Influence of the Ignition Source on Passenger Seat Burning

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Summary
The paper describes the results of first stage of studies conducted in the framework of a project funded by Railway Institute. The first stage of the work refers to tests on the furniture calorimeter according to the draft of the new European standard constituting a modification of the method according to EN 45545-2: 201. Above tests performed on different upholstered passenger seats, which met the PN and the UIC fire requirements, showed that none of the standard seats mets current requirement MARHE for HL3 category. Next part presents the results of research on the furniture calorimeter using different ignition sources (paper bag, travel bag, gas burner) with a power of 7 kW to 67 kW. Results showed that, for the MARHE, HRR and TSP a logarithmic increase in value with the increase of the power sources of ignition was achieved. At the same time it was found that the maximum values of HRR and TSP occurred in less than 4 minutes after seat ignition, which is a very important time for the evacuation of passengers.

Keywords: fire protection, passenger rolling stock, heat release rate, travel bag, furniture calorimeter, EN 45545-2

1. Introduction

Topics concerning fire safety in rail traffic have been taken in a number of research works and simulation projects in Europe and other countries. At the same time, as is demonstrated by analysis of laboratory tests and numerical considerations a variety of sources of ignition and/or a variety fire size was assumed, which resulted in obtaining highly divergent results.

For example, Sanchez and Kwok of Hyder Consulting Ltd in Hong Kong [1] carried out simulation of ventilation requirements for the railway tunnel for two variants of heat release during a fire train (6 MW and 10 MW). Luo and Yau of Ove Arup & Partners in Hong Kong [2] described scenarios for passenger evacuation in a fire in a tunnel, developed assuming the total amount of heat generated in the range 12–17 MW.

G. Duggan in Duggan's method for estimating fire development for flashover scenarios, with fire spread to an entire carriage interior, reached 5 MW of fire size [3] – using summation of heat release rates of each individual interior materials in his calculation.

In EUREKA project, fire sizes for the metro carriages were calculated by number of researchers, using various techniques. The results ranged from 15–20 MW [4] and 24 MW [5] to 35 MW [6].

In fire hazard analysis performed by NSTIR [7] the results of full-scale passenger rail car tests with an ignition power of 17–25 kW and 200kW were used. Once ignited the heat release rate of the seating ranged from approximately 100 kW to 350 kW in the FIRESTAR project [8].

Tests carried out by Mia Kumm showed, that different passenger bags in metro and commuter trains of Stockholm in short time develops (50–850) kW of HRR [9]

Jie Zhu Xiao Ju Li Cheng Feng Mie showed in their study for double seats of high speed China train, that with an ignition power of 100 kW, the THR was higher than the THR with an ignition power of 20 kW [10].

M. Łukomski and G. Sztarbała confirm that modern computer methods also require the appropriate database , too, and obtained simulation results should be verified by laboratory tests [11].

Therefore, taking into account that the initial conditions often determine the course of the whole phenomenon, studies were undertaken to determine the effect of ignition sources on the development and consequences of the process of burning passenger seat used in Polish trains. These items constitute a significant mass of non-metallic materials in the vehicle and are also subject to arson attack.

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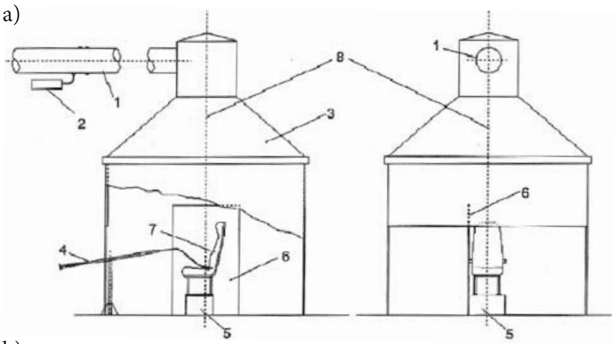
2. Laboratory tests

Laboratory tests were performed with use of the furniture calorimeter according to ISO/TR 9705-2 [12] with regard to changes in prEN 16989 [13] in the framework of the European Working Group CEN/TC256/WG1 TF Seats. The scheme of the test stand and its general view is shown in Fig. 1.

a)



b)

Fig. 1. Furniture calorimeter: a) Complete Seat Test Metod Schematic [2]: 1) exhaust duct, 2) exhaust duct instrumentation, 3) hood and side sheets, 4) burner, 5.) seat support, 6) side panel, 7) seat, 8) vertical axis of the hood; b) General view of test stand [Source: Archives of Laboratory]

2.1. Tests according to new proposal of EN Standard on different types of passenger seats

In the first stage of the work we carried out tests according to the draft of the European standard prEN 16989 [13], constituting a modification of the method according to EN 45545-2: 2013 [14] Annex B. The aim of the work was to compare the results obtained by proposals of new European requirements with existing Polish requirements.

As the ignition source used in accordance with the above-mentioned draft standard, modified gas burner with a capacity of (15±2) kW was used. The burner was flamed after 60 seconds from switch on the stopwatch and after a further 60 seconds (for the flame stabilization), lowered onto the seat. Contact time of the burner with the surface of the seat was 3 min (from 121s to 300s of the test time). In the study, the following data were recorded and calculated:

- Heat Release (peak of Heat Release Rate – HRR_{peak} [kW], Total Heat Release – THR [MJ]).
- Smoke Production (Total Smoke Production – TSP [m^2], Smoke Production Rate – SPR [m^2/s]).
- MARHE (Maximum Average of Rate Heat Emmission) [kW].
- Tests were performed on 8 different upholstered passenger seats, which met the requirements of PN: K-02502:1992 [15] and the UIC 564-2 Annex 13 [16]. The seats numbered A117/15 (standard version) and A118/15 (the seat A117/15 in vandalproof version) and A227/15 (standard version) and A228/15 (the seat A227/15 in vandalproof version) were specially purchased for implementation in this project. The remaining seats were archival objects of our Laboratory, produced in 2013–2015. All the seats had upholstery filled with polyurethane foam with various additives and thickness of 4–6 cm. Padding was a plush fabric with different contents of wool and polyamide.

Table 1

Results of the fire test of different passenger seats using gas burner 15kW/3 min

No		MARHE [kW]	HRR_{Peak}[kW]	Time of HRR_{Peak}[s]	THR [MJ]	THR_{10min} [MJ[	TSP [m^2]
Standard seats							
1	**A46/13**	23,60	27,89	162	5,3	5,2	33,6
2	**A381/13**	24,89	30,55	213	6,0	5,7	41,3
3	**A227/15**	23,73	27,10	210	5,9	5,7	86,8
4	**A117/15**	25,97	32,18	168	6,0	5,9	67,3
5	**A366/13**	21,18	24,91	159	5,2	4,9	29,0
Antivandal seats							

[Source : own]

- The tests were done on 2 or 3 seats of the same type, dependent on availability. However, high repeatability of recorded values was achieved.
- Sample photos are shown in Fig. 2, while the statement of the average final results could be find in Table 1.

Fig. 2. Different types of passenger seats tested according to new proposal of EN standard: a) seat No A46/13, b) seat No A381/13, c) seat No A227/15, d) seat No A117/15, e) seat No 366/13, f) seat No A87/16, g) seat No A228/15, h) seat No A118/15 [Source: Archives of Laboratory]

Fire tests for seats that meet the requirements of PN and UIC, carried out according to EN draft revised test method, showed that:

- None of the seats produced in the standard version (tested with a cut fabric upholstery) meets current requirement MARHE for HL3 category, amounting to ≤20 kW.
- Two seats produced in antivandal version revealed value MARHE <20 kW. However, those seats had emitted in the burning process more smoke than the standard seats version, due to the properties of upholstery fabrics.

2.2. Tests with different types of ignition sources

Taking into account that the ignition models 1 and 2 (simulating arson) and 3 (of developed stage) as described in EN 4545-1 [4], Annex A, as well as the literature analysis [1, 3, 9–10, 15] we decided, in this stage of the project, to use as sources of ignition paper cushion, a gas burner and travel bag in the following configurations:

- cushion of 100 g paper according to UIC Code 564-2 Appendix 13 [18] and PN:K-02502:1992 [13],
- gas burner of 7 kW applied by 3 min according to EN 45545-2:2013 [5] Appendix B,
- gas burner of 15 kW applied by 3 min according to prEN 16989 [14],
- gas burner of 25 kW applied by 3 min,
- gas burner of 50 kW applied by 3 min,
- travel bag ignited by paper cushion according to ARGE Guideline – Part 2 [1],
- travel bag ignited by gas burner of 25 kW applied by 90 s according to [15],
- 2 travel bags ignited by gas burner of 25 kW applied by 90 s.

The content of travel bag was assumed similar to that used in ARGE Guideline – Part 2 [1] and shown in Fig. 3 and in Table 2. Fig. 4 shows exemplary images from the tests, while in Table 3 – obtained characteristics of the different sources of ignition sorted by ascending values of MARHE (from about 7 to 67 kW) are given. THR maximum value reached of 90 M for two travel bags ignited by gas burner of 25 kW applied by 90 s.

Table 2

Content of travel bag (similar to ARGE Guideline – Part 2)

No	Content (material)	Quantity	Average mass [g]
1	Bag (100% poliester)	1	320
2	Sweater (100% akrylate)	1	475
3	Hand towel (100% cotton)	1	147
4	Bath towel (100% cotton)	1	549
5	T-shirt (100% cotton)	3	374
6	Pair of socks (100% cotton)	3	84
7	Toilet bag (100% poliester)	1	33
8	Toothpaste	1	106
9	Tooth mug (100% polietylen)	1	33
10	Toothbrush	1	15
11	Soapbox	1	35
12	Soap	1	98
13	Journal 1	1	375
14	Journal 2	1	209
15	Slippers (rubber, poliester, cotton)	1	83
16	Standard wood (100% pine)	1	319
	Total mass		**3255**

[Source: own]

a)

b)

Fig. 3. Ignition source: a) small travel bag, b) content of travel bag [source: archives of Laboratory]

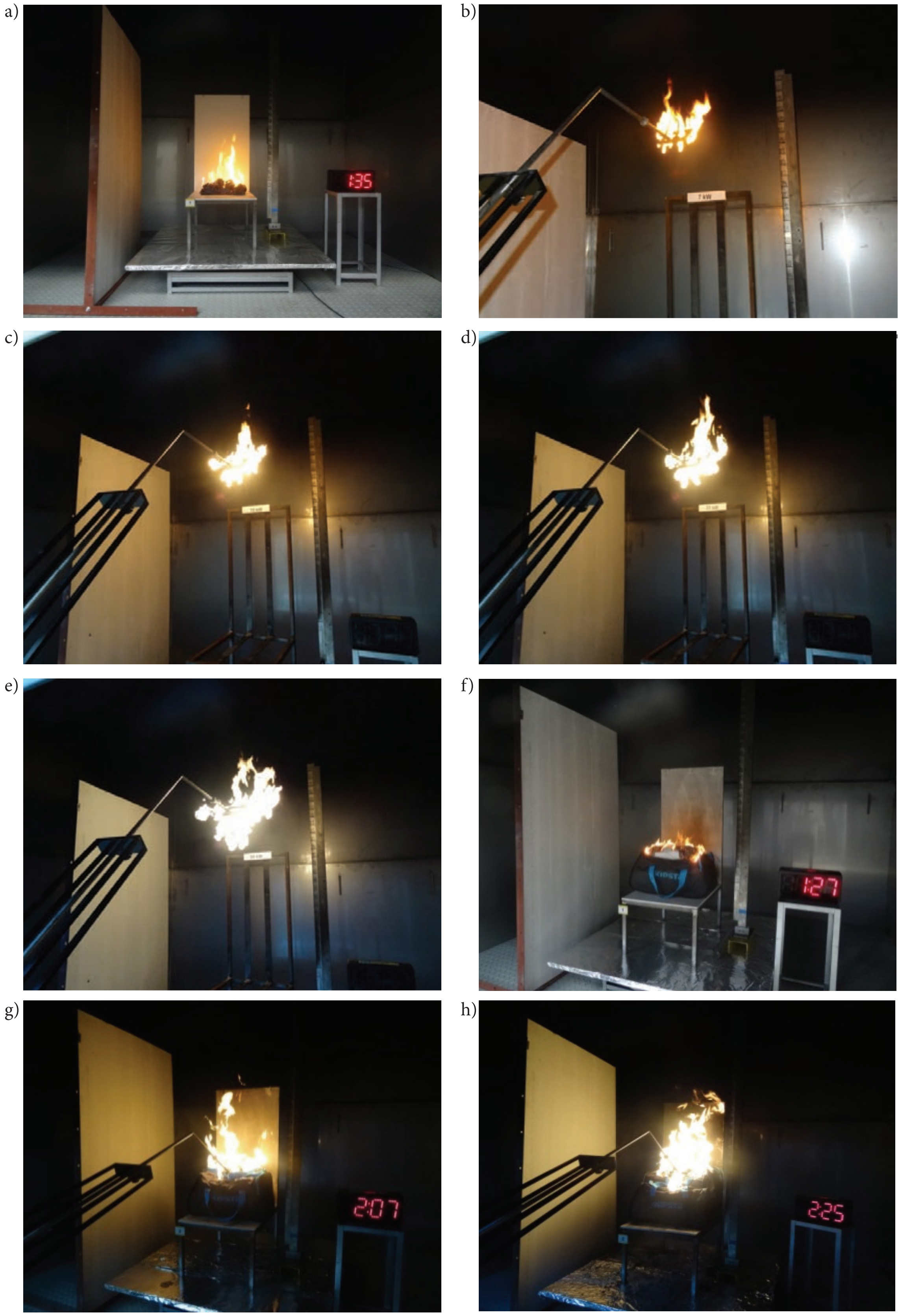


Fig. 4. Different types of ignition sources: a) paper cushion (according to UIC 564-2 and PN-K-02502:1992), b) gas burner 7 kW, c) gas burner 15 kW, d) gas burner 25 kW, e) gas burner 50 kW, f) small travel bag ignited by paper cushion, g) travel bag ignited by gas burner of 25 kW/90 s, h) 2 travel bags ignited by gas burner of 25 kW/90 s. [Source: Archives of Laboratory]

Fig. 5. Tests with different types of ignition sources. Seats ignited by: a) paper cushion (according to UIC 564-2 and PN-K-02502:1992), b) gas burner 7 kW, c) gas burner 15 kW, d) gas burner 25 kW, e) gas burner 50 kW, f) small travel bag ignited by paper cushion, g) travel bag ignited by gas burner of 25 kW/90 s, h) 2 travel bags ignited by gas burner of 25 kW/90 s. [source: Archives of Laboratory]

Table 3

Parameters of ignition sources

No	Ignition source	MARHE [kW]	HRR_{Peak} [kW]	THR [MJ]	TSP [m²]
1	**Gas burner of 7 kW/3 min**	7,0	8,7	1,7	1,7
2	**Paper cushion**	8,2	14,8	1,1	0,53
3	**Gas burner of 15 kW/3 min**	15,0	16,48	2,7	1,9
4	**Gas burner of 25 kW/3min**	25,0	27,58	5,1	1,5
5	**Travel bag ignited by paper cushion**	45,3	74,7	26,1	161,5
6	**Gas burner of 50 kW / 3 min**	50,0	53,1	10,8	1,3
7	**Travel bag ignited by gas burner of 25 kW/90 s**	54,7	71,57	24,3	106,4
8	**Two travel bags ignited by gas burner of 25 kW/90 s**	67,6	90,47	49,9	150,8

[Source: own]

One type of standard passenger upholstered seat designed to Class 1 was used in the study. Filling of the upholstery was a polyurethane foam, covered by the pile fabric composed of 80% wool and 20% polyamide. Headboard was covered with eco leather. Fig. 5 shows exemplary photos of test seats with each type of ignition source. Table 4 presents a summary of research results. At the same time Fig. 6 shows the average waveform HRR recorded during the tests. Figure 7 shows the distribution of the HRR_{peak} and MARHE, depending on the ignition source, and Fig. 8 shows the values of HRR_{peak} and MARHE reduced by the value emitted by the ignition sources used. The following graphs (Fig. 9, 10, 11) show analogous values obtained for the TSP.

Table 4

Results of the fire test of passenger seat using different ignition sources

No	Ignition source	MARHE [kW]	HRR_{Peak} [kW]	T of HRR_{Peak} [s]	THR [MJ]	THR_{10min} [MJ]	TSP [m²]
1	**Gas burner of 7 kW/3 min**	9,72	11,9	259	2,4	2,3	20,7
2	**Paper cushion**	9,26	11,1	95	1,4	1,4	14,6
3	**Gas burner of 15 kW/3 min**	25,97	32,2	168	6,0	5,9	67,3
4	**Gas burner of 25 kW/3min**	42,00	50,2	168	9,8	9,2	103,3
5	**Travel bag ignited by paper cushion**	76,80	123,0	186	32,8	26,0	325,6
6	**Gas burner of 50 kW/3 min**	84,18	109,0	162	18,2	18,2	182,2
7	**Travel bag ignited by gas burner of 25 kW/90 s**	89,97	152,4	201	46,3	31,4	534,0
8	**Two travel bags ignited by gas burner of 25 kW/90 s**	113,46	169,4	309	73,8	49,9	423,4

[Source: own]

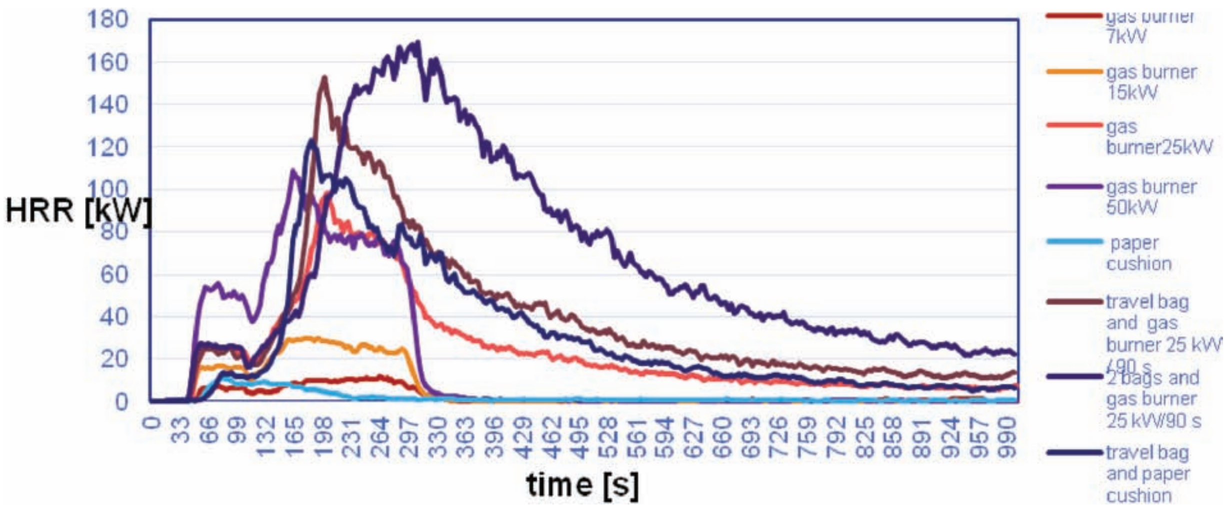


Fig. 6. HRR results for tested seats No A117/15 [source: own]

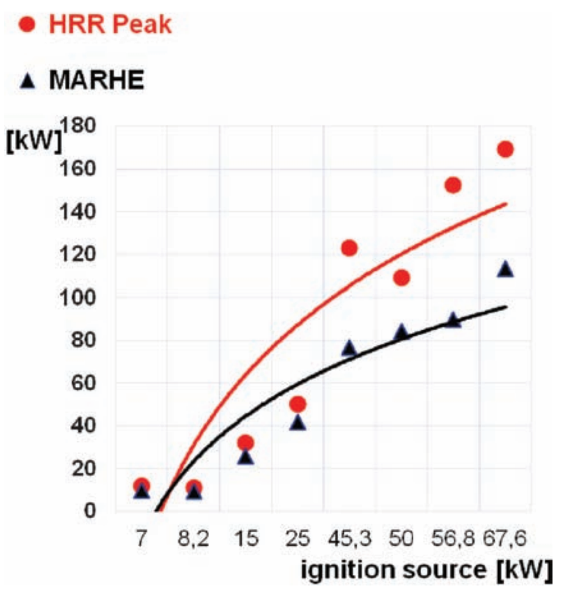


Fig. 7. MARHE and HRR_{Peak} results for tested seats No A117/15 [source: own]

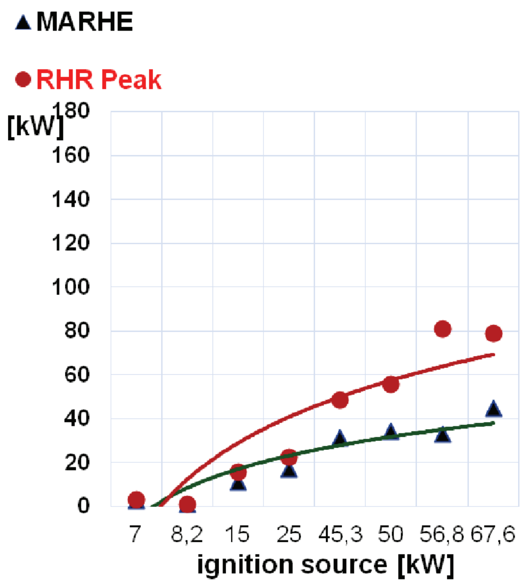


Fig. 8. MARHE and HRR_{Peak} results for tested seats reduced of values caused by the ignition source [source: own]

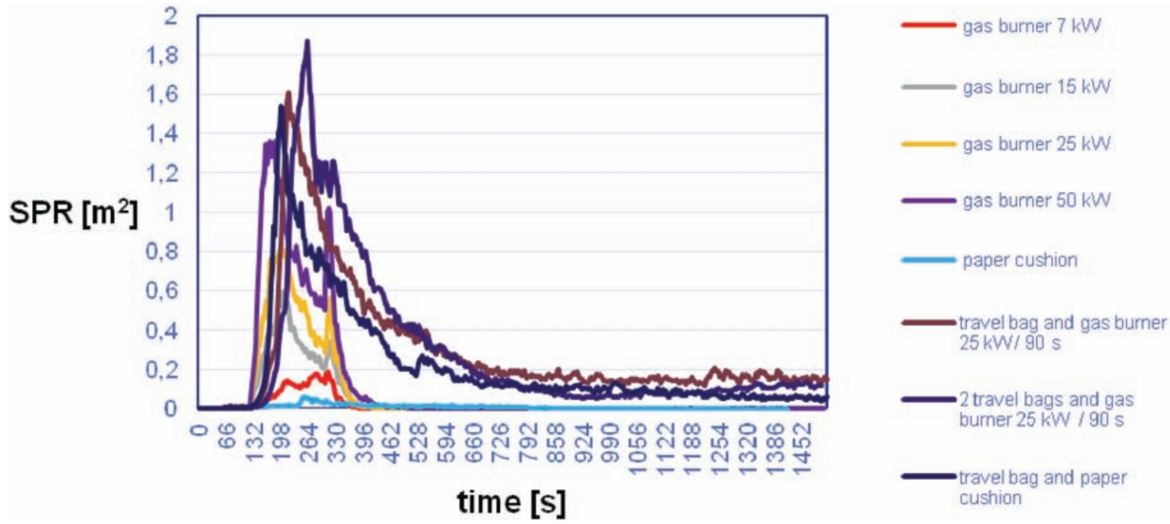


Fig. 9. TSP results for tested seats No117/15 [source: own]

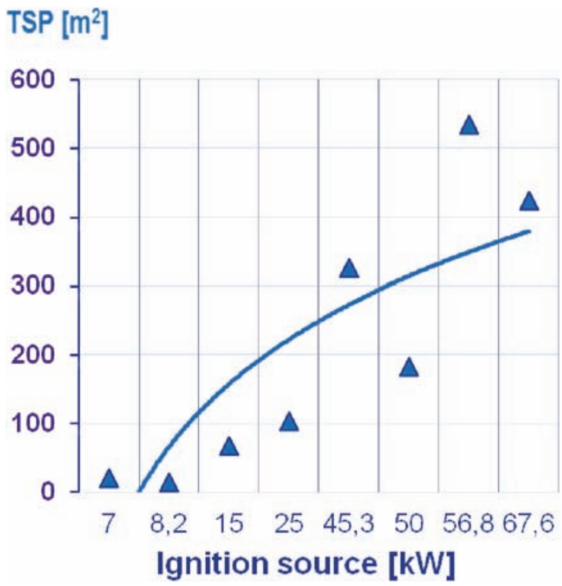


Fig. 10. TSP results for tested seats No117/15 [source: own]

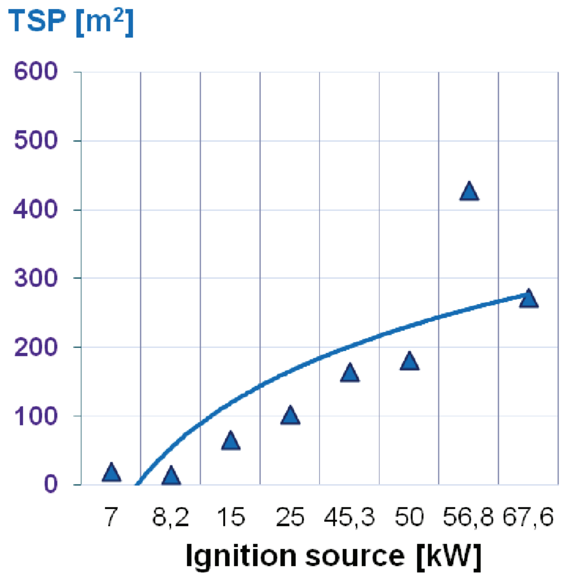


Fig. 11. TSP results for tested seats No117/15 reduced of values caused by the ignition source [source: own]

Analysis of burning process of objects for different sources of ignition and recorded waveforms shown in Figure 6 and 9 demonstrates that in all cases the maximum values of HRR and TSP occurred in less than 4 minutes after seat ignition. However, according to the requirements of EN 45545-1 [4] for vehicles traveling on sections of underground tunnels and / or on flyovers, time to get to the place of safety in case of fire should be 4 minutes for operating categories 2 and 4, and 15 min for operating category 3. For above periods of time passengers and crew should be protected in safe conditions in the vehicle.

At the same time, for testing using the travel bag, the combustion process lasted much longer than for the other sources of ignition. For the parameters shown in Figure 7, 8, 10 and 11, a logarithmic increase of value was achieved with the increase of the ignition source power.

3. Summary and conclusions

Results of current research allow to formulate the following conclusions:

1. Increase of the ignition source power, regardless of its type (paper cushion, gas burner, travel bag) causes increasing of the seat burning intensity, characterized by the thermal power increase (MARHE increased from about 9 kW to about 113 kW). And with the increase of the burning process intensity, the emission of smoke increases (TSP value up to 534 m^2).
2. For the MARHE, HRR and TSP a logarithmic increase in value with the increase of the power sources of ignition was achieved.
3. The maximum values of HRR and TSP occurred in less than 4 minutes after seat ignition.
4. Continuation of tests, with use of ignition source with greater power (100 kW), as well as realization of comprehensive result analysis, particularly in terms of their impact on the conditions of evacuation of a train with a fire on board, will be performed as a next step of the project.

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Wpływ źródła zapłonu na spalanie siedzenia pasażerskiego

Streszczenie

Artykuł opisuje wyniki badań przeprowadzonych w pierwszym etapie projektu finansowanego ze środków Instytutu Kolejnictwa. Pierwszy etap pracy dotyczy badań na kalorymetrze meblowym według projektu nowej normy europejskiej, stanowiącej modyfikację metody badawczej według EN 45545-2: 2013. Testy wykonane dla różnych tapicerowanych foteli, spełniających wymagania ogniowe PN oraz UIC wykazały, że żaden ze standardowych foteli nie spełnia aktualnych wymagań parametru MARHE dla kategorii HL3. Przedstawiono wyniki badań na kalorymetrze meblowym przy zastosowaniu różnych źródeł zapłonu (poduszka papierowa, torba podróżnego, palnik gazowy) o mocy od 7 kW do 67 kW. Wykazały one logarytmiczny wzrost parametrów MARHE, HRR oraz TSP wraz ze wzrostem mocy źródła zapłonu. Jednocześnie stwierdzono, że maksymalne wartości HRR i TSP wystąpiły w czasie krótszym niż 4 min od zapłonu fotela, czyli w czasie bardzo istotnym dla ewakuacji pasażerów.

Słowa kluczowe: ochrona przeciwpożarowa, tabor pasażerski, szybkość wydzielania ciepła, bagaż podróżnego, kalorymetr meblowy, EN 45545-2

Влияние источника зажигания на сжигание пассажирского сидения

Резюме
В статье описаны результаты исследований проведенных в рамках первого этапа проекта финансируемого из средств Железнодорожного института. Первый этап работы касался исследований на мебельном калориметре согласно проекту новой Европейской нормы, являющейся модификацией метода исследований согласно норме EN 45545-2: 2013. Вышеуказанные тесты проведены на разных подбитых сидениях, соответствующим требованиям на огнестойкость польской нормы PN и UIC показали, что никакой из стандартных сидений не соответствует действующим требованиям параметра максимального среднего теплоизлучения (MARHE), для категории HL3. В дальнейшем были представлены результаты исследований на мебельном калориметре при употреблении разных источников зажигания (бумажная подушка, багаж пассажира, газовая горелка) мощностью 7 кВ до 67 кВ. Они показали логарифимический рост параметров MARHE, скорости выделения теплоты (HRR) и общего выпуска дыма (TSP) вместе с ростом мощности источника зажигания. Одновременно было установлено, что максимальные значение HRR и TSP выступали в течение времени короче 4 мин с момента зажигания сидения, то есть в участок времени очень важный для эвакуации пассажиров.

Ключевые сдова: противопожарная защита, пассажирский подвижной состав, скорость выделения тепла, багаж пассажира, мебельной калориметр, EN 45545-2