CHOICES OF FLAME RETARDANT MATERIALS FOR CABLES WITH IMPROVED BEHAVIOUR IN FIRE

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ABSTRACT

This paper describes three different applications of halogen free flame retardant (HFFR) compounds, covering high voltage, optical fibers and low voltage cables. In each example, the cable design is described and the results obtained in term of physical properties as well as reaction to fire are presented. This article focuses on the importance of the material formulation with respect to the particular design and specifications of the cable. It is shown that HFFR materials can combine good mechanical, thermal and fire (flame propagation and smoke density and toxicity) behaviour.

KEYWORDS

HFFR compound, high voltage, optical fibres, OGP, fire behaviour

INTRODUCTION

More or less recent events (tunnel of the Mont Blanc, Austria funicular, National library in Paris) showed the catastrophic effects of the fires, for the people and the goods.
During these disasters, we could measure the importance of the side effects related to the fires:

- the opacity of the smoke, which makes very difficult the localisation of the fire,
- the toxicity of combustion gases, at the origin of approximately 60 % of the human losses.

Although they are not directly at the origin of disasters, the cables, because of their linear feature, can contribute to their propagation.
However, the large users such as the Railways, oil and gas industry, power utilities, understood for a long time the interest to reduce the side effects of fires.
In cable-making industry, the reduction of these side effects means the replacement of chlorinated polymers, by specific halogen free flame retardant materials. The current trend is to generalize the use of these compounds for sensible applications, and in particular for installations in closed environments. This is supported by the European CPD (Construction Products Directive), which concerns all the materials that could be found in a building.
A classification of cables according to their heat release during a fire has recently been introduced in this Directive.
We present today some developments of fire retardant cables, in 3 different fields:

- High Voltage,
- Optical Fibres,
- Oil, Gas and Petrochemicals applications.

A-PRESENTATION OF THE TESTING METHODS

From their behaviour in fire, the electric cables are looked under several aspects:

1. Propagation of fire

Two International standards are used to evaluate the behaviour of the cables in the event of fire:

- Propagation of flame (EN 50265-2-1)

A sample of 600 mm long is subjected to the flame of a 1 kW gas-burner during 1 to 5 minutes. After the test we check the undestroyed length, which must be higher than 50 mm.

- Propagation of the fire (IEC 60332-3)

The test consists to subject a layer of 3.5 m height to a 20 or 40 kW gas-burner, during 20 or 40 minutes. The destroyed height must be lower than 2.5 meters.

2. Smoke opacity (IEC 61034)

The smoke opacity is one of the important side effects to take into account.
It is possible to measure the opacity of the smoke released by lengths of cable, which are placed in a cubic tight room of 3 meters edge above an heating source constituted by a flamed alcoholic solution. Smoke develops in the room, which is provided with a source of light on one side, and with a photometric cell of reception on the other side.
We measure finally the loss of luminous transmission, in term of optical density (D = log 100/T) at a distance of 3 meters.

3. Halogen content (IEC 60754-1)

The test is used to evaluate the amount of halogen acid gas (except hydrofluoric acid) produced during the combustion of a material sample. It allows to know the corrosive feature of combustion gas, which could cause damages on equipment surrounding the burning cable. The sample is heated in a tube furnace in a stream of dry air, and the gas is bubbled in 0.1M sodium hydroxide solution. The quantity of halogen acid is measured by colorimetric titration and should not exceed 5 mg/g.

B. HIGH VOLTAGE CABLE

Introduction

The medium and high voltage cables are intended to transport high electrical powers.
In this aim, it is possible to arrange in the same time the section of the conductor, which defines the transmitted intensity, and the thickness of the insulation which depends on the voltage of the current.

Table 1 presents, for some models and according to the geometry of the cable, the power which can be transmitted.

	Alu Cable 12/20 kV	Alu Cable 60/90 kV	Alu Cable 225 kV
Conductor section (mm²)	630	630	500
Insulator thickness (mm)	4.5	9.0	22.0
Transmitted power (kW)	19000	75000	112500

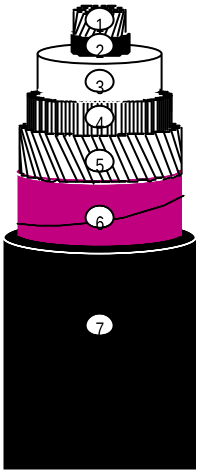
Table 1 : Transmitted power of high voltage cables as a function of the conductor section and the insulation thickness.

When we want to improve the behaviour of cables under fire, it is possible, in the case of low tension, to fireproof in the same time the insulator and the sheath.

In the medium and high voltage cables, constraints in term of insulation electrical gradient being very high, its fireproofing has to be proscribed.
Thus, the improvement of the behaviour in fire of the cable will have to be made primarily by the external screen-sheath unit.

Description of the cable

As example, we describe a 23 km connection, intended for a tunnel.
It acts as a power cable, with a section of 500 mm², and a voltage of 225 KV.
Figure 1 gives a description of the cable section.
The sheath has to reach a compromise of characteristics, including the following elements:
- o high mechanical properties, to secure the handling and laying of the cable
- o ability to be installed in vertical or horizontal position,
- o impact resistance,
- o high fire propagation resistance,
- o low smoke opacity,
- o low toxicity of combustion gas
- o watertighthness



1. Aluminium conductor
2. Extruded inner semi-conducting layer
3. Crosslinked polyethylene insulation
4. External smooth semi-conducting layer
5. Screen, formed by a wire layer wrapped around the insulator
6. Laminated aluminium foil
7. Composite external sheath, halogen free and flame retardant, with a semi conductive coating.

Figure 1 : Design of a high voltage cable for tunnel application

To achieve a convenient thermomechanical behaviour with flame retardancy, we developed a composite sheath which ensures an acceptable thermal behaviour to support the heating of the cable during line operation, and provides a good resistance against fire. Finally, a conductive layer is placed on the sheath, in order to test the conductivity of the cable after its installation.

Properties of the sheath

The selected polymer of the flame retardant compound is an alloy, containing a majority of Ethylene copolymer which can be cross linked.
The selected alloy contains 3 kinds of atoms (C, H and O), and is combustible by nature.

To make it flame retardant, we primarily added alumina hydrate which, under the influence of heat, releases water (2/3 of the weight approximately), starting at 180°C.
A second filler improves cohesion of ash during combustion, thus providing a better protection of subjacent sheath and insulation.
A detailed attention was given to the choice of the additives (plasticizer, lubricants, antioxidant), initially to bring the desired complementary characteristics, but also to limit the release of smoke and the toxicity of combustion gases, these two aspects being watched as primordial in the schedule of conditions.
This study has induced us to develop a new formulation, whose characteristics are gathered in table 2.

Characteristic	Test Standard	Result Obtained	Required Performance
Mechanical properties TS (MPa) EB (%)	EN 60811 1-1	15 150	> 10 > 125
Properties after ageing 7d. at 100 °C TS (MPa) EB (%)	EN 60811 1-2	18 135	> 10 > 125
Hot set test at 200 °C under 0.2 MPa, (%)	EN 60811 2-1	80	< 175
Thermo plasticity at 80 °C (%)	EN 60811 1-3	15	< 50
Elongation at - 15°C (%)	EN 60811 1-4	84	> 50
Water absorption test during 14 d. at 85 °C (mg/cm²)	EN 60811 1-3	4	< 10
Saline fog	EN 60068	Conform to standard	No pitting
Maximum Halogen Content (mg/g)	IEC 60754-1	0.2	< 5
Limit Oxygen index (%)	ISO 4589	34	> 30

Table 2: Physical and chemical properties of the sheath

According to the cable design described above, the result in term of fire resistance is excellent, and summed up on the table below. One can note that the IEC 332-3A is the most severe IEC requirement.

Characteristic	Test Standard	Result Obtained	Required Performance
Smoke opacity : Minimum light transmission of smoke density (%)	IEC 61034	64	> 50
Vertical fire propagation on cable bundles (m)	IEC 60 332-3, category A	0.85	< 2.5

Table 3: Fire performance of the high voltage cable

C- OPTICAL FIBRES CABLE

Introduction

The increasing request for high data rates and interactive telecommunications has a direct impact on the deployment of the optical networks. The current trend is to reduce the cost of civil engineering and to install a maximum of fibers in an existing or new infrastructure, with dimensions as small as possible.
In this context, a new concept of optical fibres cable with a compact microsheath structure has been developed.
In order to appreciate its advantages, we remind the differences between a cable with a loose tube structure, and a compact cable (figure 2).

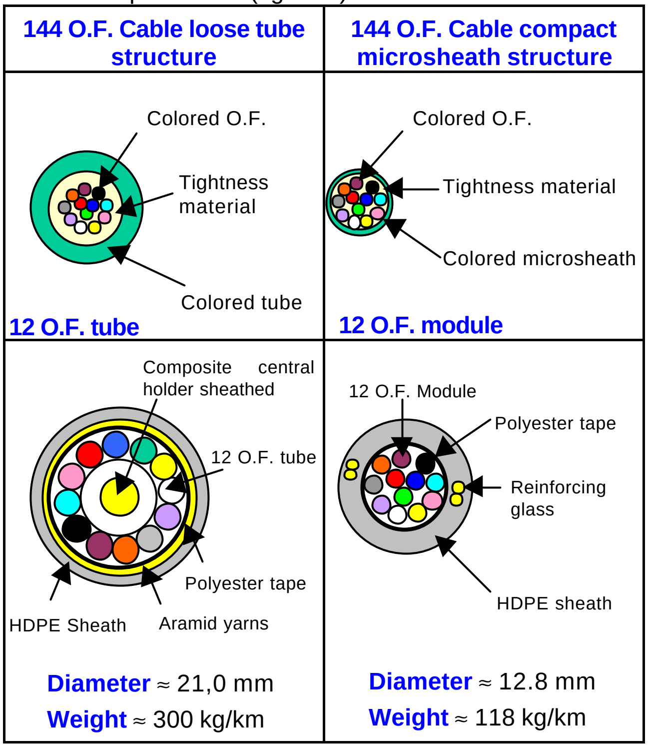


Figure 2: Two schematic structures of 144 OF cables

With equal capacity of fibres, compact cables have an external diameter almost 2 times smaller, and a weight 3 times less than structures with tubes. When these cables are used inside the buildings, from their design, the volume of combustible materials is much smaller.
By choosing adapted materials, these cables thus give an optimal answer to the whole of the requirements of optical transmission and fire resistance.

Description of the cable

By way of example, we will describe a realisation of a halogen free fire retardant cable with 48 O.F., reinforced by armour and intended for a railway tunnel (K209 for RATP cable type). Figure 3 gives a presentation of the cable.

Figure 3 : Picture of a 48 optical fibers HFFR cable.

Except the various elements of structure previously described, 2 halogen free flame retardant materials were designed for the realisation of the cable:

1 – An internal thermoplastic sheath which presents, in addition of its flame retardant nature:

- o a high hardness in order to ensure the protection of optical fibres against crushing,
- o a tear strength increased, to guarantee a good insertion of the strength members embedded in the material.

In this purpose, we chose an alloy of thermoplastic polymers, associated with a mix of selected flame retardant filler.
A detailed attention was given to the choice of the compatibility additives, in particular to combine fireproofing and tear resistance.
The principal characteristics of this internal thermoplastic sheath are gathered in the table 4.

Characteristic	Test Standard	Result Obtained
Mechanical properties TS (MPa) EB (%)	EN 60811-1-1	14 140
Hardness (Shore D)	ISO 868	53
Tear (N/mm) with 23°C	K 20	55
Limit Oxygen index (%)	ISO 4589	39
Smoke opacity (non flaming mode) Dm VOF4	IEC 60695-6	210 40
Smoke opacity (flaming mode) Dm VOF4	IEC 60695-6	180 115
Conventional toxicity index	NFC 20454	3.9

Table 4: Mechanical and physical properties of the internal thermoplastic sheath

2 - An external cross linked HFFR sheath, which ensures protection against the chemical aggressions (HCl, NaOH, oil).

Of course, it takes part in the fireproofing of the cable, in order to satisfy the propagation resistance of fire test, and, in the point of view of environment, the sheath must also generate low smoke opacity, and a reduced toxicity of combustion gas.

All these requirements can be satisfied by using a compound based on a grafted polymer alloy, which can be crosslinked by silane process. A particular attention is given to the adhesion capacity of the material on the armour and also on the flexibility to avoid stress in the sheath. The main characteristics of the cross linked external sheath and the finished cable are presented in table 5.

Characteristic	Test Standard	Required Performance	Result Obtained
Hot set test at 200 °C under 0.2 MPa, (%)	EN 60811 2-1	< 175	85
Hardness (D shore)	ISO 868		32
Mechanical properties RT (MPa) AR (%)	IEC 60811 Part 1-1	> 7 > 100	12 175
LOI	ISO 4589	> 28	33
Smoke toxicity index	NFC 20454	< 5	4.3
Opacity of the fume without flame Dm VOF4	IEC 60695-6	< 250 < 100	220 80

Table 5 : Mechanical and physical properties of the external crosslinked sheath

By combining the compact structure of the cable, and the properties of the two sheathing compound, we have designed an optical fibers cable with very high properties toward fire (see table 6).

Characteristic	Test Standard	Required Performance	Result Obtained
Propagation of fire on cables bundle (mm)	NFC 32070, test N°2	< 300	210
Propagation of fire on cables (m)	IEC 60332-3 C category	2.50	0.40

Table 6 : Properties of the 48 O.F. cable towards fire

Moreover, the same cable without external sheath (K210 type for RATP) also satisfies these two tests.

D – LOW VOLTAGE CABLE: OIL, GAS AND PETROL APPLICATIONS

Introduction

During the last years, there has been an evolution, due to safety reasons, in materials used for OGP cables (oil, gas and petrochemicals applications). Currently the polymeric materials used in the design and manufacturing process of these cables are halogen-free, low smoke according to IEC 61034 (light transmittance always exceeding 60 %) and low toxicity. Due to this fact, the cables can be used in critical service applications such as accommodation spaces, where people evacuation routes must be clear from visual obstruction and acid/toxic gases release during a fire.
Compared to a chlorinated material, it keeps its effectiveness in terms of fire performance, being the overall cable flame retardant (non vertical propagation of fire according to IEC 60332-3 Category A as well as flame on

single cable) and having good resistance to different types of fluids.

The same flame retardant cable constructions are also available with the additional feature of fire resistance (IEC 60331-21 and 31), maintaining circuit integrity during a fire (ensured power service of emergency equipment: generators, gas and fire detectors, communication devices, extinguishing systems such as water pumps or sprinklers….).

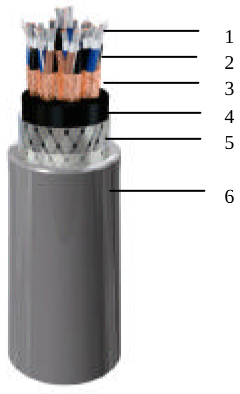
This change began in low voltage cables (< 1 kV) and afterwards it was extended to medium voltage cables when the power demand increased.

Description of the cable

Depending on their use, the cables are distributed into the following groups:

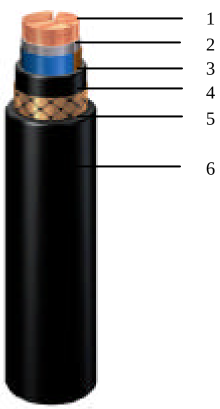
- Low voltage power cables
- Control cables
- Signal/Instrumentation cable
- Medium voltage cables

As an example, we will describe two types of cables:



1. Copper conductor
2. Insulation (HF EPR) Ethylene propylene rubber halogen free
3. Individual Screen (copper/polyester tape with drain wire)
4. Bedding – Halogen free compound
5. Armour – Tinned copper wire braid
6. Outer Sheath – Halogen free thermoset compound

Figure 4.: Instrumentation (individually screened, armoured) OGP cable



1. Copper conductor
2. Mica tape
3. Insulation (HF XLPE) Crosslinked polyethylene halogen free
4. Inner sheath – Halogen free thermoplastic
5. Armour – Copper wire braid
6. Outer Sheath – Halogen free thermoplastic polyolefin

Figure 5.: Power OGP cable

These examples show the diversity of existing designs:

Conductor:

Annealed copper (optionally tinned):

- Class 2: Rigid conductors
- Class 5: Flexible conductors

Insulation materials:

- HF EPR: EPR designed for halogen free cables. A thermosetting elastomer.
- HF XLPE: Crosslinked polyethylene designed for halogen free cables. A thermosetting material.

Armour- Braid:

- Galvanised steel
- Plain annealed copper
- Tinned annealed copper
- Bronze

Screening:

Braid: - Plain annealed copper
- Tinned annealed copper

Tape: - Aluminium/polyester
- Copper/polyester

Sheathing materials:

- SHF1: Halogen free thermoplastic compound
- SHF1+: Halogen free thermoplastic compound
- SHF2: Halogen free thermosetting compound
- SHF2 mud: Halogen free thermosetting compound mud resistant

Properties of the sheath

There are four types of sheaths for these cables:

SHF1: Halogen free thermoplastic compound

SHF1+: Halogen free thermoplastic compound. Advanced thermoplastic compound technology affords this material most of the properties including oil resistance that were previously thought to be reserved exclusively to thermoset materials of SHF2 class.

SHF2: Halogen free thermosetting compound

SHF2: mud: Halogen free thermosetting compound mud resistant. Improves the characteristics of thermosetting compound SHF2. A greater resistance to the so-called “drilling fluids” (NEK 606:2004)

See in the table 7 the comparison between the new developed materials versus chlorinated (thermoplastic PVC – thermosetting chlorosulphonated rubber compound -CSP). It is referred to values to flame retardancy, toxicity and mechanical properties of the halogen free flame retardant sheaths.

SHEATING MATERIAL	Standards	Units	ST2	SH	SHF1 Halogen free	SHF1+ Halogen free	SHF2 Halogen free	SHF2 mud Halogen free
			PVC Thermoplastic	CSP Thermosetting	EVA Thermoplastic	Thermoplastic	EVA Thermosetting	Thermosetting
Index oxigen limit	ASTM-D-2863	%	22	28	35	35	36	36
Temperature index	ASTM-D-2863	°C	160	230	280	290	290	290
Halogen content	EN 50267-2-1 IEC 60754-1	%	> 25	30	< 0,5	< 0,5	< 0,5	< 0,5
Acidity	EN 50267-2-2 IEC 60754-2	pH	< 4,3	< 4,3	> 4,3	> 4,3	> 4,3	> 4,3
Conductivity		µS/mm	> 10	> 10	< 10	< 10	< 10	< 10

MATERIAL MECHANICAL CHARACTERISTICS

Unaged Tensile Strength	IEC 60092-359	N/mm²	12,5	10	9	9	9	9
Unaged Elongation at Break		%	150	250	120	120	120	120
Ageing in air over	IEC 60092-359		7 d @ 100 °C	7 d @ 100 °C	7 d @ 100 °C	7 d @ 100 °C	7 d @ 120 °C	7 d @ 120 °C
Oil resistance	IEC 60092-359		n.a	24 h @ 100 °C	n.a	---	24 h @ 100 °C	24 h @ 100 °C
	IEEE 1580 (clause 5.17.8)					96 h @ 100 °C (cable)		
Mud resistance	NEK 606		Non	OK	Non	Non	Non	OK

Table 7 : Comparison of the sheathing materials properties

Indeed, it is demonstrated that these sheaths (SHF1, SHF2, SHF1+, SHF2 MUD) offer a lot of benefits, with higher performance in some cases than chlorinated sheaths.

E – CONCLUSION

The examples described in this presentation show that it is possible today, with adapted materials, to reduce in an important way the side effects of the fires: opacity of the fume, fire propagation and toxicity of combustion gases, while preserving the basic characteristics of the cables, that is the transport of energy, transmission of information, or guarantee the operation of the safety circuits.