of transmittance of a white light beam crossing the cabin.
2.1.2.3. Acidity of combustion products: a1, a2, a3

Acidity of combustion products is measured by the EN 50267-2-3 [12] standard (figure 8). All the covering materials of the cable sample are burnt in a tubular furnace at a temperature over 900°C. The decomposition gases are caught by bubbling in water. The acidity Euroclasses are determined in function of the pH and the conductivity of the collected aqueous solution (table 4 & figure 8).

2.1.3. A mandatory criterion: the non-propagation of flame.

A mandatory minimum criterion for fire reaction performance: the non-propagation of flame.

The European classification defines the vertical flame propagation along a cable as primary performance criterion. This test EN 60332-1-2 [13] has been largely used in...
emit gases, the nature and concentration of which can present a toxicity risk for persons when evacuating buildings, and for rescue teams when fighting against fire.

Standards NF C 20-454 and NF X 70-100 describe methods for physicochemical analysis of gases (CO, CO₂, HCl, SO₂, HCN), which might be generated during the thermal degradation of materials.

The equipment (figure 10) consists of a heat resisting silica tube, 1000 mm long, with a 40 mm inner diameter, placed on its central part in a 600 mm long furnace regulated at 800°C (+/- 10°C).

Each non metallic cable element is tested in the form of a 1 gram test sample placed in a porcelain boat, dimension 45 x 25 x 10 mm, positioned in the centre of the tube.

A conditioning on each sample is realized, to stabilize the product moisture. The sample from which 1 gram of the material to be tested will be taken is conditioned during 48 hours at 23°C (+/- 2°C) and at 50% (+/- 5%) of relative humidity.

Air is circulating in the tube, with a rate of 120 dm³/h (+/- 10%), and after introduction of the boat containing the test piece, pyrolysis is maintained for 20 minutes. The gas flow coming from the pipe is then purified when going through a wad of silica wool, and directed towards washing bottles (dosage of halogenated hydracids, of sulfur dioxide and of hydrocyanic acid) then towards gas analyzers for continuous dosage of carbon monoxides and dioxide.

The quantities of the various emitted gases expressed in mg of gas per gram of constituent are weighted by values connected to the toxicity and to the physiological effects of each gas. The values obtained are added up to get a conventional toxicity index characteristic of the material (CTI). A CTI value under 5 is considered as satisfactory.

The critical concentration of a given gas is the maximum concentration that an individual can endure during 15 minutes without irreversible biological effects (table 5).

Critical concentrations of analyzed gases are defined in the table hereunder.

**Table 5:**

<table>
<thead>
<tr>
<th>Gas</th>
<th>CCz (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>1750</td>
</tr>
<tr>
<td>CO₂</td>
<td>90 000</td>
</tr>
<tr>
<td>HCl</td>
<td>150</td>
</tr>
<tr>
<td>HBr</td>
<td>170</td>
</tr>
<tr>
<td>HCN</td>
<td>55</td>
</tr>
<tr>
<td>HF</td>
<td>17</td>
</tr>
<tr>
<td>SO₂</td>
<td>260</td>
</tr>
</tbody>
</table>

Toxicity index characteristic (TIC) = \( \frac{100}{m} \sum \frac{Mz}{CCz} \)

with:

- \( m \) = Test piece weight
- \( Mz \) = Weight of gas emitted during combustion in mg
- \( CCz \) = Critical concentration
2.2.2. Tests on materials of the two types of cables, standard and low fire hazard cables

So as to prepare real fire comparative tests (chapter 3) for standard cables and low fire hazard cables, SYCABEL provided the French Central Laboratory of Police Prefecture (LCPP) with samples of the two types of cables.

Constitutive elements of energy and data transmission cables were tested. Thermal degradation of samples was realized with tubular furnaces as above mentioned.

Analysis of total acidity, chloride and bromide ions, concentrations of carbon monoxide and carbon dioxide were realized.

Dosage of acidity of HBr and HCL was realized by bubbling in a distilled water solution.

A series of 3 tests was realized for each type of analysis.

2.2.3. Additional investigations, VOC and aldehyde

Beyond elements usually investigated, LCPP has reserved a second furnace for sampling required for volatile organic compound (VOC) analysis and aldehyde analysis.

Values noted on formaldehyde analysis are far smaller for low fire-hazard cables, while VOC values show similar concentrations between the two types of insulation design. It is also to be noted that differences found, mainly result from the nature of the outer sheath of each cable, the insulating material of each conductor being identical (polyethylene).

The analysis carried out by LCPP highlighted the two cables types elements characteristics.

3. Real fire tests

Real fire tests described hereunder complete the investigation process undertaken to highlight the differentiated behaviour between standard cables and low fire hazard cables. Instrumentation, setting up of cable lengths, operations phasing, and methodology to get data were defined by LCPP.

LCPP contacted SDIS 77, who accepted to lend an installation (figure 11.1 to 3) adapted for this type of tests in Gurcy le Chatel (77) training centre.

These tests aim at estimating, from a prescribed fire source, the flame spread on a vertical then horizontal run, temperatures reached in the nearby environment, concentration of combustion gases emitted (CO, CO\(_2\), aldehydes, nitrogen oxides, VOC) oxygen heat fluxes and smoke opacity.
3.1. Experimental procedure

The instrumentation was as follows (figure 12):

- 3 cameras (1.8 m, 1.2 m and 0.6 m from ground level) in the axis of a prop located at 4 m from the cable run front, and 1 camera located below (0.2 m from the ground level) on a wood plate located at 1.0 m from the cable run axis.
- 1 thermobarohygrometer to note initial and final test conditions.
- 1 water cooled total heat flux meter was settled in front of the cable run, 1.3 m from cable run and at 1.5 m height.
- 2 gas probes placed at 1.5 m and 2.0 m from the ground level (not presented here).
- 12 thermocouples in a regular meshing (2.2 m, 1.9 m and 1.6 m high), and in the chamber depth (1.8 m, 1.4 m, 1.0 m and 0.6 m from the bottom), at 0.6 m from the chamber left wall.
- 4 other thermocouples (not presented here)
- 2 white light differential opacimeters

A 20 kW burner, during 25 minutes, was advocated by SYCABEL to keep an analogy with the burner required by standards in force. Because of the experimental site nature, an ethanol flame was selected.

Each configuration has been tested 3 times so as to have sufficient series to calculate experimental variations.

The number of “LAN” cables has been voluntarily limited to 4 because of the great quantities of chlorides emitted by the “standard” series during combustion, as noticed during laboratory tests.

Series N° 1: cable runs are fitted with standard cables (10 “energy” cables and 4 “LAN” cables).
Series N° 2: cable runs are fitted with low fire-hazard cables (10 “energy” cables and 4 “LAN” cables).

3.2. Results

3.2.1. Temperature

The following graphs (Fig.13&14&15) show temperature levels reached during tests. Smoke stratification (hot layer) being established, a test is represented by a single level of grey. The relative position of the curve on each graph is thus equivalent to that of the sensor associated during the tests.

A good repeatability has been noted on tests 1 and 2. A slight gap is visible for test 3 after the first 2 minutes. Nevertheless, the measured temperature ranges are similar. The growing, established and decrease phases have appreciably the same profile.
The levels of temperatures reached on top with standard cables are high enough to set fire to a majority of materials classified as combustible. All the same, the temperature of 150°C reached at 190 cm may cause severe damages to these same materials.

Values measured for LFH cables in the most exposed axis (1.4 m) i.e. in the cables plane are much lower than in the case of « standard » cables. It is to be noted that tests 1 and 3 give very close values, whatever the measured point might be. Thermal levels reached under 190 cm are compatible with levels admissible during people evacuation for LFH cables.

3.2.2. Radiative Heat Flux

Radiative flux measurement at 130 cm from cable run at 1.5 m height is significant as regards the values noted. In the developed fire phase, the commonly admitted limit
Figure 15. Comparison between the two series.

Figure 16. LFH

Figure 17. Standards cables.

Figure 18.
of 2.5 kW / m² is exceeded in the case of standard cables, while the radiative flux is about 0.5 kW / m² in the case of low fire-hazard cables.

3.2.3. Flame propagation (figures 16, 17 & 18)

Standard cables are burnt down along the whole height and the 2/3 of the horizontal run in ceiling.

Low fire-hazard cables are burnt along 120 cm for tests 1 and 3, and along 70 cm for test 2.

For standard cables, during the 2nd temperature rise, there are falls of burning materials (between 6 and 8 minutes). At the end of the 2nd peak, there is a decrease in the horizontal fire propagation on the top of the cable run, and a split between the vertical and the horizontal centre of the fire. The temperature decrease at 2.20 m after 5 min 30 test can be explained by the lower fire intensity at the bottom of the vertical cable run, all combustible materials having burnt. This fall intensity decrease is not counterbalanced by the centre of fire at which stagnates at the horizontal cable run level at the top of the testing installation.

3.2.4. Flame Height (figure19)

Height marks every 10 cm were positioned on the left side of the cable run. The 3 cameras placed in the visualization axis of the centre of the fire allowed to extract the flame height values according to the time.

Two temperature peaks can be seen on the data of thermocouples installed at a 220 cm height. The first peak at the 326th second (400°C), with a faster temperature rise from the 270th second, the second one at the 376th second (430°C), with a slack (340°C) at the 356th second. From the “CABLE” camera images, the quick rise of temperature at 220 cm happens when the fire has ended its vertical progression, and started its horizontal propagation. The intermittent flame area under ceiling reaches sometimes an exceeding 50 cm length. The intermittent flame area length decreases.

Conclusion of tests on site

The series of 3 tests allowed estimating the repeatability of experimental approach and of materials behaviour.

In the configuration proposed, low fire-hazard cables appeared to be performing well in terms of limitation of flame spread and of smoke toxicity emitted while burning, in comparison with “standard” cables.

These tests show that the use or installation in horizontal or vertical runs of low fire-hazard cables in evacuation routes can appreciably improve the practicability of these exits in case of fire. These electric cables will no longer be privileged vectors of fire propagation.

The high toxicity of « LAN » cables combustion smoke needs to be taken into account in the installation of this type of installation. It is to be noted that the higher computerization in buildings leads to a more and more massive installation of these cables. It is now necessary to take these cables into account when evaluating a building potential risks, so as to reduce the fire load and toxic effluents potentially to be emitted during a fire.
4. Fires reproduction via numerical simulation

After examining the available data, it was decided that a computer model could be used, in an attempt to reproduce the differences observed between the two different types of cables. The Fire Dynamics Simulator (FDS 5.4.1, see [14] for details) release was chosen to perform the comparison.

**Preliminary tests:**

FDS is a Computational Fluid Dynamics (CFD) model, based on Large-Eddy Simulation (LES) analysis. This code provides a computationally efficient method of calculating fluid flow and temperatures in a fire environment. The model allows the user to observe the calculated development of the fire through the use of a computer generated presentation of the model calculations.

The geometry was first constructed in FDS to form an accurate 3-D model of the structure of the involved area. A virtual 20 kW-burner was introduced in order to ignite cable trails. The combustion reaction considered here is the ethanol one for gas and soot production of (if soot and smoke movement would have been studied here, another combustion reaction would have been used).

For convergence analysis, different mesh sizes were tested (cells of 15, 10, 7.5, 5 and 2.5 cm). The calculation convergence was analysed with regard to Heat Release Rate (HRR) values and temperatures at two points. Regarding the results above, a grid size of 2.5 cm is used for all the final computations, which is a good compromise between calculation time, convergence criterion and the previous studies made by Suzanne [17].

**Input parameters:**

Data used as input parameters for modelling are extracted from:
Bomb calorimeter for the heat of combustion of PVC and Low Fire Hazard cables.
- Ignition temperature of 300°C for both types of cable from Quintieri [15].
- Heat release rate curves from Van Hees [16].
- Peak of heat release and total calorific load from tests described above and following EN 50399.

Results: (figure 20 to 25).
Pictures below are extracted from modeling results at maximum fire intensity. FDS results show good capability of flame height prediction in both cases.

Standard cable combustion behaves as in real conditions with a peak between 5 and 8 minutes in terms of flame spread, and propagation to horizontal cable trail after 5 minutes of test.

For Low Fire Hazard cables, the peak flame height is around 1 meter.
In terms of temperature, there is reasonable agreement for standard cable, with a difference of around 50°C (respectively 350 and 400 °C) and a delay of 2 minutes for calculated maximum temperatures. For Low Fire Hazard cables, temperature levels and delay are in good agreement with testing with maximum temperatures of around 80°C.

Perspectives:
For fire safety engineering purpose, fire modeling can be used in order to predict risk involved by cable trails in different parts of building. For instance, pictures below represent temperature profiles at the center of the test room and at the exit of an exhaust vent. Such results can be used to size fire safety equipment that can be affected by a cable fire.
Results obtained here are promising but need further improvement, especially for standard cables.

In order to improve fire safety predictions, examples of elements that need to be investigated are listed below:

• Accurate measurement of ignition temperature in adapted configurations
• Improvement in pyrolysis models implemented in CFD codes
• Characterization of smoke produced by cable combustion.

5. Conclusion

In view of the construction constant developments, the changes in populations’ ways of life, the societal stakes (modern conveniences, access to information, durability of goods) or also the major requirements linked to the necessity of insulating buildings to reduce energy consumption, the response to fire hazards in buildings becomes more complicated. It is therefore necessary to seize the positive contribution of technical innovations proposed by the various industries.

Whenever you are in a cinema, in a theatre, a school, or in an office building, cables run along all buildings, they guarantee their good running, and provide interconnection between all equipments participating in users’ well-being.

It is therefore essential that be added to their basic functions of electricity supply and information transmission, characteristics contributing to limit nuisances in case of fire.

Low fire hazard cables proposed by cable manufacturers are part of these innovations, which are a response to persons and goods improved safety requirements.

References


