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A comparative study of test methods for assessment of fire safety performance of bus interior materials

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SUMMARY

This work concerns the assessment of fire performance of interior materials in buses. The widely used test method ISO 3795/FMVSS 302 has received much criticism mainly based on the fact that the test is a small-scale method not suited for bus fires induced by for example fire in the engine compartment or fire in a tyre. Furthermore, test specimens are oriented horizontally, whereas much fire spread in a real bus fire occurs on vertically oriented products. Seventeen products were investigated: 11 textiles, four solids and two insulations. Three test methods were compared: ISO 3795, ISO 6941 and ISO 5658-2. Given the existing criteria for interior materials, it was found that ISO 6941 and ISO 5658-2 place harder requirements on the materials.

When the three methods were compared, it was found that ISO 3795/FMVSS 302 and ISO 6941 are insufficient for simulating bus fires typically occurring today. Such fires are often initiated by a fire in the engine compartment or in a tyre and can hardly be simulated by small-scale methods as ISO 3795/FMVSS 302 or ISO 6941 even if the ISO 6941 method to some extent gives results similar to the established large-scale ISO 5658-2 method.

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1. INTRODUCTION

The test method ISO (International Organization for Standardization) 3795 [1] is prescribed for approval of interior material in buses [2,3]. According to this method, specimens are tested in horizontal orientation, and the burning rate is measured and used as the parameter to assess compliance. The method, or the similar method FMVSS (Federal Motor Vehicle Safety Standard) 302 [4], has received severe criticism, especially during recent years [5–7]. Basically, the criticism concerns the fact that it is a small-scale method not suited for bus fires induced by for example fire in the engine compartment or fire in a tyre. Furthermore, the test sample is oriented horizontally. Fire performance is expected to be worse for products oriented vertically, such as seat backs or wall linings. As a result, alternative or complementary test methods have been proposed. These are ISO 6941 [8,9] and ISO 5658-2 [10,11]. ISO 6941 is a method originally conceived for relatively thin textile fabrics such as curtains. ISO 5658-2 is a method for assessing the fire performance of vertically oriented materials, and it is already used in international fire regulations for ships [12] and trains [13].

In this study, we have compared the three test methods (ISO 3795, ISO 6941 and ISO 5658-2) for 17 materials that can be used in bus passenger areas.

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2. MATERIALS AND METHODS

2.1. Tested products

All 17 products, except products No. 16 and No. 17, are typically used as interior material in buses today. A summary of the products' properties is given in Table I.

2.2. Test of surface spread of flame (ISO 5658-2)

To determine a product's behaviour regarding lateral flame spread, the international standard ISO 5658-2 is used in the proposed European system for fire safety on trains CEN/TS 45545-2 [13]. The same test procedure but with some additional measurements is used as the main flame spread test for interior linings in passenger ships under the IMO Resolution A.653(16) [12].

The lateral flame spread is determined on vertically orientated specimens exposed to radiant heat from a methane-fuelled rectangular radiant panel at an angle to the specimen as shown in Figure 1. A small gas burner flame impinging on the sample acts as the pilot ignition source [6].

The distance of the flame spread is used for reporting the critical heat flux at extinguishment (CFE) value for both trains and ships. The CFE value is the incident heat flux at the specimen surface at the point along its horizontal centreline where the flame ceases to advance. The CFE value, kW/m^2, is determined by measuring the maximum spread of flame and relating this value to the corresponding heat flux value from the heat flux profile curve, the calibration curve, which is based on measurements conducted using a non-combustible board and heat flux meters.

The textile specimens were attached to a non-combustible backing board using staples along the upper edge. During the test, the staples were hidden under the specimen holder and did therefore not affect the measurements.

2.3. Test of horizontal burning rate (ISO 3795, ECE (Economic Commission for Europe) Reg. No 118 annex 6, directive 95/28/CE annex IV)

At present, products for use in the interior of buses are mainly regulated by the international standard ISO 3795 [3]. The principle of ISO 3795 is that a 100 mm × 356 mm sample is mounted horizontally in a U-shaped holder and is exposed to the action of a well-defined low-heat release flame for 15 s in a combustion chamber. The flame is applied to the free end of the sample (see Figure 2). The test

Table I. Summary of the tested products.

Prod. no.	Bus component	Description	Content	Thickness (mm)	Weight per area (g/m^2)
1	Wall, ceiling	Plastic	ABS	3.1	3040
2	Wall, ceiling, partition	Perstorp laminate	Paper-reinforced thermosetting plastic	5.8	8780
3	Wall, ceiling, seat	Fabric	Wool velvet blend, FR	2.8	311
4	Seat	Artificial leather	91.5% PVC+0.5% polyamide, FR	1.1	814
5	Wall, ceiling, seat	Fabric	70% Polyester+30% wool, FR	3.2	627
6	Wall, ceiling, seat	Fabric	55% Polyester+45% wool, FR	3.9	829
7	Wall, ceiling, seat	Fabric	Wool velvet blend, FR	4.4	973
8	Wall, ceiling, seat	Fabric	85% wool+15% nylon, FR	4.3	856
9	Curtain	Fabric	Polyester, FR	0.8	341
10	Wall, ceiling, seat	Fabric	56% wool+35% cotton+9% nylon, FR	4.2	826
11	Wall, seat	Fabric	Polypropylene fibre, FR	4.4	510
12	Instrument board	Plastic	ABS/TPU (TPU=thermoplastic PUR)	5.0	5155
13	Instrument board	Plastic	ABS	5.1	5234
14	Engine room	Insulation	Polyurethane	27.9	898
15	Inside walls	Insulation	PET	37.4	909
16	Not in buses	Fabric	Polyamide 6,6 with FR coating	0.3	233
17	Not in buses	Fabric	Polyamide 6,6 with FR coating	0.7	399

ABS, acrylonitrile butadiene styrene; FR, flame retardant; PVC, polyvinyl chloride; PET, polyethylene terephtalate.

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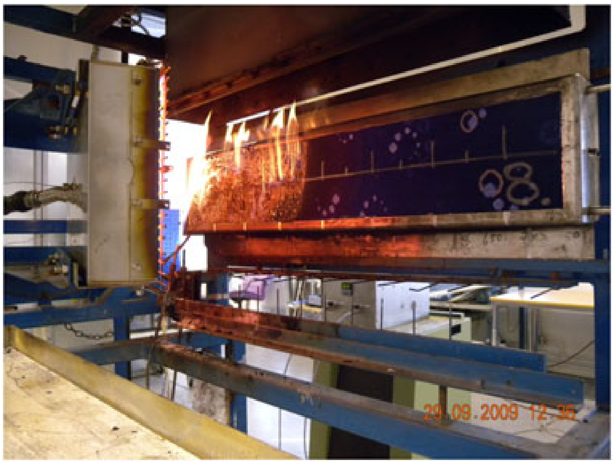

Figure 1. Test of product no. 8 according to ISO 5658-2.

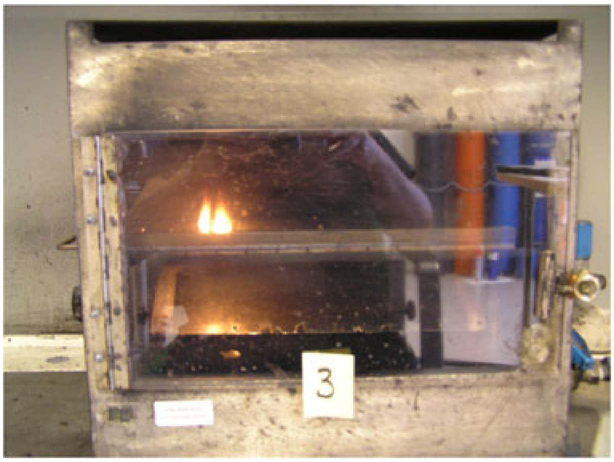

Figure 2. Test of product no. 3 according to ISO 3795.

determines if and when the flame extinguishes or the time at which the flame passes a measured distance, resulting in a burning rate in millimetres per minute (mm/min) [6].

A similar test method is FMVSS 302 [4]. The differences are very small, and test results from one of the tests can be directly compared with the other. This test is widely used all over the world for passenger car fire safety testing.

2.4. Test of vertical burning rate (ISO 6941, ECE Reg. No 118 annex 8, directive 95/28/CE annex VI)

Curtains, blinds and other vertically hanging materials in buses are presently regulated by the ECE Reg. No 118 annex 8, which describes a test method which is identical to the international standard ISO 6941 [8].

The principle of ISO 6941 is that a sample is held vertically, fastened by pins located on a steel frame. The sample is exposed from below with a 40-mm long flame for 5 or 15 s. At three different heights, a marker thread is placed horizontally across the sample surface. The time for the flame to burn off each marker thread is measured. The vertical burning rate to each marker thread is calculated, and the fastest burning rate is taken into account for classification (see Figure 3).

3. RESULTS AND DISCUSSION

The results from the tests are presented in Figures 4–6.

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Figure 3. Test of product no. 11 according to ISO 6941.

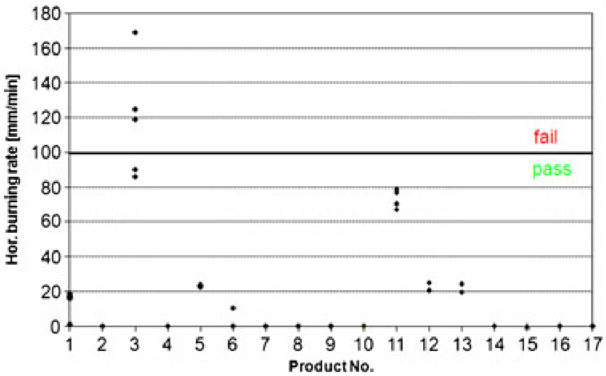

Figure 4. Results for horizontal burning rate according to ISO 3795, ECE Reg. No 118 annex 6, directive 95/28/CE annex IV.

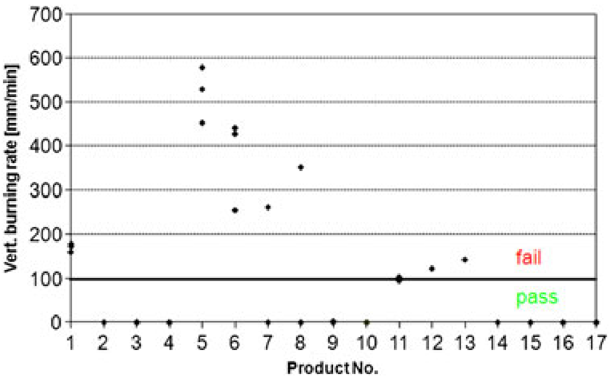

Figure 5. Results for vertical burning rate according to ISO 6941, ECE Reg. No 118 annex 8, directive 95/28/CE annex VI.

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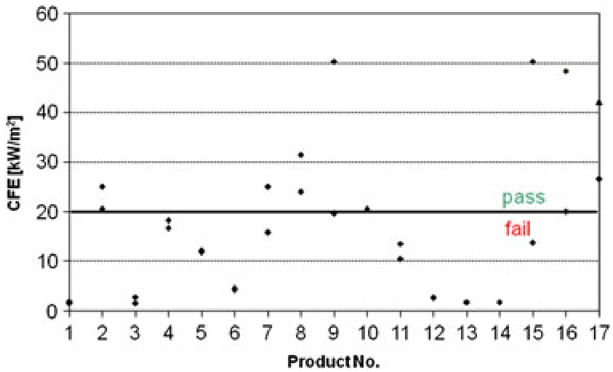

Figure 6. Results for critical heat flux at extinguishment (CFE) according to ISO 5658-2 (surface spread of flame).

3.1. Comparison of results

According to ECE Reg. No 118 [3] and directive 95/28/CE [2],[1] the result of the tests shall be considered satisfactory if, taking the worst results into account, the horizontal, for ISO 3795, or vertical, for ISO 6941, burning rate is not more than 100 mm/min.

According to IMO Res A.653(16) [12] and prCEN 45545-2 [13], Requirement 1, the average CFE should be 20 kW/m^2 or higher when evaluated according to the test standard ISO 5658-2, Surface Spread of Flame, for a material to be considered satisfactory.[2] As a consequence, 20 kW/m^2 has been suggested as an amendment to ECE Reg. No 118 [14].

Table II summarizes all test results. It is clear that ISO 3795, horizontal burning rate, is the most lenient test method given the criteria for approval above. Approximately 94% (16/17) of the products

Table II. Summary of test results. For horizontal and vertical burning rate, the worst result is presented. For surface spread of flame, the average test result is presented.

	ISO 3795		ISO 6941		ISO 5658-2	
	Horizontal burning rate		Vertical burning rate		Surface spread of flame	
Prod. no.	(mm/min)	Pass/fail	(mm/min)	Pass/fail	(kW/m^2)	Pass/fail
1	19	Pass	178	Fail	2	Fail
2	0	Pass	0	Pass	23	Pass
3	169	Fail	0	Pass	2	Fail
4	0	Pass	0	Pass	18	Fail
5	24	Pass	578	Fail	12	Fail
6	10	Pass	440	Fail	4	Fail
7	0	Pass	262	Fail	20	Pass
8	0	Pass	351	Fail	28	Pass
9	0	Pass	0	Pass	35	Pass
10	0	Pass	0	Pass	21	Pass
11	79	Pass	103	Fail	12	Fail
12	25	Pass	122	Fail	3	Fail
13	24	Pass	142	Fail	2	Fail
14	0	Pass	0	Pass	2	Fail
15	0	Pass	0	Pass	32	Pass
16	0	Pass	0	Pass	34	Pass
17	0	Pass	0	Pass	34	Pass

[1]From 2014 EU directive 95/28/CE, as well as around 40 other directives, will be phased out and replaced by corresponding ECE regulations. In particular, EU directive 95/28/CE will be replaced by ECE Reg. No 118.
[2]This criterion is not required for floor coverings.

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passed the requirement for ISO 3795. If the products are tested for their vertical burning rate according to ISO 6941 instead, the situation is different. Fifty-three per cent (9/17) of the products pass the requirements for ISO 6941. This could be expected since vertical flame spread is more effective due to more effective heat transfer from the flames to the specimen. Finally, 47% (8/17) of the products pass the requirements for spread of flame according to ISO 5658-2.

In general, the correlation is very poor between ISO 3795 and the other methods ISO 6941 and ISO 5658-2. The ISO 6941 method to some extent gives results similar to the large-scale ISO 5658-2 method.

3.2. Evaluation of methods

ISO 5658-2 is a widely accepted test method for interior materials. It is a prescribed test method for railway applications in Europe [13] as well as for passenger ship applications worldwide [15]. Ignition is initiated by a large radiant heat exposure.

ISO 3795 and ISO 6941 evaluate the ignitability of a material exposed to a 38-mm or 40-mm length gas flame, respectively. These are small-scale methods that were originally conceived to mimic a small ignition source such as a cigarette or a match. That type of threat was most relevant some 40 years ago when the test method ISO 3795 was defined, but today other fire sources are more relevant. Examples of typical fire sources in bus fires today [16] are tyre fires [17] and fires in the engine compartment [18]. The fact that the ignition source in ISO 3795 is small means that many materials extinguish by themselves or do not ignite at all. This is indeed an attractive property when the ignition source is small, but it does not reflect the outcome from a fire where the heat attack is larger or when large amounts of hot gases enter the passenger compartment via the floor (fire in the engine compartment) or via the windows or side walls (fire in a tyre). In such cases, most materials will ignite, and the important fire property will be how far the fire will spread when the material is exposed to the larger scale ignition source. Other important properties are production rates of heat and smoke.

Another argument that is repeatedly presented against the use of ISO 3795 is that the sample is positioned in a horizontal position, whereas much material in bus passenger areas is actually mounted vertically. This is one of the reasons why it has been suggested to replace ISO 3795 with ISO 5658-2 or possibly with ISO 6941. However, the small-scale nature or ISO 6941 makes it less appropriate for test of bus materials as discussed above.

The amount of plastic materials in the interior of buses has increased considerably over time. In ISO 3795 and in ISO 6941, burning droplets often occur for plastic materials. This can lead to extinguishment of the fire on the sample if the flame is anchored solely to the part that falls off. It can be argued that this is advantageous for a curtain since the flame spread on the curtain stops. However, a wall material, as opposed to a curtain, is typically attached to a backing, and burning droplets do not easily remove the fire from the material. This shows that ISO 6941 is a reasonable test for curtains but should be avoided for other types of interior materials since the burning rate of 0 mm/min (the burning part falls off) can be achieved in the test, whereas this would not be the case in a real situation with the material attached to a wall. Burning droplets *per se* are also a big risk since they can extend the fire from higher to lower areas. Some, but not all, elevated materials are required to be tested for their melting behaviour in the current ECE Reg. No 118.

Furthermore, the flames in ISO 3795 and ISO 6941 are localized to one end of the product. This is the reason why the material stops burning if the burning part falls off. The distance from the flame to the remaining material is then too large for re-ignition to occur. This is not typical for a situation where flames are propagating into the passenger area. The ignition source can then be expected to be more homogeneous, partly consisting of radiant heat. This means that a large part of the material is exposed to high enough heat load for ignition. The material could therefore in a real bus fire reignite even after burning parts have fallen off.

An interesting observation from test results of ISO 6941 is that flames in general develop on both sides of the material. In most cases, the flames are bigger on the rear side, where there are no marker threads. The fact that flames on the rear side are not measured according to the standard is questionable for materials such as curtains which are free burning on both sides.

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The marker threads in ISO 6941 are not reliable detectors for the flame spread. For example, in the test of product 13, the entire product was for a while engulfed in flames, whereas both the second and third threads were intact (see Figure 7). The reason for this was probably that the flames mostly occurred a few centimetres out from the sample, far away from the sample where the threads were. In another test, the thread attached to the melting and buckling material. This gave the result that the thread never broke. It was observed that the results of the test were very sensitive to the distance between thread and sample for several products. The nominal distance between the thread and the sample is 3 mm [8].

Finally, testing thick plastic materials, such as ABS boards for example, poses a fire hazard to the cabinet (see Figure 7).

4. CONCLUSIONS

ISO 3795 and ISO 6941 are small-scale methods capable of assessing the ignitability for materials ignited by a small ignition source, such as a lighter. However, thermal attacks larger than a lighter could ignite and induce sustained flaming on materials that do not ignite in ISO 3795 and ISO 6941. In fact, the classification criteria for the tests even allow some limited burning when products are exposed to the small ignition source. If a small-scale method should be used, it is suggested that the criterion for compliance is that the sample does not ignite at all instead of the allowed burning rate of 100 mm/min.

Fires in the passenger area of buses are often initiated by intruding flames or hot fire gases from a fire in the engine compartment or in a tyre. For these types of fires, the small-scale methods are not useful but need to be replaced by a test method that can assess the fire properties of materials exposed to ignition sources of varying sizes. One such test method is ISO 5658-2, and it is suggested that ECE Reg. No 118, concerning fire properties of interior materials in buses, is amended with this method.

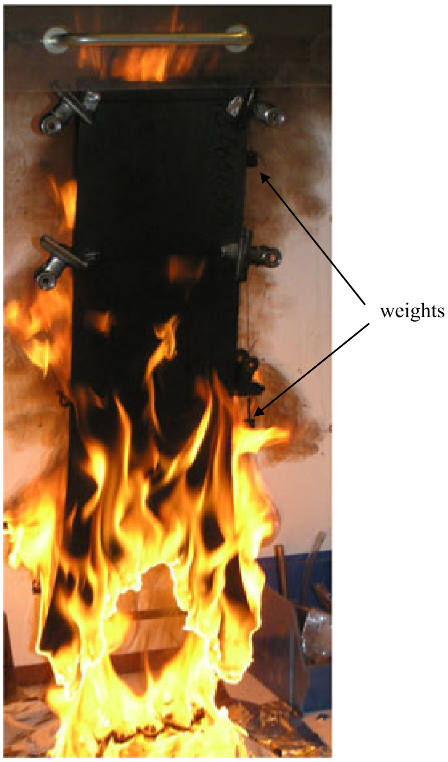

Figure 7. Product 13 (5 mm ABS) completely engulfed in flames in the ISO 6941 test. Notice that both the second and the third threads are still intact. This can be seen on the weights that have not yet fallen down (These weights are attached to the marker threads so when the threads sever the weights fall down).

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