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Fire Properties of Railway Rubber Products

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Abstract. The article discusses the use of rubber elements in rail vehicles and their desired functional properties. Then, the requirements for materials in the field of fire safety as well as fire test results for individual groups of rubber products are presented. Next, the directions and results of modifications of elastomer mixtures for railway elements are discussed.

Introduction

Rubber is an elastomer made of aliphatic polymer chains, crosslinked in the vulcanization process of natural rubber (obtained from the resin of the *Hevea brasiliensis* tree) or synthetic (polybutadiene and other polyolefins), or mixtures thereof. It was invented and used for the first time in South America by the Maya and Aztecs, and it was brought to Europe in the 15th century by Christopher Columbus. The rubber production method was patented in 1843, while after processing in 1946 the technology for cold vulcanizing of rubber with sulfur chloride, the production of rubber products on an industrial scale was developed. This material has gained great popularity, especially due to its high flexibility, which is characterized by resistance to deformation and vibration damping, as well as mechanical strength. In addition, rubber is characterized by high chemical resistance and good dielectric properties. However, rubber in the strict sense is not resistant to high temperatures and burns giving off black, pungent smoke. At the same time, the properties of particular mixtures strictly depend on the type and proportion of individual components and can be very diverse [19]. Thanks to the above, these materials have been used in many industrial sectors, including railways.

Rubber products in rail vehicles

Rubber in rolling stock began to be introduced as a replacement for leather and fabrics in the second half of the 20th century. In currently manufactured vehicles, elements made of various types of rubber compounds, depending on the type of rolling stock, constitute about 7-10% of the mass of all non-metallic materials used for its construction and equipment.

The most popular group are longitudinal seals. These are window seals, door connectors, loop handles, panel joints and technical cabinet seals, for which, above all, high mechanical strength and flexibility are required, and for elements used outdoors, resistance to environmental conditions such as rain, snow and large temperature differences from -30°C to + 40°C. EPDM (ethylene propylene) and the increasingly popular silicone rubber and its mixtures are the most commonly used rubber compounds for their production. These mixtures are characterized by high resistance to atmospheric conditions.

Flexible rubber and metal-rubber assemblies which can be found in the chassis are another group of railway products. These include, among others: suspension elements of the bogies, shock absorbers, bumpers, steering pins, air bags for pneumatic suspension joints, tyres as well as various types of rings, washers and sleeves. These products should be characterized above all by very good thermal and mechanical resistance (low permanent deformation under compression) and resistance to oils. For its production nitrile (NBR), natural (NR), styrene butadiene (SBR) mixtures are used.

Rubber is also used for the production of a wide range of hoses used inside and outside vehicles. For example, they are:

- brake hoses, often made of two different external and internal mixtures,
- pressure hoses in compressed air systems, among others for systems for removing excess gravel from tracks, pneumatic control of pantographs and contactors (silicone mixes),
- hoses in cooling systems are usually suction and pressure hoses made of silicone rubber.

All hoses should be highly flexible in a wide range of temperatures. In addition, resistance to pressure and transported media (fuel, oils, hydraulic fluids, water) is necessary.

Membranes of intercommunication gangways constitute an important mass group in the passenger vehicle. These elements should be characterized by good mechanical properties (resistance to loads, stretching and occurrence of vibrations), resistance to changing environmental conditions and high stability of parameters, i.e. resistance to ageing. Earlier they were produced from rollers made of thick EPDM rubber plates. In contrast, new vehicles use lighter skeletal structures covered with rubberized fabrics using silicone compounds.

Another group of rubber products are insulation materials used inside the body shell as insulation of walls (internal vertical surfaces), ceilings (internal horizontal surfaces facing down) and floors (internal horizontal surfaces facing up). In this case, properties such as flexibility, high resistance to water vapor diffusion, low thermal conductivity and low specific weight are necessary. Products made of foam rubber based on synthetic rubber, e.g. Armaflex, are used.

As the last group, cable insulation should be mentioned. They must above all meet the requirements in the field of electrical parameters (electric permeability, dielectric strength), but also have to be resistant to mechanical factors, environmental conditions andoils. However, currently this type of insulation is being abandoned, because, among others, cross-linked polyolefins, plastic and EVA (ethylene vinyl acetate copolymer) are more and more popular.

Fire properties requirements

In order to ensure the required level of fire safety for rail vehicles, non-metallic materials including rubber products should also, in addition to the functional properties described above, meet the requirements for fire parameters. These requirements are contained in the TSI (Technical Specifications for Interoperability) [6] and harmonized with European standards. The series of standards EN 45545 [7- 13] discuss all aspects that should be taken into account when designing rail vehicles to minimize the risk of fire, and in the event thereof - minimizing the spread of fire and smoke to the inside and outside of the vehicle. Part 2 of the above mentioned standards [8] contains requirements for materials. Table 1 below presents the groups of requirements (R) assigned to the product groups described earlier, while Table 2 below shows the required values of the applicable parameters. At the same time, these requirements vary depending on the level of hazard (HL) for vehicles, resulting from its operational category and the railway infrastructure in which it moves. The most rigorous requirements are assigned to the HL3 level, i.e. for vehicles that drive on underground sections, tunnels and/or elevated structures, where the available evacuation time is very short.

It should be noted that according to the previously applicable national standards (including PN standards), many rubber products that did not have direct contact with passengers did not require testing for fire performance. Only EN 45545-2 [8] introduced the obligation to test all elements located in the chassis, cabinets and technical compartments. Unfortunately, it is not always possible to meet applicable requirements,especially for rubber. Therefore, the standard

[8] (in p. 4.7) allows for the use of a material that does not meet the requirements in terms of fire protection due to its other properties necessary for the proper functioning of the vehicle. This provision applies to:

- the situation when, prior to the conclusion of the contract, there is no product available on the market in the given group that meets the requirements specified in p. 4.1 of the standard [8],
- use of a limited amount of material and requires a risk analysis.

Table 1. Groups of R requirements for rubber products according to EN 45545-2 [8]

Product No	Product Name	Set of requirement
IN16	Interior seals	R22
EX12	Exterior seals	R23
M1	Flexible metal/rubber units	R9
M2	Hoses - Interior	R22
M3	Hoses - Exterior	R23
EX9	Air bags for pneumatic suspension	R9
EX11	Tyres	R9
EX7	Exterior surfaces of gangways	R7
IN1A	Interior vertical surfaces	R1
IN1B	Interior horizontal downward- facing surfaces	R1
IN1C	Interior horizontal upwards- facing surfaces	R22
EL2	Cable containment (linear product) – circular crossection	Depending on the application and circuit: R22, R23, R6 or R9
	Cable containment (linear product) – rectangular crossection	Depending on the application and circuit: R1, R6, R7, R17, R9, R22 or R23.

Table 2. Sets of requirements for rubber products according to EN 45545-2 [8]

Set of requirement	Test method	Parameter Unit	HL1	HL2	HL3
R1	ISO 5658-2	CFE [kW/m^2]	≥ 20	≥ 20	≥ 20
	ISO 5660-1, 50 [kW/m^2]	MARHE [kW/m^2]	-	≤ 90	≤ 60
	EN ISO 5659-2, 50 [kW/m^2]	D_{s4} [-]	≤ 600	≤ 300	≤ 150
		VOF_4 [min]	≤ 1200	≤ 600	≤ 300
	EN ISO 5659-2, 50 [kW/m^2]	CIT $_G$ [-]	≤ 1.2	≤ 0.9	≤ 0.75
R6	ISO 5660-1, 50 [kW/m^2]	MARHE [kW/m^2]	≤ 90	≤ 90	≤ 60
	EN ISO 5659-2, 50 [kW/m^2]	D_{s4} [-]	≤ 600	≤ 300	≤ 150
		VOF_4 [min]	≤ 1200	≤ 600	≤ 300
	EN ISO 5659-2, 50 [kW/m^2]	CIT $_G$ [-]	≤ 1.2	≤ 0.9	≤ 0.75
R7	ISO 5658-2	CFE [kW/m^2]	≥ 20	≥ 20	≥ 20
	EN ISO 5659-2, 50 [kW/m^2]	MARHE [kW/m^2]	-	≤ 90	≤ 60
	EN ISO 5659-2, 50 [kW/m^2]	D_{smax}[-]	-	≤ 600	≤ 300
		CIT G [-]	-	≤ 1.8	≤ 1.5
R9	ISO 5660-1, 25 [kW/m^2]	MARHE [kW/m^2]	≤ 90	≤ 90	≤ 60
	EN ISO 5659-2, 25 [kW/m^2]	D_{smax}[-]	-	≤ 600	≤ 300
		CIT G [-]	-	≤ 1.8	≤ 1.5
R17	ISO 5658-2	CFE [kW/m^2]	≥ 13	≥ 13	≥ 13
	ISO 5660-1, 50 [kW/m^2]	MARHE [kW/m^2]	-	≤ 90	≤ 60
	EN ISO 5659-2, 50 [kW/m^2]	D_{smax} [-]	-	≤ 600	≤ 300
		CIT $_G$ [-]	-	≤ 1.8	≤ 1.5
R22	EN ISO 4589-2	Zawartość tlenu [%]	≥ 28	≥ 28	≥ 32
	EN ISO 5659-2, 25 [kW/m^2]	D_{smax} [-]	≤ 600	≤ 300	≤ 150
	NF X 70-100-1 oraz 2 600 [°C]	CIT $_{NLP}$ [-]	≤ 1.2	≤ 0.9	≤ 0.75
R23	EN ISO 4589-2	Oxygen Index [%]	≥ 28	≥ 28	≥ 32
	EN ISO 5659-2, 25 [kW/m^2]	D_{smax} [-]	-	≤ 600	≤ 300
	NF X 70-100-1 and 2 600 [°C]	CIT $_{NLP}$ [-]	-	≤ 1.8	≤ 1.5

Results of laboratory fire tests

Due to the implementation of EN 45545-2 standard [8], manufacturers of rubber components and rail vehicles began testing their products. The results of laboratory tests carried out at the Instytut Kolejnictwa for rubber materials intended for particular elements are presented in Table 3 below and in charts (Fig. 1-4). At the same time, due to the fact that smoke properties are the most difficult to meet for rubber, tests were started as a rule from this parameter and no other parameters were determined when negative smoke results were obtained. In the case of gaskets, as part of control tests, their scope was limited.

Table 3. Laboratory test results for selected rubber mixtures carried out in 2015-2019

Application	Material	Sample No	CFE, kW/m^2 ISO 5658-2	MARHE, kW/m^2 ISO 5660-1	D_{s4}, EN ISO 5659-2	VOF_4, min EN ISO 5659-2	D_{smax}, EN ISO 5659-2	CIT_G, PN-EN 45545-2, Annex C	CIT $_{NLP}$ NF X 70-100-1 oraz 2	OI, % EN ISO 4589-2
Requirements R22, R23										
internal and external seals, loop handles and profiled cords	silicone mix	A54/15	nb	nb	8.5	6.96	68.77	nb	nb	>48.6%
		A33.1/17	nb	nb	nb	nb	160.2	nb	nb	34.4
		A33.2/17	nb	nb	nb	nb	187.7	nb	nb	34.4
		A34.1/17	nb	nb	nb	nb	273.5	nb	nb	29.7
		A34.2/17	nb	nb	nb	nb	188.1	nb	nb	29.7
		A35.1/17	nb	nb	nb	nb	255.9	nb	nb	31.7
		A35.2/17	nb	nb	nb	nb	192.9	nb	nb	31.7
		A86/17	nb	nb	nb	nb	257	nb	nb	30.5
		A87/17	nb	nb	nb	nb	162.6	nb	nb	34.6
		A126/17	nb	nb	nb	nb	162.2	nb	nb	36.1
		A127/17	nb	nb	nb	nb	176.1	nb	nb	37.3
		A198/17	nb	nb	nb	nb	177.1	nb	nb	32.6
		A199/17	nb	nb	nb	nb	230.9	nb	nb	31.2
		A136/17	nb	nb	nb	nb	124.9	nb	nb	37.0
		A1/15	nb	nb	nb	nb	92.81	nb	nb	>48.6%
		A2/15	nb	nb	nb	nb	92.8	nb	nb	nb
	rubber EPDM	A159/18	nb	nb	288.9	528.9	295.4	nb	nb	26.0
		A160/18	nb	nb	214.3	338.8	257.1	nb	nb	29.9
		A203/19	nb	nb	nb	nb	nb	nb	nb	32.5
		A204/19	nb	nb	nb	nb	nb	nb	nb	33.1
		A205/19	nb	nb	nb	nb	nb	nb	nb	33.6
Requirements R1, R7										
intercommunication gangways	silicone mix on textile	A156/18	22.6	85.1	150.4	343.4	176.9	0.01	nd	nd
		A5/19	28.6	87.4	155.5	190.7	413.9	0.01	nd	nd
		A6/19	25.3	102.6	119.8	184.2	423.2	0.01	nd	nd
		A7/19	26.6	84.7	148.5	253.4	271.0	0.02	nd	nd
		A8/19	26.9	85.6	185.4	347.3	361.8	0.02	nd	nd
	rubber mix	A40/16	16.7	82.0	nb	nb	nb	nb	nd	nd
		A98/16	13.3	84.3	nb	nb	nb	nb	nd	nd
		A173/16	17.8	nb	nb	nb	nb	nb	nd	nd
		A21/17	nb	80.6	484.2	1037.3	1151.5	2.2	nd	nd
		A144/17	nb	nb	512.9	1145.3	1320.0	1.2	nd	nd
		A47/18	nb	nb	499.9	931.1	741.2	nb	nd	nd
		A115/19	18.1	85.0	491.5	1027.5	1100.1	2.3	nd	nd
Requirements R22, R23										
brake hoses	two layer of rubber mix	A148/19	nd	nd	nd	nd	251	nd	nb	47.9
		A149/19	nd	nd	nd	nd	227.1	nd	nb	nb

nd - not referred, nb – not tested

As it results from the presented tables and charts, gasket products made of silicone and most of silicone mixtures meet the requirements for all parameters at the HL1 and HL2 hazard levels.

The tests carried out for the materials of the gangways have shown that EPDM rubber mixtures do not meet any of the acceptable criteria. However, for silicone mixtures used in skeletal constructions, the requirements for HL1 and HL2 have been met.

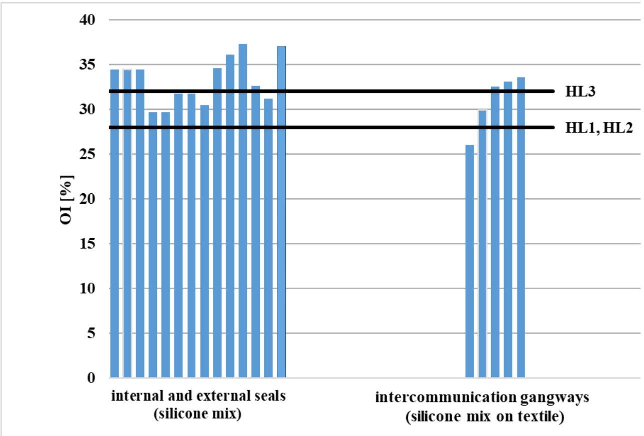

Fig. 1. Oxygen Index (OI) values for rubber mixtures for various products

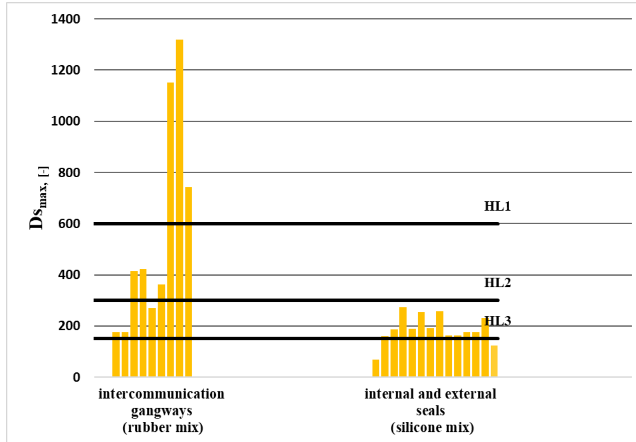

Fig. 2. Maximum optical density (D_{smax}) values } for rubber mixtures for various products

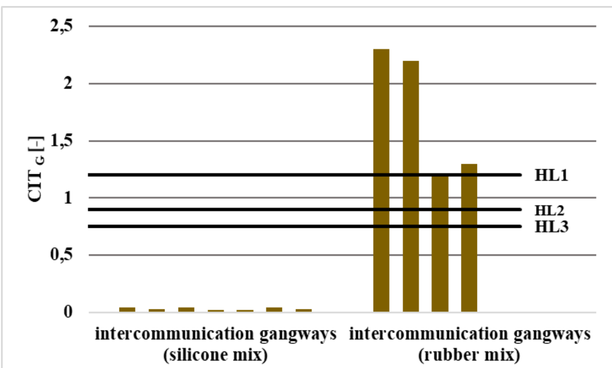

Fig. 3. Conventional Index of Toxity (CIT_G) values for various rubber mixtures

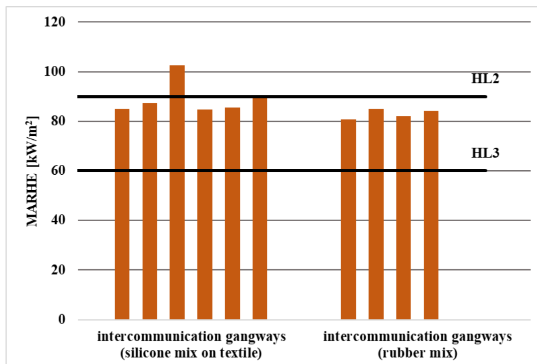

Fig. 4 MARHE values for various rubber mixtures

Exemplary photographs (Figs. 5. 6) show that some rubbers burn intensively. The sample within the OI test exceeded the criterion of time and length of the burnt part.

Fig. 5. Oxygen Index test for EPDM.

Fig.6. Test according to ISO 5658-2 (determination of CFE) for EPDM.

Modification directions for rubber mixtures

As it was shown earlier, silicone rubber is the least susceptible to burning. However, it is not possible to use it for all rail vehicle applications. On the other hand, flame retardant rubber is not an easy task to be done because it usually causes a significant reduction in impact strength. tensile strength and elongation at break [1]. The methods used include [1- 3. 20]:

- introduction of an inorganic filler (among others: magnesium hydroxide $Mg(OH)_2$, aluminum hydroxide $Al(OH)_3$, zinc hydroxyzinate $ZnSn(OH)_6$ and hydrated zinc borate $2ZnO\cdot3B_2O_3\cdot3.5H_2O$).
- applying a synergistic effect by simultaneously introducing $Al(OH)_3$, graphite and paraffin.
- introduction of phthalocyanides.
- introduction of nanoparticles (e.g. zinates and borates of zinc. silicates).

However (despite the provision in p. 4.7 of the standard [8]), many manufacturers have undertaken research and development work aimed at modifying rubber mixtures in order to meet, or at least improve fire properties while maintaining very important functional features.

According to publication [4], the Austrian manufacturer has already managed to develop a technology for producing rubber that meets the requirements of R9 for the purpose of flexible rubber and metal-rubber assemblies found in the chassis (M1. EX9. EX11), while maintaining the required mechanical parameters. BATEGU rubber mixes BATEGU® 9559 and BATEGU®9713 for elements with anti-vibration properties (with the required hardness in the range of 40-60 Shore A) meet the fire requirements of R9 at the HL2 level. However, in the hardness range of 65-83 they meet the requirements of R9 at the HL3 level.

On the other hand, modification works for mixtures used for coating fabrics in skeleton solutions showed that materials from one manufacturer marked A156/18, A5/19, A6/19, A7/19, A8/19 (Table 3) met the requirements of HL1 and HL2 threats. Therefore, the producers of this type of product face the challenge to create such a material that will meet the requirements at HL3 hazard level.

However, not all of the work undertaken brought the expected effect, as in the case of rollers for intercommunication gangways. The test results for samples A40/16, A98/16, A173/16, A21/17, A144/17, A47/18 and A115/19 presented in Table 3. refer to subsequent product modifications of the same manufacturer, for which a slight improvement of parameters was obtained. However, the most difficult to meet are parameter CFE (the best result is 18.1 kW/m^2 with a minimum requirement $\geq 20\ kW / m^2$) and CIT (the best result is the minimum required. i.e. 1.2).

Summary

The introduction from January 1. 2018 of the requirements of EN 45545-2 [8] to the mandatory application proved to be a great challenge for rubber products used in rail vehicles. Rubber is used for elements that require specific mechanical properties that are essential for the proper functioning of rolling stock. In contrast, the flammability of natural rubber found in large components (rollers for inter-wagon passages) is a serious fire hazard in a train due to the rapid spread of flame and the intense release of black obstructing visibility and very toxic smoke. Particularly dangerous conditions occur when passing through a tunnel [1]. Therefore, undertaking further research and development work aimed at developing new rubber compounds that meet the requirements in the field of fire properties while maintaining very important mechanical properties should be considered extremely important.

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