fire

MDPI

Article

Review of Fire Tests on Seats for Passenger Coaches and the Materials Used in Them

Dieter Hohenwarter

Federal Testing Institute TGM, Department of Plastics Technology and Environmental Engineering, Fire Test Laboratory and Laboratory of Polymer Engineering LKT, Wexstrasse 19-23, A 1200 Vienna, Austria; dhohenwarter@tgm.ac.at

Abstract: This study shows how the fire regulations for railway seats used in international traffic have changed over the last 30 years. In the past, a paper cushion was used as a flame source, and today, a 15 kW burner is used; consequently, the requirements have increased. In the paper cushion test, a foam with a density of between 60 and 95 kg/m^3, a flame-retardant fleece, and a cover fabric was usually sufficient in terms of fire safety. Today, a high-quality flame-retardant foam is necessary to meet the requirements for flaming with the 15 kW burner. Two comparable seat structures show very different heat release and smoke formation in the paper cushion test due to different foam additives. If high-quality flame-retardant foams with a cover fabric are used for the 15 kW flame treatment, the results of the two test institutes show good agreement. If the seats that meet the requirements of the paper cushion test are flamed using the 15 kW treatment, they can catch fire and thus exhibit very different heat release rates, as the CERTIFER interlaboratory test with 12 participating test institutes shows. The heat release of old and new leather was examined, and it was found that the flame retardant applied to the leather surface appeared to have aged over the years and that the flame retardant was therefore no longer effective. The heat release of flame-retardant foams with a cover fabric was measured using irradiation with a cone calorimeter and flame treatment. Very different curves were observed, which means that it is not possible to draw simple conclusions about the heat release during flame treatment from the cone measurement.

Keywords: fire tests of railway seats; paper cushion fire test; aging of flame-retardant leather; seat fire tests with flame treatment; comparison of railway seat fire tests

check for updates

Academic Editors: Long Yan, Xuebao Wang and Yachao Wang

Received: 11 December 2024
Revised: 13 January 2025
Accepted: 14 January 2025
Published: 17 January 2025

Citation: Hohenwarter, D. Review of Fire Tests on Seats for Passenger Coaches and the Materials Used in Them. *Fire* **2025**, *8*, 32. https://doi.org/10.3390/fire8010032

Copyright: © 2025 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The fire behavior of seats in rail vehicles significantly determines the overall fire behavior of the rail vehicles; therefore, this behavior is considered in this study. The fire behavior of seats in rail vehicles and seats, in general, has received surprisingly little attention in scientific publications. Babrauskas and Grayson [1] pointed out that the fire behavior of upholstered furniture is determined by the fact that one or more thin surface layers lie over a very thick foam layer and that these individual layers show very different fire behavior. A book edited by J. Troitzsch and E. Antonatus [2] describes the technical fire properties of textiles and the flame retardants commonly used for textiles.

The flame retardancy of expandable graphite, ammonium polyphosphate, and alginate as coatings for polyurethane (PU) foam was investigated in detail in a recently published study that used aircraft cabin materials as an application case [3]. In [4], the flame resistance performance of thin silicon pads for application in the railway industry was examined. The

fire characteristics of upholstery material in seats for apartments or hotels containing a smoldering cigarette or a gas burner (equivalent to a match or a small open flame) were examined, and various seat upholstery fabrics were considered [5,6]. In addition to these two fire tests with low load or power, the Federation of the European Union Fire Officer Association (FEU) also recommends open flame ignition by a wooden crib to investigate the fire safety of upholstered furniture and mattresses in the domestic area [7].

In a study titled Numerical Investigations on the Propagation of Fire in a Railway Carriage, it is mentioned that the fire behavior of the seat cover materials is a very important parameter for the spread of flames in the railway carriage [8].

The fire behavior of railway equipment materials and railway seats was also presented in a paper published in 2016 [9]. In [9], it was shown that a flame-retardant fleece glued to the foam of the seat and possibly to the lower part of the backrest was an effective measure to improve the fire behavior of the seat in the paper cushion test. Five different types of foam with a textile cover layer were tested, and one foam caught fire; four foams passed the paper cushion test. It was shown that only foams with a density of 60 kg/m^3 or more met the fire safety requirements of the paper cushion test. The foams with a density range between 60 and 90 or 95 kg/m^3 very often met the fire safety requirements of the paper cushion test.

This study investigates the historical development of the regulations for the fire testing of railroad seats. Fire tests were conducted using the application of a 15 kW flame, and the results from a round-robin test involving 12 test centers are presented. For these reasons, the study is referred to as a review paper.

Changes in Fire Testing Regulations for Railway Seats over Time

Table 1 shows the changes in fire test regulations for seats in rail vehicles from 1991 to 2023. Unfortunately, the test regulations from before 1991 are not available.

Table 1. Regulations for the testing of seats in rail vehicles.

Regulations	Flaming Method	Fume Extraction	Fire Behavior Requirements	Smoke Development Requirements
UIC 564-2: 1991, Anlage 13, [10]	Paper cushion with 100 g newsprint, dried for 3 h at 70 °C	Test in a closed draught-free room	Burning time ≤10 min; no burning parts are allowed to fall off	--
E DIN 5510-2: 1996, [11] DIN 54341: 1988 [12]	Paper cushion with 100 g newsprint, conditioned for 24 h at 23 °C and 50% relative humidity	Draught-free room; the resulting smoke is extracted	Burning time ≤15 min, flame height ≤ 100 cm; side edge must not be reached	--
E DIN 5510-2: 2003 [13]	Paper cushion with 100 g standard paper, conditioned for 24 h at 23 °C and 50% relative humidity	Resulting smoke is extracted	Burning time ≤15 min, flame height ≤ 100 cm; side edge must not be reached	--
E DIN 5510-2: 2007 [14]	Paper cushion with 100 g standard paper, conditioned for 24 h at 23 °C and 50% relative humidity	Exhaust air flow (0.6 ± 0.1) m^3/s	Burning time ≤15 min, flame height ≤ 100 cm; side edge must not be reached	Total smoke production ≤ 60 m^2; smoke gas toxicity acc. EN ISO 5659-2 [15]
DIN 5510-2: 2009 [16]	Paper cushion with 100 g standard paper, conditioned for 24 h at 23 °C and 50% relative humidity	Exhaust air flow (0.6 ± 0.1) m^3/s	Burning time ≤15 min, flame height ≤ 100 cm; side edge must not be reached	Total smoke production TSP ≤ 60 m^2; smoke gas toxicity acc. EN ISO 5659-2

Table 1. *Cont.*

Regulations	Flaming Method	Fume Extraction	Fire Behavior Requirements	Smoke Development Requirements
EN 45545-2: 2016 [17]	Square burner, power (7 ± 1) kW, flame exposure time 180 s	Exhaust air flow (0.60 ± 0.05) m^3/s	HL1/HL2/HL3 ISO/TR 9705-2 [18] MARHE ≤75/≤50/≤20 kW RHR Peak ≤350/≤350/≤350 kW	--
EN 45545-2: 2020 [19] EN 16 989: 2018 [20]	Square burner, power (15 ± 3) kW, flame exposure time 180 s	Exhaust air flow (1.20 ± 0.05) m^3/s	HL1/HL2/HL3 MARHE ≤80/≤55/≤25 kW Flame height -/≤1180/≤1180 mm	HL1/HL2/HL3 TSP_{600} F-/-/≤60 m^2
EN 45545-2: 2023 [21], EN 16989: 2018 [20]: same values as EN 45545-2: 2020 [19]				

The UIC regulations [10] only refer to newsprint; later, the DIN regulations precisely defined the paper to be used in fire tests. From the UIC guidelines (1991) to DIN 5510-2: 2009, (DIN corresponds to Germany Industry Standard), the paper cushion, was always used, but in the beginning, only the generated smoke was extracted. In 2009, an extraction speed of 0.6 m^3/s was used; this corresponded to the reality of the ventilation systems, and it led to the tightening of the requirements for the seats.

The regulations require that the paper cushion with 100 g of paper on a mineral base should burn for 2.5 ± 0.5 min. Assuming that the paper has a calorific value of 17.6 MJ/kg, the resulting heat output is 14.7 to 9.8 kW, with a burning time of 2 to 3 min. According to EN 45545-2: 2020 [19], seats tested according to EN 16 989: 2018 [20] are to be flamed for 3 min, with a flame output of 15 kW. In terms of flame output, the two tests match each other well, but with the burner used according to EN 16 989 [20], the flames act downwards, while with the paper cushion the flames are visible at the top.

The burner was introduced instead of flaming using a paper cushion because the international opinion was that the paper cushion did not deliver comparable results. According to EN 45545-2:2016 [17], flaming with a 7 kW burner was intended; in the later separate seat test standard (EN 16989:2018 [20]), the flaming power was increased to 15 kW. Standard EN 45545:2020 [19] also specifies limit values for the flame treatment of seats in rail vehicles.

Tests in 2004, for example, showed that four out of five foams with a density of between 60 and 90 kg/m^3 with a cover fabric passed the test specifications at the time [9]. One foam showed an interaction between the foam and the upholstery fabric; consequently, the foam failed the test. At that time, only the resulting smoke was extracted. When extraction at 0.6 m^3/s was added after 2007 [14], the foams on the seat surface frequently had to be fitted with a fire protection fleece to pass the paper cushion test. Seats that passed the paper cushion test also frequently met the requirements of the 7 kW flame test according to [17]. In order to meet the current test specifications for flame treatment with 15 kW and an extraction rate of 1.2 m^3/s [19,20], high-quality flame-retardant foams must be used. Fire tests of seats with the paper cushion and simultaneous measurement of heat release and smoke production rate.

The fire behavior of a seat ignited with a paper cushion was tested once with a slotted seat surface and once with a non-slotted seat surface. This test was carried out on a test stand in accordance with EN 16989; therefore, the total heat release rate (HRR/tot [kW]) and the total smoke production rate (SPR/tot [m^2/s]) were measured and recorded in detail.

According to the instructions of the DIN test specification for the paper cushion test, the paper cushion should lie against the backrest in the case of the non-slotted seat surface

and approximately in the middle of the seat surface in the case of the slotted seat surface. These two instructions resulted in the seats being damaged differently in the two fire tests.

2. Fire Tests of Seats with the Paper Cushion and Simultaneous Measurement of Heat Release and Smoke Production Rate

The fire behavior of a seat ignited with a paper cushion was tested once with a slotted seat surface and once with a non-slotted seat surface. This test was carried out on a test stand in accordance with EN 16989; therefore, the total heat release rate (HRR/tot [kW]) and the total smoke production rate (SPR/tot [m^2/s]) were measured and recorded in detail.

According to the instructions of the DIN test specification for the paper cushion test, the paper cushion should lie against the backrest in the case of the non-slotted seat surface and approximately in the middle of the seat surface in the case of the slotted seat surface. These two instructions result in the seats being damaged differently in the two fire tests.

2.1. General Preliminary Remarks on the Fire Tests Carried Out

Prior to all tests, the test samples were conditioned for at least 3 days at 23 °C and 50% relative humidity and the tests were carried out in accordance with the stated standards. In the test according to EN 16989, the test specimen (for example a railway seat) is flamed with a square burner with 15 kW power. In the ISO 5660-1 test, the 10 cm × 10 cm test specimen is irradiated with a cone-shaped radiator with an irradiation intensity specified in the standards (25 or 50 kW/m^2) or, for research purposes, very frequently with 35 kW/m^2 and with a uniform intensity on the surface. In both cases, the heat release rate is determined by measuring the reduction in the oxygen content of the exhaust gas compared to the ambient air. The difference in oxygen content is proportional to the heat of combustion (heat release rate). A comparison of the fire behaviour of irradiation and flame treatment shows that the flame retardants used are often optimized in one direction and therefore have a better effect in one case or the other. For polypropylene with different flame retardants, it was shown that irradiation with the cone calorimeter and strong flame treatment resulted in significant differences in the order of effectiveness for the two types of exposure [22].

2.2. Paper Cushion Test of a Single Seat with the Flame-Retardant Fleece Glued to the Elastoflex Foam with 95 kg/m³ Density

This seat has a flame-retardant fleece glued to the foam. The seat surface consists of a velour fabric comprising 85% wool and 15% polyamide (Figure 1). The foam is a polyurethane molded foam (named Elastoflex) from Weserland with a density of 95 kg/m^3.



Figure 1. Paper cushion ignited on Elastoflex foam after the fire test with a damaged fabric cover.

In the test with the slit seat surface, only the fabric cover was folded away from the surface as the flame-retardant fleece was glued to the foam (Figure 2).



Figure 2. Paper cushion ignited on Elastoflex foam with the glued-on flame-retardant fleece after the fire test.

In these tests, the maximum length and width of the area destroyed by the flames are always measured. The maximum length and width of the destroyed area should provide an orientation of the area of the destroyed surface. The maximum depth of the destroyed area provides an important indication of the technical fire properties of the foam. The period after the flames on the seat are extinguished is the most important assessment parameter of the fire tests using the paper cushion; thus, this period is also specified (Table 2).

Table 2. Paper cushion test on a single seat with Elastoflex foam.

	Non-Slit Seat Surface	**Slit Surface**
Destroyed seat surface	35 cm × 24 cm = 840 cm^2	33 cm × 21 cm = 693 cm^2
Maximum depth	4 cm	5 cm
Destroyed backrest surface	26 cm × 34 cm = 884 cm^2	0
Maximum depth on the backrest	2 cm	0
Autonomous extinguishing of the flames	2:39 Minutes: Seconds	3:13 Minutes: Seconds

The diagram (Figure 3) shows that the fabric cover (non-slit version) caused a higher heat release than the foam with the glued-on flame-retardant fleece. In the test with the slotted seat, the heat release rate was lower, but the foam that burnt under the flame-retardant fleece caused more smoke. Figure 4 shows that the foam under the flame-retardant fleece burned to a maximum depth of 5 cm and that this caused a high level of smoke production.

2.3. Paper Cushion Test of a Double Seat with the Flame-Retardant Fleece Glued to the PU Foam with 95 kg/m^3 Density

This double seat had a flame-retardant fleece glued to the foam. The seat surface consisted of a velour fabric comprising 85% wool and 15% polyamide and polyurethane (PU) foam with a density of 95 kg/m^3 from the company Weserland. The difference compared to the seat shown above was not only due to the difference between a single seat and a double seat, which has no effect in terms of fire safety; it was also because different foams from the same manufacturer were used in each of the cases.

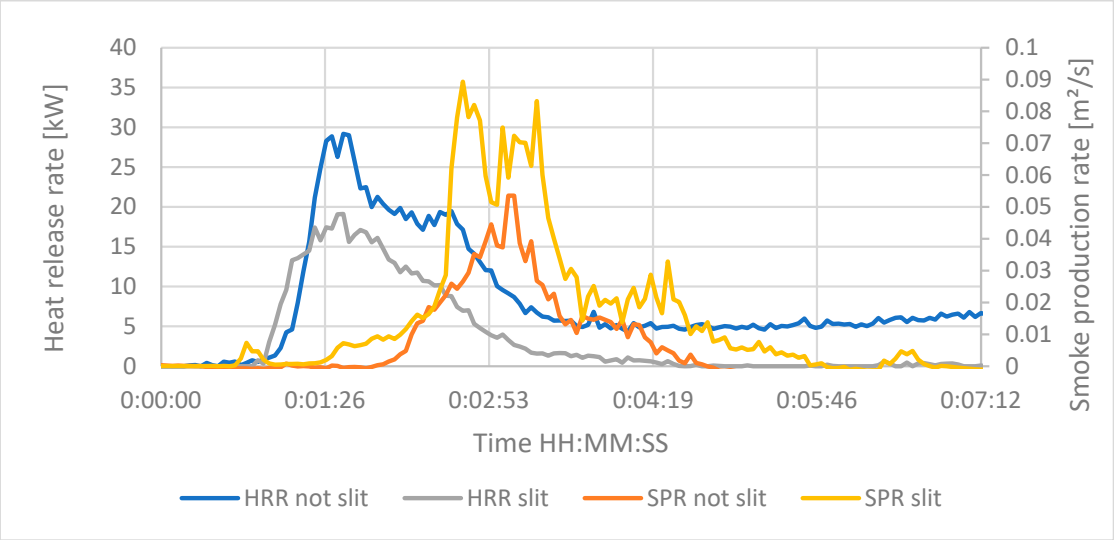


Figure 3. Diagram of heat release (HRR) and smoke production rate (SPR) of a paper cushions test of a seat with Elastoflex foam (non-slit and slit surface).



Figure 4. Elastoflex foam after the fire test; the glued-on flame-retardant fleece was cut away.

In this seat, the flame-retardant fleece was glued to the foam surface, therefore, only the fabric cover was folded away after slotting (Figure 5). In the pictures of the seats after the fire tests, the burnt parts of the upholstery fabric and the burnt flame-retardant fleece were removed to make the damage to the foam visible (Figures 6 and 7).



Figure 5. Seat with glued-on flame-retardant fleece on foam and paper cushion and slotted seat surface before the fire test.



Figure 6. Seat with glued-on flame-retardant fleece on foam after the fire test. Paper cushion ignited on the fabric cover; burnt parts of the cover fabric were removed.



Figure 7. Seat with glued-on flame-retardant fleece on foam after the fire test. Slit seat, burnt parts of the cover fabric, and flame-retardant fleece have been removed.

The destroyed area and the burning time is presented in Table 3.

Table 3. Paper cushion test on a double seat with Weserland foam.

	Non-Slit Seat Surface	**Slit Surface**
Destroyed seat surface	30 cm × 31 cm = 930 cm^2	35 cm × 24 cm = 840 cm^2
Maximum depth	1 cm	9 cm
Destroyed backrest surface	29 cm × 23 cm = 667 cm^2	0
Maximum depth on the backrest	1 cm	0
Autonomous extinguishing of the flames	5:15 Minutes: Seconds	4:40 Minutes: Seconds

It was interesting to note in these tests that the slotted and non-slotted seat surfaces had almost the same heat release rate (see Figure 8). The smoke formation of the non-slit seat surface was lower and mainly caused by the cover fabric. The smoke formation of the slit seat surface, i.e., the seat with foam, which was damaged to a depth of 9 cm, was considerably higher than that in the non-slit test (Figure 8).

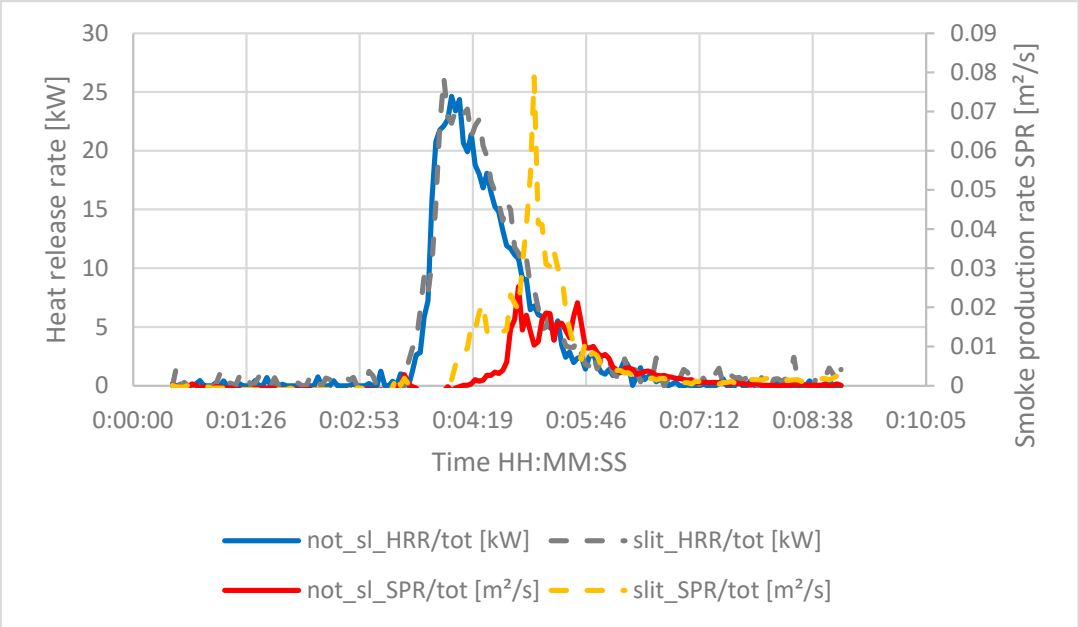


Figure 8. Diagram of heat release (HRR) and smoke production rate (SPR) of a paper cushion test of a seat with Weserland foam (non-slit and slit surface).

This test shows that the fabric cover and the foam with a very high density have very similar fire properties; however, the smoke formation is much higher with the foam than with the fabric cover.

2.4. Causes of the Different Fire Behaviour of Seats Made of Flexible Polyurethane Foam with the Same Density Investigated Using the Paper Cushion Test

In summary, the results presented in Sections 2.2 and 2.3 show that outwardly apparent similar seat cover materials and polyurethane foams with a density of 95 kg/m^3 were used. Different additives in the foam resulted in different levels of heat release and smoke formation in the two-test series. The different levels of heat release and smoke formation result from the additive-induced interaction between the foam and the upholstery fabric.

The burning behavior and smoke toxicity of nine upholstered furniture composites used in Great Britain were assessed using a cone calorimeter and other fire tests, and the results are shown in [23].

The flammability of flexible polyurethane foam has two reasons: the internal reason is that the polyurethane chain contains more flammable hydrochar chain segments and C-NH bonds with poor thermal stability; the external reason is that its high porosity (more than 90%) structure augments the surface area in contact with oxygen, and its low thermal conductivity, which easily leads to the accumulation of heat [24]. The flame-retardant mechanism of flexible polyurethane foam mainly includes gas-phase flame retardant, condensed-phase flame retardant, synergistic flame retardant, and flame retardant by interrupting heat exchange. In the case of halogen-free flame retardants, phosphorus-containing flame retardants are often used because of their low price, low smoke emission, low toxicity, good flame retardancy and no corrosive gases [24]. Nitrogen-based flame retardants applied to flexible polyurethane foams are mainly melamine and related components. Expanded graphite is an intumescent flame retardant which is highly effective and environmentally friendly flame retardant.

The smoke suppression and flame retardancy of phosphorus-containing Polyester Diols and expanded graphite flame retardants in PU foams are investigated in [25].

The various mechanisms of action of flame retardants in flexible PU foams were presented from the literature and it was also shown which additives are used for smoke suppression.

3. Comparison of the Results of Fire Tests on Seats According to Seat Test Standard EN 16989 from Two Different Test Centers

As part of the development of the EN 16989 standard, tests were carried out by a test center in Germany (DMT) with two different types of foam and two different cover fabrics. These foams and fabrics were obtained, and comparative tests were carried out.

Two different types of foam were tested by the foam manufacturer Metzler:

The melamine system, Metzoprotect FRM-U (light gray), melts and drips off when exposed to flame.

The expanded graphite foam, Transprotect HM06 (dark gray), expands when exposed to flame, and black soot flakes form.

Two different seat covers were provided by the Schöpf company (a textile manufacturer, Austerfeld, Germany):

Article Maestrale_EN: top layer wool/PA 85/15%;

Article Quadrat: Trevira CS 100%.

For the standardization session, the DMT test center conducted tests using two fabric covers and two foam types in accordance with the new EN 16989 [20]. For the approval of the test stand at the TGM, comparative tests were carried out with the same foam types and fabric covers.

The DMT and TGM tests are compared in Table 4; to save resources, not all of the tests were carried out.

Table 4. Comparison of test results from two test centers using the same foams and seat covers.

Cover Fabric/Foam Type		HRR_{peak}	MARHE	THR
		kW	kW	MJ
Trevira CS/Expanded graphite foam	DMT 3	49.5	29.2	7.8
Trevira CS/Expanded graphite foam	TGM	49.7	31.8	6.8
Trevira CS/PU melamine foam	DMT 5	42.5	25.8	6.8
Trevira CS/PU melamine foam	TGM	48.1	26.4	5.4
Wool/PU melamine foam	DMT 7	18.8	15.5	4.4
Wool/PU melamine foam	TGM	21.5	17.0	3.4
Wool/Expanded graphite foam	DMT 1	20.3	16.9	5.5

It is not known in detail how the experiments at the DMT were carried out, but the heat release results show a fairly good agreement between the DMT and the TGM experiments.

These results show that the foam is a decisive factor in the fire behavior in the tests conducted in accordance with EN 16898 [20] when flaming with 15 kW. In these tests, a flame-retardant foam with expanded graphite and melamine foam, which presumably has inherent flame retardancy, were used.

The limit value according to EN 45545-2:2020 [19] for seats in passenger coaches (hazard level HL3) is 25 kW. The results show that the Trevira CS fabric with the two foams just exceeded the MARHE $\leq$ 25 kW limit value, while the wool cover material with PU melamine foam and/or expanded graphite foam fell well below the 25 kW limit value.

This means that the combination of the top layer with the foam also plays an important role in flame treatment using the burner. In the tests shown here, the wool top layer was significantly better than the top layer with Trevira CS.

4. Results of CERTIFER Round Robin Test with Seats According to Seat Test Standard EN 16989

Every one to two years, CERTIFER carries out international comparative tests on the fire behavior of rail equipment materials in accordance with EN 45545-2. All the essential test methods listed in the standard are examined by a large number of test centers, using similar test sent by CERTIFER, and the results are made available to the individual test centers. The systematized results are also published on the Internet [26,27].

In the last comparative test completed by CERTIFER (EUROCOMPARISON 2023), seats were also fire-tested in accordance with EN 16989. Three seats from each of the 12 different laboratories were fire tested (Figure 9). The heat release rate (HRR) and the maximum value of the average heat release (MARHE) in kW were determined. The total smoke production (TSP) was also determined.



Figure 9. Seat of CERTIFER round robin test (Seat TGM number 2) before the fire test.

During the test, it was discovered that CERTIFER had sent seats that might have passed the paper cushion test but which caught fire at the TGM test center. This statement about the burning of the seats can only be made for our test center, because no information on this is available from the other test centers.

All the seats caught fire (Figures 10 and 11). Seat 2 (Figure 12) and Seat 3 (Figure 13) look different after the fire tests; therefore, they also have different heat release rates (see Figure 14).



Figure 10. Seat 2 during flaming with burner.

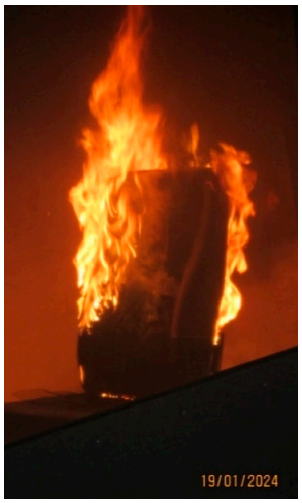


Figure 11. Burner was removed and burned independently.



Figure 12. Seat 2 after the fire test.



Figure 13. Seat 3 after the fire test.

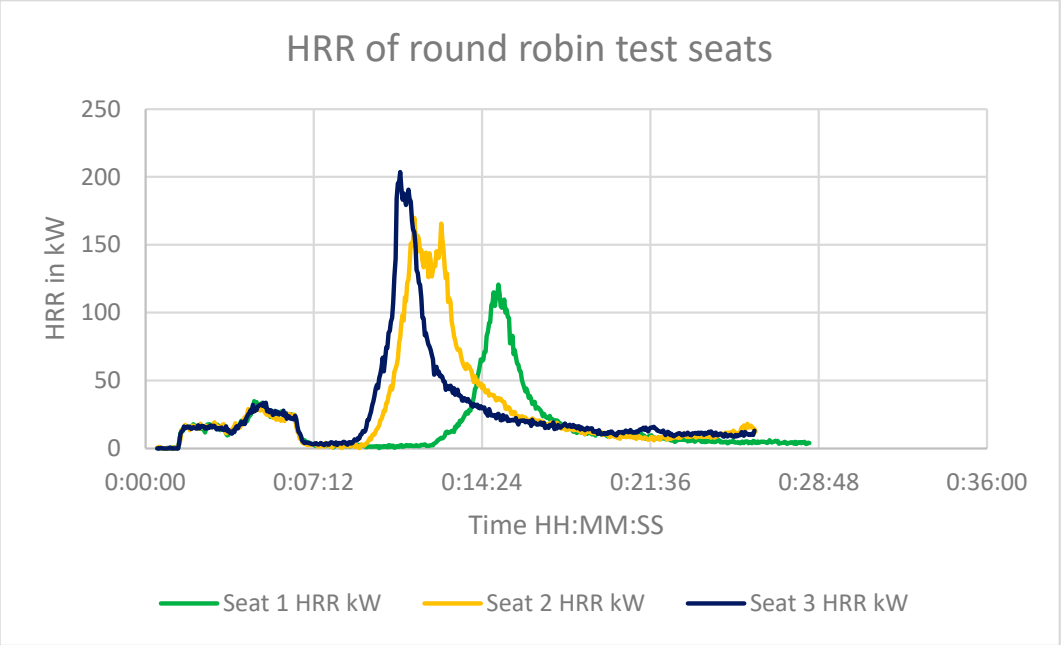


Figure 14. Heat release rate (HRR) of the seats provided by CERTIFER, which caught fire at the TGM test center when exposed to 15 kW of flame.

The results shown in Table 5 and Figure 15 are taken directly from the CERTIFER/2023 report [27] with the permission of CERTIFER.

Table 5. Results (MARHE) of all test bodies that took part in the CERTIFER/2023 round-robin test for the seat test in accordance with EN 16989 [27].

	Seats/MARHE [kW]				
Laboratory	**Test 1**	**Test 2**	**Test 3**	**Average**	**Standard Deviation**
N	20.81	21.43		21.12	0.44
P	46.00	69.00	55.00	56.67	11.59
R	49.60	44.60	47.10	47.10	2.50
T	67.50	52.70	73.30	64.50	10.62
U	26.80	52.20	52.30	43.77	14.69
V	70.10	73.60	74.50	72.73	2.32
X	38.97	48.73	45.85	44.52	5.01
Z	78.80	76.30	81.10	78.73	2.40
ZD	23.30	44.80	43.30	37.13	12.00
ZG	22.00	77.00	74.00	57.67	30.92
ZK	26.00	30.40	24.00	26.80	3.27
ZS	11.20	11.60	12.10	11.63	0.45
	Average	**Repeatability**		**Reproducibility**	
	m	**r**	**r/m %**	**R**	**R/m %**
Seats/MARHE	46.86	33.54	71.57	63.49	135.48

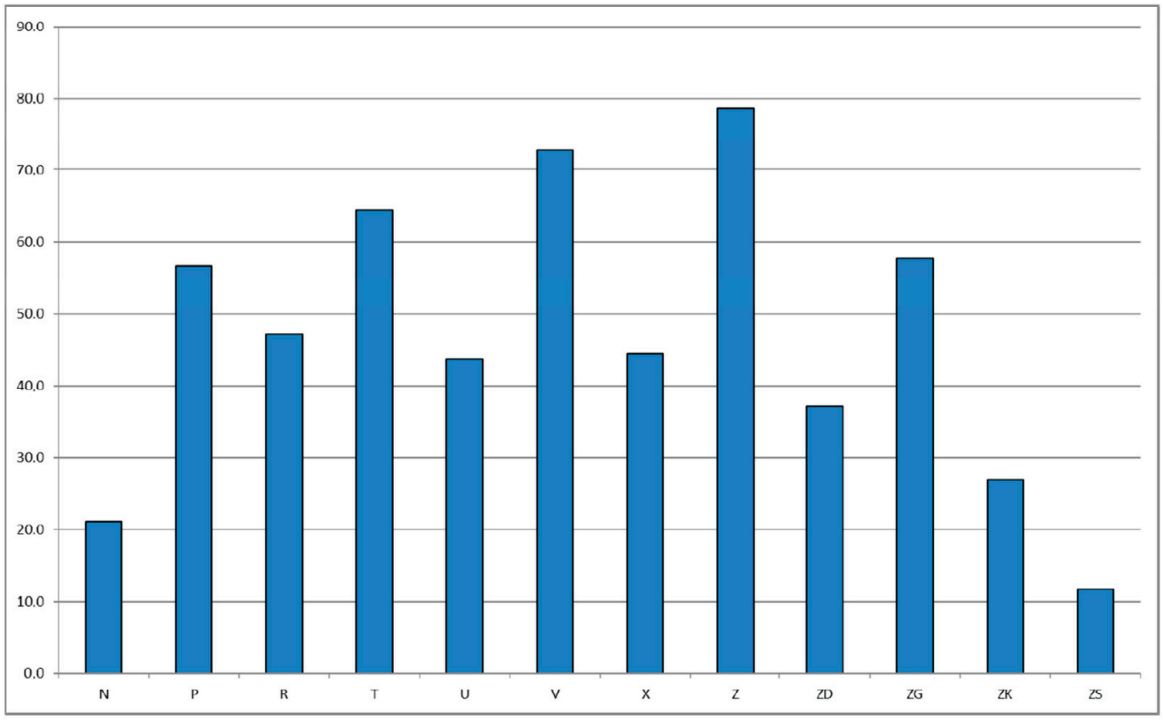


Figure 15. Graphical representation of the results (MARHE) of all test centers that participated in the CERTIFER/2023 round-robin test for the seat test in accordance with EN 16989 [27]. Sequence of test centers is the same as in Table 5.

The results of the fire tests on the seats show a very wide range of variation at the various testing laboratories, which is probably related to the fact that the seats caught fire and showed very different behavior during the full fire. Presumably, CERTIFER used a seat for the round-robin test that met the requirements for the paper cushion test for passenger coaches. The results clearly show a wide range of variation, and most of the test bodies did not meet the requirements for passenger coaches (HL3) in accordance with EN 45545-2 of MARHE $\leq$ 25 kW.

In summary, this presumably means that a seat that passes the paper cushion test has little chance of meeting the new requirements for passenger coach seats with a flame rating of 15 kW.

As part of the international development of EN 16989, a testing institute compared the fire behavior of the paper cushion with the 15 kW flame treatment and found an approximate match. Our tests showed that seats that passed the paper cushion test met the requirements of EN 45545-2:2016 with a 7 kW flame impingement power.

It should be mentioned that other fire test methods used in the CERTIFER interlaboratory test by the various test laboratories provided quite consistent results.

5. Aging of Leather Investigated in Terms of Heat Release Rate Using a Cone Calorimeter (ISO 5660-1)

In 2022, old leather from 2007 and leather from 2021 were compared in terms of fire technology using a cone calorimeter. Leather that was laminated on the back was also examined. This lamination was used so that it lay flat on the seat when in use.

The leather was flame-retardant, and it was assumed that the effectiveness of the flame protection decreased with increasing age. In accordance with ISO 5660-1 [28], a cone calorimeter was used to determine the heat release rate in kW/m^2 of horizontally arranged samples when ignited by an external heat source.

The measurements were carried out using an irradiation intensity (heat flux) of 25 kW/m^2, as this irradiation intensity is prescribed for upholstery and headrests in the passenger area in accordance with requirement R21 of EN 45545-2. All the tests were carried out using a grid, but the leather contracted considerably during irradiation, and this may have influenced the heat release rate in these measurement results. The fleece was glued to the leather by the leather supplier. The fleece was laminated onto the leather so that the surfaces (especially the larger areas) looked smooth, which was not the case without the fleece. The fleece therefore affected the mechanical properties of the leather but did not fulfill any fire protection purposes. Leather without fleece was used for small surfaces.

Figures 16 and 17 show uneven fire behavior in the cone test with a grid, which could be due to the fact that leather is a natural product with possibly uneven absorption of flame-retardant impregnation.

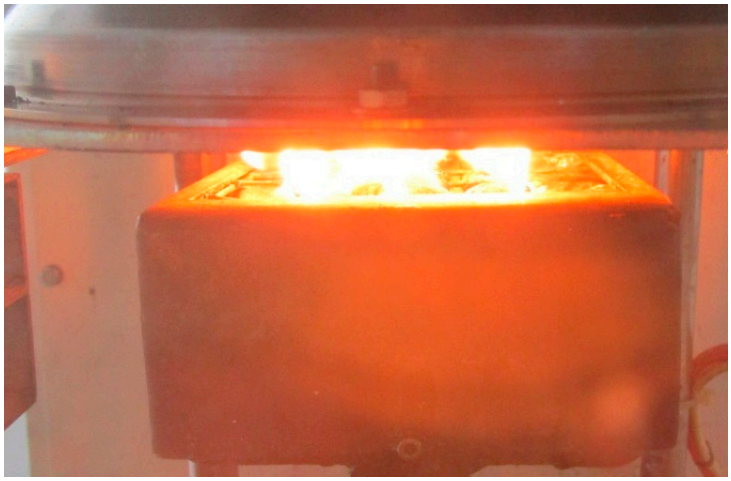


Figure 16. Irradiation of leather using a cone calorimeter and uneven flame formation during the test.



Figure 17. Uneven damage to the leather after the cone test.

Figure 18 shows the slightly different heat release rates of the leather from 2007. Figure 19 shows the heat release rates of new leather from two different leather manufacturers and the respective mean values. Due to a different proportion of flame retardants, the two leathers have different heat release rates.

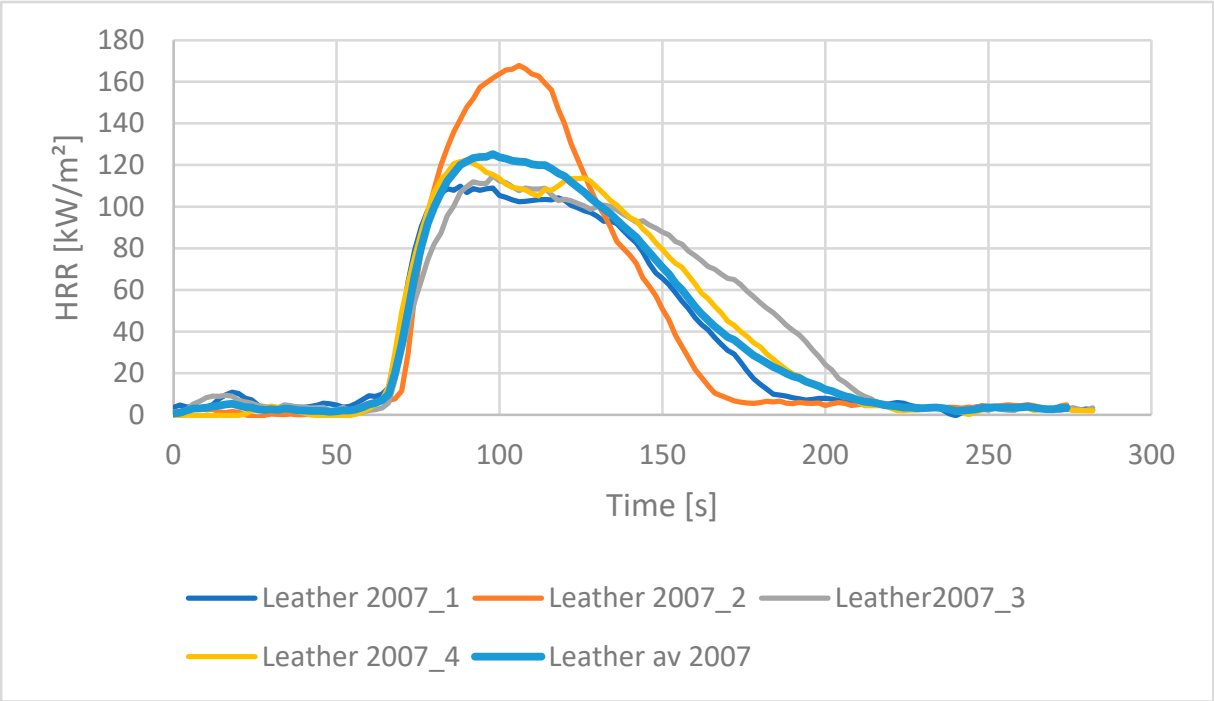


Figure 18. Heat release rates (HRR) of old leather from 2007 and average.

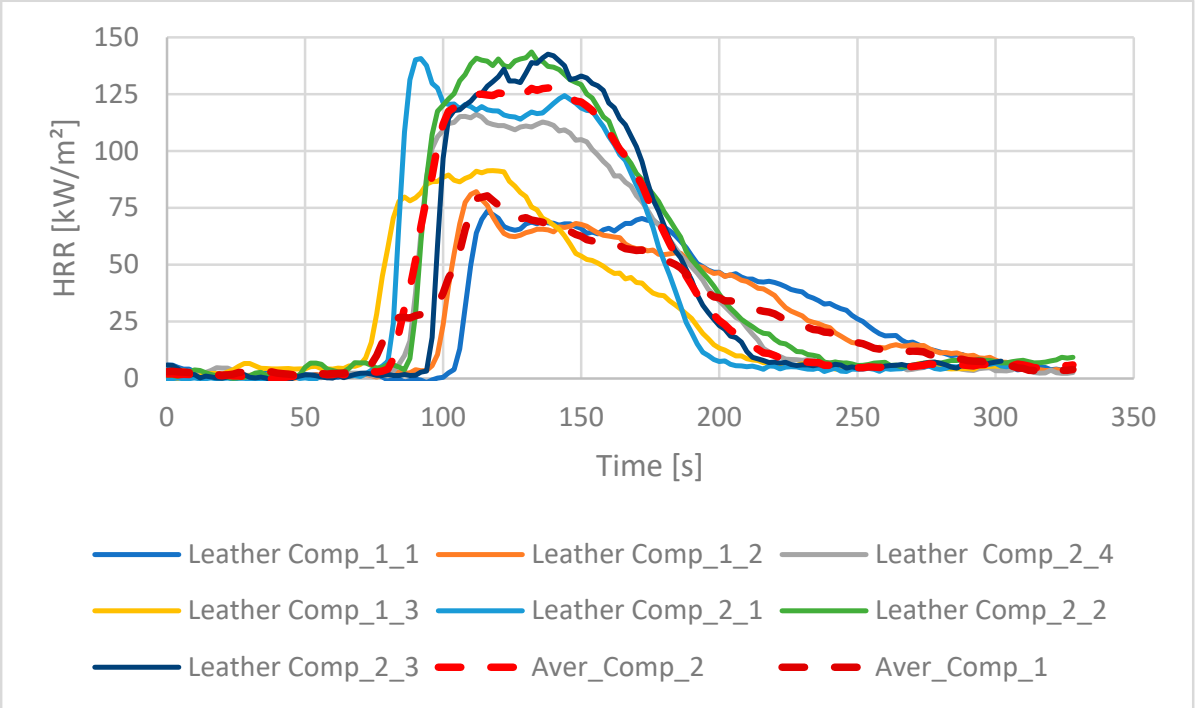


Figure 19. Heat release rates (HRR) of new leather from two different manufacturers.

The results of the mean values for the leather from the two leather manufacturers are also compared with the heat release rates for the leather with fleece lamination, where the fleece material was dyed green (Figure 20). The bonding and the fleece have an influence on the heat release.

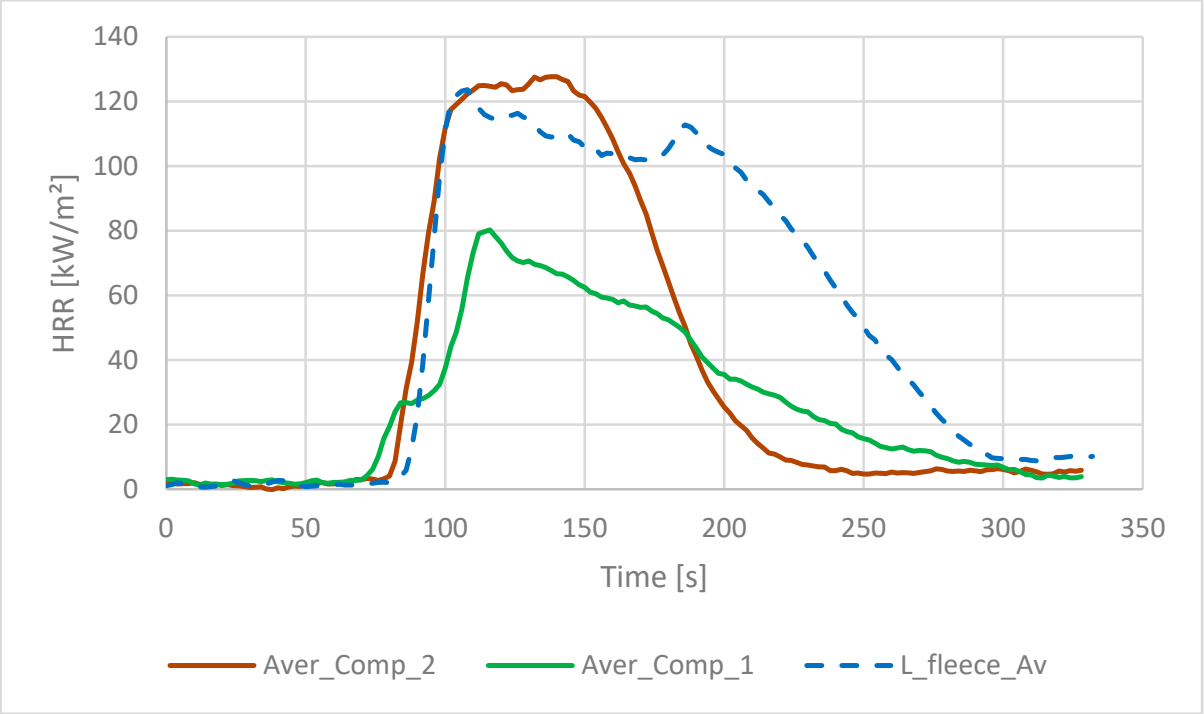


Figure 20. Mean values of heat release rates (HRR) from the two leather manufacturers and mean value of HRR of leather laminated with fleece.

Figure 21 compares the heat release rates of the leather from 2007, which was 15 years old at the time of the test in 2022, with the leather from company 1 from 2021.

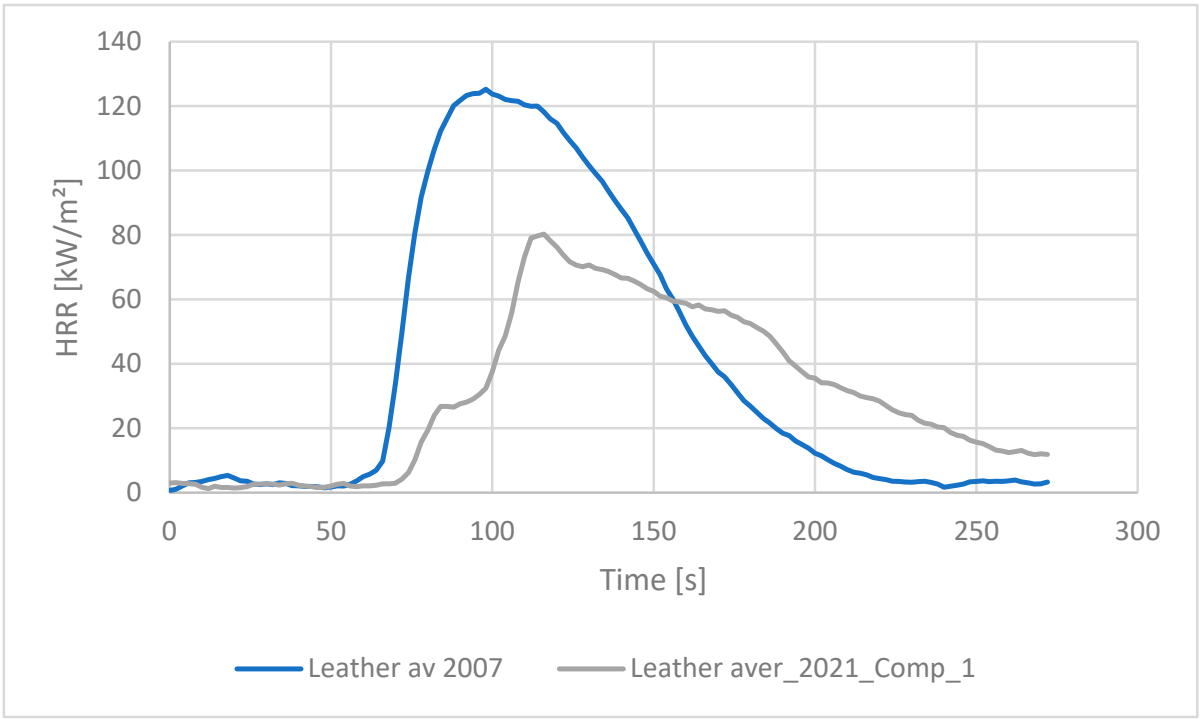


Figure 21. Heat release of leather from 2007 compared to new leather with low heat release from 2021 (all measurements were taken in 2022).

The results of the heat release measurements conducted according to ISO 5660-1 give the impression that the flame protection in the leather becomes less effective with increasing age.

No statements can be made about the examined leather regarding how and with which agent the flame protection was achieved. In [29], it is stated that the flame protection of leather is often achieved in the finishing process by spraying or rolling. According to this study, it is more economical and efficient if the flame retardants are applied earlier, during the tanning process. The effect of the various flame retardants applied in this way is being investigated [29].

6. Comparison of the Results of Flame Exposure and Irradiation of a Simple Seat Structure

The tests conducted according to EN 16989 with a 15 kW flame output were only carried out with two types of foam (melamine and expanded graphite foam) and one upholstery fabric. To achieve conditions that are approximately comparable to those of the ISO 5660-1 [28] test using a cone calorimeter, only the seat surface (without backrest) was flamed with foam and upholstery fabric. The fabric cover with a square pattern consisted of Trevira CS 100%.

6.1. Heat Release Tested Using a Cone Calorimeter (ISO 5660-1)

Only materials with a maximum thickness of 50 mm can be used in a cone calorimeter, which is why the foams with the fabric were also tested using this specimen thickness. However, this had no influence on the results of these tests.

In the case of expanded graphite foam, an expanded graphite layer (Figure 22) forms during irradiation, which protects the foam from further irradiation; thus, the fire behavior is slowly terminated. The Trevira CS textile only increases the heat release of the expanded graphite foam and textile by around 30 kW/m^2.

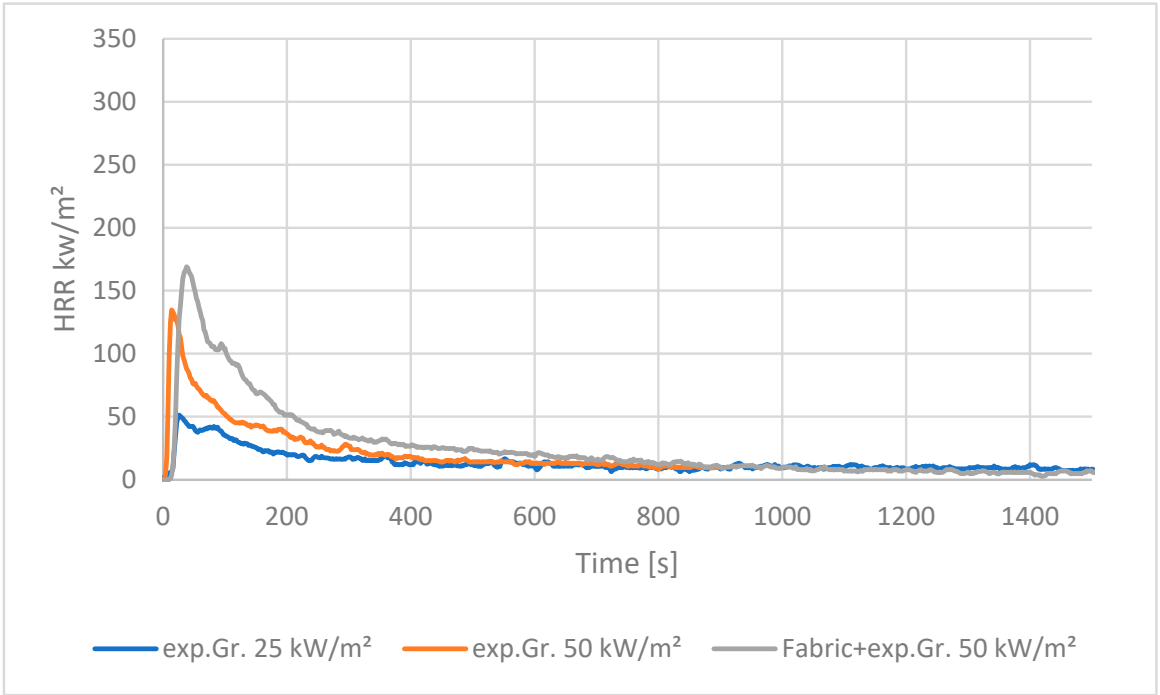


Figure 22. Heat release rate of expanded graphite foams irradiated with 25 and 50 kW/m^2 and foam covered with Trevira CS irradiated with 50 kW/m^2.

The melamine foam shows a completely different fire behavior from the foam with expanded graphite. If the melamine foam is irradiated with 50 kW/m^2, a heat release of around 170 kW/m^2 is initially observed due to the surface layer (see Figure 23). The heat release then reduces and increases to just over 300 kW/m^2 after just under 10 min. If the textile Trevira CS is on the foam, the heat release increases to around 330 kW/m^2 at the beginning. The Trevira CS textile significantly increases the heat release of the melamine foam and textile by around 150 kW/m^2, which is considerably more than the combination with expanded graphite foam. It can be seen that there is an interaction between the melamine foam and the Trevira CS upholstery fabric, with a significantly increased heat release.

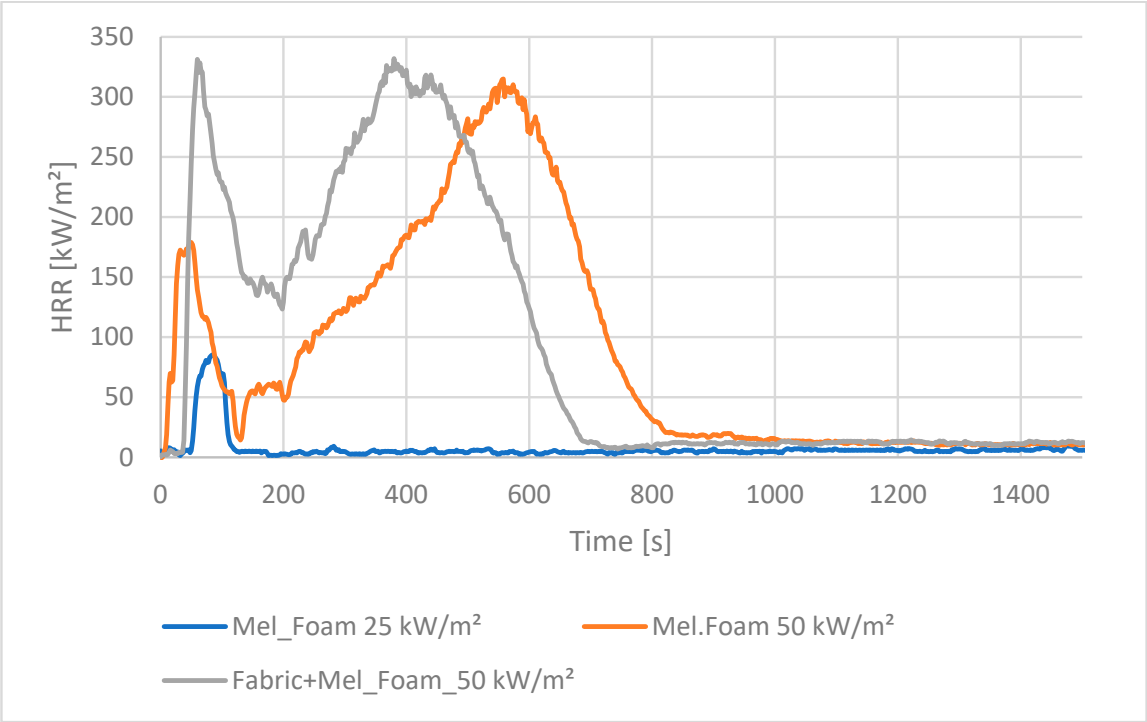


Figure 23. The heat release rate of melamine foam irradiated with 25 and 50 kW/m^2 and foam covered with Trevira CS irradiated with 50 kW/m^2.

The measurements of heat release through irradiation using a cone calorimeter reveal significant differences in the combination of expanded graphite foam or melamine foam with the Trevira CS textile.

6.2. Heat Release Tested According to the Seat Standard EN 16989 with 15 kW

The expanded graphite and melamine foam with the upholstery fabric Trevira CS were flamed in accordance with the EN 16989 standard with a burner output of 15 kW (Figure 24). A foam that symbolized the seat was provided with the upholstery fabric and was flamed.

In the diagrams for the heat release as a function of time (Figure 25), a 3-min period at the beginning of the burner calibration is shown; during this time, the burner is above the test sample. The actual test begins when the burner is lowered onto the test sample, which is when the smoke production rate (SPR) also begins. In both cases, the cover material burns first; then, the formation of the protective layer begins in the case of the expanded graphite foam, with stronger smoke formation. The melamine foam continues to burn and, in the end, has a slightly higher heat release than the expanded graphite foam, but a lower smoke production rate (Figure 25).



Figure 24. (**Left**): melamine (destroyed depth 10 cm) and expanded graphite (destroyed depth 3 cm, (**right**)) foam covered with Trevira CS fabric after flame treatment with 15 kW.

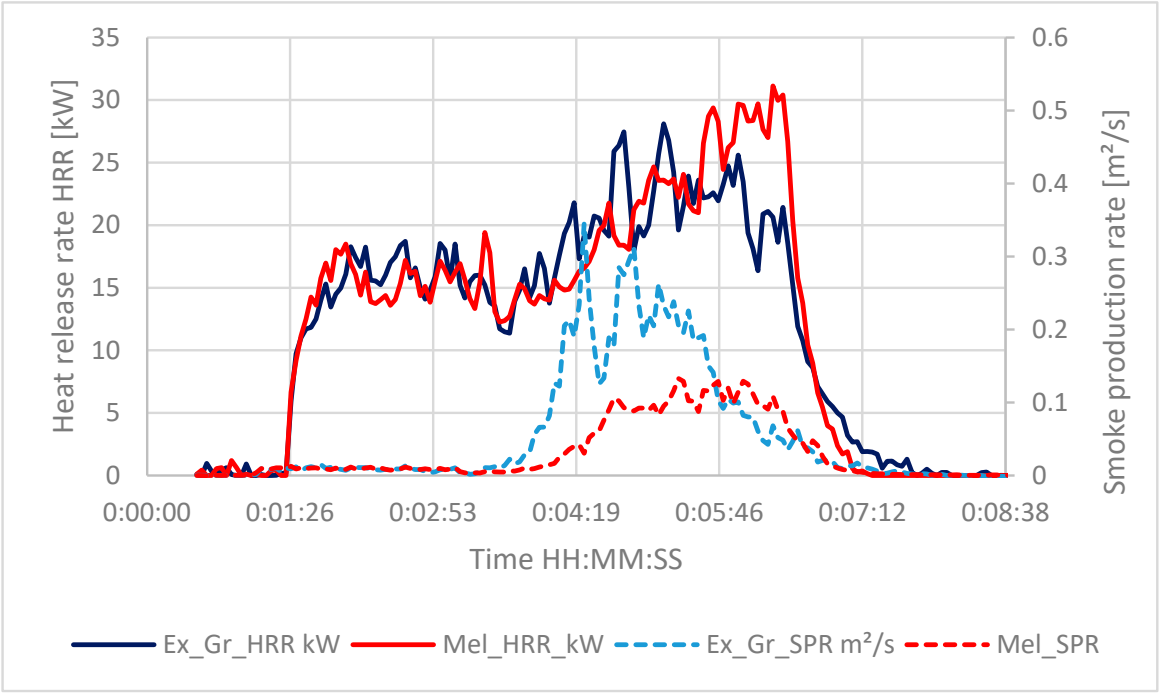


Figure 25. Heat release rate (HRR) and smoke production rate (SPR) of melamine and expandable graphite foam covered with Trevira CS fabric when exposed to 15 kW of flame.

The differences between the tests involving irradiation of the test samples using the cone calorimeter and those involving flame treatment of the foam–textile combination using the burner are interesting. When the foam–textile combination was irradiated using the cone calorimeter, clear differences were seen between the expanded graphite and melamine foam. When flaming using the 15 kW burner in accordance with EN 16989, there were almost no differences in fire behavior between the two foams.

Overall, it can be concluded from these results that there is no simple correlation between the results of irradiation using the cone calorimeter and those of the flame treatment using the burner. Seats also exhibit different behaviour when exposed to radiation and flame, as does polypropylene with different flame retardants [22].

By measuring the heat release at the different irradiation intensities of different plastic materials, very good correlations can be established using highly developed simulation

techniques [30]. These simulation techniques have been developed over many years by a major supplier of rail vehicles and can even be used to simulate full fires in rail vehicles. A full fire in a rail vehicle was carried out in reality, and the measured heat release was compared with the simulation results.

In order to fulfil the high requirements for the fire behaviour of seats in local rail transport (trams and underground trains), the trend is towards wooden seats, possibly with a thin seat cover.

7. Conclusions

This study shows how the fire test regulations for railway seats changed over time, from the paper cushion test conducted according to UIC 564-2 to the later DIN 5510-2 guidelines, which were subsequently replaced by flame treatment using a burner. Overall, there has been an increase in the fire requirements for railway seats over time. In the paper cushion test of railway seats, it was initially sufficient if the combination of cover fabric and foam with a density of 60–95 kg/m^3 was suitable. Later, the exhaust gas volume flow was increased to 0.6 m^3/s during the measurement, and a flame protection fleece was often required between the fabric cover and foam on the seat surface. When using the 15 kW burner for flame treatment, a high-quality flame-retardant foam must be used. The increase in the requirements for railway seats is clearly shown by the fact that seats that pass the paper cushion test catch fire when exposed to 15 kW flames applied in accordance with the seat test standard EN 16989. In the CERTIFER Eurocomparison 2023, 12 test centers tested the same seat type in accordance with EN 16989, and very different results were found due to the seats being fully burned. When the foam exhibited good fire behavior on exposure to a 15 kW flame, the fire-related results from any two test centers were in fairly good agreement.

During experiments using the paper cushion test, the heat release and smoke formation were also measured, and it was shown that the different seat types can have very different or identical fire behavior depending on the cover material and the flame retardants of the foam.

The heat release of 14-year-old leather was compared with that of new leather using a cone calorimeter. Fourteen years ago, no cone tests were carried out on the then-new leather; therefore, the following statements are not entirely reliable. The results presented in this study and the results from tests not shown suggest that the flame retardant used at the time for the natural leather product deteriorated over time. It can therefore be assumed that the flame retardant used at the time for the leather was not stable over time and that this significantly increased the heat release in the cone test. The ageing of the leather flame retardant could also have something to do with the presumed application of the flame retardant to the leather surface.

In the rig of the seat test conducted according to EN 16989, a melamine foam seat and an expanded graphite foam seat covered with a cover material commonly used in rail transport were examined, and the heat release and smoke formation were measured and displayed. The foams and the seat structure with foam and upholstery fabric were analysed in the cone calorimeter with different irradiation intensities and the heat release rate was determined. Overall, the results of the heat release with irradiation using the cone calorimeter and those of the flame exposure using the EN 16989 burner showed such different curves that no simple correlation could be made between irradiation and flame exposure.

Using highly developed simulation techniques, the fire behavior of a rail vehicle can be modeled very effectively using the heat release at different irradiation intensities, even in the event of a full fire, and good agreement with real fire behavior is shown.

Information about our fire investigations can be found at https://www.lkt-tgm.at/brandtechnische-untersuchungen-2/, accessed on 16 December 2024.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: Many thanks to Matthias Berger from our institute, who carried out the cone measurements and also provided other metrological support. Many thanks to the reviewers and the academic editor for their tips regarding the improvement of this paper.

Conflicts of Interest: The author declares no conflicts of interest.

References

1. Babrauskas, V.; Grason, S.J. *Heat Release in Fires*; Elsevie: Amsterdam, The Netherlands, 1992; Reprint 2009; Chapters 14 and 15; ISBN 978-0-9556548-4-8.
2. Troitzsch, J.; Antonatus, E. *Plastics Flammability Handbook*, 4th ed.; Carl Hanser Verlag: Munich, Germany, 2021; Chapter 4; ISBN 978-1-56990-762-7.
3. Loewenthal, O.; Doley, P.; Wang, C.; Yeoh, G.H.; Kabir, I.I. Investigating Intumescent Flame-Retardant Additives in Polyurethane Foam to Improve the Flame Resistance and Sustainability of Aircraft Cabin Materials. *Fire* **2024**, *7*, 351. [CrossRef]
4. Jang, H.; Kwon, T.; Choi, S.K.K. Flame Resistance Performance of Silicone Pad for Application in Railway Industry. *Fire* **2024**, *7*, 255. [CrossRef]
5. Osvalová, L.M.; Marková, I.; Vandlícková, M.; Titko, S.G.M. Fire Characteristics of Upholstery Materials in Seats. *Int. J. Environ. Res. Public Health* **2020**, *17*, 3341. [CrossRef]
6. Mitrenga, P.; Osvalová, L.M.; Marková, I. Observation of Fire Characteristics of Selected Covering Materials Used in Upholstered Seats. *Transp. Res. Procedia* **2021**, *55*, 1775–1782. [CrossRef]
7. Hagen, R.; Karemaker, M.; Larsson, I.; Hörnqvist, A.; Brants, D.; Elorza, J.; Watts, D.; Van Maloziec, E.; Maloziec, D.; Paloluoma, P.; et al. Fire Safety of Upholstered Furniture and Mattresses in the Domestic Area: European Fire Services Recommendations on Test Methods. FEU. 2017. Available online: https://europeanfiresafetyalliance.org/wp-content/uploads/2018/11/Report-Fire-safety-of-upholstered-furniture-and-mattresses-in-the-domestic-area.pdf (accessed on 16 December 2024).
8. Craig, M.; Asim, T. Numerical Investigations on the Propagation of Fire in a Railway Carriage. *Energies* **2020**, *13*, 4999. [CrossRef]
9. Hohenwarter, D. Experience Gained from Fire Tests According to EN 45 545-2 and DIN 5510-2 for Testing of Seats. *Problemy Kolejnictwa* **2016**, *171*, 27–38.
10. *UIC 564-2, Vorschriften über Brandverhütung und Feuerbekämpfung für die im Internationalen Verkehr Eingesetzten Schienenfahrzeuge, in denen Reisende befördert oder die der Reisezugwagenbauart Zugeordnet Werden Können (3. Ausgabe 1.1.1991)*; Anlage 13: Versuchsmethode zur Prüfung des Brandverhaltens der Sitze (Regulation of „Internationaler Eisenbahnverband"); International Union of Railways: Paris, France, 1991.
11. *E DIN 5510-2: 1996-02*; Preventive Fire Protection in Railway Vehicles—Part 2: Fire Behavior and Fire Side Effects of Materials and Parts; Classification, Requirements and Test Methods (Draft February 1996). DIN Deutsches Institut für Normung e.V.: Berlin, Germany, 1996.
12. *DIN 54341: 1988-01*; Testing of Seats in Railways for Public Traffic; Determination of Bruning Behaviour with a Paper Pillow Igition Source. DIN Deutsches Institut für Normung e.V.: Berlin, Germany, 1988.
13. *E DIN 5510-2: 2003*; Preventive Fire Protection in Railway Vehicles—Part 2: Fire Behaviour and Fire Side Effects of Materials and Parts; Classification, Requirements and Test Methods (Draft September 2003. DIN Deutsches Institut für Normung e.V.: Berlin, Germany, 2003.
14. *E DIN 5510-2: 2007*; Preventive Fire Protection in Railway Vehicles—Part 2: Fire Behaviour and Fire Side Effects of Materials and Parts; Classification, Requirements and Test Methods (Draft October 2007). DIN Deutsches Institut für Normung e.V.: Berlin, Germany, 2007.
15. *ISO 5659-2:2017*; Plastics—Smoke Generation. Part 2: Determination of Optical Density by a Single-Chamber Test. ISO: Geneva, Switzerland, 2017.

16. *DIN 5510-2: 2009*; Preventive Fire Protection in Railway Vehicles—Part 2: Fire Behaviour and Fire Side Effects of Materials and Parts; Classification, Requirements and Test Methods (Ausgabe 2009-05-). DIN Deutsches Institut für Normung e.V.: Berlin, Germany, 2009.
17. *ÖNORM EN 45545-2: 2016*; Railway Applications—Fire Protection on Railway Vehicles—Part 2: Requirements for Fire Behaviour of Materials and Components (Ausgabe 2016-03-01). Austrian Standards Institute: Wien, Austria, 2016.
18. *ISO/TR 9705-2:2001*; Reaction-to-Fire Tests—Full-Scale Room Tests for Surface Products. Part 2: Technical Background and Guidance. ISO: Geneva, Switzerland, 2001.
19. *ÖNORM EN 45545-2: 2020*; Railway Applications—Fire Protection on Railway Vehicles—Part 2: Requirements for Fire Behaviour of Materials and Components (Ausgabe 2020-09-15). Austrian Standards Institute: Wien, Austria, 2020.
20. *ÖNORM EN 16989: 2018-11*; Railway Applications—Fire Protection on Railway Vehicles—Fire Behaviour Test for a Complete Seat (Ausgabe 2018-11-15). Austrian Standards Institute: Wien, Austria, 2018.
21. *DIN EN 45545-2: 2023-12*; Railway Applications—Fire Protection on Railway Vehicles—Part 2: Requirements for Fire Behaviour of Materials and Components. DIN Deutsches Institut für Normung e.V.: Berlin, Germany, 2023.
22. Hohenwarter, D.; Mattausch, H.; Fischer, C.; Berger, M.; Haar, B. Analysis of the fire behaviour of polymers (PP, PA 6 and PE-LD) and their Improvement using various flame retardants. *Materials* **2020**, *13*, 5756. [CrossRef]
23. Lane, J.A.; Hull, T.R. Variation of flammability and smoke toxicity of upholstered furniture composites with fire retardant treatment. *J. Mater. Sci. Technol.* **2024**, *202*, 140–151. [CrossRef]
24. Shen, C.; Shao, R.; Wang, W.; Wu, X.; Zhou, B.; Zhao, L.; Siddique, A.; Xu, Z. Progress of flame-*retardant* research on flexible polyurethane foam. *Eur. Polym. J.* **2024**, *220*, 113478. [CrossRef]
25. Wang, H.; Liu, Q.; Li, H.; Zhang, H.; Yan, S. Flame-retardant and smoke-suppressant Flexible polyurethane foams based on Phosphorus-containing polyester diols and expandable graphite. *Polymers* **2023**, *15*, 1284. [CrossRef] [PubMed]
26. Available online: https://www.certifer.eu/wp-content/uploads/2024/01/LISTE_DES_LABORATOIRES-EN45545-2023_v2.pdf (accessed on 24 October 2024).
27. Certifer. *Certifer Eurocomparison 2023 Report, Inter-Laboratory Comparison on Railway Fire Behaviour Tests*; Certifer: Valenciennes, France, 2023.
28. *ISO 5660-1:2015/Amd.1: 2019(E)*; Reaction-to-Fire Tests—Heat Release, Smoke Production and Mass Loss Rate, Part 1: Heat Release Rate (Cone Calorimeter Method) and Smoke Production Rate (Dynamic Measurement). ISO: Geneva, Switzerland, 2019.
29. Olivares, G.S.; Battig, A.; Goller, S.M.; Rockel, D.; Gonzalez, V.R.; Schartel, B. Imparting Fire Retardancy and Smoke Suppression to Leather during Tanning Processes. *ACS Omega* **2022**, *7*, 44156–44169. [CrossRef] [PubMed]
30. Murtinger, G. Brandsimulation und Brandversuche in der Bahnindustrie, Der Eisenbahningenieur, Internationale Fachzeitschrift für Schienenverkehr & Technik, 8/24. Available online: https://eurailpress-archiv.de/Search.aspx?q=*Murtinger&o=1&t=EI&issue=08&sy=2024&ey=2024 (accessed on 13 January 2025).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.