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FIRE PROPERTIES OF ANTICORROSION COATINGS FOR ROLLING STOCK

WŁAŚCIWOŚCI OGNIOWE ANTYKOROZYJNYCH ZABEZPIECZEŃ LAKIEROWYCH TABORU SZYNOWEGO

A b s t r a c t

The article presents current requirements and the results of fire tests for surface protection systems proposed for rolling stock securing. The influence of coating thickness and the type of filler used on the determined parameters is shown.

Keywords: *fire spread*, *paint coatings*, *filler*, *rolling stock fire safety*

S t r e s z c z e n i e

W artykule przedstawiono aktualne wymagania i wyniki badań ogniowych dla systemów ochrony powierzchni proponowanych do zabezpieczenia taboru szynowego. Omówiono wpływ grubości powłoki oraz rodzaju zastosowanej szpachli na określane parametry.

Słowa kluczowe: *rozprzestrzenianie ognia*, *powłoki lakierowe*, *szpachla*, *bezpieczeństwo pożarowe taboru szynowego*

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1. Introduction

Paint coatings for rolling stock have to meet a number of requirements regarding their mechanical, physico-chemical, protective and decorative properties. However, until recently, the most important features considered were: protection of structural material from the effects of corrosive agents under operating conditions and giving a product a desired aesthetic appearance. Striving to achieve a product that meets the expectations of manufacturers and operators of rail vehicles (or making the product permanent − retaining its properties at the required level as long as possible) as well as easy application and exploitation of the product, affected the development of paint industry. For these reasons, new materials were introduced (acrylic, alkyd-phthalate, epoxy, polyurethane, polyester), as well as their various combinations and modifications. However, the development of research in the field of rolling stock fire safety (also with taking into account the analysis of events as they occur) lead to the conclusion that paint coatings also have an impact on the development of possible fire in the rail vehicle. A fire in the Rydultowy, where a spread of fire on paint coatings of a wagon and locomotive took place [1, 2], is an example confirming the necessity of implementing safety requirements also for paint coatings.

2. Fire requirements

Initially, introduced fire requirements were related to non-metallic materials intended only for construction and interior equipping of vehicles. Exterior paint coatings were not taken into account. However, the real examples of fire spread upon paint coatings as well as the fact that coatings weight in currently built vehicles in the range of 150 to 300 kg/unit (which gives a substantial share in the total mass of non-metallic materials used in rail vehicles, typically of 1 700−8 700 kg/unit) led to the conclusion that this product cannot be ignored in assessing fire safety. Therefore, at the turn of the century, in some countries, including Poland, the need to meet the criteria of fire requirements of paints has already been introduced. Below, current Polish and European requirements in force in this field are described.

2.1. Test methods and requirements according to Polish standards

In Poland, only three parameters were initially standardized. Then, with the development of voluntary certification for coatings in compliance with the PN-K: 02511:2000 [3], other parameters for fire properties were included into to test range. Currently, until the end of the transitional period related to the implementation of European requirements, i.e. EN 45545:2013 [4] and TSI LOC & PAS [5], the following leading standards are obligatory:
– for passenger rolling stock PN-K-02511: 2000 [3]
– for electric traction vehicles PN-K-02506: 1998 [6]
– for combustion traction vehicles PN-K-02507: 1997 [7].
These standards include the need to meet requirements for the following parameters.

Flame spread along the surface. Tests in accordance with PN-K-02512:2000 [8] consist in subjecting a sample to thermal radiation of the intensity of 35 kW/m^2 in the presence of a gas pilot burner whose role is to attempt to set fire to the emitted products of thermal decomposition. During the test the following parameters are recorded: the time in which the flame front passes through each zone of sample surface as well as the initial and the maximum flue temperature in the chimney. The *Flame Spread Index (I)* is calculated by means of the formula given in the standard. Safety requirements according to PN-K-02511:2000 [3] are as follows: for a coating on the ceiling: $I \leq 20$ [–] and for other elements: $I \leq 75$ [–].

Smoke properties. In a test performed according to PN-K-02501:2000 [9], a sample is placed in a closed chamber with a volume of approx. 0.56 m^3 and treated with a flame of a gas burner. Then changes of the light passing through the chamber intensity over time is determined. The result of the test are: *exposure S* [lx s] during the first four minutes of the test and the *light intensity* after 4 minutes of testing E_4 [lx]. Safety requirements according to PN-K-02501:2000 [3], PN-K-02511: 2000 [3] and the UIC 564-2 [10] App. 15 are as follows: $S \geq 9000$ lx s, $E_4 \geq 20$ lx.

Concentration of gases toxicity. A test in accordance with PN-K-02505:1993 [11] consists in subjecting a crushed material sample in a closed chamber with a volume of 0.56 m^3 to pyrolysis. The sample is placed at a quartz dish set on an electric heater with the power of 500 W. After 5 minutes *concentration of carbon monoxide and carbon dioxide* is measured for the extracted gas samples with use of Drager tubes. The safety requirements according to PN-K-02505: 1993 [11], PN-K-02511:2000 [3] are as follows: 20 CO + + $CO_2 \leq 6000$ ppm.

Combustible properties. The method according to p.4.1 PN-K-02508:1999 [12] (in accordance with the UIC Code 564-2 [10] App. 4) consists in an alcohol flame impingement on a sample arranged in a frame inclined at the angle of 45 ° to the horizontal position. During the test the *time of the sample burning* (*t*) after putting off the burner is measured as well as the course of burning is observed. After the test the *surface of the sample burned part* (*s*) is measured. The safety requirements according to PN-K-02508:1999 [12], PN-K-02511:2000 [3] and the UIC 564-2 [10] App. 4 are as follows: no falling burning particles, $t \leq 10$ s, $s \leq 150$ cm^2.

Oxygen index. A test according to PN-EN ISO 4589-2: 2006/Ap1: 2006 [13] is performed in accordance with the UIC Code 564-2 [10] App. 7. It consists in determining the lowest concentration of oxygen in a mixture of oxygen with nitrogen, at which minimal burning of material remains. The safety requirements according to PN-K-02511: 2000 [3] and the UIC 564-2 [10] App. 7 are as follows: *Oxygen index* OI ≥ 28%.

2.2. Test methods and requirements according to EN 45545-2: 2013

The European standard EN 45545-2: 2013 [4] introduced the need for mandatory testing of coatings, making the type of required tests as well as criterial values of individual parameters dependent on the location of paint coatings. Table 1 presents categories of requirements assigned to individual groups of materials. The next Table 2 shows types of required tests and criteria values of individual parameters.

Table 1

Categories of requirements for vehicle components covered with paintings according to EN 45545-2 [4]

Product No.	Name of painted elements	Requirement
IN1A	Interior vertical surfaces	R1
IN1B	Interior horizontal downward-facing surfaces	
IN1C	Interior horizontal upward-facing surfaces including body shell	R10
EX1A	Walls of external body shell	R7
EX1B	External surfaces of cab housing	R17
EX2	Roof of external body shell	R8
EX3	Under frame of external body shell	R7

Table 2

Test methods and criterial values for parameters for each category of R requirements, taking into account HL threat levels according to EN 45545-2 [4]

Test method, parameter	Requirement	Values required for particular hazard level HL		
		HL1	HL2	HL3
ISO 5658-2, CFE [kWm^{-2}]	R1, R7	≥ 20 a	≥ 20 a	≥ 20 a
	R17	13 a	13 a	13 a
EN ISO 9239-1, CHF [kWm^{-2}]	R8, R10	≥ 4,5	≥ 6	≥ 8
ISO 5660-1, MARHE [kWm^{-2}]	R1*), R7*), R17*)	a –	≤ 90	≤ 60
	R8**)	–	≤ 50	≤ 50
EN ISO 5659-2, $D_s(4)$ [–]	R1*)	≤ 600	≤ 300	≤ 150
EN ISO 5659-2, $D_s$max [–]	R7*), R8**), R17*)	–	≤ 600	≤ 300
	R10**)	≤ 600	≤ 300	≤ 150
EN ISO 5659-2, VOF_4 [min]	R1*)	≤ 1 200	≤ 600	≤ 300
EN ISO 5659-2, CIT_G [–]	R1*), R17*)	≤ 1,2	≤ 0,9	≤ 0,75
	R7*), R8**), 10**)	–	≤ 1,8	≤ 1,5

*) test for the radiation intensity of 50 kWm^{-2},
**) test for the radiation intensity of 25 kWm^{-2}, a – if flaming droplets are reported or the material does not ignite in ISO 5658-2 [14], required additional test acc. to EN ISO 11925-2 [15].

Below, the relevant test methods are described.

Test according to ISO 5660-1 [16]. The test is performed with use of the cone calorimeter, wherein the principle used is an oxygen consumption calorimetry [17]. During the test a number of parameters is measured, but for classification according to EN 45545--2 [4], parameter MARHE [kW/m^2] *Maximum Average Rate of Heat Emission* (*MARHE*) is determined during 20 minutes of the test.

Test according to ISO 5658-2 [14]. The method consists in subjecting a vertical sample to an external heat flux of a standardized density distribution. During the measurements, the time of flame transition in the central part of the sample is recorded. After the test, the length of the burned part of the sample is determined in order to be calculated with the numerical code of the *Critical Flux at Extinguishment CFE* [kW/m^2].

Test according to EN ISO 9239-1 [18]. The method consists in subjecting a vertical sample to an external heat flux of a standardized density distribution. During the measurement, the time of flame transition through succeeding zones is recorded. After the test, the length of the burned part of the sample is determined in order to be calculated with the numerical code of the *Critical Heat Flux CHF* [kW/m^2].

Test according to EN ISO 5659-2 [19]. The method consists in subjecting a horizontally located sample of a thermal irradiation of 25 or 50 kW/m^2 in an closed chamber, with or without the use of a pilot burner. The reduction of light beam intensity passing through the smoke emitted is measured. The results are given as *optical density* D_s and as VOF_4 – the *cumulative value of specific optical densities* in the first 4 min of the test**.**

Test according to EN ISO 5659-2 [19] and EN 45545-2 [4] Annex C. The test consists in determination, by means of a spectrophotometer, of the emission of toxic gases during combustion of a sample in a smoke chamber, according to EN ISO 5659-2 [18]. On the a basis of concentrations of CO_2, CO, HBr, HCl, HCN, HF, NO_x, SO_2 gases, the *Conventional Index of Toxicity CIT* parameter [–] is calculated.

3. The test results

3.1. The test results according to PN

The results of the tests of surface protection systems designed for body shell of rail vehicles show that the tested products meet Polish requirements. For most parameters, the values obtained were within relatively narrow ranges (very close to each other), regardless of the coating thickness and composition. They were as follows:

- Oxygen index at a very good high level of – OI: 46–48%,
- Concentration of toxicity of the emitted gases at a very good low level of – 20 CO + + CO_2: 813–1080 ppm,
- Smoke Properties at a very good high level of *S*: 22830–23600 lxs, E_4: 89–99 lx,
- Combustible properties at a very good low level of *t*: 0 s, *s*: 18–33 cm^2.

Only in the case of the *Flame Spread Index* over the surface, the influence of coating thickness and type of the fillers on value *I* was observed. As shown in the diagram (Fig. 1), the coating with epoxy filler revealed lower values of this parameter, however increasing with the thickness of coating on 8,5 to 35,0 [–]. For shells with polyester filler parameter *I* changed from 23,5 to 65,8 [–]. However, it should be noted that the thickness of the tested systems does not exceed 500 μm, which means that the applied layer of putty was very thin. For paint systems that do not contain filler, index *I* was below the value of 10,0 [–].

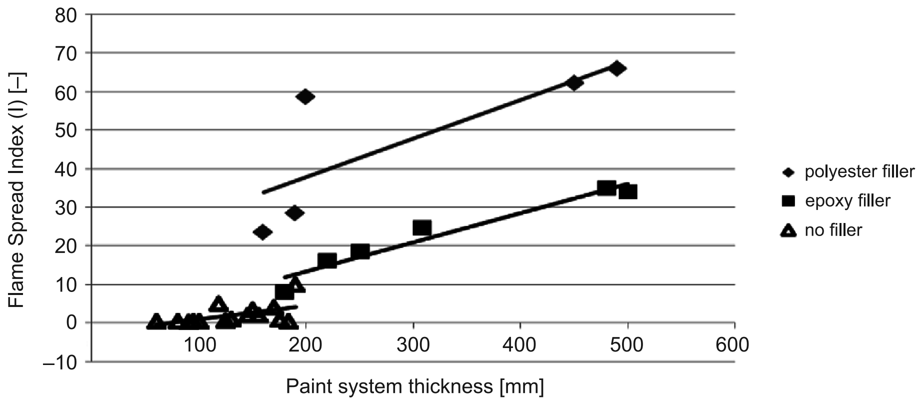

Fig. 1. Test results of *Flame Spread Index (I)* [–] of surface protection systems for rolling stock (archive IK, 2000–2014)

3.2. The test results according to EN

The results of the already completed tests of coatings designed for steel substrate show that the following parameters comply with the requirements of EN 45545-2:2013 [4] for the requirements of R1, R7 and R17 for HL1 and HL2 (however, the influence of the thickness of coatings and their composition is visible):

– $D_s(4)$ – for sets with epoxy filler < 100 [–], for sets with polyester putty 100–280 [–],
– $D_s max$ – for sets with epoxy filler < 100 [–], for sets with polyester putty 100–300 [–],
– VOF_4 – for sets with epoxy filler: 139–286 min, for sets with polyester putty: 242–585 min,
– CIT_g – (0.01 to 0.06 [–]).

However, as results from the following plots (Fig. 2 and 3), requirements for the *MARHE* and CFE are difficult to meet for paint systems containing a polyester putty. In terms of the *Maximum Average Rate of Heat Emission* (*MARHE*) coating with the epoxy filler revealed lower values, increasing with the thickness of coating from 25.3 to 54.8 kW/m^2. But for coatings with polyester filler this parameter changed from 58.2 to 149.5 kW/m^2.

In the case of the *Critical Flux at Extinguishment* (*CFE*), much better results were obtained similarly for systems with epoxy filler (19.0–32.8 kW/m^2) than with polyester (7.3–21.5 kW/m^2). Also, for both variants, a deterioration of properties with increasing coating thickness occurred. It should also be noted that these thicknesses reached oven to 2 500 μm, which reflects the real conditions on the wagons. In contrast, all systems that did not include fillers met the requirements.

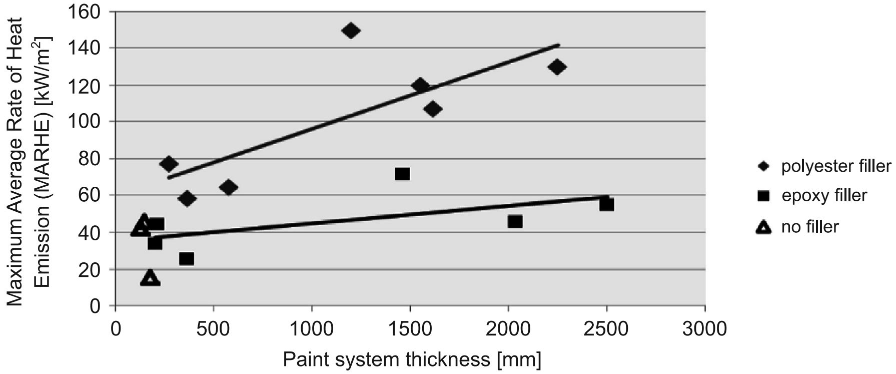

Fig. 2. Test results of *Maximum Average Rate of Heat Emission* (*MARHE*) [kW/m²] of surface protection systems for rolling stock (archive IK, 2014–2015)

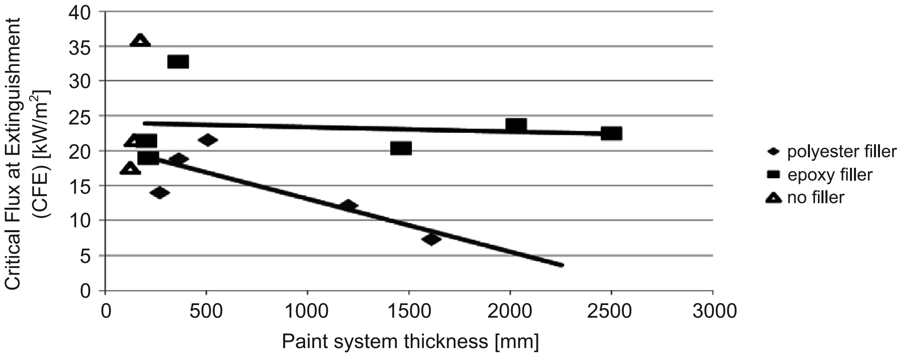

Fig. 3. Test results of *Critical Flux at Extinguishment* (*CFE*) [kW/m²] of surface protection systems for rolling stock (archive IK, 2014–2015)

4. Summary and Conclusions

The results of the already completed studies at the Railway Institute show that coatings systems used for anticorrosion protecting of rail vehicles meet the requirements of PN-K-02511:2000 [3], but the determined values are worse when the coating thickness increases.

In contrast, the tests carried out in accordance with EN 45545-2: 2013 [4] show that:

– Systems with epoxy fillers are characterized by more favourable, in terms of fire safety, coatings fire properties than those with polyester fillers, which in most of the cases did not meet the requirements;
– With increasing thickness of the coatings, their fire performance becomes worse. In this connexion, during renovation of vehicle old paint should be fully removed;
– Because of favorable physical and mechanical properties (elasticity, adhesion, resistance to punching and bending) of the polyester putty in relation to the epoxy putty, paint industry is facing another challenge for modification of these products.

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