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The smoke emission properties of selected elements of passenger car interior design

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Abstract. The paper presents the results of tests for smoke optical density conducted on five various elements of car interior design. The tested samples were taken from the dashboard, ceiling lining, floor lining, seats and side door upholstery. A smoke density chamber was used to measure the propensity of the materials to generate smoke after being exposed to a heat source. The specific optical density, as a function of time, was determined for each material. There were two burning conditions simulated: radiant heating in the absence of ignition, and flaming combustion in the presence of supporting radiation. The highest values for specific optical density were measured for the side door upholstery and driver's dashboard. The tests results were compared with international optical smoke density requirements for the interior design of ships and trains.

1 Introduction

According to statistical data, over 80% of fatalities during fires are caused by the hazards posed by smoke [1]. Limiting the visibility splay is one of the main hazards related to smoke release in fire conditions. Other important components are high temperature, the ensuing thermal radiation and toxicity. Dense smoke generated by burning materials hinders evacuation from buildings and extinguishing the fire. Limited movement possibilities in an area compromised by a fire intensifies the feeling of imminent danger, impairs body capacity and may even cause panic [2]. It is considered that places with limited height and cubage, which are relatively quickly filled with smoke, in such a way directly affecting the people present in them, are particularly dangerous. Such places comprise among others, parking lots, underground garages or tunnels.

An appropriate selection of the material for the interior finishing element of a passenger car depends primarily on aesthetic values, resistance to wear and tear and comfort of usage. As a consequence, elements of car interior furnishings are mainly made of plastics, which easily undergo thermal decomposition at elevated temperatures, generating concurrently relatively large amounts of smoke. The most frequent causes of car fires are leaks of easily flammable liquids, arson, defects of the electrical wiring and electronics, failures of the exhaust gas system, or failure of the engine and fittings or the ignition of sound-insulating materials [3].

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Regulations pertaining, among others, to garages contained in the Polish technical regulations and the building code are primarily oriented at minimising the consequences of the adverse impact of smoke released from burning cars by imposing the obligation of installing garage space smoke control systems. The safety of this type of space may also be enhanced by limiting the amount of smoke generated from the interior of a burning car, which may be achieved by establishing requirements for smoke generation properties of materials used as elements of interior furnishings of car interiors. Unfortunately, this direction for safety enhancement is not reflected in the binding applicable legislation.

A characteristic feature of a fire is the generation of smoke, which hinders the execution of rescue and extinguishing actions. Smoke limits the visibility splay, and the toxic products contained in it cause an increase in the number of victims. Persons present in the smoke-logged place lose their orientation and start to panic when forced to stay inside longer, and that in turn causes further inhalation of toxic gases. This hazard keeps intensifying due to the ever growing application of polymer materials in the construction industry, as they constitute approximately 10-15% of the total mass of flammable materials in apartments. As a result of the combustion of materials, including especially plastics, smoke is generated, which comprises solid or liquid particles. Apart from the structure of the material, the intensity of smoke generation depends on temperature and the access of air into the burning zone [4]. Significant smoke emission takes place in conditions of oxygen shortages. In such conditions the combustion is incomplete or partial, and products of those transformations are the main components of the smoke dispersed phase. As regards the group of polymer materials, the lowest smoke generation was recorded, for example, for wood, polypropylene and polyethylene; while a considerable intensity of smoke generation is usually ascertained for poly(vinyl chloride) or polystyrene [5, 6]. Smoke generation properties during the combustion process of polymer materials is affected by several factors, starting with the type of material (chemical ingredients) up to the type of combustion. Intense dense smoke generated during combustion causes difficulties for rescuers in gaining access to the place where the fire has started as well as to victims in need of evacuation,exerts a significant impact on changes of the surrounding environment.

In this work an attempt has been made at determining the smoke generating properties of interior finishing elements of a selected passenger car with reference made to results obtained from maritime and railway standards.

2 Materials and methods

2.1 Description of materials for testing

For research purposes, use has been made of elements of the furnishing of a BMW model e36 representative passenger car. Five components have been selected from the furnishings of this vehicle. The testing specimens were taken from the following places:

1) dashboard,
2) floor lining,
3) ceiling lining, the so-called headliner,
4) side door upholstery,
5) seat upholstery.

Table 1 presented the qualitative composition of car fit-out elements selected for studies.

Table 1. Composition of particular elements of interior furnishings from the BMW e36.

No.	Part of interior furnishings	Material components
1.	Dashboard	ABS/PVC PUR PP-TV40
2.	Floor lining	PP
3.	Ceiling lining	PES+PA+PUR/PE+GF PUR/PE+GF PES+CV
4.	Side door upholstery	PVC/PRESSSTOFF
5.	Seats upholstery	VELOUR

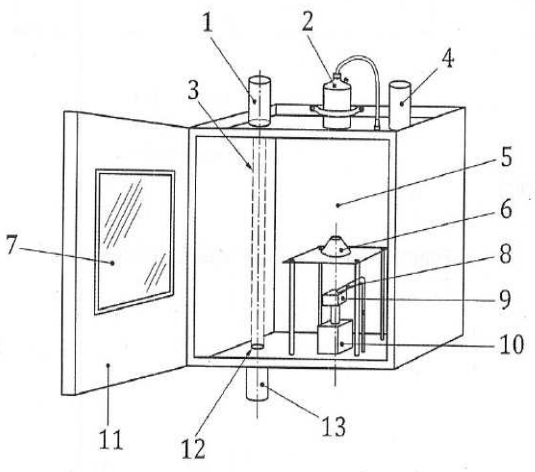
Table 2 presented a specification of symbols used to describe the material ingredients of particular parts of the interior fit-out of cars [7, 8, 9].

Table 2. Description of materials used to execute particular car fit-out materials.

No.	Material	Description
1.	ABS	Acrylonitrile-butadiene-styrene polymer– obtained in the polymerisation process of 1.3-butadiene and copolymerisation of acrylonitrile with styrene and with concurrent grafting of the produced polymer on polybutadiene.
2.	PVC	Poly(vinyl chloride) – synthetic polymer, obtained in polymerisation of vinyl chloride.
3.	PUR	Polyurethane – polymer made as a result of additive polymerisation of multifunctional isocyanate with polyols.
4.	PP-TV40	Polypropylene filled with talc – polypropylene homopolymer stabilised at high temperature, filled in 40% by talc.
5.	PP	Polypropylene – organic chemical compound obtained as a result of low-pressure propene polymerisation
6.	PES	Polyester – group of synthetic fibres produced as a result of polycondensation of dicarboxylic acid with polyhydroxyl alcohols, most frequently terephtalic acid with ethylene glycol.
7.	PA	Polyamide – polymer containing amide bonds in its primary chain. Obtained as a result of polymerisation or polycondensation.
8.	PE	Polyethylene – ethen polymer.
9.	GF	Polymer-glass composite– glass fibres contained in a polymer material matrix.
10.	CV	Viscose – semi-synthetic fibres – It is obtained from purified wood pulp subjected to soda lye, and then carbon disulphide. This semiproduct is dissolved in diluted solution of soda base.
11.	PRESSSTOFF	Substitute leather made of specially coated and processed paper pulp.
12.	VELOUR	Textile of pile yarn belonging to the group of velvets.

2.2 Characteristic features of the research method

To determine the smoke generating properties of the selected materials, a so-called single-chamber test was performed according to [10]. Figure 1 presents a diagram of the research stand.



1. Optical measurement system,
2. Pressure controller,
3. Optical path,
4. Exhaust with shutters,
5. Smoke chamber,
6. Cone radiator,
7. Window
8. Pilot flame,
9. Specimen holder,
10. Scale,
11. Chamber front door,
12. Floor inspection viewer of optical system,
13. Light source.

Fig. 1. Chamber for testing optical density of smoke.

The basic characteristic feature delimited based on conducted measurements was a change of the proper optical density of smoke in the time function determined in accordance with the equation [11]:

$$\frac{Ds = \frac{Vk}{S \cdot L} logT_{ro}}{Tr} = \frac{Vk \cdot D}{S \cdot L} \tag{1}$$

where:
Ds – proper optical smoke density [-],
V_k – volume of measurement smoke chamber [m^3],
L – thickness of smoke layer [m],
S – active surface of sample [m^2],
T_{ro} – initial transmittance of light [%],
T_r – light transmittance [%],
D – optical density of smoke [-].

To allow executing a wider analysis, such derivative values as the time until achievement of Ds_max, the value of proper optical density after 4 minutes Ds._4 and the area under curve of proper optical density during the first 4 minutes VOF_4 were also recorded.

The tests were performed in two configurations, i.e. with the use and without the use of a gas burner to ignite thermal decomposition products. The value of thermal radiation intensity flux as adopted at the level of 25 kW/m^2.

2.3 Methods of preparing samples for testing

Samples cut from the car interior according to the standard [12] were cut to the dimensions of 75 x 75 mm. Each placement of the specimens in the crucible with the external part towards the cone radiator was to reflect the actual exposition of car furnishing elements to thermal radiation in fire conditions. The samples were not air conditioned.

3 Results and discussion

The average values of defined parameters were presented in Tables 3 and 4 and on Figures 2 and 3.

Table 3. Listing of average values of delimited parameters – tests without the presence of a burner flame.

No.	Tested material	Average time of combustion start [s]	Average time of combustion end [s]	Average Ds_max [-]	Average time until achievement of Ds_max [s]	Average Ds_4 [-]	Average VOF_4 [min]
1.	Dashboard	-	-	582.7	1062.5	372.8	705
2.	Floor lining	-	-	569.2	932.5	304.8	401.8
3.	Ceiling lining	-	-	282.3	407.5	237.3	523
4.	Side door upholstery	-	-	699.7	810	529	1165.8
5.	Seat upholstery	-	-	223.9	1100	167.6	342.1

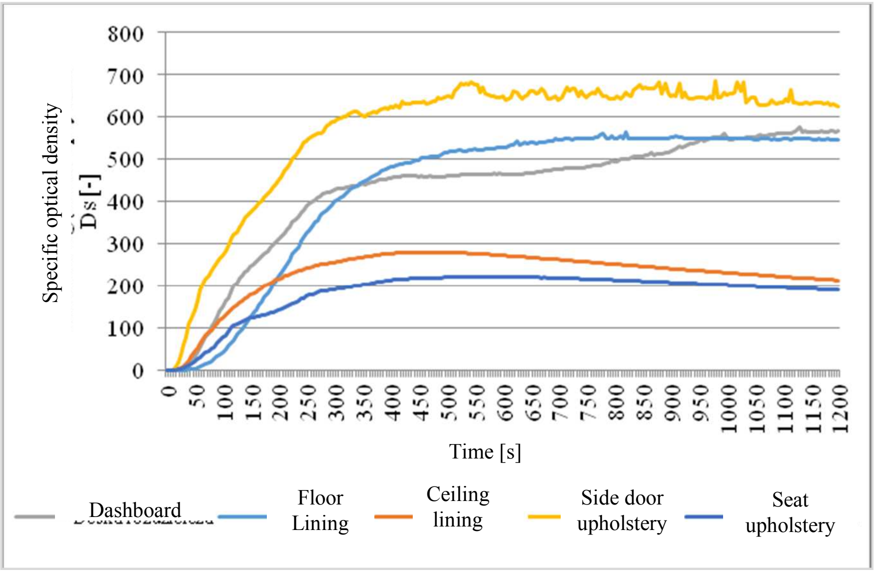


Fig. 2. Average values of the course of curves Ds(t) – testing without a burner flame.

Table 4. Listing of average values of delimited parameters – tests in the presence of a burner flame.

No.	Tested material	Average time of combustion start [s]	Average time of combustion end [s]	Average Ds_max [-]	Average time until achievement of Ds_max [s]	Average Ds_4 [-]	Average VOF_4 [min]
1.	Dashboard	26	-	637.8	107.5	564.7	1756.2
2.	Floor lining	44.5	505.5	204.1	190	195.5	474.5
3.	Ceiling lining	17	245.5	140.4	135	129.9	398.1
4.	Side door upholstery	11	536	699.7	267.5	556.5	1472.5
5.	Seat upholstery	23	75.5	122.9	62.5	97.6	351.6

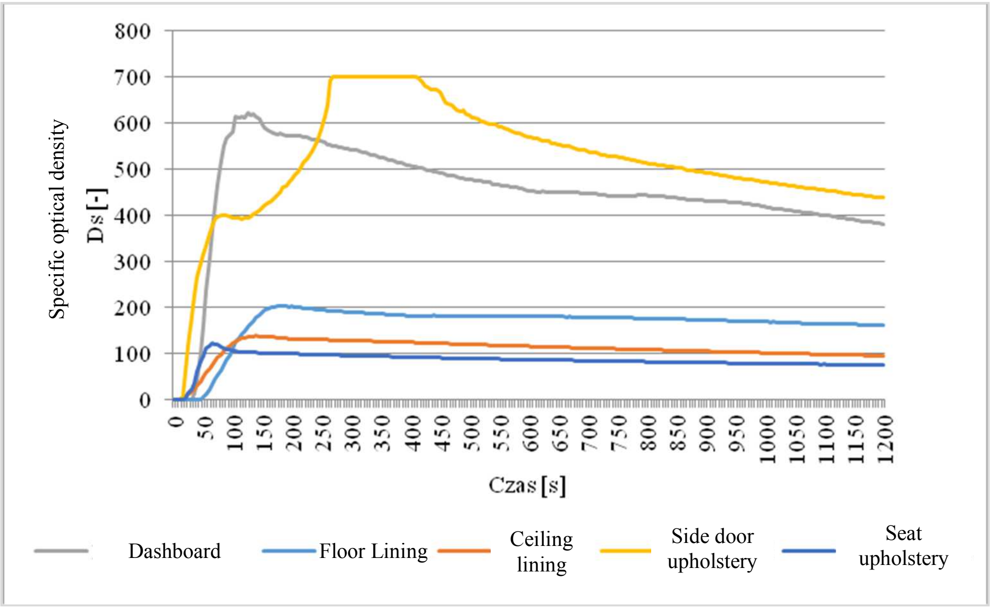


Fig. 3. Average values of the course of curves Ds(t) - tested in the presence of a burner flame.

In none of the tests, in which no burner flame has been used and regardless of the material, flame combustion of the sample has taken place.

As has been shown in Figure 2, the highest values of proper optical density were recorded for materials used for internal leather door inlays, floor lining and the dashboard. The average Ds_max values of those materials presented in Table 3 amounted successively to ca. 699, 569 and 583. A similar course of curves indicates the similar dynamics of smoke generation by comparable materials. Stabilisation of the Ds value of approximately 10 minutes for door inlay material and seat upholstery proves a low propensity of smoke particles to coagulation and settlement in testing conditions.

The presence of a gas burner directly over the specimen caused a relatively early transition of specimens from flameless decomposition into flame combustion. The tests pointed to a lack of clarity as regards limiting the amount of generated smoke during flame combustion. As has been shown in Table 4, flame combustion of material used as door inlay started (on average) in the 11th second, and as regards the dashboard at ca. the 20th second. The course of curves Ds(t) presented on Figure indicates that the appearance of the flame over the specimen intensified the rate of smoke emission from those materials. As regards the dashboard, the time until achievement of Ds_4 was shortened almost ten-fold; while for door leather inlays – ca. three-fold. As regards the remaining materials, it should be borne in mind that flame combustion clearly limited the amount of smoke released, especially for material used as seat upholstery.

Given the lack of legal regulations pertaining to the smoke generation properties of materials used as finishing elements of car interiors, the obtained results were compared with maritime requirements formulated on the basis of the second part of the international code of applying procedures for fire testing and railway requirements specified in the standard [12]. For the maritime legislation, it was ascertained that none of the elements meet requirements posed to partitions installed on ships. Materials of the headliner and seat upholstery met requirements for materials of first decking. The material of car floor lining met requirements for floor lining in the shipbuilding industry. On the other hand, materials used for the dashboard and leather door inlays failed to meet requirements of maritime regulations in any scope.

Taking into consideration the exceeding of the admissible value of Ds_max materials used to door inlays and the dashboard could not have been used as finishing element of railway wagons. Velour used as seat upholstery, which achieved the average value of Ds_max at the level of 122.9 could be successfully used as seat upholstery in railway wagons. The car lining and the ceiling lining could also be applied in the railway industry, albeit to a limited extent. The lining that achieves the average value of Ds_max at the level of 204.1 meets requirements posed to horizontal surfaces directed upwards as to the HL 2 hazard. Similarly, the ceiling lining material reached the average value of Ds_4 amounting to 129.9 and VOF_4 amounting to 398.1 min.

The following conclusions may be drawn from the conducted testing:

- Elements of passenger car furnishings show a diversified degree of smoke emission, both during flameless and flame combustion.
- The amount of smoke generated during thermal decomposition of elements contained in interior furnishings of a passenger car in building structures may pose a direct hazard for persons staying in them.
- Not all elements contained in the interior finishing of cars meet criteria for maritime and railway transport.
- There is a justified need of taking up discussions concerning requirements related to the smoke generation of elements of interior finishing in cars.
- Direct adaptation of railway or maritime regulations to road transport appears to be risky, owing to the diversified nature of hazards that occur during the fires of those transport means.
- Further research should be undertaken with respect to smoke generation of car finishing materials, particularly taking into account mass relations of particular elements.
- Attempts should be made to verify the obtained results using full-scale tests.

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