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Fire Tests of Non-Metallic Materials for Walls and Ceilings in Rolling Stock

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Abstract. The article discusses fire parameters of composites made on the basis of polyester resin, proposed for use in rail transport. The modifications and their effect on the flammable properties of these materials have been described. It has been shown that achieving the intended goals such as weight reduction or improvement of the aesthetics of the surface significantly changes parameters related to heat emission and flame propagation. In connection with the above, the scope of the introduced changes requires conducting control tests in the field of fire safety.

Introduction

The dynamic development of rail transport forces the rolling stock manufacturers to apply more and more modern technical and material solutions. It is associated with the need to ensure safety, including fire safety. This great emphasis on safety in means of railway transport caused intense development of requirements and methods in this area, and, as a consequence, contributed to the development of materials and products. There was a need to develop new and modify existing materials used in rail vehicles, which reduce the risk of people being threatened and improve the overall safety. An important effect of the existing fire (posing a deadly threat to passengers and impeding evacuation) is the spread of flame on the surface and the rate of heat released as a result of the combustion of materials constituting the lining of walls and ceilings of railway vehicles. Therefore, these materials, in accordance with the requirements of EN 45545-2 [1], must be subjected, inter alia, to tests according to ISO 5658-2 [2] and ISO 5660-1 [3]. These are fire parameters that characterize the material's resistance to external sources of fire.

The most commonly used materials are composites based on unsaturated polyester resins, which are characterized by high resistance to atmospheric and chemical factors, ease of processing and good mechanical properties. On the other hand, the ignition of resins by introducing appropriate flame retardants improves their fire-resistant properties [4-9]. These features are important from the point of view of their use as construction materials for walls and ceilings of rail vehicles [10-11].

Testes of selected fire properties

Laminates made on the basis of fiberglass and polyester resins have been tested. The composition of individual materials is presented in Table 1. However, the research was carried out in accordance with the methodologies described below.

Table 1. Determination and composition of samples of composites based on polyester resin

Sample	Resine	Modifications of the laminate
GRP(D1)	**resin: Giralithe Ditra 2109-10XP** glass mat **gelocoat: Nuvopol Gelcoat 37-05 TGP**	**topcoat**
GRP(D2)		**topcoat**
GRP(D3)		**topcoat**
GRP(E1)	**resin: Endyne H86181 TF** glass mat **gelocoat: Polytor 2335**	**none**
GRP(E2)		**foam PUR 20 mm**
GRP(E3)		**foam PUR 15 mm, topcoat**
GRP(E4)		**foam PUR 20 mm, topcoat**
GRP(B1)	**resin: Büfa-Firestop 8175-W-1** glass mat **gelocoat: Büfa-Firestop S285**	**none**
GRP(B)		**none**
GRP(B2)		**none**
GRP(B3)		**topcoat**
GRP(B4)		**topcoat**
GRP(B5)		**topcoat**
GRP(B6)		**coremat 5 mm, topcoat**
GRP(B7)		**foam PUR 5 mm, topcoat**

Fire test according to ISO 5658-2 [2]. The standard ISO 5658-2 [2] is based on the method of the IMO (International Maritime Organization) published as IMO resolution A.653 (16) [12]. It specifies a method of test for measuring the lateral spread of flame along the surface of product oriented in a vertical position as shown in Fig. 1. During the test, the *CFE* (Critical Heat Flux at *Extinguishment)* parameter is determined. The lower is the value of *CFE*, the greater is the fire hazard.

Fig. 1 The sample during test in IK according to ISO 5658-2 [2]

Fire test according to ISO 5660-1 [3]. Standard ISO 5660-1 [2] specifies a method for assessing heat release rate of specimen exposed in the horizontal orientation to controlled levels of irradiance with an external igniter using a cone calorimeter (Fig.2). The heat release rate is determined by the measurement of oxygen consumption based on the measure of oxygen concentration and the flow rate in the combustion products stream.

Fig. 2 ISO 5660-1[3] stand and sample during the test in IK

Generally, the net heat of combustion is proportional to the amount of oxygen used to burn a specimen. That is approximately 13.1×10^3 kJ of heat release per kilogram of oxygen consumed. During the test, the *MARHE* parameter (Maximum Average Rate of Heat Emission) is determined. The higher its value, the greater the fire hazard. An example of a graph of heat release rate with *MARHE* (orange line) for GPR is presented in Fig. 3.

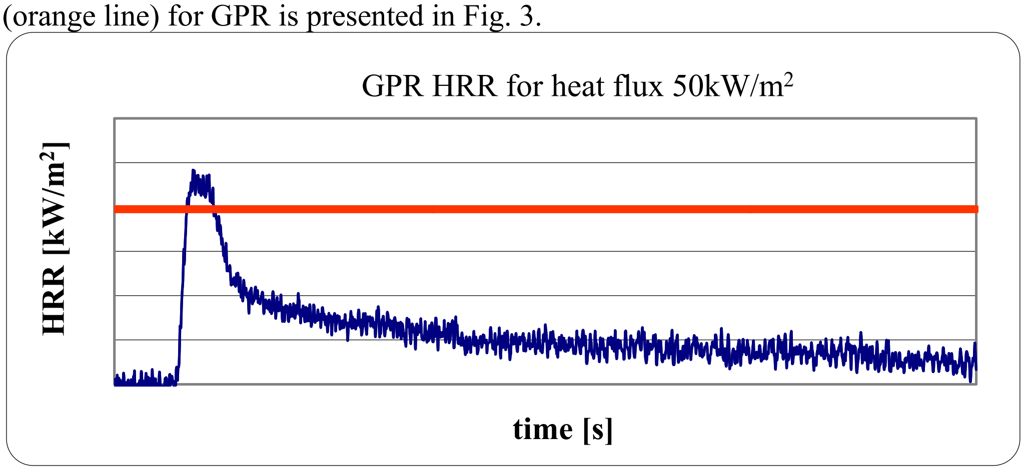

Fig. 3 Graph presenting heat release rate with MARHE (orange line) for GPR

Studies of fire properties

The results of the tests of the flame spreading on the surface and the heat release rate during combustion of the tested laminates are presented in Tables 3-5.

Table 3. Fire properties of polyester-glass laminates made on the basis of Giralithe Ditra 2109-10XP resin

Sample	**thk [mm]**	t_{ig} [s]	**CFE**[kW/m^2]	MARHE [kW/m^2]	HRR$_{max}$ [kW/m^2]
GRP(D1)	3	31	20.7	79.3	92.5
GRP(D2)	5	33	21.8	73.0	82.65
GRP(D3)	9	44	24.3	50.2	5.0

Table 4. Fire properties of polyester-glass laminates made on the basis of Endyne H86181 TF resin

Sample	**thk [mm]**	t_{ig} [s]	**CFE** [kW/m^2]	MARHE [kW/m^2]	HRR_{max} [kW/m^2]
GRP(E1)	3.5	45	36.2	51.0	107.0
GRP(E2)	30.0	49	23.9	79.0	127.0
GRP(E3)	30.0	51	23.9	83.2	124.2
GRP(E4)	30.0	206	25.8	81.4	126.9

Table 5. Fire properties of polyester-glass laminates made on the basis of Büfa-Firestop 8175-W-1resin

Sample	**thk mm]**	t_{ig} [s]	**CFE** [kW/m^2]	MARHE [kW/m^2]	HRR_{max}[kW/m^2]
GRP(B1)	3.0	113	27.5	91.9	194.1
GRP(B)	5.0	160	31.2	84.7	185.0
GRP(B2)	6.5	205	34.9	69.5	174.9
GRP(B3)	3.0	20	21.3	74.6	125.0
GRP(B4)	5.0	29	22.9	77.0	125.0
GRP(B5)	6.0	36	26.2	81.6	144.4
GRP(B6)	10.0	25	28.0	68.3	109.2
GRP(B7)	10.0	31	23.9	69.9	165.0

The influence of the thickness of GRP laminates on their fire properties. The analysis was carried out on laminate samples made on the basis of Giralithe Ditra 2109-10XP resin. The obtained results are shown in Fig. 5.

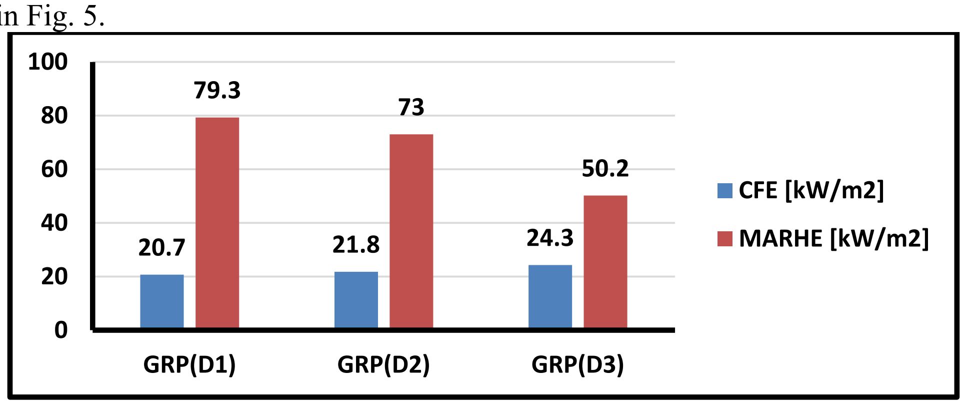

Fig. 5. CFE and MARHE values of laminate (Giralithe Ditra 2109-10XP resin) with different thicknesses

The GRP sample (D1), which was the thinnest of the respondents, revealed the fastest ignition under the influence of thermal radiation and obtained the largest range of flame, which is associated with the smallest critical radiation stream (*CFE*). However, the GRP sample (D3), which was the thickest of the studied, under the influence of thermal radiation ignited after the longest time and obtained the smallest range of the flame, which is associated with the largest critical radiation flux

(*CFE*). A similar relationship was also observed when determining the maximum average heat release rate. The GRP sample (D1) during the test on a cone calorimeter was characterized by considerable flammability. The maximum value of *MARHE* for this sample was 79.23 kW/m^2 and was greater by more than 39% from the *MARHE* GRP sample (D3).

Influence of modification on fire properties of GRP laminates

The modification of the tested polyester-glass laminates consisted of the following:

- applying a lacquer coat to the gelcoat in order to improve the aesthetics of the surface,
- adding polyurethane foam or cork to increase the physico-mechanical properties and reduce weight with the need to use samples with thicknesses> 10 mm.

The obtained results are shown in Figs. 6 and 7.

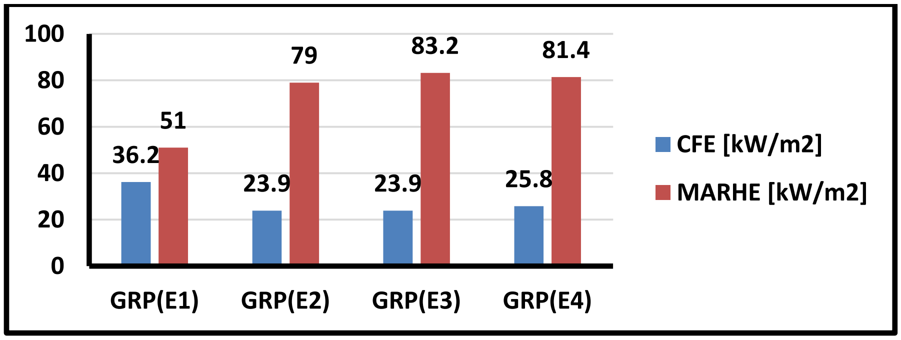

Fig. 6. Impact of thickness of laminate samples (Endyne H86181 TF resin) on CFE and MARHE values

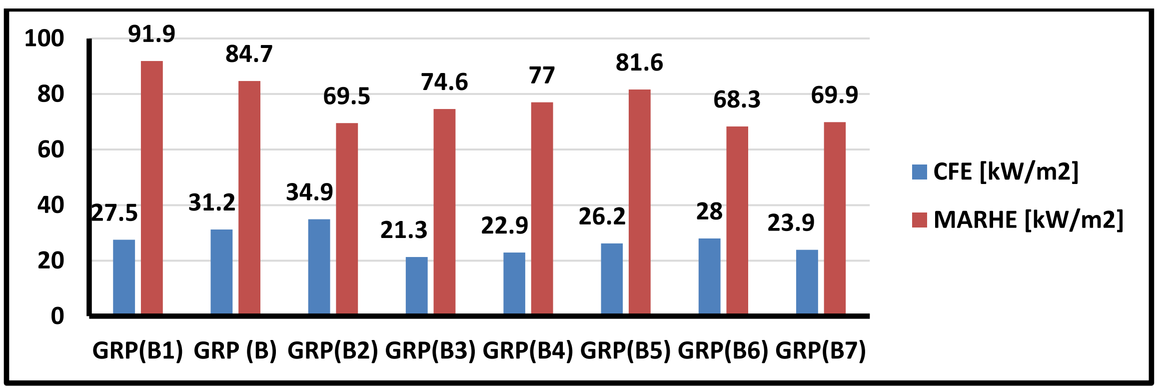

Fig. 7. Effect of thickness and modification of laminate samples (Büfa-Firestop 8175-W-1 resin) on CFE and MARHE

In the case of polyester-glass laminates based on the Endyne H86181 TF resin, a deterioration of the *CFE* parameter with respect to the initial sample was noticed. This may be due to the application of a lacquer coat to the gelcoat, which accelerates the ignition time and increases the range of the flame. However, the increase in the *MARHE* parameter is due to the addition of a 25 mm layer of polyurethane foam, which burns with the emission of a large amount of heat.

A similar relationship was also observed in the case of Büfa-Firestop 8175-W-1 resin laminates (Fig.7). Both modification methods (application of a varnish coat, laminating foam) caused a deterioration of the CFE parameter. It was associated with an additional layer of material that was easier to ignite, so that its critical heat flow supporting the burning was smaller. A reverse dependence occurred for the *MARHE* parameter. In the case of heat emission for both modifications, this parameter was improved. In the case of varnish coatings this may be due to cutting off the air directly to the surface of the laminate. The additional coating ignites and isolates the remaining layers of material. This causes a slower combustion of the whole sample, which extends the burning

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time of the material but reduces its heat release intensity (despite the addition of an additional layer in the form of 5 mm foam or 5 mm cork).

Summary

The tests of polyester-glass laminates based on various polyester-glass resins has confirmed the effect of thickness on the critical heat flux (*CFE*) and the maximum average rate of heat release (*MARHE*). The increase in thickness of the tested samples improved both the value of the *CFE* and *MARHE* parameters.

Studies have also shown that:

- laminate modifications aimed at improving the aesthetics of the surface by applying a lacquer coating caused a deterioration of the fire properties in the area of critical heat flux (*CFE*). The *MARHE* parameter was improved.
- modifications of laminates, aimed at improving their physicochemical properties and weight reduction by adding an inner layer of foam, affected the deterioration of the *MARHE* parameter. However, the *CFE* parameter did not change.

In connection with the above, the scope of introduced changes requires each time a control test in the field of fire safety.

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