Test Methods and Instrumentation for Assessing Reaction to Fire Properties of Railway Rolling Stock

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Summary
This paper briefly reviews the current instruments used in assessing the fire performance of railway rolling stock and those to be used in new European regulatory tests. The latter are a result of major developments towards harmonizing Railway Vehicle fire performance testing and classifications, initially developed under European Public Procurement directives and latterly via the Technical Specification for Interoperability (TSI). In many senses the interoperability of railway vehicles between different EU countries makes harmonization a very desirable requirement. The test specifications to be utilized for this process are described in EN 45545.
The formation of the European Union and the subsequent agreements that several products should be tested using harmonized testing methods throughout the EU make the EU market the developed world's biggest market for most constructed products. Each member state is currently able to continue to classify the products using the traditional (often national) methods alongside the new methods during a transition period.

Keywords: Railway, EN45545-2, fire, linings, flooring, cables, seats

1. Railway Vehicles

Railway vehicles and especially high speed trains regularly cross European borders so it is sensible that there would be a need for inter-operability requirements. Railway Rolling stock will be classified quite differently from construction products both in terms of the testing methods used for assessment, and the general shape of the classification system. These are all set out in EN 45545 Part 2 [1] which gives both the test methods and the performance requirements for products to qualify for each class**.** This EN has just been balloted received a positive ballot and the text was finalized in March 2013 as EN 45545-2.

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2. European Interoperability Directives

Interoperability requires the ability of the trans-European high-speed rail system to allow the safe and uninterrupted movement of high-speed trains built to specified levels of performance, throughout the entire network. The EC Directives 96/48/EC (Interoperability of the trans-European high-speed rail system) [2] and 2001/16/EC [3] (Interoperability of the trans-European conventional rail system) have created a new set of mandatory technical regulations. These are the TSIs (technical specifications for interoperability). The European Commission Decision 2002/735/EC [4] established the trans-European high-speed rolling stock subsystem (HS TSI).

The development of this regulatory system has been underway since the early 1990s. During the consolidation stages when some of the TSIs and the draft ENs were being revised, a transition period exists which allows some national standards to be used for interoperability of high-speed trains. The scope of these interim measures is detailed in EC Decision 2008/232/EC [5]. Pending publication of EN 45545-2 or of an annex to the HS-TSI (EC Directive 96/48/EC), conformity with the requirement on fire prevention measures is satisfied by the verification of conformity to the material fire safety requirements of the notified national rules (using the appropriate operation category of the railway vehicle) from one of the following sets of standards:

- UK BS6853 and GM/RT2130 (2 August 2008),
- France NF F 16-101:1988 and NF F 16-102:1992,
- Germany DIN 5510-2:2003 and its supplement on toxicity measurements (2009),
- Italy UNI IEC 11170-1:2005 and UNI IEC 11170-3:2005,
- Poland PN-K-02511:2000 and PN-K-02502:2005.

These standards along with NFPA 101 are the major codes that are used worldwide and in countries that rely on imported engineering technology BS6853 and NFPA 101 are particularly well used.

These codes are similar in that they often use the respective national building code reaction to fire tests for flame spread and heat release, supplemented by a smoke opacity assessment. In jurisdictions where there have been extensive underground mass transit systems (e.g. London, UK and Paris, France) these have been further supplemented by combustion gas analysis testing which is used as a toxicity indicator.

2.1. UK, BS 6853

BS 6853 principally uses four tests for major product assessment. Two are from the UK National Building Products code, BS 476 these are supplemented by a smoke and a gas analysis tests. BS 476 Part 7 (Fig. 1, 2) is the surface spread of flame test and is used for determining that property for both traditional Building product classification and for railway applications. BS 476 Part 6 is the British Fire Propagation test which is also part of UK national regulation and a crude heat release test.

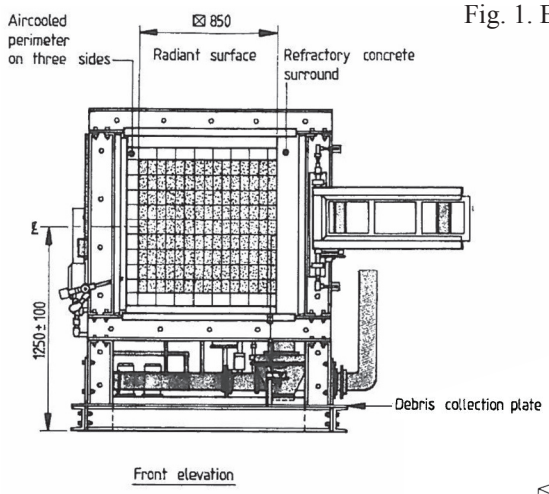


Fig. 1. BS 476 Part 7 Flame spread apparatus

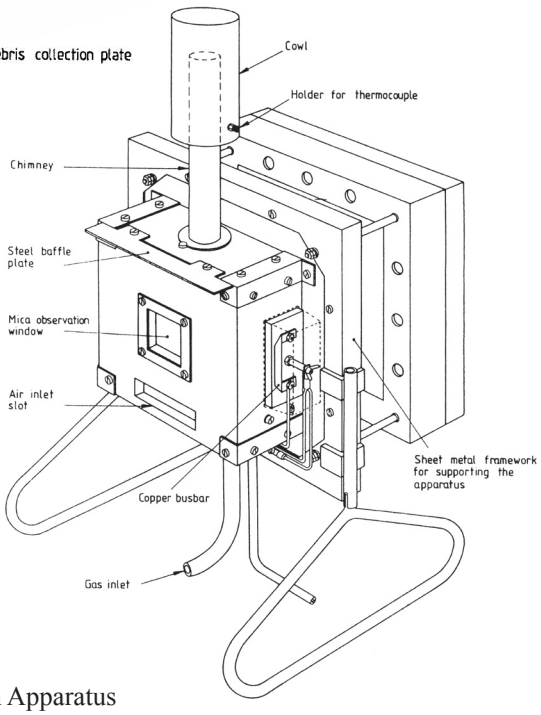


Fig. 2. BS 476 Part 6 Fire Propagation Apparatus

Smoke is assessed using a 3 m cube where the specimen is subject to fire sources in a 27 cubic meter chamber and the optical transmission across the chamber monitored to assess the smoke opacity. Figure 3 shows the 3 m cube whist Figure 4 shows the specimen exposures for panels and seating products. The panels are exposed to the flames from an alcohol fire source whilst seating products are exposed to heat from a burning charcoal source.

Fig. 3. 3 m Cube

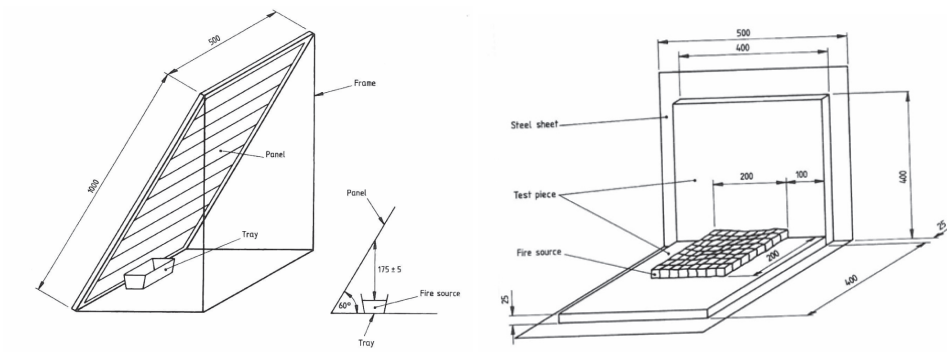


Fig. 4. Specimen Exposure for Panels and Seating

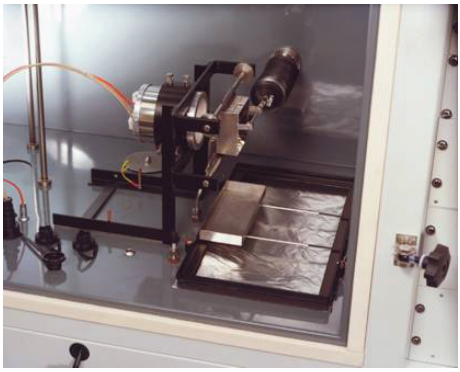
Toxic Fumes can be tested in one of two ways either on the area based test method based on ISO 5659-2 (Figure 5) with the specimen being exposed at 25 kW/m^2 or as a mass based method based on NFX 70-100. In both cases the combustion products are analyzed for specific range of gases and an index calculated.

Fig. 5. ISO 5659-2 Smoke Density Chamber

2.2. France, NF F 16-101

NF F 16-101 calls up use of the Epiradiator test method which is the principal test method used for construction products in France supplemented by the NFX 70-100 toxicity test and a smoke opacity test based on the Smoke Density Chamber. In the latter case the old ASTM E662 vertical furnace which operates at 25 kW/m^2 is used to heat the specimen (Figure 6).

ISO 5659-2



ASTM E 662

Fig. 6. ISO 5659-2 and ASTM E 662 Heaters

2.3. European Standards

EN 45545 2013 „Fire protection of railway vehicles" has been developed by the CEN/TC 256 & CENELEC/TC 9X Joint Working Group and consists of seven parts with the main components for reaction to fire classification defined in part 2 Requirements for fire behavior of materials and components.

The classification requirements are expressed as Fire Hazard Levels, which are HL1, HL2 and HL3. The requirements result from train operation categories and design categories defined in EN 45545 Part 1 [6]. The train operational categories defined in Part 1 are:

Operation Category 1

Vehicles that are not designed or equipped to run on underground sections, tunnels and/or elevated structures and which may be stopped with minimum delay, after which immediate side evacuation to a place of ultimate safety is possible.

Operation Category 2

Vehicles that are not designed or equipped to run on underground sections, tunnels and/or elevated structures, with side evacuation available and where there are stations or emergency stations that offer a place of ultimate safety to passengers, reachable within a short running time.

Operation Category 3

Vehicles that are not designed or equipped to run on underground sections, tunnels and/or elevated structures, with side evacuation available and where there are stations or emergency stations that offer a place of ultimate safety to passengers, reachable within a long running time.

Operation Category 4

Vehicles that are designed or equipped to run on underground sections, tunnels and/or elevated structures, without side evacuation available and where there are stations or emergency stations that offer a place of ultimate safety to passengers, reachable within a short running time.

Vehicles are additionally classified under the following design categories:

A: Vehicles forming part of an automatic train having no emergency trained staff on board,

D: Double decked vehicles,

S: Sleeping and couchette vehicles,

N: All other vehicles (standard vehicles).

The requirements for fire performance of products in EN 45545 Part 2 are related to the risk levels of the train operations; e.g. High-risk Operation Category 4 will require the highest performance products (HL3). The classification requirements are expressed as Fire Hazard Levels, which are HL1, HL2 and HL3. The hazard levels shown in Table 1 are used in EN 45545 Part 2 for defining classification requirements.

Table 1

Relationship between operating category and Hazard level for each design category

Operation	N	A	D	S
Category	Standard vehicles	Automatic vehicles having no emergency trained staff on board	Double decked vehicles	Sleeping and couchette cars (double decked or single deck)
1	HL1	HL1	HL1	HL2
2	HL2	HL2	HL2	HL2
3	HL2	HL2	HL2	HL3
4	HL3	HL3	HL3	HL3

The requirements in EN 45545 Part 2 [1] cover all products used to construct and furnish the vehicle. In all EN 45545 part 2 tabulates 46 „listed groups" (17 interior product groups; 13 exterior located product groups; 10 furniture product groups; 15 electro technical equipment groups; and 1 mechanical equipment group) and each group has a requirement reference. In all there are 25 different requirement sets (R1–R25).

These requirements are tabulated in EN 45545 Part 2 [1] and the tables show the test methods used and the performance requirement to qualify to each HL. Parameters covered in the assessments include ignitability, flame spread, heat

release, smoke density and toxicity of fire effluents. The tests and the conditions required depend on the type of product and its location on the train. A summary of all the test methods is given in Appendix I. The test methods and performance requirements for interior products (such as wall and ceiling linings, luggage storage racks, drivers desks, interior surfaces of gangways, curtains and sunblinds) are shown in Table 2.

Table 2

Requirements for interior linings on European trains (EN 45545-2)

Requirement set	Test Method Reference	Parameter Unit	HL1	HL2	HL3
R1	ISO 5658-2 (Fig. 7)	CFE kW/m^2	20	20	20
	ISO 5660-1 at 50 kW/m^2 (Fig. 8)	MARHE kW/m^2	–	90	60
	ISO 5659-2 at 50 kW/m^2	$D_s(4)$ dimensionless	600	300	150
	ISO 5659-2 at 50 kW/m^2	VOF4 Minutes	1200	600	300
	ISO 5659-2 at 50 kW/m^2	CIT_G dimensionless	1,2	0,9	0,75

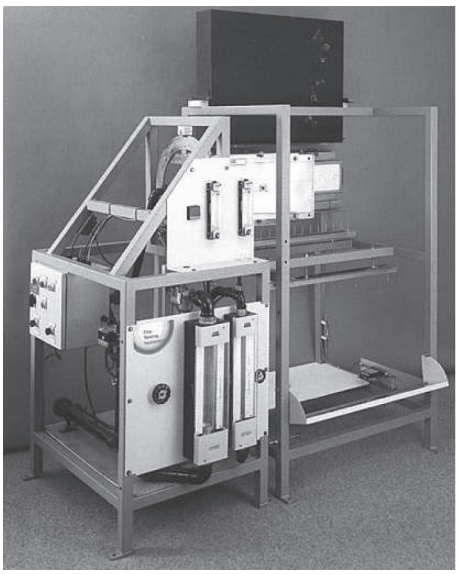


Fig. 7. ISO 5658-2, Spread of Flame

Fig. 8. ISO 5660-1, Cone Calorimeter

The test methods and performance requirements for Flooring composites, are shown in Table 3. Note that the cone calorimeter test (ISO 5660-1) and the ISO 5659-2 tests used for flooring assessments are carried out at the lower heat flux exposure of 25 kW/m^2.

Table 3

Requirements for Floor Composites in European trains (EN 45545-2)

Requirement set	Test Method Reference	Parameter Unit	HL1	HL2	HL3
R10	EN ISO 9239-1 (Fig. 9)	CHF kW/m^2	4,5	6	8
	ISO 5660-1 at 25 kW/m^2	MARHE kW/m^2	–	–	–
	ISO 5659-2 at 25 kW/m^2	D_s(4) dimensionless	600	300	150
	ISO 5659-2 at 20 kW/m^2	CIT_G dimensionless	1,2	0,9	0,75

Fig. 9. EN ISO 9239-1

The test methods and performance requirements for Upholstery for passenger seats, headrests composites and items for seats are shown in Table 4.

Table 4

Requirements for Upholstery for passenger seats and headrests

Requirement set	Test Method Reference	Parameter Unit	HL1	HL2	HL3
R18, R19, R20	ISO/TR 9705	MARHE kW/m^2	70	50	20
	ISO/TR 9705	RHR Peak	350	350	350
	ISO 5660-1 at 25 kW/m^2	MARHE kW/m^2	75/50	50	50
	ISO 5659-2 at 25 kW/m^2	D_s max dimensionless	200	200	200
	ISO 5659-2 at 20 kW/m^2	CIT_G dimensionless	1,2	0,9	0,75

The test methods and requirements for cables for interior vehicle usage, are shown in Table 5.

Table 5

Requirements for Cables for Interiors

Requirement set	Test Method Reference	Parameter Unit	HL1	HL2	HL3
R15	EN 60332-1-2	Unburnt length mm	Burnt part less than 540 Sunburnt more than 50	Burnt part less than 540 Sunburnt more than 50	Burnt part less than 540 Sunburnt more than 50
	EN 50266-2-4	m	2,5	2,5	2,5
	EN 50305:2002, 9.1.1	m	2,5	2,5	2,5
	EN 50305:2002, 9.1.2	m	1,5	1,5	1,5
	EN 61034-2	Transition %	25	50	70
	NFX 70-100-1 and 2 600°	CIT_G dimensionless	10	10	6

3. Future European activity

CEN is committed to early revision of EN 45545-2 to resolve some of ballot comments that were not resolved in the standard dated March, 2013. These were principally in the test methods dealing with seating and toxic gas analysis. The seating testing EN 45545-2 had been based on a calorimetry test where work had shown that the sensitivity of the calorimetry method was challenged by the performance requirements of then code. The Transfeu group also felt that the toxic gas analysis method should be modified from the single point analysis to a continuous FTIR based one.

The CEN drafting committee has recommended that two new standards are developed to address these two issues and be designated EN 45545-8 and EN 45545-9 for the new test method form seating and toxic gas analysis respectively.

Appendix I: Summary of Test Methods

Ref.	Standard	Short description	Parameter	Unit	Test Criteria	Additional explanation
1	2	3	4	5	6	7
T01	EN ISO 4589-2	Determination of burning behaviour by oxygen index Part 2: Ambient temperature test	OI	Usually reported as '% oxygen'	Minimum	OI is the abbreviation for Oxygen Index.
T02	ISO 5658-2	Lateral flame spread	CFE	kW/m^2	Minimum	CFE is the abbreviation for Critical Flux at Extinguishment
T03.01	ISO 5660-1	Reaction-to-fire tests – Heat release, smoke production and mass loss rate – Part 1: Heat release rate (cone calorimeter method)	MARHE	kW/m^2	Maximum	MARHE is the maximum average rate of heat emission. The data collection interval shall be 2 s and data collection shall be terminated at 20 min. The heat flux shall be 50 kW/m^2. 5.3.6 is also applicable where specified. Results of ARHE and MARHE are expressed in units of kW/m^2 – (heat emission rate per unit area).
T03.02	ISO 5660-1	Reaction-to-fire tests – Heat release, smoke production and mass loss rate – Part 1: Heat release rate (cone calorimeter method)	MARHE	kW/m^2	Maximum	MARHE is the maximum average rate of heat emission. The data collection interval shall be 2 s and data collection shall be terminated at 20 min. The heat flux shall be 25 kW/m^2. 5.3.6 is also applicable where specified. Results of ARHE and MARHE are expressed in units of kW/m^2 (heat emission rate per unit area).

Appendix I cd.

1	2	3	4	5	6	7
T04	EN ISO 9239-1	Radiant panel test for horizontal flame spread of floorings	CHF	kW/m^2	Minimum	CHF is the Critical Heat Flux at extinguishment.
T05	EN ISO 11925-2	Ignition when subjected to direct impingement of flame	30 s flame application		No spread > 150 mm within 60 s	
T06	ISO/TR 9705-2	Furniture calorimeter vandalised seat	MARHE	kW	Maximum	MARHE is the maximum average rate of heat emission. Annex B. Results of MARHE are expressed in units of kW.
T07	EN ISO 12952-2	Textiles – Assessment of the ignitability of bedding items – Part 2: Ignition source: match-flame equivalent	Afterburn time	s	Maximum	No ignition is defined as follows: • sustained flaming less than 10 s, • no flames reaching any edge of the specimen.
T08	ISO 2592 ISO 2719	Determination of flash and fire points − Cleveland open cup method	Class K Fire point	°C	Minimum	
T09.01	EN 60332-1-2	Tests on electric and optical fibre cables under fire conditions – Part 1-2: Test for vertical flame propagation for a single insulated wire or cable – Procedure for 1 kW pre-mixed flame	Height of charred zone and height of unburned zone	mm	Length of unburned cable > 50 mm	Preliminary test for all cables. Definitions of the „burned part" and „unburned part" are given in Annex A of the test method.
T09.02	EN 60332-3-24	Common test methods for cables under fire conditions – Test for vertical flame spread of vertically-mounted bunched wires or cables Part 2–4: Procedures – Category C	Height of charred zone front side and backside	m	Maximum 2,5	Test for cables with D ≥ 12 mm

Appendix I cd.

1	2	3	4	5	6	7
T09.03	EN 50305:2002, 9.1.1	Railway applications – Railway rolling stock cables having special fire performance – Test methods	Height of charred zone front side and backside	m	Maximum 2,5	Test for cables with 6 mm < D < 12 mm
T09.04	EN 50305:2002, 9.1.2	Railway applications – Railway rolling stock cables having special fire perform-ance – Test methods	Height of charred zone front side and backside	m	Maximum 1,5	Test for cables with D ≤ 6 mm.
T10.01	EN ISO 5659-2	Plastics – Smoke generation Part 2: Determination of optical density by a single-chamber test	Ds (4) see 3.1.3	Dimensionless	Maximum	Heat flux 50 kW/m^2 without pilot flame. Test duration is 10 min. Ds (4) is the optical density in the test chamber 4 min into the test multiplied by a factor, which depends on the instrument and on the specimen size.
T10.02	EN ISO 5659-2	Plastics – Smoke generation Part 2: Determination of optical density by a single-chamber test	VOF4 see 3.1.4	Minute	Maximum	Heat flux 50 kW/m^2 without pilot flame. Test duration is 10 min. VOF4 is the cumulative value of specific optical densities.
T10.03	EN ISO 5659-2	Plastics – Smoke generation Part 2: Determination of optical density by a single-chamber test	Ds max see 3.1.3	Dimensionless	Maximum	Ds max is the maximum optical density in the test chamber. Test duration is 10 min. Heat flux 25 kW/m^2 with pilot flame.
T10.04	EN ISO 5659-2	Plastics – Smoke generation Part 2: Determination of optical density by a single-chamber test	Ds max see 3.1.3	Dimensionless	Maximum	Ds max is the maximum optical density in the test chamber. Test duration is 10 min. Heat flux 50 kW/m^2 without pilot flame.

Appendix I cd.

1	2	3	4	5	6	7
T11.01	EN 45545-2:2013 Annex C	Gas analysis in the smoke chamber EN ISO 5659-2, using FTIR technique	CIT_G at 4 and 8 min.	Dimensionless	Maximum	CIT is the Conventional Index of Toxicity Heat flux 50 kW/m^2 without pilot flame. Test duration is 10 min.
T11.02	EN 45545-2:2013 Annex C	Gas analysis in the smoke chamber EN ISO 5659-2, using FTIR technique	CIT_G at 4 and 8 min	Dimensionless	Maximum	
T12	NF X70-100-1 NF X70-100-2	Gas analysis for the 8 gases described on 3.1.5	CIT NLP	Dimensionless	Maximum	
T13	EN 61034-2	Gas analysis for the 8 gases described on 3.1.5	Transmission	Dimensionless Transmission is reported as a percentage.	Minimum	
T14	EN 13501-1	Fire classification of construction products and building elements – Part 1: Classification using test data from reaction to fire tests	Table 1	Dimensionless classification	Minimum	
T15	EN 50305	Railway applications – Railway rolling stock cables having special fire performance – test methods	ITC	Dimensionless classification	Maximum	
T16	EN 60695-2-11	Fire hazard testing – Part 2–11: Glowing/hot-wire based test methods Glow-wire flammability test method for end-products	Glow wire temperature	°C	Minimum	
T17	EN 60695-11-10	Fire hazard testing – Part 11–10: Test flames – 50 W horizontal and vertical flame test methods	Vertical small flame test	Dimensionless classification	Minimum	

Literature

1. EN 45545:2013: *Fire protection of railway vehicles* – Part 2: *Requirements for fire behaviour of materials and components.*
2. EC Directive 96/48/EC: *Interoperability of the trans-European high-speed rail system*.
3. EC Directive 2001/16/EC: *Interoperability of the trans-European conventional rail system*.
4. EC Decision 2002/735/EC: *The trans-European high-speed rolling stock subsystem (HS-TSI)*.
5. EC Decision 2008/232/EC: *A technical specification for interoperability relating to the rolling stock sub-system of the trans-European high-speed rail system*.
6. EN 45545:2013: *Fire protection of railway vehicles* – Part 1: *General*.

Metody badań i aparatura stosowana do oceny właściwości reakcji taboru kolejowego na ogień

Streszczenie
Autor przekrojowo omawia rozwój metod badawczych przeznaczonych do badań właściwości palno-dymowych materiałów. Przedstawia przede wszystkim badania i aparaturę stosowaną w Wielkiej Brytanii, a także metody rozwinięte w projektach europejskich oraz testy uwzględnione w nowej normie europejskiej EN 45545:2013. Podkreśla korzystny wpływ ujednolicenia procedur badawczych i wymagań na rozwój europejskiego rynku kolejowego.

Słowa kluczowe: właściwości palno-dymowe materiałów**,** badania, aparatura badawcza, jednolite procedury badawcze

Методы испытаний и оборудование, применяемое для оценки горючих и дымовых свойств железнодорожного подвижного состава

Резюме
Автор делает обзор развития испытательных методов, предназначенных для исследований горючих и дымовых свойств материалов. Главным образом рассматривает испытания и оборудование, используемые в Великобритании, а также методы, разработанные в рамках европейских проектов, и тесты, включённые в новый европейский стандарт EN 45545. Подчёркнуто положительное влияние унификации испытательных процедур и требований на развитие европейского железнодорожного рынка.

Ключевые слова: горючие и дымовые свойства материалов, испытания, испытательное оборудование, однородные испытательные процедуры