Numerical prediction of cables fire behaviour using non-metallic components in cone calorimeter

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1 Introduction

Electrical cables must fulfil the Construction Product Regulation (CPR) enacted by the European Union 205/2011 since 2016. This regulation provides a frame where the employed materials must fulfil a series of limits of resistance and some dangerous substances are avoided, i.e., all cables must be evaluated and classified under a single criterion. In particular, the standard UNE-EN 13501-6 [1] establishes the classification of electrical cables and how to obtain it through flame propagation test EN 50399 [2]. This regulation forces manufacturers to improve their cables, achieving better performance. The way to increase the performance of the cables can lead to a trial and error process. In order to skip the trial and error process and obtain some evidences of the fire behaviour of the cables, the researches have been executing bench scale tests: Meiner et al. [3] analyse the effects of the gap between cables in the test holder and its influence on the energy released; Martinka et al. [4] study the effect of the gap between cables and the insulation of the unexposed face of the sample holder; finally, Magalie et al. in [5], analyse the influence of radiation level, number and location of cables, the thickness and mass of the sheaths.

The cone calorimeter test (CC) is widely employed due to its versatility, i.e. the test is executed using small samples, but large enough to be representative, (100 × 100 mm^2 surface area) under several radiance fluxes. However, the dimensions of the sample are not large enough to represent all effects present in a full scale test such as fire propagation or dripping. To overcome these limitations some authors have introduced some modifications for the CC tests. For instance, in [6] Gallo et al. developed a small-medium-scale test method, modifying CC apparatus, trying to test cables in vertical configuration using the CC, Girardin et al. [7] modified the CC apparatus for testing pieces of sheaths with a total length of 500 mm and establishing some correlations with larger scale test.

However, the execution of these tests to develop new cables requires the design and development of the whole cable. These stages could represent time-consuming issue; therefore, the prediction of the fire response of the cables without their development would decrease the cost and save time. Computational models represent a powerful tool to fulfil this task and they are widely employed in fire engineering area. Researches have been focusing their efforts trying to characterize the materials and replicate them with computational models, in bench scale or in a larger scale. Basis in this idea, we can highlight the works of: Matala et al. [8] where using the inverse modelling, obtained and modelled the properties for different pieces of the cables and represent them in CC tests; or the works of [9] [10] [11],where authors use the data obtained in CC tests to characterize the cables, and afterwards, use them to reproduce fire tests in larger scales.

As a novelty, in this work, we propose the characterization of the cable materials separately (sheath and insulation), applying the inverse modelling, and then replicate the results of CC tests of two different multipolar cables. Testing pieces of cable before fabricate them allow manufactures to discard low efficiency materials.

Two multipolar RZ1-K cables are analysed: 3×1,5 mm^2 and 5× 1,5 mm^2 and their characteristics are listed in Table 1. As in Table 1 or in [7] [6] is indicated, most of the electrical cables are composed mainly by non-metallic materials. Considering this feature, in this work, we explore the possibility to analyse and characterize using the inverse modelling method the non-metallic elements that compose the cable in CC, and then, model the CC tests for the cable in its final state. We compared the heat release curves (HRR) for the CC tests to the sheath (it represents more than 50 % of the initial mass of the sample) and cables, and the simulation HRR from the simulations.

Table 1: Characteristics of tested samples.

Properties	RZ1-K 3 × 1,5 mm^2	RZ1-K 5 × 1,5 mm^2
Class	Cca-s1b,d1,a1	
Ø exterior (mm)	9,67	12,24
Sheath	Halogen-free thermoplastic polyolefin	
Sheath thickness (mm)	1,72 ÷ 1,80	2,33 ÷ 2,39
Conductor / section (mm^2)	3 / 1,5 mm^2	5 / 1,5 mm^2
Ø conductor (mm)	2,95	0.3
Insulation for the conductors	Cross-linked polyethylene XLPE	
Insulation thickness (mm)	0,82 ÷ 0,83	0,87 ÷ 0,93
% mass sheath	61,7	58,9
% mass insulation	11,7	15,7
% mass conductors (cooper)	26,4	25,4
% non-metallic mass	73,5	74,6

2 Tests and simulations

All CC tests were executed according to ISO 5660 [12] under two radiance levels, 50 and 75 kW/m2, the unexposed face of the sample is insulated and the sample holder incorporated a grill. CC tests have been performed for the individual polymer materials that compose the cables (sheath and insulation) and for the whole cables. The samples for the pieces of sheath and insulation have an average thickness of 4,6 mm and 100 × 100 mm of area. For the cable samples, the number of tested cables covers all surface, i.e. there is no gap between them. 10 pieces of cable (100 mm length) and 8 pieces (100 mm length) for RZ1-K 3×1,5mm^2 and RZ1-K 5×1,5mm^2 respectively were placed in the sample holder for each test. These cables have an external diameter larger than 4 mm, therefore, according to FIPEC [13], the extremes of each piece of cable was insulated with a small piece of concrete. Each test was executed 3 times to ensure the repeatability. Next Figure 1 gathers the HRR curves of the tests.

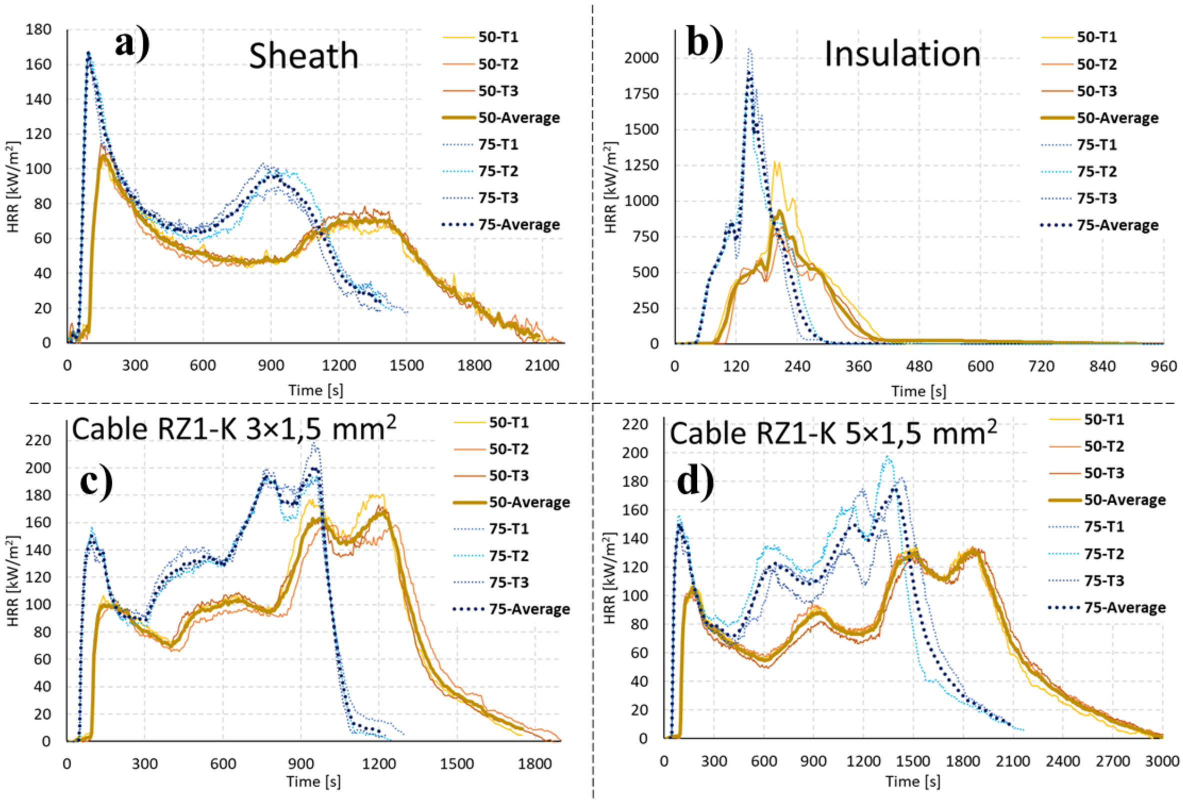

Figure 1. HRR curves for CC tests carried out: a) sheath element; b) insulation element; c) RZ1-K 3×1,5 mm^2 cables (10 pieces); d) RZ1-K 5×1,5 mm^2 cables (8 pieces).

Basis on the HRR curves of sheath and insulation from CC test, we applied the inverse modelling combining FDS software and Shuffled Complex Evolution- University of Arizona algorithm (SCE-UA) to obtain the thermal and kinetic parameters of these materials, based in the developed works of [14] [15]. Next Table 2 gathers the values obtained after the process.

Table 2: Thermal and kinetic properties obtained from CC tests to elements: sheath and insulation.

	Sheath			Insulation	
	Material 1	Submat. 1	Residue	Material 1	Residue
Emisivity (-)	0,846	0,758	0,586	0,621	0,84862
Density (kg/m^3)	1570	960,4	622,67	900	6,9461
Conductivity (W/m·K)	2,205	3,112	1,945	1,098	0,54742
Specific heat (kJ/kg·K)	3,706	1,611	2,085	2,290	2,3633
Reaction order (-)	7,34	5,40		4,41	
Pre-exponential factor (s^{-1})	4,8E+27	4,7E+27		7,7E+47	
Activation energy (kJ·kmol^{-1})	264783	241915		543093	
Absortion coeficient (1/m)	4,1E+09	3,8E+09	4,94E+09	6,9E+09	7,6E+09
Heat of reaction (k) (kJ/kg)	3237	5015	-	2152	

Heat of combustion (kJ/kg)	21231	21231	-	36075	

Using the data from Table 2, we modelled the CC tests of complete cables. The cable was modelled following the methodology proposed in [8]. The conductors are not included, and three layers define the non-metallic components: top and bottom layer (sheath) have the thickness of the cable sheath and the middle layer is a mixture of sheath and insulation, with a thickness that makes the initial mass amount of each material similar to CC tests.

Two ways to represent the resistance of the cone was used: 1) simple model, where the resistance is represented by a layer with the same gap of the CC apparatus and at the temperature that produces the desired irradiance level on the surface of the sample; 2) a detailed model, modelling the cone with a high level of precision, located at the same place and with a temperature calibrated to obtain the irradiance level required. Figure 3 shows how the CC resistance or radiation source is modelled.

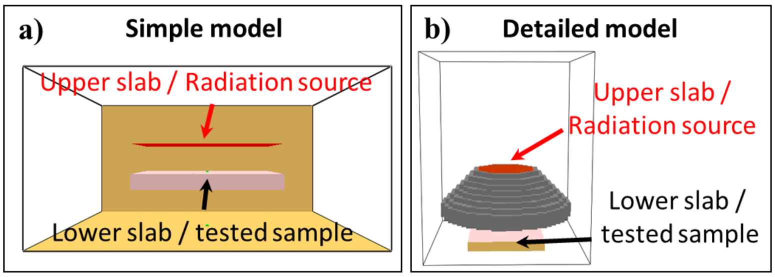

Figure 3. Representation of the CC radiation source: a) simple model; b) detailed model.

Figure 4 represents the results obtained, comparing the HRR curves of the cable tests (both) and the ones obtained in the simulations (both models).

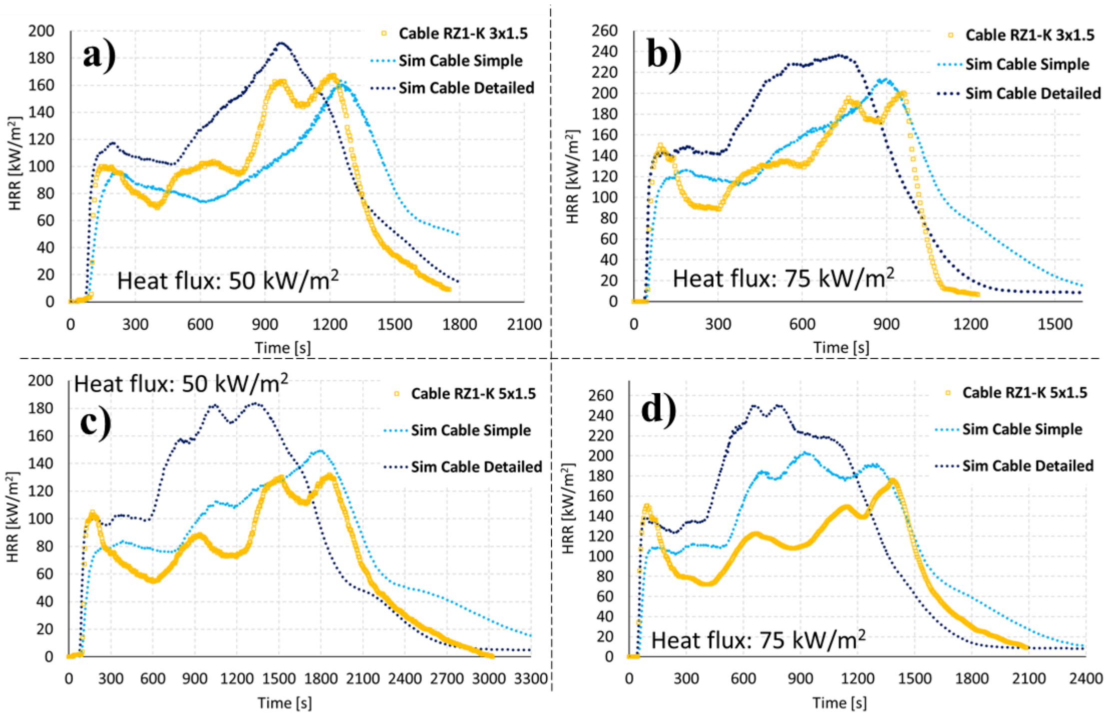

Figure 4. HRR curves for CC tests to cables and simulations curves: a) RZ1-K 3×1,5 mm^2 cable at 50 kW/m^2; b) RZ1-K 3×1,5 mm^2 cable at 75 kW/m^2 pieces; c) RZ1-K 5×1,5 mm^2 cable at 50 kW/m^2; d) RZ1-K 5×1,5 mm^2 cable at 75 kW/m^2.

3 Discussion and conclusions

The CC results could be divided into two stages: first one up to first HRR peak, and second one, from this peak up to the end of the test. For the first stage, the simulated HRR curves achieve results that are more accurate. The simulated HRR curves, for both models, are able to reproduce the ignition time, value of the first peak of the HRR curve and when it is produced. The detailed model has less error for these parameters. For the second stage, the simple model commits less error, i.e. the differences between the HRR CC tests and the simple model have lower values than the HRR CC tests and the detailed model. The detailed model tends to generate more elevated HRR values than the experimental ones. However, the simple model, for moments, HRR values are higher than the experimental ones and for moments are lower. The value for the last HRR peak and the time when takes place it is also more precise for the simple model. These features represent an advantage since the simple model uses less cells, and therefore, it takes less time to simulate de CC tests.

The application of the inverse modelling technique to obtain the thermal and kinetic properties to the cable elements has been proved helpful for modelling CC tests to complete samples of cable. In the light of results, simple model obtains a reasonable level of accuracy, with the undoubtable advantage of employ less computational time.

This methodology allows understanding the fire reaction of cable by analysing CC tests of the cable component. It represents a decrease of the cost of production of the cables and boost the new cables design process.

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