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Influence of Irradiance Level on the Toxic Gases Emission During the Combustion of Materials used in Floor Constructions in Rolling Stock

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Abstract. This article presents the results of studies on the influence of irradiance level on the thermal decomposition of a non-metal materials used in floor constructions in rolling stock. This paper contains an analysis of emitted products of combustion and their evolution rate during the potential fire of railway vehicles. The irradiance level of the most intense individual gas emissions was determined, which allowed estimating the safe evacuation time of passengers and staff.

Introduction

Construction of modern rolling stock vehicles is associated with the need to apply the latest technical and material solutions. This must be connected with necessity to ensure fire safety. The main purpose of fire protection in the event of fire on board in a rail vehicle is to allow passengers and crew to evacuate to the area of maximum safety. On the other hand, the time when passengers are stranded in the vehicle should be as short as possible. One of the worst effects of fire is toxic gases release, which poses a lethal threat to passengers and impedes or even makes the evacuation impossible. Floor composites are an important group of materials (in terms of weight and volume) included in the construction of railway vehicles.. Thus, it is very important to select them properly in the scope of requirements related to fire protection of rolling stock. Therefore, materials that meet the requirements of PN-EN 45545-2+A1:2015 [9] are used for the construction of railway vehicles. In addition to fire parameters characterized by resistance to external sources of fire such as:

- flame propagation (length and speed of flame front travel over a specimen of the material after initiating its combustion) [1],
- heat release rate (amount of heat released in a unit of time during sample combustion) [1-3],
- smoke emission (optical density of air in the environment of a burning specimen) [4],

they must also meet the requirements for toxic gases emissions.

Floor composites consist of a floor substrate (including thermal insulation) and floor covering elements (together with fixing elements and an adhesives used in final use conditions). The most common materials used for floor constructions are composites based on, e.g.:

- flame-retardant polyester resins [5, 6], which are characterized by good mechanical properties and technological processing [8], most often installed in toilets,
- fireproof impregnated plywood with a rubber-cork spacer,
- aluminum cork systems

to which the following floor coverings are glued:

- carpets,
- elastics based on plasticized polyvinyl chloride with the addition of anti-pyrenes,
- elastics based on rubber.

Materials and methods – Toxic gas emission test

Floor composites made on the components mentioned above were used for the tests. Their detailed material composition is presented in Table 1. The tests were carried out in accordance with the methodologies described below.

Table 1. *Marks and composition of tests specimens of prepared floor composites.*

Specimen	Composition of floor composites
A36/17	– covering based on PCV, GRABO, thickness - 2.5 mm, – adhesive for coverings Macroplast, – plywood with a rubber-cork spacer, thickness 18 mm,
A44/16	– carpet, Lantal, thickness - 3 mm, – adhesive for carpets, – aluminum-cork laminate, thickness -18 mm
A117/17	– rubber covering, Noraplan Mobile Stone, thickness - 2 mm, – adhesive for coverings Macroplast, – plywood with spacer, thickness - 18 mm,
A27/19	– rubber covering, Noraplan Mobile Stone, thickness - 2 mm, – adhesive for coverings Macroplast, – glass - polyester laminate GRRALITHE, thickness - 3 mm,

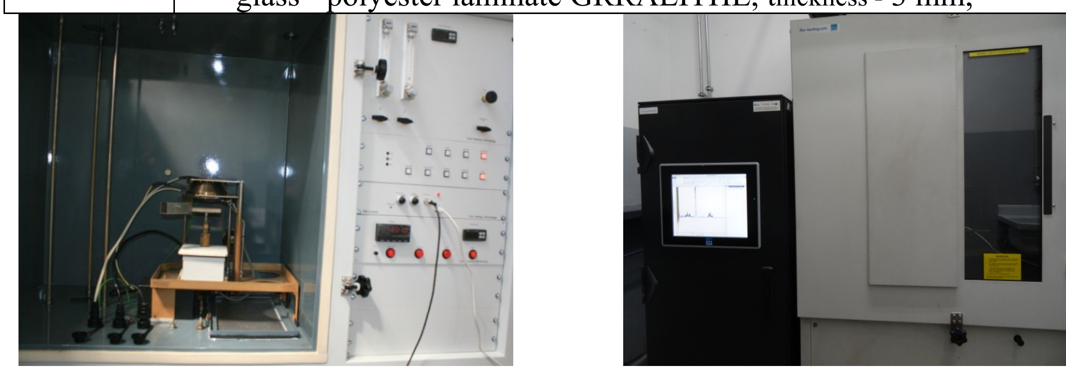

Fig. 1 Smoke chamber (on the left) and FTIR analyzer conjugated with it for determination of gas toxicity according to PN-EN 45545-2:A1:2015 [1] (source: Materials & Structure Laboratory Instytut Kolejnictwa)

The commonly used method for determination of toxic gases emitted during a fire uses the Fourier Transform Infrared Spectroscopy FTIR technique [8]. However, the method does not take into account the irradiant level on the thermal decomposition of products during a potential fire. Still, it exerts the main influence on the resulting of combustion products and the rate of emission. For testing, the FTIR analyzer was used in accordance with PN-EN 45545-2+A1:2015 Annex C [9], ISO 19702:2015 [10] and PN-EN 17084:2019 [11] conjugated with a smoke chamber in accordance with the EN ISO 5659-2:2017 [12]. The test method relies on measuring the amount of smoke (by measuring of optical density) formed during the combustion of a specimen subjected to a specific level of thermal radiation, and then determination of the amount and type of toxic gases released.

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The evaluation of toxic products that arise in a closed smoke chamber is made by analyzing the concentration of the following 8 gases: carbon (IV) oxide CO_2, carbon (II) oxide CO, hydrogen bromide HBr, hydrogen chloride HCl, hydrogen cyanide HCN, hydrogen fluoride HF, nitrogen (IV) oxide NO_2 , nitrogen (II) oxide NO and sulfur (IV) oxide SO_2. The gases are taken with a sampling probe in the 4th and 8th minute of the test during the measurement of the optical density of smoke in the smoke chamber according to PN-EN ISO 5659-2 [12]. The smoke chamber is shown in Fig. 1 (on the left) for determination of optical density and FTIR analyzer conjugated with it (on the right) for determination of the concentration of toxic gases.

Results –- Toxicity testing of floor composites

The tests results for determination of emission of toxic gases emitted during the combustion of floor composites are summarized in Tables 2-5. Values recorded below the limit of detection are marked as n.o.

Table 2. *Emission of toxic gases during the combustion of the material A36/17*

Gas	Time at sampling time	Concentration, mg/m^3				
		10 kW/m^2	20 kW/m^2	30 kW/m^2	40 kW/m^2	50 kW/m^2
CO_2	4 min.	756.89	845.82	903.2	1112.4	1284.6
	8 min.	910.5	1246.9	1542.6	2145.7	2525.3
CO	4 min.	32.6	54.7	86.5	101.1	106.5
	8 min.	71.9	93.6	132.4	153.4	179.2
SO_2	4 min.	n.o	19.6	35.6	54.3	69.2
	8 min.	21.3	48.8	56.4	77.8	95.7
HCL	4 min.	35.6	53.6	106.9	121.4.4	146.7.
	8 min.	102.5	135.6	184.6	206.8	225.2

Table 3. *Emission of toxic gases during the combustion of the material A44/16*

Gas	Time at sampling time	Concentration, mg/m^3				
		10 kW/m^2	20 kW/m^2	30 kW/m^2	40 kW/m^2	50 kW/m^2
CO_2	4 min.	716.5	1054.2	1625.6	2154.7	2864.3
	8 min.	1856.8	2256.4	3354.4	4556.3	5325.7
CO	4 min.	14.4	23.5	31.3	38.5	41.3
	8 min.	26.4	38.2	58.4	76.5	89.5
SO_2	4 min.	19.6	35.1	54.3	72.3	88.4
	8 min.	36.4	51.2	98.3	121.3	143.2
NO_x	4 min.	n.o.	11.5.	16.4	22.3	32.5
	8 min.	n.o.	22.4	49.7	61.2	76.8

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Table 4. *Emission of toxic gases during the combustion of the material A117/17*

Gas	Time at sampling time	Concentration, mg/m^3				
		10 kW/m^2	20 kW/m^2	30 kW/m^2	40 kW/m^2	50 kW/m^2
CO_2	4 min.	916.5	1854.2	2869.4	3546.2	4125.8
	8 min.	1546.7	2157.3	4894.2	7256.8	8952.9
CO	4 min.	19.6	32.6	43.8	55.1	63.2
	8 min.	31.9	43.6	82.4	115.8	136.5
SO_2	4 min.	12.1	31.4	61.4	85.6	103.8
	8 min.	34.9	58.6	114.6	154.6	174.9
HCN	4 min.	n.o.	n.o.	n.o.	n.o.	24.3
	8 min.	n.o.	n.o.	n.o.	n.o.	31.5
NO_x	4 min.	n.o.	n.o.	11.2	18.6	24.7
	8 min.	16.5	24.7	44.8	72.7	82.6

Table 5. *Emission of toxic gases during the combustion of the material A27/19*

Gas	Time at sampling time	Concentration, mg/m^3				
		10 kW/m^2	20 kW/m^2	30 kW/m^2	40 kW/m^2	50 kW/m^2
CO_2	4 min.	1689.4	2861.7	3629.8	4026.4	4634.3
	8 min.	3517.4	6186.8	8181.4	8752.6	9052.1
CO	4 min.	21.6	43.7	59.3	62.4	70.1
	8 min.	44.5	80.6	115.4	127.6	138.8
SO_2	4 min.	10.8	33.7	67.6	89.9	106.5
	8 min.	42.1	66.4	130.6	171.1	177.6
HCN	4 min.	n.o.	n.o.	n.o.	21.4	52.6
	8 min.	n.o.	n.o.	32.0	43.1	76.8
NO_x	4 min.	n.o.	n.o.	15.7	22.6	27.4
	8 min.	14.6	33.8	39.1	71.4	85.1

Analysis – The influence of irradiance level on the emission of toxic gases depending of the composition of floor composites

The floor composite with PVC lining A36/17 (plasticized polyvinyl chloride) is characterized by a relatively low level of CO_2 emission, which comes mainly from a layer of wood material in the compact (plywood with a spacer). The high level of emitted HCL is caused by the thermal decomposition of PVC from the surface layer of the composite. The process of PVC dechlorination begins at low temperatures, therefore this gas was determined at the irradiance level of 10kW/m^2. After exceeding the initial temperature of 180ºC on the specimen surface, which corresponds to the irradiance level of 30 kW/m^2 (according to Fig. 2), increasing HCL emission in 4th min. of the test was observed. The same process, only intensified, took place in the 8th minute of the test. From this irradiance level, an increase in CO emission was also noted. The graph of toxic gases concentrations as a function of irradiance level is presented in Fig. 2.

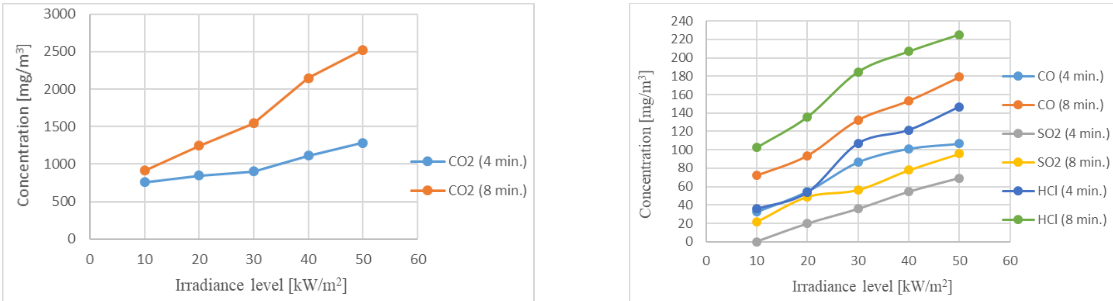

Fig. 2 Graph of toxic gases concentrations as a function of irradiance level for the floor composite A36/17.

The floor composite with rubber covering A44/16 (polyamide fleece) has a medium level of CO_2 emission related to the thermal decomposition of polyamide from the covering and cellulose from the base and a low level of CO emission. The amount of CO_2 increased after exceeding 180ºC of the initial temperature on the surface which is a response to the irradiance level of 30 kW/m^2. In addition to these gases, nitrogen oxides were also detected which were emitted in quantities allowing their determination when the irradiance level equaled 20 kW/m^2. They came from the thermal decomposition of the polyamide as the top layer of the composite.

The graph of toxic gases concentrations as a function of irradiance level is presented in Fig. 3.

The floor composite with rubber covering A117/17 and A27/19 (cross-linked NBR rubber) shows a high level of CO_2 emission, especially in the 8th minute of the test for a higher irradiance level on the specimen surface (40 kW/m^2 and 50 kW/m^2). It is caused by the influence of a layer of wood material in the compact (plywood, pine scantlings).

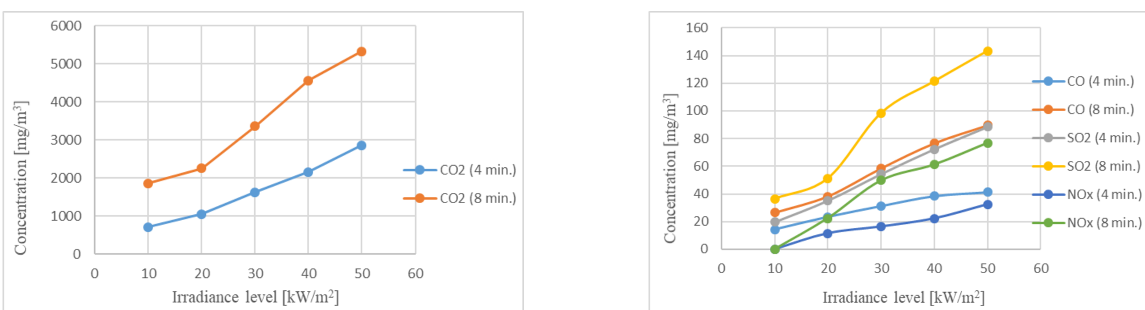

Fig. 3 Graph of toxic gases concentrations as a function of irradiance level for a floor composite A44/16

A large amount of SO_2 evolved due to the oxidation of sulfide bonds to sulfenic and tiosulfoxylic acids, and then to SO_2 to a small extent to SO_3 in the boundary layer of the burning elastomer cross-linked with sulfur. The toxicity of emitted gases of the tested composite is also significantly affected by the release of amounts of toxic nitrogen compounds, especially in the 8th minute of the test, at the irradiance level exceeding 30 kW/m^2. Particularly toxic HCN was also determined for the highest irradiance level. A similar distribution of toxic gas emissions was observed during the thermal decomposition of a floor composite consisting of the same rubber but glued onto a glass-polyester laminate.

The graph of toxic gases concentrations as a function of irradiance level is presented in Fig. 4 and 5.

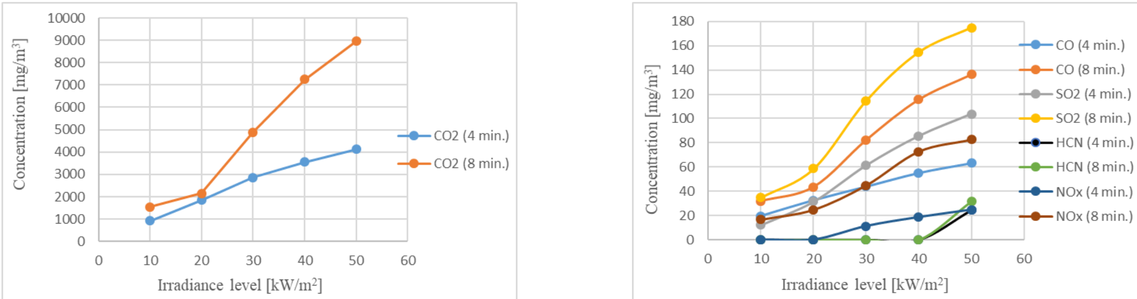

Fig. 4 Graph of toxic gases concentrations as a function of irradiance level for a floor packet no. A117/17

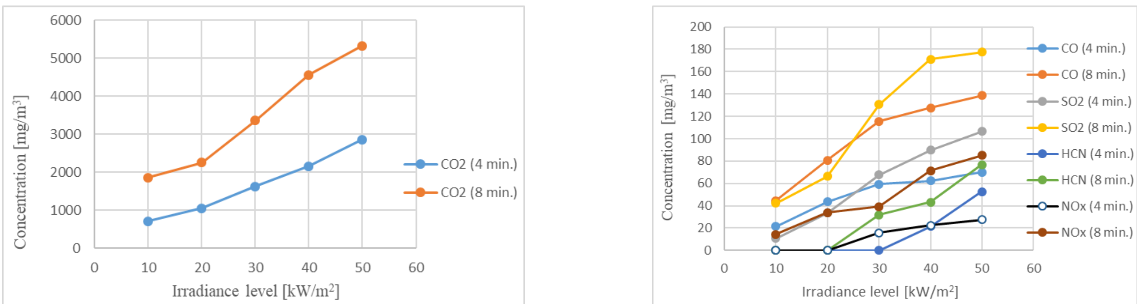

Fig. 5 Dependencies of toxic gases concentrations as a function of heat radiation intensity for a floor packet no A27/19

Summary

The performed tests allowed for determining the influence of irradiant level on the amount and type of gases emitted during combustion. The results of experiments carried out in laboratory conditions were used to identify particularly hazardous substances, which even in small quantities pose a threat to the health of passengers and crew. These substances include, in particular, nitrogen oxides, hydrogen cyanide, sulfur oxide (IV) and carbon oxide (II). In contrast, large amounts of toxic and highly corrosive HCL were recorded when testing a compact floor with PVC coverings. It was shown during the tests that after exceeding the irradiant level of 30 kW/m^2, there was an intensive increase in toxic gases emissions. Obtained concentration values increased significantly after exceeding the first four minutes of testing. This confirms that the safe evacuation time in the event of a fire should be as short as possible, not exceeding three minutes according to TSI LOC&PAS [13], taking into account the large amount of non-metallic materials used to build the rolling stock and the associated emissions of toxic compounds for humans.

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