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Fire and Smoke Properties of Electric Cables and Wires in Case of Different Geometric Structure and Composition

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Abstract. The purpose of this work was to assess the influence of multi-core cables construction on their fire properties determined when the bunch of cables was burned, and determination of their flammability class. Seven-core cables with a 1.5 mm^2 single core cross-section were selected for the tests. These cables consist of two types of insulation materials, four types of filling materials and three types of coating materials.

Introduction

Modern trends and safety in rolling stock seek to limit potential losses through the use of such materials and design solutions that inhibit the spread of fire and retain functional abilities of a system during fire. The cables used in rolling stock must provide a low level of total fire risk, which includes minimizing the probability of emergence and spread of fire as well as minimizing its effects on people and equipment. Fire properties are taken into account here (ignition point, self-extinguishing, smoke density, emission of toxic gases etc.) that must meet specific requirements to ensure fire hazard on a minimum level. Insulation materials and sheathed cables, like other materials, components construction, finishing or equipment elements in rolling stock should be characterized by the following features [1]:

- low flammability,
- low ability to spread fire,
- low smoke emission,
- low emission of toxic and irritating gases.

Damage caused directly by fire is not usually the main cause of people's death. The emission of dense smoke containing irritating and toxic gases proves to be much more dangerous.

Electric cables have two roles in a fire protection aspect. Firstly, they are part of fire protection systems and assist in escape and rescue. Secondly, they may be the cause of fires, increase the propagation of fire and contribute to greater damage [2].

Halogens (fluorine, chlorine, bromine) whose presence significantly decreases flammability the total hazard level is increasing. In the fire zone, where the flame is supported by other burning materials, halogen-containing plastics decompose, emitting toxic gases. Halogen formed at that time, together with hydrogen compounds (hydrogen chloride, hydrogen fluoride, hydrogen bromide) have a very high irritating and toxic effect on humans and cause damage to electronic equipment, especially after contact with fire extinguishing water (corrosion of electronic equipment and constructing structures). Plastic containing halogen also emits a lot of thick smoke under the influence of fire, which significantly limits visibility, making it difficult to evacuate people from a burning train. Halogen containing plastics also pose a threat to the natural environment by difficulties in their decomposition [1].

Furthermore, by putting pressure on the electrical industry, the consumer lobby and environmental organizations prompted to look for halogen-free alternatives in manufacture technology of flame retardant products. As a result of introduction of halogen-free materials in the cable industry, it is possible to simultaneously ensure a high level of fire safety, health care, and environmental protection. Halogen-free materials are already offered for all typical applications for thermoplastic and thermosetting plastics. Low content of halogens in cable insulations are characterized by low toxicity, low corrosivity and low smoke emission while maintaining other fire properties like flame spread and flammability. That is why halogen-free electric cables are more often used in technical and transport infrastructure elements. Currently, halogen-free cables in Europe are required for rail transport in accordance with the requirements of EN-45545-2:2015 [5]. This type of cables are also recommended for use in buildings with large clusters of people or where, as a result of fire and the emission of corrosive gases, material losses and casualties can occur e.g. in hospitals, airports, department stores, skyscrapers, hotels, theaters, cinemas or schools. For these applications, electric cables in higher flammability classes are used in accordance with the requirements of the Regulation of the European Parliament and of the Council (EU) no. 305/2011 (CPR for Construction Products Regulation) [6]. This applies especially to escape routes in buildings, tunnels and fire protection installations. Therefore, it is very important to refine the construction of cables so that their plastic components such as insulation, filling, coating, insulating or shielding tapes are not only halogen-free, but also meet the flammability classes B2ca-s1, d0, a1 according to EN-13501-1: 2018 [7].

Experimental

The purpose of this work is to assess the influence of multi-core cable construction on their fire properties determined when a bunch of cables was burned, and thus on their flammability class. Seven-core cables with a 1.5 mm2 single core cross-section were selected for testing. This type of cable uses a filler between insulated conductors as a reinforcing element. During the tests, the influence of plastics used as filler (four types) in two thicknesses was checked. The most exposed parts of the cable are the outer sheath and filler material. Therefore, their type and amount have the greatest influence on the rate of flame spread and the amount of heat released. Thus, selected cables for testing contain only one type of insulation - cross-linked flame retardant polyethylene. To confirm the necessity for flame retardant polyolefin insulation, one type of polyethylene insulation cable without flame retardants was also tested and the obtained fire properties were compared.

To sum up, two types of insulation materials, four types of filler material and three types of coating material were used in the tested cables. Samples for testing were prepared by the Polish manufacturer Technokabel S.A. and delivered to the Railway Research Institute. Nine different seven-core halogen-free cables were selected for testing. The tested cables consisted of the elements shown in Table 1 and were arranged in different configurations. An oxygen index characterizing ignition ability was also determined for each plastic element. Three types of EVA copolymer flame-retardant with aluminum and magnesium compounds were used as the filler in the tested cables [3]. Table 1 presents information on the types of materials used, whereas Table 2 - the composition of tested cables.

In order to determine fire properties mentioned above such as flammability, flame spread, smoke and toxic gases emission, the tests are carried out according to Polish and European standards.

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Table 1 Composition of the tested cables.

<table>
<tr><th>Element of cable</th><th>Type</th><th>Density [g/cm3]</th><th>Oxygen Index [%]</th></tr>
<tr><td rowspan="2">insulation</td><td>XLPE Cross-linked polyethylene non fire retardant (a)</td><td>0.92</td><td>17</td></tr>
<tr><td>XLHFFR -Cross linked halogen-free, crosslinked with silanes flame-retardant compound (b)</td><td>1.42</td><td>31</td></tr>
<tr><td rowspan="4">filler thickness</td><td>TPE-O - flame retardant based on Olefin Thermoplastic Elastomer (c)</td><td>1.94</td><td>45</td></tr>
<tr><td>flame retardant EVA based on thermoplastic elastomer (d)</td><td>1.82</td><td>45</td></tr>
<tr><td>flame retardant EVA based on thermoplastic elastomer (e)</td><td>1.8</td><td>52</td></tr>
<tr><td>flame retardant EVA based on thermoplastic elastomer (g)</td><td>1.78</td><td>60</td></tr>
<tr><td rowspan="3">sheet</td><td>HFFR -Halogen Free Flame retardant based on polypropylene (h)</td><td>1.54</td><td>37</td></tr>
<tr><td>HFFR - Halogen Free Flame retardant (i)</td><td>1.55</td><td>35</td></tr>
<tr><td>HFFR -Halogen Free Flame retardant (j)</td><td>1.5</td><td>36</td></tr>
</table>

Table 2 Composition and geometric of tested cables.

<table>
<tr><th>Specimen number</th><th>Symbol</th><th>Ø [mm]</th><th>Insulation materials</th><th>Filler thickness</th><th>Filler</th><th>Coating material</th></tr>
<tr><td>1</td><td>Cable N2XH-J B2ca 0,6/1kV 7x1,5mm2</td><td>11.9</td><td rowspan="8">XLHFFR (b)</td><td>1.00</td><td rowspan="2">EVA (g)</td><td>HFFR (h)</td></tr>
<tr><td>2</td><td>Cable N2XH-J B2ca 0,6/1kV 7x1,5mm2</td><td>11.9</td><td>1.00</td><td>HFFR (i)</td></tr>
<tr><td>3</td><td>Cable N2XH-J B2ca 0,6/1kV 7x1,5mm2</td><td>11.8</td><td>1.00</td><td rowspan="2">EVA (e)</td><td>HFFR (j)</td></tr>
<tr><td>4</td><td>Cable N2XH-J B2ca 0,6/1kV 7x1,5mm2</td><td>12</td><td>1.00</td><td rowspan="6">HFFR (h)</td></tr>
<tr><td>5</td><td>Cable N2XH-J 0,6/1 kV 7x1,5 mm2 (2)</td><td>10.7</td><td>0.30</td><td>EVA (g)</td></tr>
<tr><td>6</td><td>Cable N2XH-J 0,6/1 kV 7x1,5 mm2 (1)</td><td>10.6</td><td>0.30</td><td>EVA (d)</td></tr>
<tr><td>7</td><td>Cable N2XH-J 0,6/1 kV 7x1,5 RE</td><td>10.5</td><td>0.30</td><td rowspan="3">TPE-O (c)</td></tr>
<tr><td>8</td><td>Cable N2XH-J 0,6/1 kV 7x1,5 RE (3)</td><td>12</td><td>1.00</td></tr>
<tr><td>9</td><td>Cable N2XH-J 0,6/1 kV 7x1,5 RE</td><td>11.2</td><td>XLPE (a)</td><td>0.30</td></tr>
</table>

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The test performed for bunch of cables and wires in large scale was conducted according to EN 50399 [8]. A bunch of cables or wires were mounted vertically in a test chamber and exposed to propane burner with the nominal heat of power 20.5kW or 30kW.

This test method simulates fire of wires in cables mounted on building or vehicle and it presented the whole range of fire properties. In this test, the following parameters were determined:
- related to heat release:
    heat release rate (HRR)
    total heat release rate (THR)
    fire growth rate index (FIGRA)
- related to smoke production:
    smoke production rate (SPR)
    total smoke production (TSP)
- related to physical properties:
    damage length
    droplets and flaming particles.

The heat release rate and derivatives such as THR and FIGRA are determined by the measurement of oxygen consumption derived from the oxygen atmospheric concentration and oxygen concentration after burning with the flow rate in the combustion product stream. The smoke production rate and total smoke production is calculated from the measurement of the obscuration of a laser light beam by the combustion product stream. The damage length is measured after the test with measuring scale and droplets and flaming particles are recorded by an operator during the whole test. The results obtained on this apparatus due to the registration of so many fire parameters can be used not only for classification tests but also used to develop fire simulation models. Such studies were carried out as part of the TRANSFEU project. [4] The test chamber is presented in Figure 1 while the results of the test are presented in Table 3.

Fig. 1 Test chamber

Fig. 2 Rack with oxygen analyzer

The same insulation material and the same filling material but two different coatings with similar OI values were used for specimens 1 and 2. There were no significant differences in the obtained parameters. Both cables constructed in this way are characterized by good fire properties - low heat release and low TSP smoke. During the test of specimen 2, dropping of burning droplets occurred.

Table 3 Results of the tests

Cable number	Ø [mm]	Damage length [m]	Peak HRR(30) [kW]	THR (1200) [MJ]	FIGRA [W/s]	TSP [m^2]	Class	Smoke production	Flaming droplets
1	11.9	0.72	26.9	13.2	53.7	8.2	B2ca	s1	d0
2	11.9	0,9	22.9	12.3	49.8	12.8	B2ca	s1	d2
3	11.8	0.7	18.1	9.3	45.2	11.1	B2ca	s1	d2
4	12	0.76	23.5	15.7	82.1	16.3	Cca	s1	d2
5	10.7	1.07	23.6 s	12.3	43.9	22.6	B2ca	s1	d0
6	10.6	1.32	35.0	18.9	69.4	57.4	Cca	s2	d0
7	10.5	2	45.2	25.9	83.8	50.1	Cca	s2	d0
8	12	1.4	44.3	20.8	83.3	62.1	Cca	s2	d2
9	1.2	3.3	332.5	89.4	428.4	135.3	Dca	s2	d2

Specimens 3 and 4 used the same insulation material and the second type of filler material and two different coatings with similar OI values. During the test, differences in HRR values and the amount of smoke emission were observed. The tested specimen 4 obtained worse parameters due to the application of a polypropylene-based coating (h).

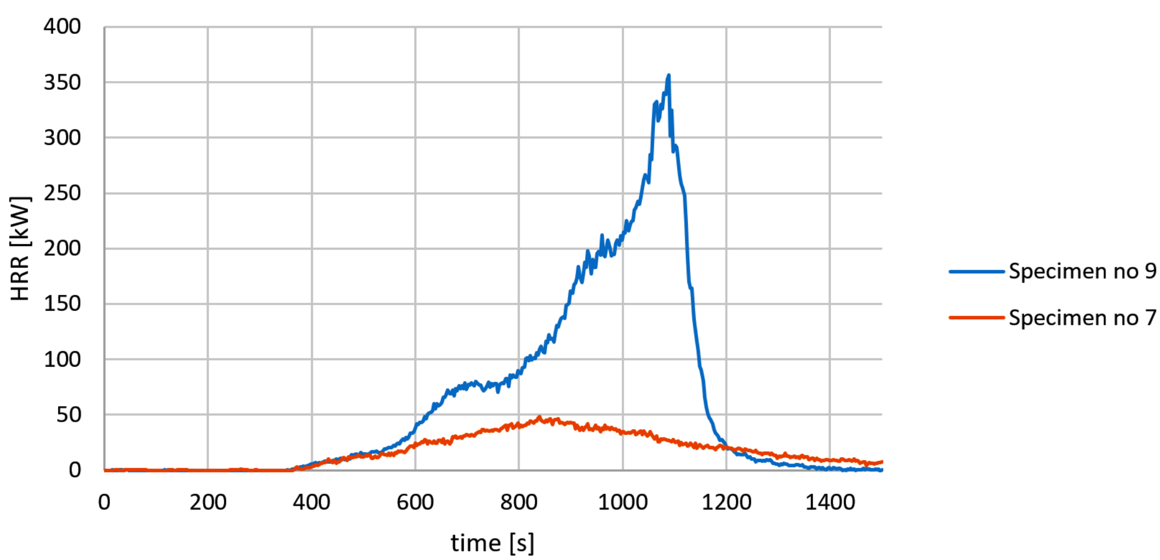

Fig 3. Graph of HRR as a function of time for specimen no 7 and 9.

Specimens 1, 4 and 8 used the same insulation and coating material, but three different fillers with different OI values and 1 mm thickness. Difference in HRR values and large difference in the amount of smoke emission were obtained. This relationship was as follows: the lower the filler oxygen index, the worse the fire and smoke parameters.

For specimens 5, 6 and 7, the same insulation and coating material were used, as well as three different fillings (different OI) in this case for the thickness of 0.3 mm. Different HRR values were observed; for specimen 5 the lowest value associated with a very high oxygen index. A significant difference in the amount of smoke emission was also registered - only specimen 5 meets B2ca class requirements.

For specimens 7 and 9 the same shell material and the same material and filling thickness were used but two different insulations: one made of flame-retardant PE (cable 7) and the other of PE without flame retardants (cable 9). A very large difference in the value of HRR and the amount of smoke emitted was observed. In the case of cable 9, because of the rapid increase in HRR, the test was stopped due to danger that could cause damage of the apparatus. The difference in HRR values is presented in Fig. 3

Specimens 1, 5, 7 and 8 with the same composition were compared in pairs, occurring in two variants of filling thickness: 0.3 mm and 1 mm. For the filling with symbol (a) there was a decrease in the value of recorded parameters (HRR, THR, FIGRA) for smaller thickness. However, no such relationship was observed for filling (c).

Summary

The tests showed that the fire properties of electric cables determined in accordance with EN 50399: 2011 depend on the type of material used for their construction and the flame retardants contained therein. The greatest influence here is the degree of flame retardancy of the insulation, as well as filler and coating materials, which is associated with the value of the oxygen index. However, no significant effect of the thickness of the filler used was demonstrated. Of the tested electric cable variants, the highest class B2ca-s1, d0 is achieved only for specimens 1 and 5 built on the same components (thinner layer of filler - 0.3 mm) in the following configuration: insulation (b) + filler (g) + coating (h). Due to the specifics of large-scale tests and the influence thereon of factors not related to the composition of the specimens, the performed tests should be extended by a larger number of further tests, taking into account also other types of flame retardant insulation. It is important to refine the increasing number of flame retardant halogen-free cable components, taking into account favorable technological and price parameters. This will increase the fire safety of critical infrastructure components using electric wires.

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