FIRE SAFETY OF BUSES - RESEARCH ACTION FOR IMPROVING VEHICLE REGULATIONS

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ABSTRACT

Although the bus belongs to the safest traffic means, single accidents can be particularly severe and concern many passengers. Especially in case of fires a high number of injured and killed persons can be the outcome. Fire safety of buses therefore is of high importance. With the increase of synthetic and plastic materials as a material for the interior equipment of buses and coaches because of their good mechanical properties combined with low weight, the question arises whether the safety level has decreased in case of a fire during the last years - also compared to other means of transport. Because of the combustible plastics and their ability to release a high amount of heat the main fire load in buses is no longer the fuel but the plastic materials which are also often easy to ignite. Besides the flammability of the equipments, the production of smoke, the smoke development and propagation and its toxicity for the people as well as the testing methods and limit values are of interest.

For those reasons research projects were initiated on behalf of the German Federal Highway Research Institute. At the one hand the fire behavior of coach interiors was examined in general focusing on fire propagation as well as fire detection and signalling. As result, recommendations with regard to early fire detection systems for the engine compartments and on-board extinguishing equipment were elaborated. At the other hand research is carried out to examine heat release, smoke, smoke propagation and its toxicity due to burning bus interior materials.

The paper describes which effective and economically reasonable fire safety requirements for interiors of buses would improve the current situation. Proposals for amendments of current requirements are recommended including the specification of appropriate limit values. In particular, it is taken into consideration which reasonable fire safety standards from other transport sectors, especially the rail sector, should be transferred to buses.

INTRODUCTION

Already in the year 2000 BASt (Bundesanstalt für Straßenwesen, Federal Highway Research Institute, Germany) initiated two research studies in order to investigate how road traffic safety of buses could be improved [1]. On the one hand fire safety performance was an issue to be dealt with. On the other hand emergency exits should be examined.

The first study with regard to burning behaviour of coach interior equipment was carried out by DEKRA, a German testing organisation [2]. Based on theoretical considerations and several real scale fire tests, a variety of recommendations was given. Especially the installation of fire detectors in the engine compartment was claimed. In addition emphasis was laid on the equipment with appropriate fire extinguishers since it turned out that already an essential safety gain would be achieved if small fires were extinguished early before they could spread.

There should be at least two extinguishers, one next to the driver's seat, filled with foam and powder for extinction of fires in the passenger cabin and the engine compartment. However, if one considers the package of parts in the engine compartment, the capability of a conventional extinguisher is limited. Also opening the engine compartment could deliver fresh air which supports the fire.

The second study was carried out by Trier University of Applied Sciences [3]. To optimise the emergency exit systems for coaches weak points in existing solutions and in regulations were analysed. On the one hand experts were consulted, on the other hand evacuation tests were carried out with test persons using coaches tilted by an angle of 90 degrees to the side. The results were summarised in a performance specification list for an optimised emergency exit system for coaches specifying e. g. the forces and maximum time for emergency exit opening, misuse countermeasures, width and number of roof escape hedges or usability of escape routes. Many of the recommendations are meanwhile part of the international vehicle regulations of the United Nations Economic Commission for Europe (UNECE). To complete the work BAM (Bundesanstalt für Materialforschung und -prüfung, Federal Institute for Materials

Research and Testing, Germany) was assigned in the year 2009 to carry out fire tests with the focus on smoke and toxicity of smoke gases. Mainly the findings of this third project are presented in the following chapters [4].

DEFINITIONS

According to the UNECE Regulations [5] buses are defined as being vehicles belonging to one of the following categories:
Category M2: Vehicles used for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass not exceeding 5 tonnes.
Category M3: Vehicles used for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tonnes.
For vehicles of category M2 and M3 having a capacity exceeding 22 passengers in addition to the driver, there are three classes of vehicles to which they belong:
Class I: Vehicles constructed with areas for standing passengers, to allow frequent passenger movement.
Class II: Vehicles constructed principally for the carriage of seated passengers, and designed to allow the carriage of standing passengers in the gangway and / or in an area which does not exceed the space provided for two double seats.
For vehicles of category M2 and M3 having a capacity not exceeding 22 passengers in addition to the driver, there are two classes of vehicles:
Class A: Vehicles designed to carry standing passengers; a vehicle of this class has seats and shall have provisions for standing passengers.
Class B: Vehicles not designed to carry standing passengers; a vehicle of this class has no provision for standing passengers.

MOTIVATION FOR THE EXAMINATION OF THE FIRE SAFETY PERFORMANCE OF BUSES

Incidents

Buses are one of the safest passenger transport means. However, if severe bus accidents or bus fires occur the number of casualties can be high and cause significant public awareness. An analysis of past bus fires [2, 6, 7] in Germany revealed the following facts: There are approximately 350 bus fires per year, of which about 75 % start in the engine compartment. Most of the accidents are less severe with no or only few casualities. However single accidents in which a majority of passengers is killed are outstanding. The main cause for injuries in bus fire cases turned out to be intoxication by smoke gas inhalation. Even small doses of certain gases can lead to permanent damage. So smoke gas development and its toxicity in bus fires are issues worth to be examined in detail.

Material properties

The amount of plastic materials used as interior parts of buses increased in the last decades since plastic components have excellent mechanical properties combined with light weight. However burning plastic materials can be able to generate toxic smoke gases. Already DEKRA [2] considered smoke and its toxicity as an issue however no recommendations with regard to limits were given at that time.
For buses the requirements for burning behaviour of interior materials and for general fire protection means are stipulated in the UNECE Regulations No. 107 and 118 [8, 9]. In the past the fundamental reaction to fire test for bus interior materials focused primarily on the horizontal burning rate. Taking new findings into account, partly elaborated within the studies at hand, in the last years extensive revisions of the UNECE Regulations were discussed with the following results which constitute a great progress for bus fire safety: A vertical test for vertical mounted materials was foreseen, reaction to fire tests were tightened, fire detectors in the engine compartments became mandatory and fire or smoke detectors in closed bus compartments will have to be installed. Details of these efforts are described further below (see section with regard to status quo of regulations). However there are no requirements with regard to heat release, smoke gas production and toxicity up to now.

Comparison with requirements for passenger trains

Generally bus and rail vehicles operate in a similar way and the evacuation conditions for the passengers in case of fire are widely comparable. However there are more reaction to fire tests for interior of passenger trains than of buses. Also the parameters for which limits have to be fulfilled are more diverse. Especially heat release of burning specimen, smoke production and toxicity of smoke gases are limited. In addition tests with complete seats have to be carried out for trains. The requirements for the rail sector are given by the standard EN 45545-2 [10].
Since the risk arising from burning rail vehicles depends mainly on how the train is operated (on tracks with or without long tunnels) three hazard levels (HL) are defined in the standard. Hazard Level 3 (mainly for subways and couchette coaches) requires most stringent fire protection properties and Hazard Level 2 is stricter than

Hazard Level 1. Correspondingly bus types could be classified in the same way in order to be allocated in different Hazard Levels. Vehicles of categories M2 / M3 of Class I, II or Class A ("city buses", with standing passengers) could be classified as to fulfill Hazard Level 1 and vehicles of category M2 / M3 of Class III or Class B ("coaches", not designed for standing passengers) could be classified as to fulfill Hazard Level 2.

All these facts mentioned above generated the idea to examine how far it is possible to transfer and adapt the requirements for train interior to buses. For that purpose a lot of burning behaviour tests with small specimens of bus interior materials, with complete seats and using whole buses were carried out which are described below.

TEST OF BUS INTERIOR MATERIAL

For rail vehicles detailed standards for the test of the fire safety performance exist. There are a variety of tests that are not required for bus interior materials. In order to investigate how far fire safety of buses can be improved by transferring requirements from rail vehicles to buses, bus equipment was taken and tested against the existing requirements for passenger trains by applying the test methods for the interior of rail vehicles (EN 45545-2). For example parts of the body insulation, the floor covering or the side panel were examined.

Heat release

Small scale tests with specimens of bus interior materials were carried out with a Cone Calorimeter (EN ISO 5660) in which the specimen is exposed to a conical heat irradiation source. With a Cone Calorimeter it is possible to determine the time to ignition and the heat release rates under predefined conditions. Only four of the fourteen tested samples passed the requirements for the maximum average heat release rate (MARHE) regarding Hazard Level 2. So most of the bus interior materials failed the heat release requirements for rail vehicles according to EN 45545-2.
With regard to the heat release not only small material specimens of interior parts were tested but also complete interior components. Because a bus is equipped with numerous passenger seats of which each is able to contain a high fire load the passenger seats were tested in whole. Paper cushions were used as ignition sources. DEKRA tested a seat within a real bus. At BAM tests were carried out according to the passenger train standard in a calorimeter. The burning behaviour of three different bus seats and one seat for train vehicles was compared. The measured differences between the tested seats were significant with regard to heat release. Here only a modern train seat and a 1995 city bus seat performed well.

Ignition and vertical flame spread

In the requirements of rail vehicles according to EN 45545-2 the Single-Flame Source Test (ISO 11925-2) is used as a test method for the ignitability and the dripping behaviour. In essence this test method is used to restrict a rapid and easy ignition of materials as well as a fast vertical flame spread. The test method of the Single-Flame Source Test contains a 20 mm high propane gas flame which flames a test specimen. Filter paper is placed below the specimen holder to observe the falling of flaming debris. Again small scale tests with specimens of bus interior material were carried out. The requirements according to EN 45545-2 were failed e. g. by the body insulation or the ceiling over seats. So it was shown that some bus interior materials ignite quickly and have a rapid vertical flame spread.

Smoke development and toxicity

Small scale tests with specimens of bus interior material were carried out with a Smoke Density Chamber (EN ISO 5659-2). The Smoke Density Chamber is a testing instrument for the determination of smoke gas production of flammable specimens which are exposed to a horizontal thermal irradiation. Photometrically the smoke density can be measured in terms of light transmission and specific optical density respectively. In addition a FTIR-spectrometer (Fourier Transform Infrared) enables the qualitative and quantitative analysis of the smoke gas composition. Of interest for toxicity are the smoke gases carbon dioxide (CO_2), carbon monoxide (CO), hydrofluoric acid (HF), hydrochloric acid (HCl), hydrobromic acid (HBr), hydrocyanic acid (HCN), sulphur dioxide (SO_2), and nitrous oxides (NOx).
The main parameter for assessing the smoke gas toxicity of railway materials is the Conventional Index of Toxicity (CIT). With applying the CIT all smoke components are limited together by a weighted sum. However manufacturers of rail vehicles use own standards in which concentrations of each single component of toxic smoke gases are limited separately since single gases might be lethal although the common limit is not exceeded.
Concerning the evaluation of toxic gas concentrations by the CIT-value e. g. the body insulation, the side panel or the foam of seats passed the requirements of Hazard Level 1 and 2 which are essential for corresponding rail vehicles. According the CIT-values of e. g. the investigated ceiling and floor covering, these materials did not

pass the tests. Results for some of the specimens are presented in Table 1.
Regarding the concentrations of single smoke gas components, especially the measured values of the side panel specimen which had a valid CIT-value according to EN 45545-2 contained extremely toxic concentrations of single smoke gas components (see HCN concentrations in Table 1 as example). Also for other parts the concentration of toxic gases in the smoke exceeded lethal concentrations by far. In conclusion all tested bus interior materials generated hazard till lethal concentrations of toxic smoke gas components. Thus it can be highly recommended to limit toxicity. When doing this, limiting toxic concentrations of single smoke gas components is more reasonable than limiting the CIT value.

Table 1.
Comparison between measured toxic smoke gas components and existing limits according to passenger train standards

	CIT (Conventional Index of Toxicity) according to EN 45545-2			HCN concentration [ppm]	
Material	meas-ured	limit HL1	limit HL2	meas-ured	limit of rvm
Body insulation	0,3	1,2	0,9	52	100
Floor covering	6,6	1,2	0,9	5	100
Side panel	0,6	1,2	0,9	245	100
Ceiling over seats	1,9	1,2	0,9	40	100
Ceiling over gangways	2,9	1,2	0,9	40	100
Foam of seats	0,3	1,2	0,9	7	100

HL: Hazard Level; rvm: rail vehicle manufacturer

Concerning the investigation of the light transmission in smoke gases the specific optical density (D_S) and the cumulative value of specific optical densities in the first 4 test minutes (VOF4) were measured. Regarding the optical density (D_S) only the body insulation and the foam of seats passed the requirements of Hazard Level 1 and 2. The side panel fulfilled Hazard Level 1 only. All other parts failed completely.
Regarding VOF4 the body insulation and the floor covering principally fulfill Hazard Level 1 and 2. However, VOF4-thresholds do not exist for the floor covering and the foam of seats though the D_S-thresholds are partially exceeded. So in summary for light transmission aspects most of tested bus interior materials fail the smoke production requirements of rail vehicles according to EN 45545-2. Results for some of the specimens are presented in Table 2.

Table 2.
Comparison between measured optical density of smoke and existing limits according to passenger train standards

	Optical Density according to EN 45545-2					
	$D_S(4)/D_{S,max}$			VOF4 [min]		
Material	meas-ured	limit HL1	limit HL2	meas-ured	limit HL1	limit HL2
Body insulation	128	600	300	261	1200	600
Floor covering	695	600	300	not req.	-	-
Side panel	560	600	300	1103	1200	600
Ceiling over seats	840	600	300	2390	1200	600
Ceiling over gangways	623	600	300	2225	1200	600
Foam of seats	101	300	300	not req.	-	-

D_S: specific optical density; $D_{S,max}$: maximum specific optical density within the 20 minutes of the test; VOF4: cumulative value of specific optical densities in the first 4 minutes of the test (time integral of D_S); not req.: not required

FIRE TESTS WITH A COMPLETE BUS

In addition to small scale and intermediate scale tests also several real scale fire tests were performed in a city bus. The test bus was a 12 m city bus from 1995. The fire scenarios represented different fire sources in the engine compartment and in the passenger cabin. The fire and smoke development were monitored and single concentrations of toxic smoke gas components were analysed during the tests. The main aim of these tests was to determine the time for a safe passenger escape regarding the smoke toxicity in different fire scenarios. Also tests to determine the benefits of fire detection systems (in passenger cabin and in engine compartment) and of extinguishing systems (in engine compartment) were performed.

Smoke development and toxicity in the passenger compartment

The smoke development in the passenger compartment was investigated under different ventilation conditions. In the city bus seven smoke detectors of two manufacturers, which were developed for the operation in trains, were installed to find out where the best positions for their installation are. Fire smoke cartridges and burning foam cubes served as smoke sources. In all tests the smoke generators were positioned at the end of the gangway (close to the engine compartment) because the majority of bus fires starts in the engine compartment.
The smoke spread tests showed that the smoke generated by a real fire streamed primarily fast to the top, spread rapidly along the whole ceiling and only then filled the cabin from the ceiling to the floor (if all openings were closed and the ventilation was off). Polyurethane foam blocks of only 100 g were already able to fill the whole bus with opaque smoke. Openings whether by raised aeration skylights, tilted windows or opened doors reduced obviously the smoke filling in the bus. The warm smoke then only filled the cabin from the ceiling down to the highest opening through which the smoke streamed out of the vehicle. So passengers might have a bigger smoke-free range in the bus to escape. Therefore fixed aeration skylights combined with smoke detectors that automatically activate the aeration skylights in case of fire could be very beneficial for a safer passenger escape. However ventilation conditions during a fire event have to be treated carefully in order to avoid promotion of the fire.
The experiments with regard to the smoke development were complemented by numerical fire simulations. For that purpose a bus with its material properties was modelled in the tool "Fire Dynamics Simulator" (Version 5) developed by the National Institute of Standards and Technology (NIST) in the United States. The fire source in the simulations was placed either in the lavatory or at the last passenger seat row. The main parameters that were varied were the interior material properties. On the one hand conventional bus equipment was chosen. On the other hand interior according to requirements for rail vehicles was modelled. As result a bus fire releases large amounts of heat and smoke, the fire propagates along the ceiling through the whole bus, even if it starts in the toilet cabin. Especially in the scenarios with equipment fulfilling passenger train standards it turned out that the fire development was retarded significantly. In the scenarios, in which arson was simulated, with train equipment the fire extinguished, with conventional bus equipment the ceiling burned.
Smoke development and toxicity were also tested in a real fire scenario. In a test at BAM with the complete bus a paper cushion served as ignition source to simulate arson. Although the fire was weak (only some adjacent seats were affected, ceiling parts above the fire begun to melt) the smoke contained concentrations of gases that cause first symptoms of intoxication.
For comparison a test reported by and carried out at SP (Sveriges Tekniska Forskningsinstitut, SP Technical Research Institute of Sweden), in which a fire in the lower rear part of a bus was generated, lethal concentrations of toxic smoke gases were reached in a few minutes [11].
Thus it can be recommended to limit the concentration of toxic smoke gases and to implement smoke detectors in all bus compartments which are not accessible to the driver's view, i. e. toilet cabin, luggage compartment and sleeping-cab.

Fire detection tests in the engine compartment

In the fire suppression tests described below fire detectors of three manufacturers were tested in order to find out reliable methods. Thirteen sensors were all placed in the engine compartment in which also the fire sources (e. g. sawdust and cotton drenched with fire load liquids) were placed. The detection principle was either thermal or optical (infrared sensor). The thermal detectors can be classified as:

- spot detectors (designed to detect a hot spot at a fixed location)
- discrete linear detectors (to detect a heating event at any point along the sensor (cable) lenght)
- averaging linear detectors (to respond when the average temperature along the whole length of the sensor exceeds a certain value)

As result, the spot thermal detectors did not provide an alarm during the tests. One reason for this result might be their sensitivity against their mounting position. In sum all linear thermal detectors and the optical detector provided an alarm within one minute, which would allow the passengers to leave the bus in time before smoke gas concentrations reach toxic values.

Fire suppression tests in the engine compartment

Seven fire suppression systems of four manufacturers were tested in the engine compartment of the bus. The agents used by the systems to suppress the fire were water spray with foam, water mist with additives, water mist with foam and additives, dry chemicals and powder. The test scenarios were based on current Swedish fire suppression standards [12], however they were slightly adapted for the tests at hand. On the one

hand a real engine compartment was used, on the other hand the engine was running during the tests. In the first test series with high additional fire load together with engine preheating and higher engine speed while testing, the fire suppression systems, which were activated manually after a determined preburn time, did not extinguish the fire completely but the systems could at least suppress the fire in its size for a certain time and could also interrupt the smoke entering into the passenger compartment. The running fan of the engine and the insulation material towards the passenger cabin were the main causes for the redevelopment of the fire after the suppression attempts. In the second series with shorter preburn times and engine at idle, all systems could suppress the fire and stopped the entrance of smoke into the passenger compartment.
During the fire tests for the suppression systems also the toxicity of the smoke in the passenger compartment generated by the fire in the engine compartment was measured. The concentrations of single smoke gas components did not reach toxic levels after the engine compartment had burnt for one minute (preburn time). With the activation of a suppression system the smoke production and thus the smoke concentration in the passenger cabin did not increase further.
Although automatic fire suppression systems cannot absolutely ensure total extinction of the fire they generate essential time for a safe escape of passengers in case of a fire in the engine compartment.

RECOMMENDATIONS

The study has shown that there is room for improvement with regard to the fire safety performance of buses and especially the burning behaviour of the bus interior equipment.
Revised requirements would help to increase the time of escape for passengers in case of a bus fire so that they are not exposed to the toxic smoke gas components that are produced when bus parts are burning.
Generally bus and rail vehicles are operated in a similar way and the dangers for the passengers in case of fire are comparable. Since for the rail sector reasonable requirements exist, it is considered to be appropriate to transfer and adapt the passenger train requirements to buses. That primarily concerns the railway standard EN 45545-2. For that purpose buses should be allocated to two different Hazard Levels. Hazard Level 2 would require more stringent fire protection properties than Hazard Level 1. City buses (ECE classes I, II or A) should be classified as to fulfill Hazard Level 1 and coaches (ECE classes III or B) should be classified as to fulfill Hazard Level 2.
In detail the following recommendations can be given as result of the various experiments described above. Attention was already payed to different findings by international legislation. So some of the recommendations are meanwhile mirrored by amendments of the relevant international vehicle regulations for bus fire safety, however some can serve as basis for necessary further revision work.

- Ignition test
  Since ignition is crucial for the further development of a fire, the ignitability of the bus interior should be limited and be included in the fire safety requirements for buses in order to ensure protection against a quick ignition of interior parts. Ignitability can be tested using the Single-Flame Source Test (EN ISO 11925-2).
- Vertical fire test
  The experiments and numerical simulations showed that for instance wall materials or backrests of seats have a significant influence on the fire development in the passenger compartment. A vertical fire test which limits the vertical spread of the flames is therefore recommended for all bus interior materials. Again the Single-Flame Source Test can be utilised for that purpose.
- Test of smoke production
  As demonstrated in the experiments, in case of a fire the air in a passenger compartment of a bus is quickly filled with large amounts of opaque smoke that impair visibility and hinder a safe escape. Therefore the smoke production should be restricted. Tests using the Smoke Density Chamber (EN ISO 5659-2) would be reasonable at a first stage. At a second stage, when ongoing standardisation work is completed, using a vitiated Cone Calorimeter might even be more suitable for limiting smoke production, since the test conditions would be more realistic, especially with regard to the oxygen being available during the test.
  In addition, in order to reduce the amount of smoke in the passenger compartment of a bus, automatic skylight openers which are coupled with smoke detectors can be regarded as reasonable equipment.
- Test of smoke toxicity
  During a bus fire the toxicity of the generated smoke is the most imminent danger for the passengers. It is therefore highly needed to limit the concentrations of toxic smoke gas components. It is not enough to limit all components together by a weighted sum as in the current railway standard (EN 45545-2) since single gases might be lethal although the common limit is not exceeded. It is rather recommended to limit concentrations for each single

component of toxic smoke gases, namely CO_2, CO, SO_2, NO_X, HCl, HF and HCN. The measurements can be carried out in the Smoke Density Chamber. In the future it might be possible to use the vitiated Cone Calorimeter as mentioned above instead and to apply the "Fractional Effective Dose" concept which takes the time of exposure and the accumulation of the different toxic components into account.

- Test of reaction on heat radiation
  Heat radiation impacting a material can be responsible for the release of flammable gases (pyrolyse) that in turn can be ignited by themselves or by a spark. In order to avoid this situation a fire test for the reaction on heat radiation should be foreseen. The test can be carried out according to the railway standard with the Cone Calorimeter (EN ISO 5660).
- Heat release test
  Some of the tested interior materials showed extreme rates of heat release. To limit the heat release rates is of great importance since a fire with high heat emissions spreads faster and ignites other parts easier. With the Cone Calorimeter also the heat release rates can be determined.
  With regard to the heat release it is not only recommended to test specimens of material but also complete interior components: Because a bus is equipped with numerous passenger seats of which each is able to contain a high fire load the passenger seat should be tested in whole in a calorimeter test according to the passenger train standard.
- Implementation of smoke detectors in secluded bus compartments
  Simulations and fire tests with smoke detectors yielded that an early detection of smoke generated by a fire is possible which then delivers more time for evacuation. Therefore smoke detectors should be installed in all bus compartments which are not accessible to the driver's view, i. e. toilet cabin, luggage compartment and sleeping-cab.
- Implementation of fire detectors and fire suppression systems in the engine compartment
  In the evaluation of a multitude of bus fires it turned out that most of them (about 75 %) start in the engine compartment. So a fire detection system in the engine compartment would be very effective. Further improvement could be reached by installing a fire suppression system additionally.
  With regard to fires in engine compartments also the choice of the noise insulation material should be scrutinised because soaked with fuel or lubricants it supports the propagation and lasting of a fire.

STATUS QUO OF EXISTING REGULATIONS FOR BUS FIRE SAFETY

The basic international documents stipulating bus fire safety performance measures are the ECE Regulations No. 107 and No. 118. [8, 9]. In the last years several studies showed that the fire safety of buses and coaches could be further improved by amendments to Regulation No. 107 and Regulation No. 118. For example the Swedish Transport Agency and the Norwegian Public Roads Administration initiated a research project together with SP Swedish National Testing and Research Institute, lasting from 2005 to 2008, with the aim to decrease the number and consequences of bus fires, to prevent and delay start of fires, to inhibit fire spread and smoke development in fire incidents and to provide more time for escape in case of fire. In France and Germany studies were carried out as well. Partially based on the findings of the studies discussed within the paper at hand, great efforts were undertaken by bus manufacturers and other stakeholders to improve bus fire safety and the corresponding requirements. Especially experts from France, Germany, Norway, and Sweden [13, 14, 15] commonly proposed several amendments of both ECE Regulations.
First Regulation No. 107 was amended to require fire detection systems in the engine compartment and the compartment where the combustion heater is located, then new requirements for smoke / fire detection systems in separate compartments, e. g. toilets, driver’s sleeping compartment were incorporated. Regulation No. 118 was amended to cover electrical cables and insulation materials. Since the existing Regulation No. 118 required testing of materials in a horizontal position independently from their real installation in the vehicle and only curtains had to be tested in vertical position, it was introduced that materials and components have to be tested taking into account their real installation situation in order to represent a realistic scenario. As an alternative to the horizontal and vertical burning behaviour test, using the test of the rail sector was allowed. In addition, the application of the tests for the passenger compartment was extended to the overall interior compartment of the vehicle.
Need for additional work was seen on two further issues:
Especially Sweden offered to support the development of new requirements dealing with

automatic fire suppression systems in the engine compartment [16, 12]. Since a significant number of fires start in the engine compartment, installation of such systems could be an important measure to improve fire safety. Suppression systems are already available on the market and are fitted on a voluntary basis by manufacturers or operators. A method for testing the performance of fire suppression systems has been developed by SP Technical Research Institute of Sweden (SP Method 4912). However, the international discussion on this issue is ongoing.
In addition, requirements for smoke development and smoke toxicity are still not included in the regulations. Here work is expected to be taken up when the German research project dealing with smoke and toxicity will be finished.
In the following the status quo of requirements for fire safety performace of M2 and M3 vehicles, resulting from the activities mentioned above, is summarised for both regulations separately:

ECE Regulation No. 107

Regulation No. 107 is titled "Uniform provisions concerning the approval of category M2 or M3 vehicles with regard to their general construction". The actual document (end of the year 2012) is the 05 series of amendments of revision 3 of ECE-R 107 which entered into force on 26 July 2012. Within ECE-R 107 the following main requirements with regard to the protection against fire risks have to be met by all vehicles (extracts from the text of the regulation are marked with quote signs):
For the engine compartment special properties of used materials and a detector system for high temperatures are required:

- "No flammable sound-proofing material or material liable to become impregnated with fuel, lubricant or other combustible material shall be used in the engine compartment unless the material is covered by an impermeable sheet."
- "In the case of vehicles having the engine located to the rear of the driver's compartment, the compartment shall be equipped with an alarm system providing the driver with both an acoustic and a visual signal in the event of excess temperature in the engine compartment and in each compartment where a combustion heater is located. The alarm system shall be designed so as to detect a temperature in the engine compartment and in each compartment where a combustion heater is located in excess of the temperature occurring during normal operation."

Also for other separate compartments than the engine compartment fire detection systems are required:

- "Vehicles shall be equipped with an alarm system detecting either an excess temperature or smoke in toilet compartments, driver’s sleeping compartments and other separate compartments. Upon detection, the system shall provide the driver with both an acoustic and a visual signal in the driver’s compartment. The alarm system shall be at least operational whenever the engine start device is operated, until such time as the engine stop device is operated, regardless of the vehicle's attitude."

However, transitional provisions are given within the regulation which schedule when certain measures will become mandatory so that some requirements do not have to be fulfilled at present but in the future. Fire detectors in the engine compartment will have to be installed from 31 December 2012 for new bus types and from 31 December 2013 for first registrations. Fire detectors (temperature or smoke) in other separate compartments become mandatory 26 July 2014 / 2015 (new types / first entry into service).

ECE Regulation No. 118

Regulation No. 118 is titled "Uniform technical prescriptions concerning the burning behaviour and / or the capability to repel fuel or lubricant of materials used in the construction of certain categories of motor vehicles". The actual document (end of the year 2012) is the revision 1 incorporating the 02 series of amendments (date of entry into force 26 July 2012). Within ECE-R 118 in essence specifications are given with regard to the burning behaviour of the components used in the interior compartment, in the engine compartment and in any separate heating compartment as well as the capability to repel fuel or lubricant of insulation materials used in the engine compartment and in any separate heating compartment (extracts from the text of the regulation are given in the bullet points).:

- The materials and / or equipment used in the interior compartment, in the engine compartment and in any separate heating compartment and / or in devices approved as components shall be so installed as to minimise the risk of flame development and flame propagation.
- Such materials and / or equipment shall only be installed in accordance with their intended purposes and the tests which they have undergone, especially in relation to their burning and melting behaviour

(horizontal / vertical direction) and / or their capability to repel fuel or lubricant.

- Any adhesive agent used to affix the interior material to its supporting structure shall not, as far as possible, exacerbate the burning behaviour of the material.

There are five main tests (each described in a separate annex of ECE-R 118) which have to be passed by the materials depending on where they are fitted in the bus (parts made of metal or glass do not have to be tested):

- Materials and composite materials installed in a horizontal position have to undergo a test to determine the horizontal burning rate. The test is passed if the horizontal burning rate is not more than 100 mm / minute or if the flame extinguishes before reaching the last measuring point.
- Materials and composite materials installed more than 500 mm above the seat cushion and in the roof of the vehicle as well as insulation materials installed in the engine compartment and any separate heating compartment have to fulfill a "drop test" in which the melting behaviour of materials is determined. The result of the test is considered satisfactory if no drop is formed which ignites the cotton wool beneath the specimen.
- Materials and composite materials installed in a vertical position have to undergo a test to determine the vertical burning rate of materials. The test is passed if the vertical burning rate is not more than 100 mm / minute or if the flame extinguishes before the destruction of one of the first marker threads occurred.
- All insulation materials installed in the engine compartment and any separate heating compartment have to be tested to determine the capability of materials to repel fuel or lubricant. The increase of the weight of the test sample must not exceed 1 g.
- Electric cables have to undergo the resistance to flame propagation test described in ISO standard 6722:2006, paragraph 12. Any combustion flame of insulating material must extinguish within 70 seconds and a minimum of 50 mm insulation at the top of the test sample must remain unburned.

Instead of the drop test and the vertical burning test described in the annexes of ECE-R 118 also testing according to ISO 5658-2 [17] which is required in the rail sector is allowed:

- Materials achieving an average CFE (critical heat flux at extinguishment) value greater or equal to 20 kW / m^2, when tested according to ISO 5658-23, are deemed to comply with the requirements, provided no burning drops are observed when taking the worst test results into account.

Again transitional provisions are given within the regulation which schedule when certain measures become mandatory. With the 01 series of amendments (date of entry into force 9 December 2010) the test to determine the capability of materials to repel fuel or lubricant and tests for electric cables were added. It becomes mandatory 9 December 2012 for new bus types and component types and 9 December 2015 for first registrations. With the 02 series of amendments (date of entry into force 26 July 2012) the requirements for material installed in a vertical position with regard to the vertical burning rate were extended and the possibility to use the tests of the railway standard was introduced. These requirements become mandatory 26 July 2016 for new component types, 26 July 2017 for new vehicle types and 26 July 2020 for first registrations.

SUMMARY

Bus fires occur frequently but are usually not accompanied with severely injured persons. In most of the cases the fire starts in the engine compartment and does not affect any passengers because they can leave the bus in time. However single accidents, in which the fire enters the passenger compartment, resulted in a high number of fatalities. More dangerous than the fire itself is the toxicity of smoke gases due to burning interior parts made of plastic materials.

Although buses and passenger trains are operated in a similar way, railway standards for fire safety performance comprise more relevant parameters and are more stringent than bus requirements. Therefore a lot of burning behaviour tests with small specimen of bus interior material, with complete seats and using whole buses were carried out in order to examine possibilities to further increase bus fire safety and to determine how far it is possible to transfer and adapt the requirements for passenger trains to buses.

Some of the outcome of the experiments is already incorporated into international legislation. Especially ECE Regulations No. 107 and 118 cover bus fire safety perfomance. E. g. fire detection systems in the engine compartment and smoke detection systems in separate interior compartments which turned out to be very useful are already required. Also the recommendations to test certain properties of insulation materials to repel fuel or lubricant as well as tests to perform a vertical burning test for vertically mounted parts are specified in the ECE Regulations. However some of the fixed measures will become mandatory only in the coming years due to transitional provisions. The most important results of the work concern smoke development and toxicity of smoke gas components which are still not covered by legislation. Revised requirements would help to increase the time of escape for passengers in case of a bus fire so that they are not exposed to the toxic smoke gas components that are produced when bus parts are burning. Smoke density and toxic smoke gas concentrations should be limited. It is not sufficient to limit all components together by a weighted sum as in the current railway standard since single gases might be lethal although the sum limit is not exceeded. It is rather recommended to limit concentrations for each single component. Besides smoke also the heat release of burning parts and the ignitability should be limited in order to avoid ignition of adjacent parts and thus minimise fire propagation. The concept to use fire suppression systems in the engine compartment also should be pursued further.

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