Experience Gained from Fire Tests According to EN 45 545-2 and DIN 5510-2 for Testing of Seats

Dieter HOHENWARTER[1]

Summary
Results of fire tests according to ISO 5658-2 and ISO 5660-1 are shown for different products. The results of GFK products are extensively analysed. The result of a body shell painting is analysed according to ISO 5658-2 and ISO 5660-1, but this painting does not have to be analysed according to DIN 5510-2. Measurements of heat release rate of tram seats show that it is difficult to fulfill the requirements of fire behavior and at the same time to fulfill the demands for comfort and mechanical requirements of tram seats. Different possibilities to improve the fire behaviour of railway coaches are presented as well as the fact that the combination of the foam and the textile covering is essential.

Keywords: fire tests of railway materials and seats, fire tests of tram seats

1. Introduction to Fire Tests according to EN 45 545-2 (ISO 5658-2:2006, ISO 5660-1:2015)

In the past, materials were investigated according to the old Austrian Standard VORNORM ÖNORM B 3800-2: 1988 regarding the designation low combustibility (combustibility class B1) and moderately combustible (combustibility class B2) including the characteristics such as smoke production and droplet formation at the TGM fire testing laboratory.

After the catastrophic fire of the Kaprun glacier funicular 2 in 2000, the work environment and the fire safety investigation of constituents of coaches was substantially expanded. It liaises with the fact that all interior fittings of coaches of the ÖBB were fire-safety tested approximately in accordance with DIN 5510-2. Shortly after the incident of Kaprun, all components were tested and found to correspond to the interior fittings of coaches ÖBB the fire safety requirements approximately according to DIN 5510-2 [1].

The fire testing of materials according to EN 45 545-2:2016 is done according to ISO 5658-2:2006 and ISO 5660-1:2015 and is carried out at the fire testing laboratory. The toxicity tests and smoke tests according to ISO 5659-2:2013 are done by another institute (ofi) in Vienna. Concerning the tests of ISO 5658-2 and ISO 5660-1 we are an approved fire laboratory by CERTIFER (Railway Certification Agency) allowed to perform tests according to EN 45 545-2.

To fulfill the requirements of EN 45 545-2 it is necessary to use flame retardant materials as an additive for the different plastic materials. Also it is common to use intumescent coating of materials to fulfill the criteria of the different standards [2].

1.1. Fire Test according to ISO 5658-2:2006

The testing according to ISO 5658-2 specifies a method of testing for measuring the lateral spread of flame along the surface of a specimen of a product orientated in the vertical position. It provides data suitable for comparing the performance of essentially flat materials, composites or assembly that are used primarily as the exposed surface of walls in buildings or transport vehicles, such as ships and trains.

A test specimen (800 mm × 155 mm) is placed in a vertical position adjacent to a gas-fired radiant panel (Fig. 1) where it is exposed to a defined field of radiant heat flux for a time of 10 minutes. Following ignition, any flame front that develops is noted and the results are expressed in terms of flame spread distance and at least the critical heat flux at extinguishment (CFE).

[1] Prof. Dipl. Ing. Dr.; Federal Institute of Technology (TGM), Plastics Technology and Environmental Engineering, Austria; e-mail: dhohenwarter@tgm.ac.at.

Fig. 1.

The correlation between flame spread distance and CFE is shown in the diagram (Fig. 2).

Fig. 3.

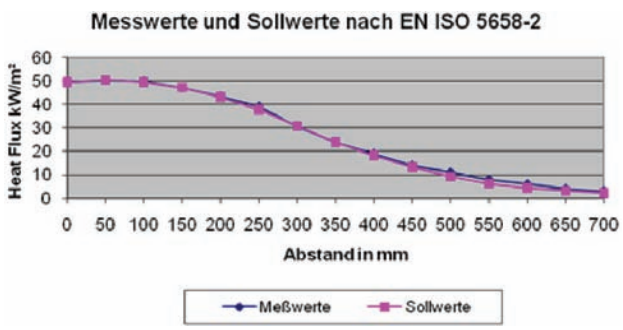


Fig. 2.

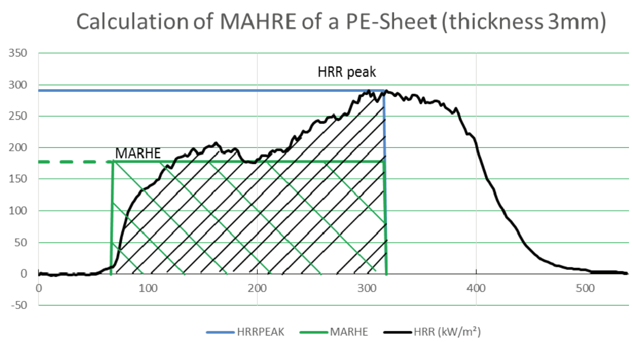


Fig. 4. The calculation of MARHE from the measured heat release rate (HRR measured in kW/m²)

1.2. Fire Test according to ISO 5660-1:2015

The test according to ISO 5658-2 specifies a method for assessing the heat release rate of a specimen exposed in the horizontal orientation to controlled levels of irradiance with an external igniter. The test method is based on the observation that, generally, the net heat of combustion is proportional to the amount of oxygen required for combustion.

Approximately 13.1 MJ of heat are released per kilogram of oxygen consumed. During the test specimens (Fig. 3) are burned under ambient air conditions (radiation in the range of 0 to 100 kW/m²) and at the same time oxygen concentration and exhaust gas flow rates are measured. Using these measurements the Average Rate of Heat Emission (ARHE) and then the Maximum Average Rate Heat Emission MARHE are calculated. The principle of the MARHE Calculation is shown in the diagram (Fig. 4).

2. Examples of Fire Tests according to ISO 5658-2 and ISO 5660-1

In the following a number of examples of tests according to the mentioned standards are presented. Fire tests of materials according to EN 45 545-2 are carried out according to ISO 5658-2 and ISO 5660-1.

2.1. GFK Material 4 mm with glas fibre + polyester resin

The testing of this GFK Material shows a significant difference of the heat release rate measured according to ISO 5660-1 between the outside and the rear side of the material. The outside shows a significant influence of the painting and gel coat while the heat release rate of the rear side is influenced by the top coat. In the following the results of 3 measurements per sample Fig. 5, 6 are shown.

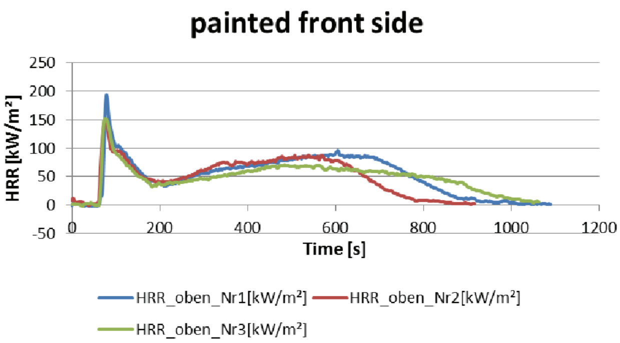


Fig. 5. GFK outside (green painted front side) Gel coat MAHRE 62 kW/m²

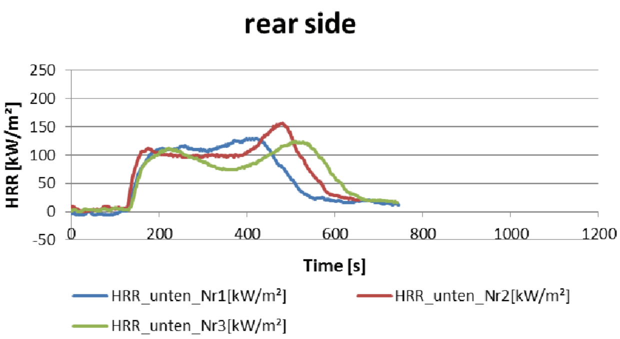


Fig. 6. GFK rear side (grey color)Top coat MAHRE 78 kW/m²

The spread of flame testing according to ISO 5658-2 of this GFK material shows no significant difference between both of the different sides of the material (Fig. 7, 8).

Fig. 7. GFK green outside CFE = 22 kW/m²

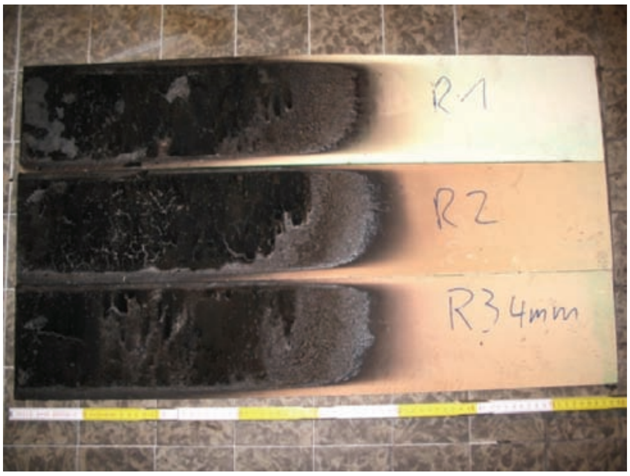


Fig. 8. GFK grey inside CFE = 22 kW/m²

2.2. Material named GFK Pultrudat thickness 2.9 mm

The testing of this GFK material was made for research purposes.

- Laminate,
- Reinforcement glass fiber roving – E-glass,
- Glass fiber mats,
- Matrix unsaturated polyester resin with Lp for high surface quality halogenfree,
- Surface polyester veil on visual outside of the profile
- Fiber weight content 48% tolerance ± 5%,
- Profiles were painted.

The Figure 9 shows the GFK material before and after the Cone test with the different layers of the glass fibre roving.

Fig. 9.

This material was radiated with different radiation intensities to study the heat release rate of this GFK material. It is clear that another heat radiation intensity yields to a different time when the material ignites. The time to ignite the material depends on the heat radiation intensity which is analyzed later.

The results in Figure 10 show that, in general, shortly after the ignition at higher radiation intensities, a large amount of heat is released. Upon irradiation with 75 kW/m² the highest amount of heat (HRR peak) is released and on exposure to 100 kW/m² a smaller amount of heat (HRR peak) than at 75 kW/m² is measured, as can be seen in the following table. This can be explained as follows: Upon irradiation with 100 kW/m² the heating leads to (short) strong fumes (outgassing) almost simultaneously with the ignition of the material and thus the heat release is reduced. Upon irradiation with 75 kW/m², however, a rather uniform smoke formation takes place as may be seen from the figure of the smoke production rate dependent on the heat radiation intensity.

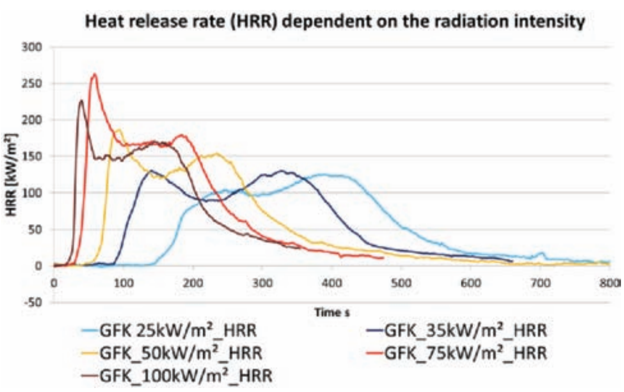


Fig. 10. Heat release rate (HRR) dependent on the radiation intensity

Likewise, the respectively extinction-coefficient and the temperature of the surface were measured during the tests with different heat radiation intensities. The extinction coefficient is proportional to the smoke production.

What is noticeable about this GFK – product is that, strong fumes (outgassing) form up at the beginning even before ignition. The outgassing is caused by low molecular weight molecule fractions which evaporate before. This brief strong degassing takes place, especially in the middle of the plate so that the specimen is deformed (just before the inflammation) in a small area and a noticeable sound is heard as well. Figures 11, 12 show the measurement of the Temperature °C: blue line, Extinction coefficient 1/m (Smoke production) black line, Heat release rate HRR kW/m² red line dependent on time and is shown for 2 different radiation intensities.

The material ignites approximately at a temperature of 340°C.

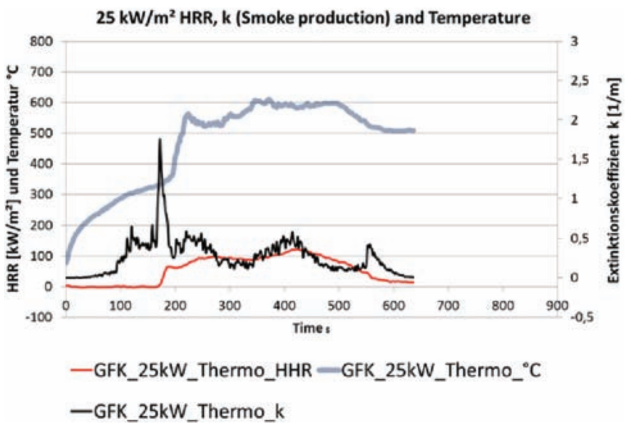


Fig. 11.

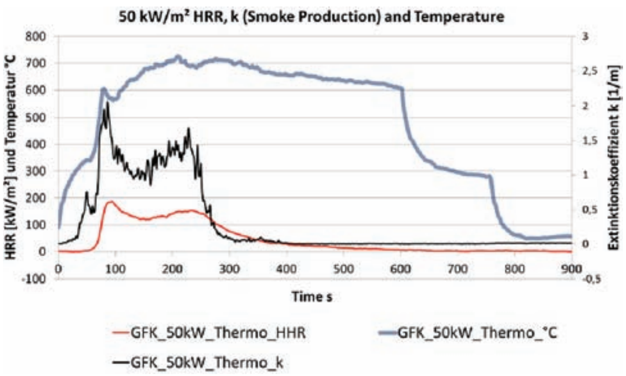


Fig. 12.

In Table 1 the results of measurements with a Cone calorimeter of a GFK product at different radiation intensities are presented.

Table 1

Radiation intensity [kW/m²]	MARHE [kW/m²]	HRR peak [kW/m²]	EHC [MJ/kg]	SPR [m²/s]	Time to ignite [s]	Burning Time [s]
25	67	133	20.0	0.0083	143	395
35	81	132	19.6	0.0091	82	363
50	104	181	19,1	0.0119	48	316
75	145	263	19.4	0.0179	23	335
100	137	227	18.7	0.0225	18	284

Where:
HRR – Heat release rate (kW/m²),
HRR peak – Peak heat release rate (kW/m²),
EHC – Effective heat of combustion per mass (MJ/kg),
SPR – Smoke production rate (m²/s).

The time until the ignition of the material depends on the radiation intensity which is shown in the table above. When radiated with high intensity, the material ignites very quickly, while the exposure to low-intensity takes longer to achieve ignition. In the Figure 13 this relationship is shown graphically. From the literature [3] the following relationship results

$$t_{ignition} = C \cdot k \cdot \rho \cdot c \left(\frac{T_{ignition} - T_{ambient}}{Heat\ Flux} \right)^2$$

Where:
C – constant,
k – thermal conductivity,
ρ – density,
c – specific heat,
$T_{ignition}$ – temperature at ignition,
$T_{ambient}$ – ambient temperature,
Heat Flux – radiation intensity.

The transformation of the equation above, for the relationship between the radiation intensity and the square root of the inverse $t_{ignition}$ (time to ignition) results in a linear relationship. In the diagram (Fig. 14) on the right side this relationship is shown and it shows up as the theoretically expected linear dependence.

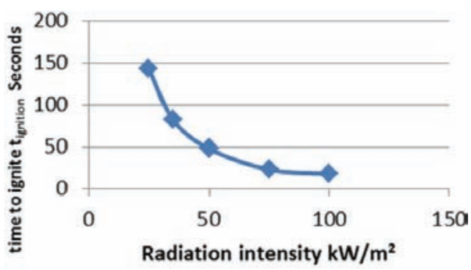


Fig. 13.

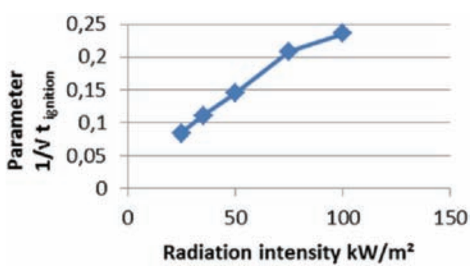


Fig. 14.

The time to ignite is dependent on radiation intensity and the radiation intensity depends nearly linear on the parameter $1/\sqrt{t_{ignition}}$.

Figure 15 shows that during a short time relatively strong fume (extinction-coefficient) is evident especially when radiated with 100 kW/m², whereas at the other radiation intensities a more uniform smoke production can be detected during a longer time range.

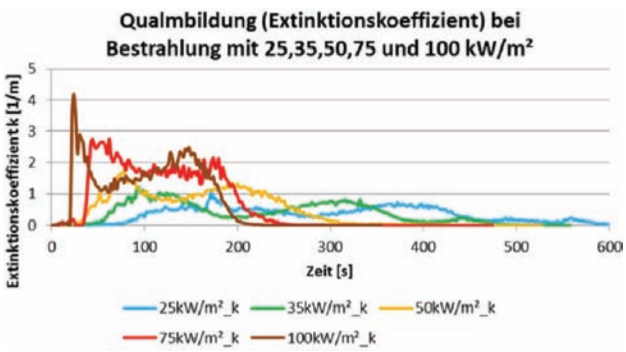


Fig. 15.

With the results of Table 1 the smoke production rate (SPR) increases approximately proportional to the intensity of irradiation which Figure 16 shows.

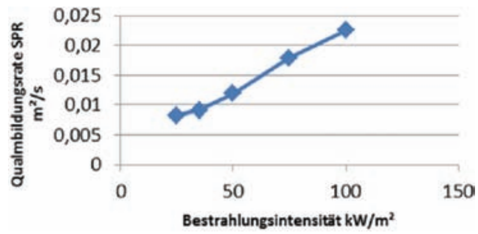


Fig. 16.

2.3. Heat release rate of PMMA dependent on the radiation intensity

Tests of a PMMA material were carried out for own research purposes. Figure 17 shows the heat release rate for different radiation intensities in the range of 5 kW/m² to 100 kW/m². These different radiation intensities which ignite the material occur at different time spans.

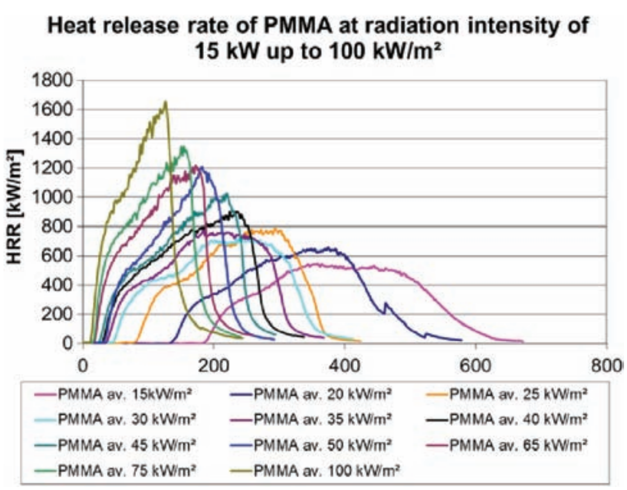


Fig. 17.

From the literature [3] the following relationship is used to show the relation between the time to ignite ($t_{ignition}$) and the heat flux which correspond to the heat radiation intensity

$$t_{ignition} = C \cdot k \cdot \rho \cdot c \left(\frac{T_{ignition} - T_{ambient}}{Heat\ Flux} \right)^2$$

Where:
C – constant,
k – thermal conductivity,
ρ – density,
c – specific heat,
$T_{ignition}$ – temperature at ignition,
$T_{ambient}$ – ambient temperature,
Heat Flux – radiation intensity.

As expected from the equation there is (nearly) a linear correlation between the time to ignite and the square of the radiation intensity (Fig. 18, 19).

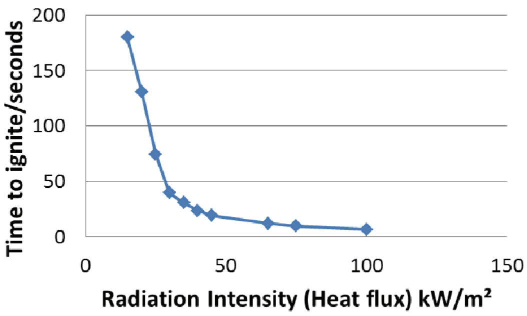


Fig. 18.

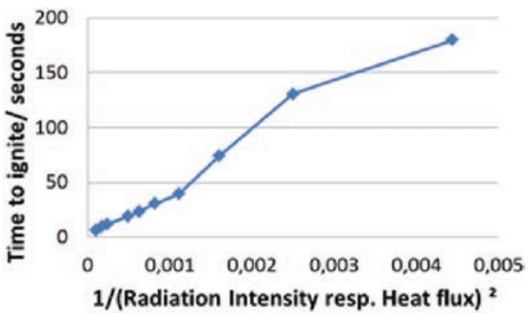


Fig. 19.

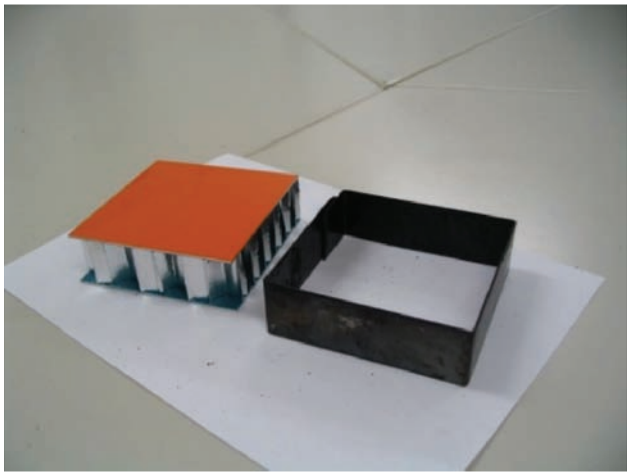
2.3. Sandwich door leaf for railway application

According to DIN 5510-2: 2009 metals and alloys with organic coatings with a nominal thickness <0.3 mm are considered as components with proven requirements and therefore they do not need to be tested (DIN 5510-2, Chapter 5.4).

According to EN 45545-2: 2016, the walls of external body shells (including painting / coating systems, films and windows) must be checked according to requirement R7. The fulfillment of the requirements of EN 45545-2 must be demonstrated by the manufacturer of such coatings.

One of these test results are shown below: The test of this Sandwich door leaf was commissioned by Knorr-Bremse GmbH, IFE Kematen Division Door Systems (Fig. 20). The sandwich door consists of the following components:
- Coated, faced aluminium honeycomb product 19.8 kg/m^2,
- Final coating: 2K HS Clear coat 50 µm,
- Second coating: Basecoat 10–20 µm,
- First coating: Water based 2-K Epoxy Primer 40 µm,
- Facing: Aluminium coil coated 40 µm,
- Honeycomb: 0,029 kg/dm^3, thickness 30 mm, cell diameter 19 mm, wall thickness 0.071 mm,
- Adhesive: Epoxy adhesive 0.2 mm,
- Facing: Aluminium 1mm.

a)



b)

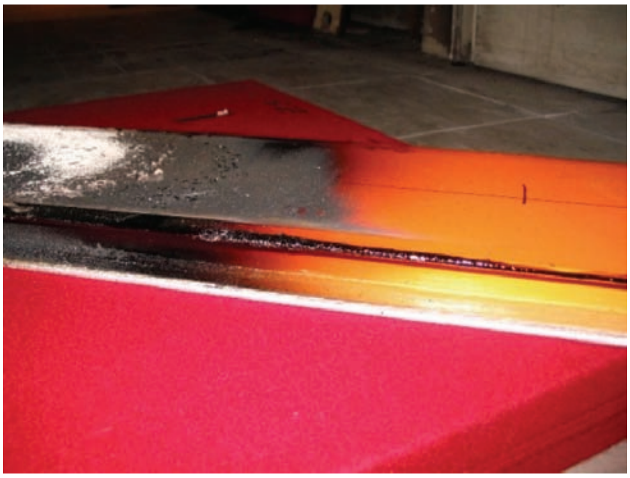
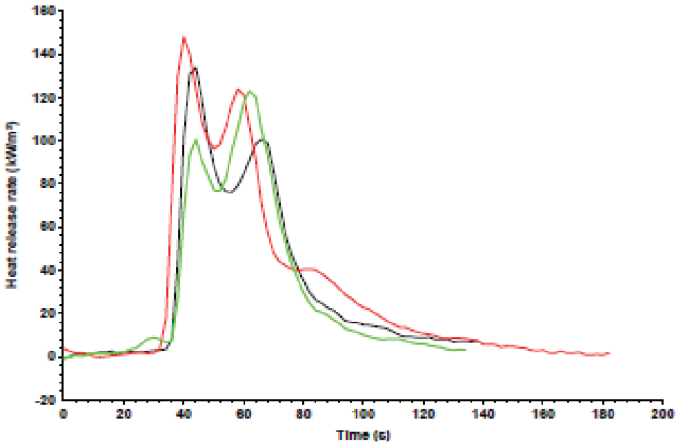


Fig. 20. Test material for the cone test: a) with honeycomb structure: b) and for spread of flame test closed structure

For the cone test the honeycomb was tested with a frame shown in the Fig. 21, 22.

a)



b)

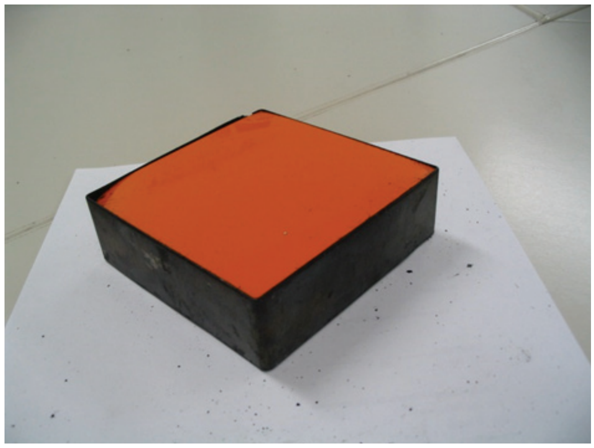


Fig. 21. Heat release rate ISO 5660-1:2002; MARHE: < 50 kW/m²

Many thanks to Knorr-Bremse GmbH Division IFE Automatic Door Systems for the permission to publish the above mentioned results.

a)

b)

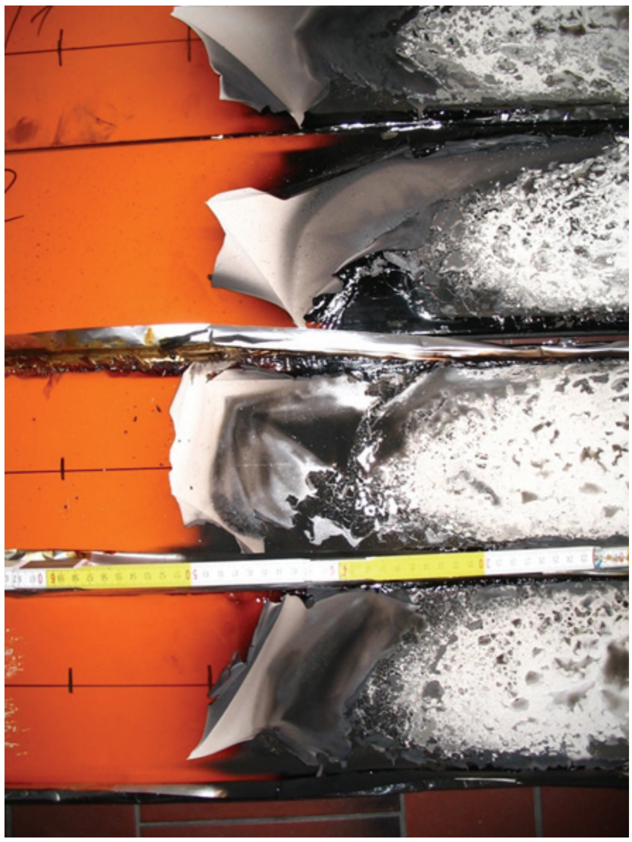


Fig. 22. Lateral spread of flame ISO 5658-2; CFE >20 kW/m²

3. Combustibility of tram seats according EN 45 545-2

Seats of trams includes most times a hard cover seat shell. That is the reason that tram seats are tested according requirement R6 of EN 45 545-2:2016 (Table 2).

In the following an example of a plywood backrest is presented (Fig. 23). It was measured with a radiation intensity of 35 kW/m²:

In the following an example of a plywood seat of an old tram backrest is presented (Fig. 24). It was measured with a radiation intensity of 35 kW/m²:

Table 2

F1C	Passenger seat shell – Base		The external surface of the base shell (including all coating or covering) shall be tested			R6
[A1]Requirement set (used for)[A1]	Test method reference	Parameter and unit	Maximum or Minimum	HL1	HL2	HL3
R6 (F1C, F1D)	T03.01 ISO 5660-1: 50 kWm^2	MARHE kWm^2	Maximum	90	90	60

a) b)

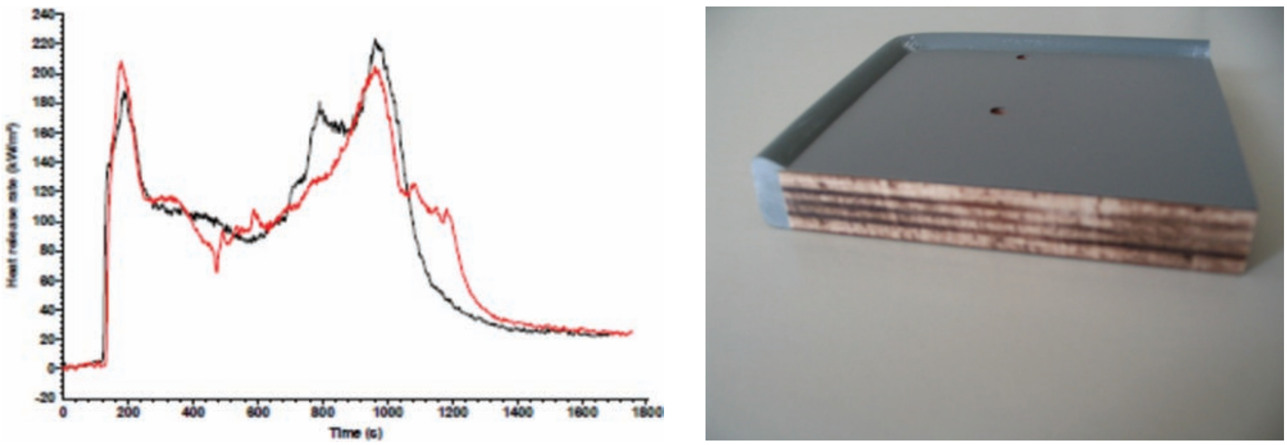


Fig. 23. Heat release rate ISO 5660-1:2015; Radiation 35 kW/m², MARHE=115 kW/m²

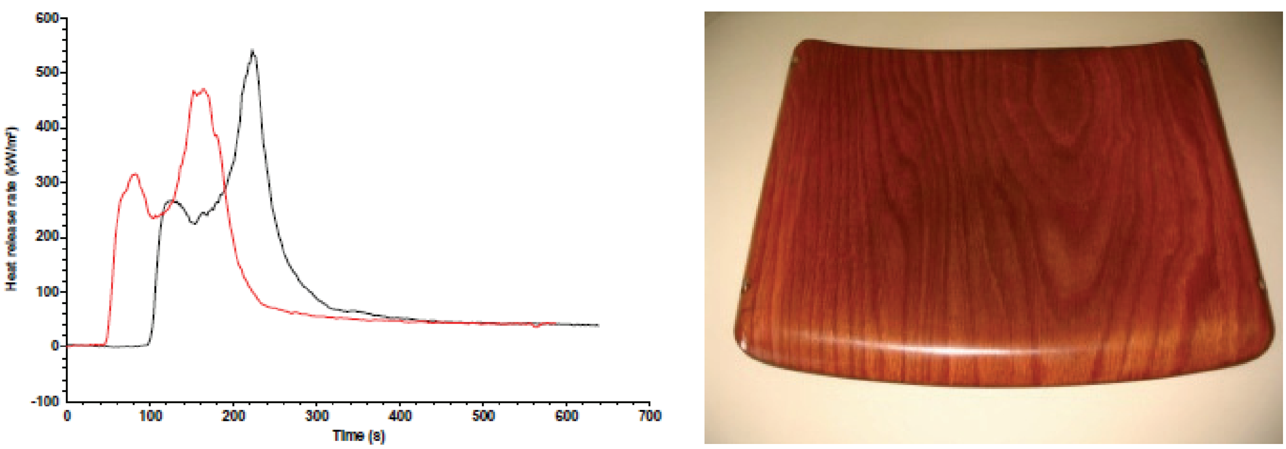


Fig. 24. Heat release rate ISO 5660-1:2015; Radiation 35 kW/m², MARHE=206 kW/m²

Modern examples of tram seats show that it is difficult to reach MAHRE < 90 kW/m². This is necessary because trams sometimes drive through tunnels.

That means, with other words that the fire behavior requirements for trams seats are too high and it is difficult to fulfill the requirements with seat materials which are comfortable and fulfill also the mechanical requirements.

4. Combustibility of seats according to DIN 5510-2

The fire performance of seats for railway cars is tested using original complete seats according to DIN 5510-2.

(Draft) E DIN 5510-2:1996

Upholstered seats must be self-extinguishing, even if the seat covering is slit open (vandalised). A 100 g paper cushion is positioned on the seat base (Fig. 25).

Fig. 25.

Ventilation system: The hood can be operated so that the smoke produced during the experiment can be just sucked off.

DIN 5510-2: 2009

Ventilation system: The volume flow should be in the range of 0.5 to 0.7 m^3/s. The ventilation system is calibrated with n-Heptan. The smoke production rate should be calculated from the measured extinction coefficient.

4.1. ÖBB seats without and with flame retardant covering of the foam

The fire testing of the seats from the Austrian Railway coaches was carried out for the ÖBB in the year 2008 and shows that in this case a flame retardant covering was necessary to protect the foam (Fig. 26, 27).

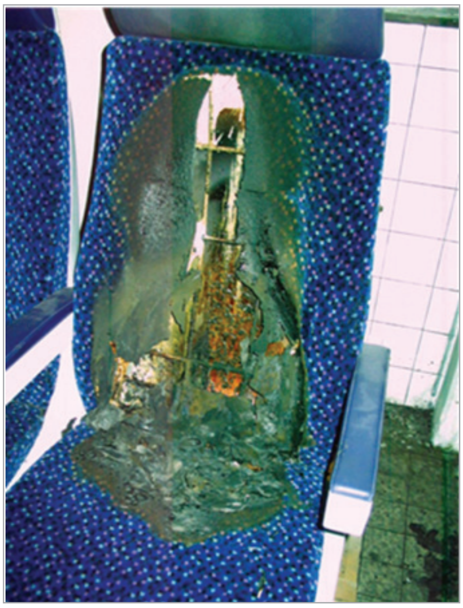


Fig. 26. Seat without flame retardant covering of the foam; Fire extinguisher was used after 13 minutes

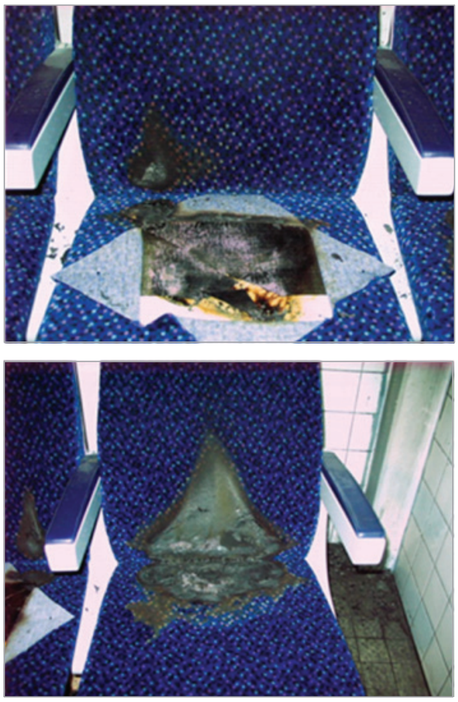


Fig. 27. Seat with flame retardant covering of the foam

4.2. Comparison (according to DIN 5510-2) of one covering material with different foams (ÖBB)

These tests to analyse which foam is compatible with the standard textile covering material used by the ÖBB, were made in the year 2005. In order to analyze the behaviour of the foam the textile covering material was cut (vandalised). **Textile covering material**: Producer Kneitz, velour chess 85% wool, 15% polyamide (Velourstoff Schach 85% Wolle, 15% Polyamid).

The foams were tested (Table 3):

Table 3

Producer	Name of the foam
Purtec	Purtec 500
Metzler	Metzoprotect Qualität FRM-U FT3307
Weserland	Weserland Qualität FSF 710 RA
Weserland	Weserland PU Muster W 5662/1
Eurofoam	LS. NR. 04004452 Qualität KF 55 B1 weiß

The sequence of the products mentioned in the table above does not correspond with the sequence of the pictures of the seats in the following two picture lines (Fig. 28, 29).

The result of this research is: one combination of fabric upholstery (textile covering) with foam leads to a full-scale fire while a different combination of foam and textile covering extinguishes after 4 about minutes.

Many thanks to ÖBB-Technische Services, Flottenengineering Nahverkehrs-Reisezugwagen (Manfred Schorm), St. Pölten for the permission to publish the above mentioned results.

a) b) c)

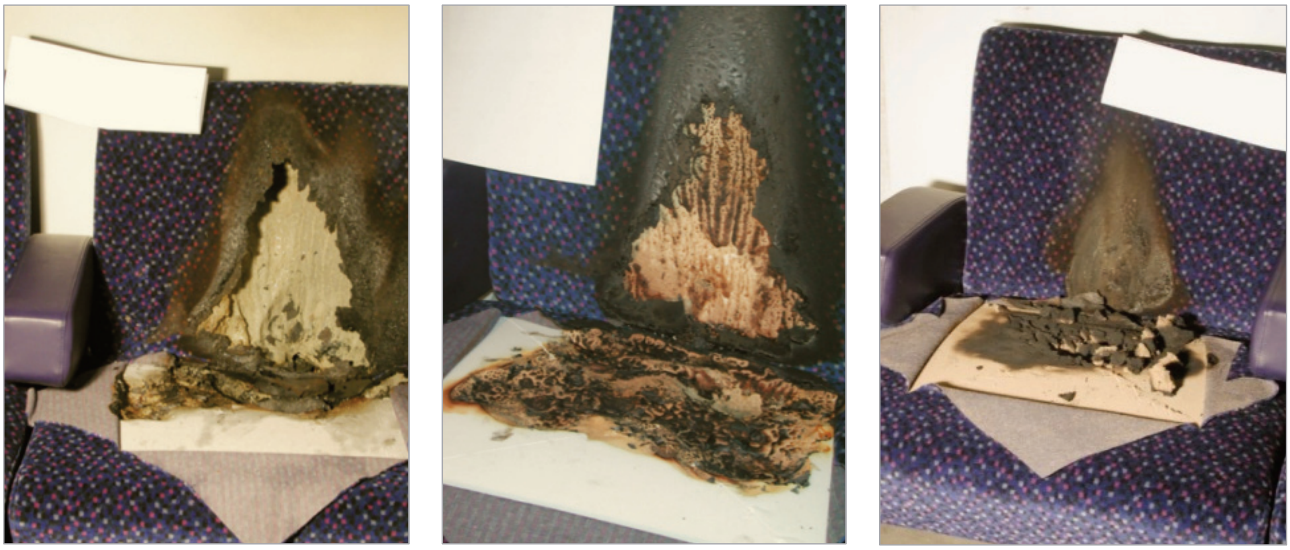


Fig. 28: a) Fire extinguisher used after10 Minutes; b) Self-extinguishing after 4:25 Minutes; c) Self-extinguishing after 6:48 Minutes

a) b)

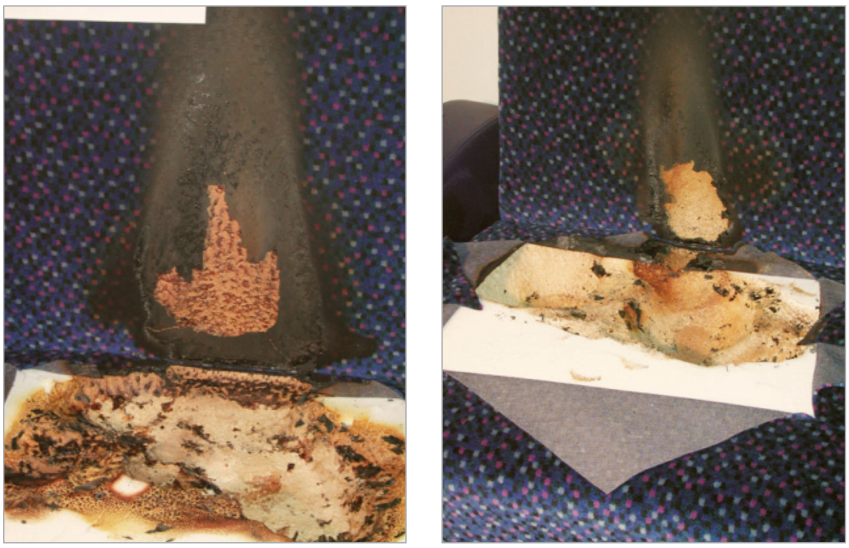


Fig. 29: a) Self-extinguishing after 4:00 minutes; b) Self-extinguishing after 4:57 minutes

5. Conclusion

5.1. Fire tests of materials according to ISO 5658-2 and ISO 5660-1

The test of a special GFK material shows a significant difference of the heat release rate measured according to ISO 5660-1 between the painted side and the rear side of the material.

Another GFK material was radiated with different radiation intensities which lead to different ignition times. This correlation fulfills the equation of the theory of fire behaviour for the ignition of thick materials. The tests for PMMA show also a good correlation between measurements and (fire) theory.

According to DIN 5510-2: 2009 metals and alloys with organic coatings with a nominal thickness of <0.3 mm are considered as components with proven requirements and therefore do not need to be tested. But according to EN 45545-2: 2013 the walls of external body shells (including painting/coating systems, films and windows) must be checked according to requirement R7. As an example the results of one painting are shown.

Measurements of heat release rate of tram seats shows that it is difficult to meet the requirements of fire behaviour and at the same time to fulfill the demands for comfort and mechanical requirements.

5.2. Fire behaviour of seats

Fire behaviour of seats depends on:

- **Density of the foam:** Density 95 kg/m³ is better than usual 85 kg/m³, however foams with 75 kg/m³ can also fulfill the requirements.
- **Flame retardant fibres** „glued" on the foam can improve the fire behaviour of the seat.
- **Combination** of the **textile covering and the foam**:
  - One textile / foam combination leads to full fire, while with another combination stops the fire after 4 Minutes.

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Standards

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2. EN 45 545-2: Railway applications – Fire protection on railway vehicles, Part 2: Requirements for fire behavior of material and components, 2016.
3. ISO 5658-2: Reaction to fire tests – Spread of flame – part 2: Lateral spread on building and transport products in vertical configuration, 2006.
4. ISO 5660-1: 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), 2015.
5. ISO 5659-2: Plastics – smoke generation – Part 2: Determination of optical density by a single-chamber test, 2013.
6. DIN 5510-2: Preventive fire protection in railway vehicles – Part 2: Fire behavior and fire side effects of materials and parts – Classification, requirements and test methods, 2009.

Doświadczenia zdobyte w testach palnościowych siedzeń przeprowadzonych zgodnie z normami EN 45 545-2 i DIN 5510-2

Streszczenie

W artykule przedstawiono wyniki badań palności różnych produktów wykonanych zgodnie z normami ISO 5658-2 i ISO 5660-1. Szczegółowo przeanalizowano wyniki badań GFK (kompozyty poliestrowo-szklane). Stosując normy ISO 5658-2 i ISO 5660-1, poddano analizie zgodność z normami malowanie korpusów siedzeń, chociaż ta zgodność nie musi być analizowana według wymogów niemieckiej normy DIN 5510-2. Zaprezentowano różne możliwości zmniejszenia palności wagonów kolejowych, stwierdzając, że połączenie pianki z pokryciem tekstylnym ma zasadnicze znaczenie.

Słowa kluczowe: testy palnościowe materiałów i siedzeń używanych na kolei, testy palnościowe siedzeń tramwajowych

Опыт полученный во время испытания горючести сидений в соответствии с нормами EN 45 545-2 и DIN 5510-2

Резюме

Результаты испытаний горючести проведенных в соответствии с нормами ISO 5658-2 и ISO 5660-1 были представлены для разных изделий. Были глубоко проанализированы результаты для изделий из стеклопластика. Анализу в соответствии с нормами ISO 5658-2 и ISO 5660-1 подвергало также покрытие корпусов сидений, хотя их соответствие не должно быть анализировано в соответствии с требованиями немецкой нормы DIN 5510-2. Измерения скорости выделения теплоты трамвайных сидений показывают, что тяжело выполнить одновременно правильные пожарные требования, как и потребность в комфорте и механические требования для этого типа сидений. Были показаны разные возможности уменьшить горючесть железнодорожных вагонов, а также факт, что соединение пенопласта с текстильным покрытием имеет главное значение в этой области.

Ключевые слова: испытания горючести материалов и сидений используемых в железнодорожным транспорте, испытания горючести трамвайных сидений