Selection of Components of Upholstery Systems

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Abstract. The article discusses methods and results of fire smoke tests of modified flexible polyurethane foams and upholstery systems carried out as part of the KOLEJMAT project at the Instytut Kolejnictwa (Railway Research Institute). The search for optimal components for ensuring fire safety of passenger rolling stock has been described. A different influence of fireproof nonwovens on the combustion process of graphite and non-graphite foam systems has been demonstrated. The results of tests of heat emission, smoke properties and toxicity are presented. The best two upholstery systems were selected.

Introduction

The development of rail vehicles designed to reduce their weight, increase operational speed and increase passenger comfort included also the construction of passenger seats. Wagon seats represent a significant mass of non-metallic materials and in the event of a possible fire - they determine the intensity and speed of fire propagation in the vehicle. These elements can therefore pose a direct threat to passengers [1,2]. Therefore, the development of passenger seats, in addition to taking into account the improvement of their ergonomics, also includes the search for non-combustible components. The above was also the aim of the KOLEJMAT project entitled: " Manufacturing Technology Basics of Passenger Seat with Use of Advanced Materials" [3], implemented in the years 2013-2016 as part of the NCBiR (National Center for Research and Development) Applied Research Program. The leader of the project consortium was the Faculty of Materials Science and Engineering at the Warsaw University of Technology, and the Partners: Transport Vehicles' Upholstery Manufacturer - TAPS - Maciej Kowalski in Łódź and Instytut Kolejnictwa (Railway Research Institute) in Warsaw. The project included the development of the following:

- modern constructions of forms, constituting the load-bearing base of the upholstery system (modification of plywood),
- armrest and table knot (selection of modified selected composite),
- upholstery system, including modifications of the PUR foam constituting the elastic element of the system.

European requirements in the field of fire properties of upholstery systems

Currently designed for European rolling stock, wagon seats and their component materials are subject to fire tests according to the EN 45545-2: 2013 requirements [4]. Table 1 presents the scope of the required tests for upholstery and requirements depending on the level of danger of HL vehicles, resulting from the combination of their design categories with the operating category according to EN 45545-2: 2013 [4].

As can be seen in Table 1, upholstery systems should meet the requirements for the following three parameters:

MARHE (Maximum Average Rate of Heat Emission) is the maximum average rate of heat release during 20 minutes of the test determined according to ISO 5660-1: 2016 [5] using a cone calorimeter. Its operation consists in using the principle of oxygen calorimetry, according to which, for most materials, each kilogram of oxygen consumed by the burning material causes the release of 13.1 [MJ] of heat (energy) with an accuracy of ± 5% [1, 6]. The use of a paramagnetic oxygen analyzer allows the exact determination of the amount of heat released and the rate of its release.

Table 1. R21 requirements for upholstery according to EN 45545-2:2013[4]

No.	Test method	Parameter	Requirement for:		
			HL1	HL2	HL3
1	ISO 5660-1: 25 [kWm^{-2}]	MARHE [kWm^{-2}]	≤ 75	≤ 50	≤ 50
2	EN ISO 5659-2: 25 [kWm^{-2}]	D_s max [dimensionless]	≤ 300	≤ 300	≤ 200
3	EN ISO 5659-2: [kWm^{-2}] + EN 45545-2 Annex C	CIT_G [dimensionless]	≤ 1,2	≤ 0,9	≤ 0,75

D_s. max (Maximum Specific Optical Density) - determined by the method according to PN-EN ISO 5659-2: [7] by the single-chamber test. The test consists in determining the optical density of the generated smoke (Ds) from the exposed surface of the test sample subjected to thermal radiation with the power of 25 [kW / m2] in the smoke chamber.

CIT_G (Conventional Index of Toxicity) determined in the fourth and eighth minute as *CIT(4)* and *CIT(8)* of the test, by FTIR spectroscopy according to PN EN ISO 5659-2 [7] taking into account EN 45545-2 [4] Annex C and ISO 19702 [8]. The applied method of infrared spectrophotometry allows for the qualitative and quantitative determination of the composition of fumes generated during the thermal decomposition of the test sample.

Laboratory tests of fire properties

2 types of PUR foams currently used at the Industrial Partner (PUR DB1 and PUR DB2) poured with use of an injection molding machine were the starting material for the selection of the optimal upholstery system. In addition, after the analysis of the bibliography regarding fire retardant polyurethane foams [9-12], three types of hand-poured foams containing expandable graphite as flame retardant [13] were prepared: PUR FRM S1, PUR FRM S2 and PUR FRM S3.

The study began with the determination of the MARHE parameter. Fig. 1 presents an example diagram of the heat release rate for one of the tested samples, showing the course of combustion in a cone calorimeter. However, the obtained results of MARHE in the form of a diagram were placed in Fig. 2. Tests made using a cone calorimeter have shown that the non-graphite foams (DB1, DB2, DB3) flamelessly melt during the measurement and emitted little heat (MARHE below 5 kW/m^2). On the contrary, graphite foams (FRM S1, FRM S2 and FRM S3) revealed MARHE at the level of (42-45) kW/m^2. The above means that too large additions of expandable graphite were used, which, as demonstrated by the parallel physical and mechanical tests, also deteriorated the static and fatigue mechanical properties of these foams.

However, in order to indicate the direction of further investigation, the effect of various fireblocker materials on all the above-mentioned polyurethane foams was evaluated. The following fireproof nonwovens were selected to the evaluation:

- BWF Protec type SFO from preoxided fibers with the weight of 150 g/m^2,
- DARA type ZWFR made of para-aramid and viscose fibers with the weight of 106 g/m^2,
- Duflot type WSM 132D from a mixture of polyacrylic, polyacrylonitrile and paraamide fibers with the weight of 250 g/m^2.

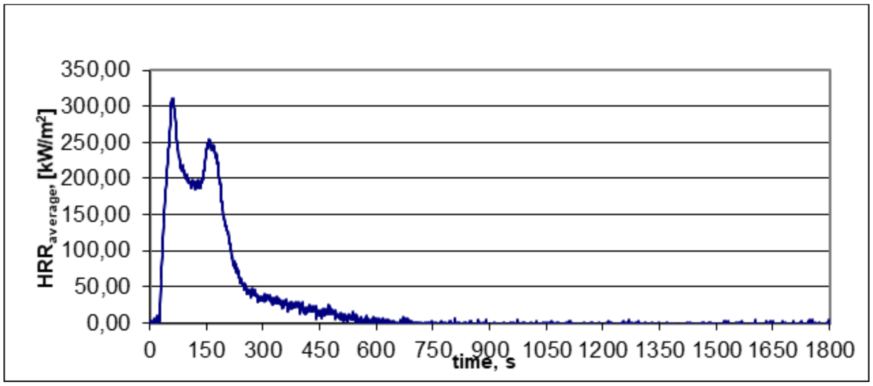

Fig.1 An example of the HRR (Heat Release Rate) chart for the FRM S1 foam.

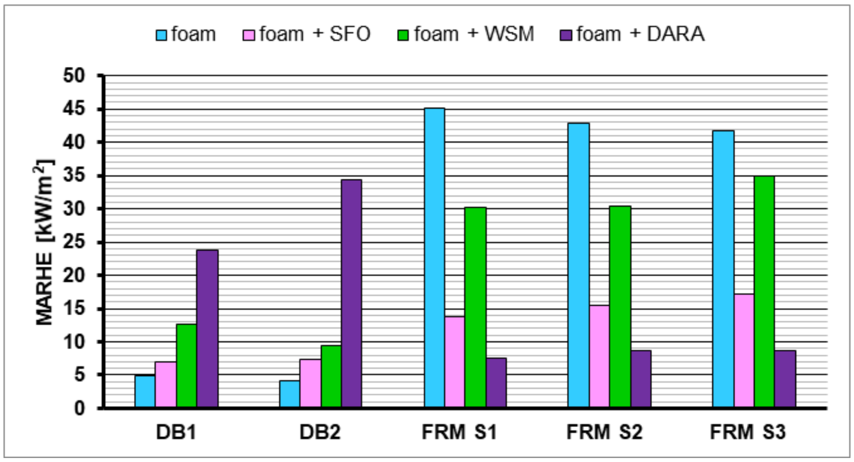

Fig.2 MARHE values for the PUR foams and foam sets with various fireproof nonwovens.

The use of nonwovens caused different behavior of the systems, depending on the type of foam applied in them. In the case of non-graphite foams, non-woven fibers from preoxidated fibers (SFO) and from a mixture of polyacrylic, polyacrylonitrile and paraamide fibers (WSM 132D) caused a slight increase in heat emission. However, the system protected with a nonwoven fabric made of paraaramid and viscose fibers (DARA-ZWFR) generated much more heat than the other systems. In connection with the above, for the examination of the full upholstery system, including the upholstery fabric, the DB1 foam was selected in a system with a SFO fire-resistant non-woven fabric made of preoxidized fibers.

However, systems with graphite foams behaved differently. In that case, MARHE values for all the systems were lower than for the foams alone. At the same time, the best results occurred for the paraaramid and viscose fiber spacers (DARA-ZWFR), due to which the MARHE value decreased about five times to the level of (7-9) kW/m^2. Non-woven fibers from preoxidated fibers (SFO) reduced the amount of heat released to the level (13-17) kW/m^2, and those made of a mixture of polyacrylic, polyacrylonitrile and paraamide fibers (WSM 132D) - to the level of (30-34) kW/m^2. On the basis of the above results, for testing of the full upholstery system of graphite foam together with upholstery fabric, a DARA-ZWFR fireproof nonwoven fabric made of para-aramid and viscose fibers was selected. Wherein, the Industrial Partner provided for testing a modified version of the foam, marked as the FRC.

Each of the two foam-nonwoven sets selected above was subjected to the tests of full upholstery systems in connection with the following upholstery fabrics:

- 100% trewira, Quadrat art. 14460, by Schoeppf, (Germany)

- 80% wool and 20% polyamide, manufactured by Runotex (Poland),
- 30% wool and 70% polyester, produced by Kneitz (Austria).

The results obtained are shown in Figures 3-5, where the following determinations of the systems studied were used:

1 - DB – SFO – Kneitz,
2 - DB - SFO – Schoeppf,
3 - DB – SFO – Runotex,
4 - FRC - DARA – Kneitz,
5 - FRC - DARA – Schoeppf,
6 - FRC - DARA – Runotex.

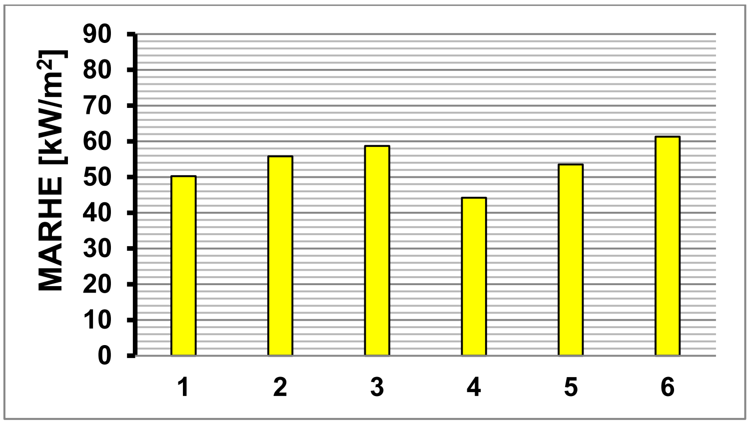

Fig.3 MARHE values for upholstery systems (foam - fireproof nonwoven - upholstery fabric).

As can be seen from the chart (Fig. 3), fulfillment of MARHE parameter requirements for hazard category HL3 (MARHE < 50 kW/m^2) was obtained only for upholstery consisting of the FRC foam, DARA / ZWFR 107 nonwoven (mixture of paraaramid and viscose fibers) and Kneitz upholstery (30 % wool and 70% polyester). In that case, the value was 44.2 kW/m^2. However, the value at the limit of the requirements for HL3 for this parameter reached the following layout: DB-free foam, SFO non-woven fiber from preoxidized fibers and above - Kneitz upholstery fabric (30% wool and 70% polyester).

Further, for all the six variants of the upholstery system, tests of smoke properties and toxicity were carried out. The results are shown in diagrams (Fig. 4 and 5).

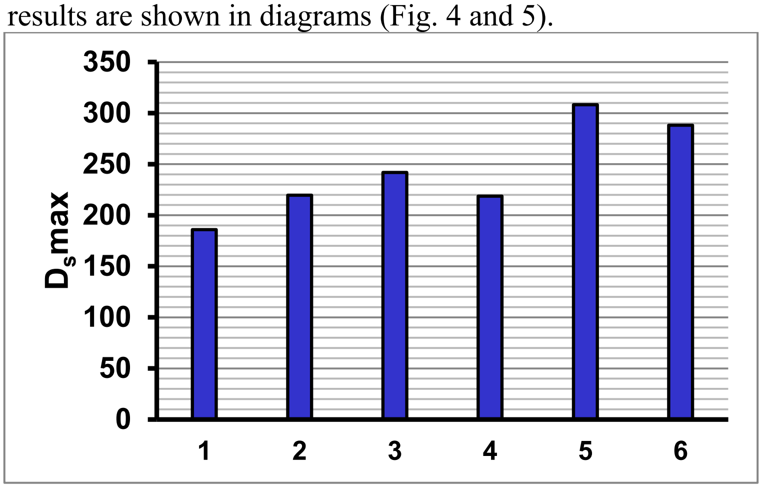

Fig.4 $D_s$max values for upholstery systems (foam - fireproof nonwoven - upholstery fabric).

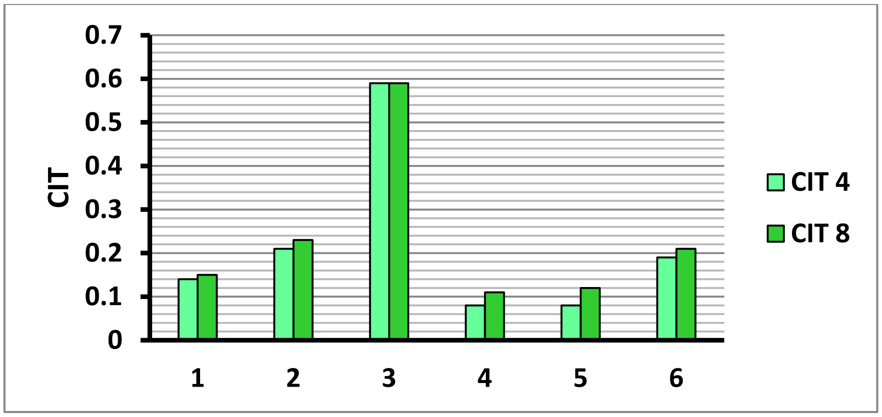

Fig.5 CIT_G (4) and CIT_G (8) for upholstery systems (foam - fireproof nonwoven - upholstery fabric).

As results from the analysis of all the obtained results for upholstery systems, the following two systems were considered the best to be subject to further modification:

- FRC graphite foam, DARA-ZWFR 107 nonwoven, upholstery 30% wool and 70% polyester, Kneitz production (values: MARHE - 44.2 kW/m^2, $D_s$max - 218.7, CIT (4) - 0.08 and CIT (8) - 0.11,
- DB foam, SFO nonwoven, upholstery fabric 30% wool and 70% polyester, Kneitz production (values: MARHE - 50.25 kW/m^2, $D_s$max - 185.9, CIT (4) - 0.14 and CIT (8) - 0.15.

However, because during a fire the greatest threat is created by smoke limiting visibility and hindering the conduct of rescue and extinguishing operations as well as often causing panic, the properties of the upholstery system with non-graphite foam should be considered as better.

Summary

1. The combustion tests using a conical calorimeter showed the following:
   – for standard polyurethane foams, the best MARHE results when protected with a pre-oxidised fiber, the values being higher than for the foam itself,
   – for polyurethane foams with expandable graphite, the best MARHE results when protected with a nonwoven made from a mixture of para-aramid and viscose fibers - the MARHE value was reduced five times in relation to the level of this parameter for the foam itself.
2. Studies on various variants of upholstery systems have shown that the best results have been achieved for the following two systems:
   – graphite foam FRC, fire-retardant material (mixture of paraaramid and viscose fibers), upholstery fabric (30% wool and 70%, polyester),
   – for DB foam, non-woven (preoxidized fiber, upholstery fabric (30% wool and 70% polyester).

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