

Fires, Fire Safety and Flame Retardants

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6. Fire testing



6.1 Building



European construction products

Regulation, classification and testing systems

- **Based on the Regulation (EU) 305/2011 basic requirements for safety in case of fire apply for construction products**
- **The European fire classification and testing systems described in EN 13501 has virtually completely substituted national systems**
- **Reaction to fire parameters such as time to ignition, flame spread, heat release and fire growth rate are the basis for the compulsory classification system**
- **Classification and tests compulsory for all EU Member States, fire safety levels still national**
- **The fire classification and testing systems apply for all European harmonized product standards**

European fire classification and testing systems

Classification systems for construction products

- Surface products
- Floor coverings
- Pipes
- Pipe insulation
- Roofing
- Cables
- Other (facades)



Classification system for surface products (walls, ceilings)

Classification “Euroclasses”

Contribution to fire

A1

No

A2s1d0

A2s1d1

A2s1d2

Virtually no

A2s2d0

A2s2d1

A2s2d2

A2s3d0

A2s3d1

A2s3d2

Bs1d0

Bs1d1

Bs1d2

Very limited

Bs2d0

Bs2d1

Bs2d2

Bs3d0

Bs3d1

Bs3d2

Cs1d0

Cs1d1

Cs1d2

Limited

Cs2d0

Cs2d1

Cs2d2

Cs3d0

Cs3d1

Cs3d2

Ds1d0

Ds1d1

Ds1d2

Acceptable

Ds2d0

Ds2d1

Ds2d2

Ds3d0

Ds3d1

Ds3d2

Ed2

Acceptable reaction-to-fire

F

No performance determined



European test methods for reaction-to fire of construction products

Test Method	Standard
Non-combustibility – Furnace test	EN ISO 1182
Calorific value (PCS) Bomb calorimeter	EN ISO 1716
Room/Corner test (Reference scenario)	EN 14390 (ISO 9705 based)
Single Burning Item (SBI) test	EN 13823
Small flame test	EN ISO 11925-2
Radiant Panel (Flooring) test	EN ISO 9239-1
Standard substrates product samples	EN 13238
Classification	EN 13501-1

Reaction to fire tests in building: small flames

Worldwide, small flame tests are used to provide basic fire safety levels for construction products

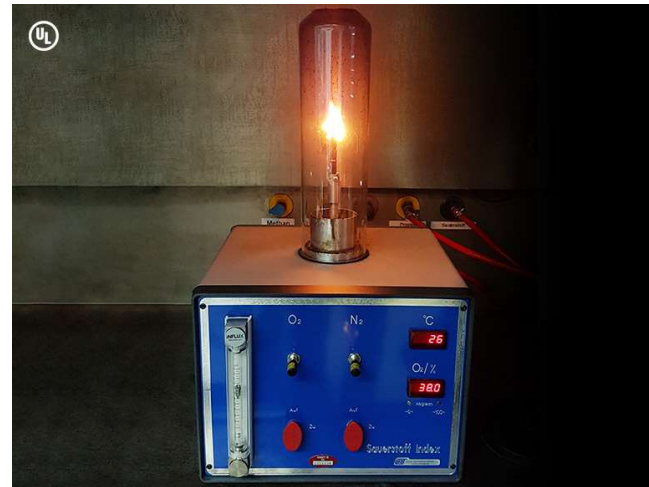
Europe, China, Asia

Small flame test
EN ISO 11925-2, GB/T 8626



China

Limiting Oxygen Index test
GB/T 2406.2



Reaction to fire tests in building: larger flames

Flame tests simulating a **larger burning item** are used to provide higher fire safety levels for walls, wall coverings, claddings

Europe, China, Asia

Single burning item test
EN 13823, GB/T 11785

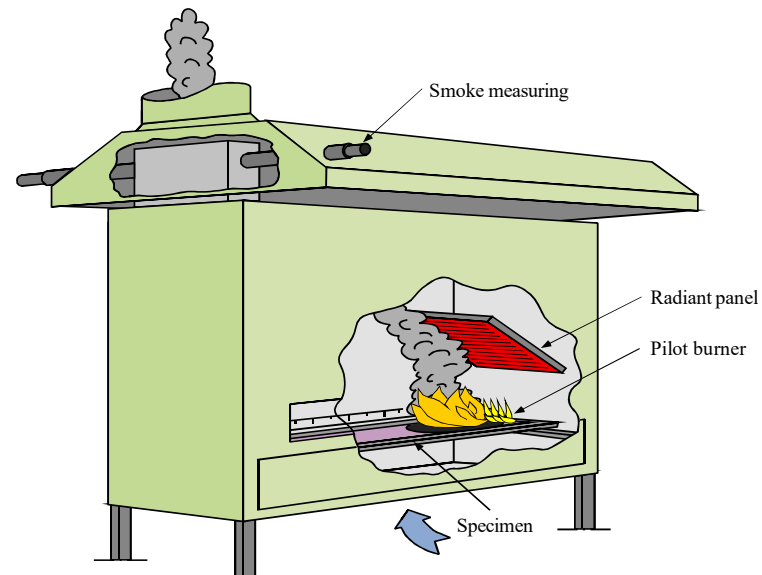


Reaction to fire tests in building: radiant panel

Flame tests with a **radiant panel** to simulate fire spread in a corridor for **floor coverings**

Worldwide

Radiant panel flooring test
EN ISO 9239-1, GB/T 20284, ASTM E648



Reaction to fire tests in building: heat release

Fire tests measuring heat released from construction products

Europe, China, Asia

Cone calorimeter test
ISO 5660, GB/T 16172



Japan

Model Box Test
ISO/TS 17431



Reaction to fire tests in building: large-scale

Large-scale fire tests simulating vertical fire propagation on external building components

Façade tests

UK, China, Asia
BS 8414-1/2, GB/T 29416



France
LEPIR test



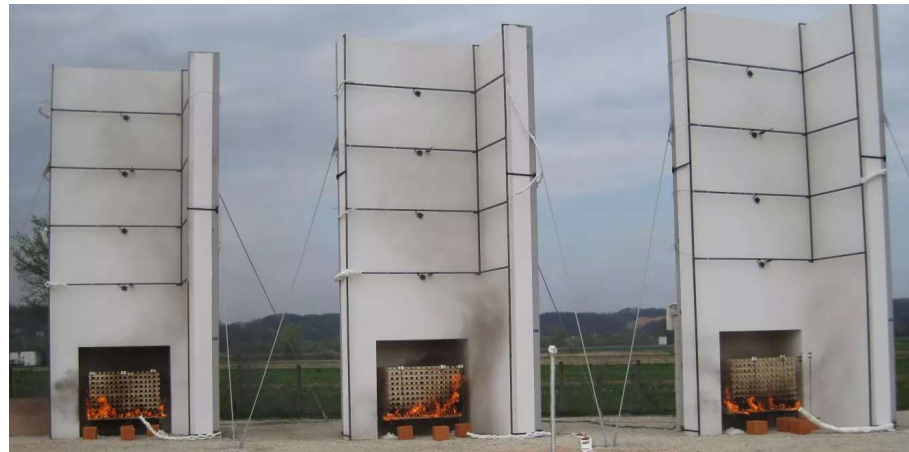
USA
NFPA 285



The situation in the European Union (EU). Status 2024

EU activities to introduce a full-scale fire test for façades

- After the Grenfell Tower fire catastrophe, the European Commission (EC) intensified the development of a full-scale fire test for façades
- Based on the national full-scale fire test methods used in Germany and the UK, and tests used in other countries with various ignition sources (from 30 to 600 kg) and test rigs (corner configurations and 2 or 3 storeys buildings), an alternative test method is under development
- The standardization work will take around 3 years and the new standard may be published 3 years after completion of the standardization work



Source: Rise

What will be the future façade full-scale fire test for Europe?

Starting point: Existing national methods use different sizes of fire sources and test rigs

Parameters measured:

- Flame spread (horizontal, vertical, internal)
- Heat (temperature or flux measurement)
- Falling parts / burning parts and droplets

Parameters not considered:

- Smoke density / smoke gas composition



Fire performance level options for future European façade test

Medium-scale test level 1: based on German DIN E 4102-20



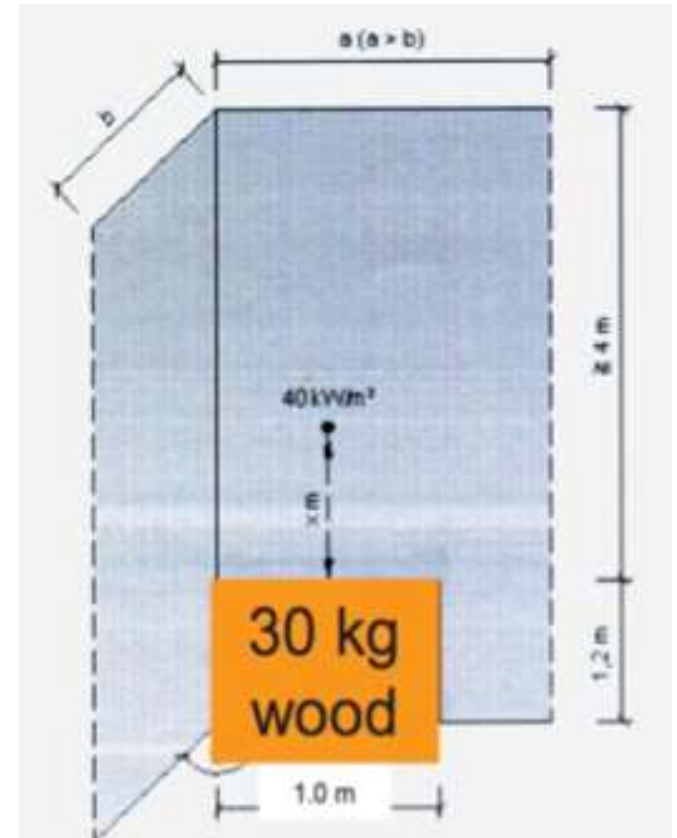
Full-scale test level 2: based on UK BS 8414-1/2



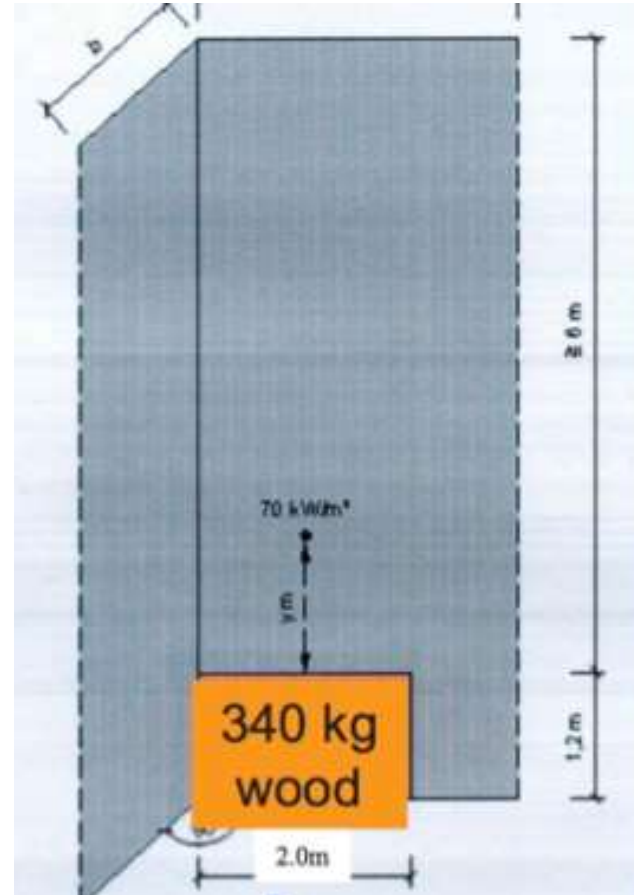
Other national tests that may be considered:

France
Hungary
Austria
Finland
Poland
Slovakia
Sweden
Switzerland

German test to DIN E 4102-20



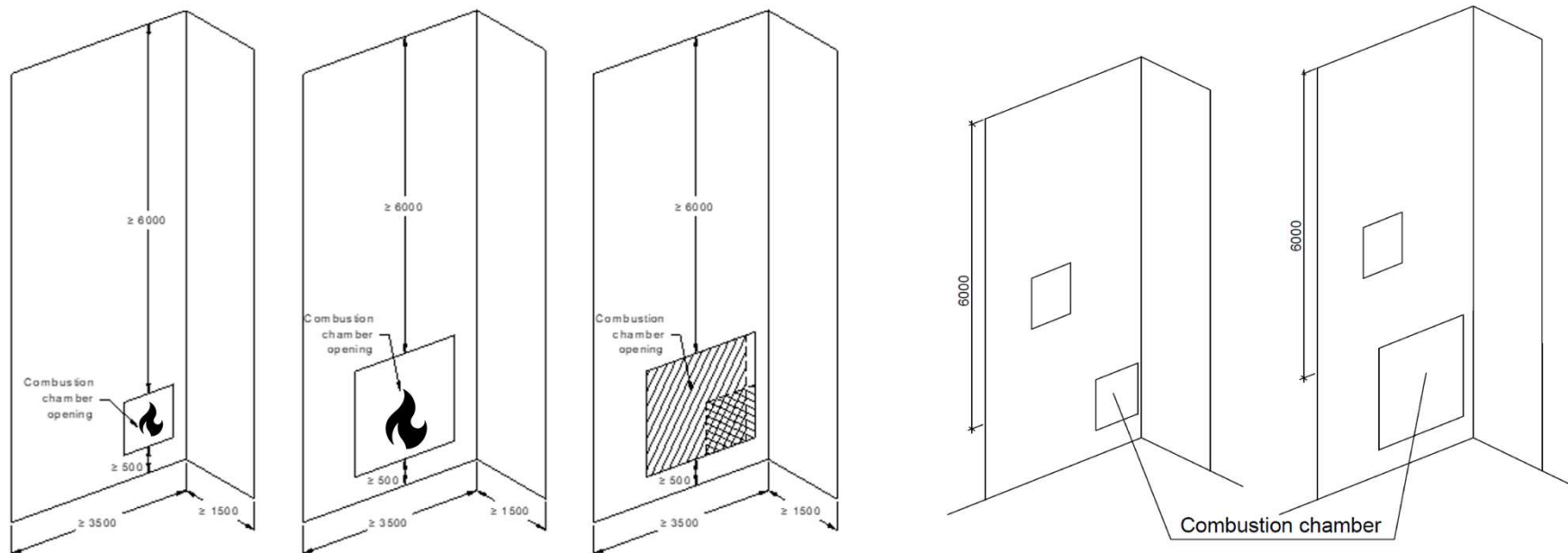
UK test to BS 8414-1/2



Alternative Method

developed in the EC Project funded by DG Grow

Project run by RISE — Research Institutes of Sweden



Proposed are a modified combustion chamber and an opening left above

EC Project funded by DG Grow:

“European approach to assess the fire performance of façades”

Started in March 2020 and completed in March 2024

Project partners

- RISE, Sweden – project leader
- BAM, Germany
- Efectis, France
- EMI, Hungary
- University of Liege, Belgium

Subcontractors

- BRE, UK
- RISE Fire Research, Norway
- EGOLF

EU activities regarding smoke toxicity of construction products

- A “Study to evaluate the need to regulate within the framework of Regulation (EU) 305/2011 on the toxicity of smoke produced by construction products in fires” has been granted by the EC to a consultants’ consortium and was recently published*
- The report concludes that EU smoke toxicity regulations for construction products only have limited benefits
- Greater benefits could arise if the flammability of furnishings and fittings was addressed across all Member States



Source: NIST

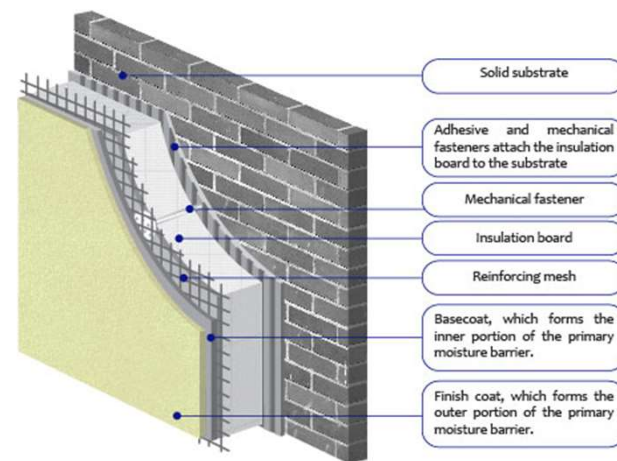
* Yates, T., European Commission. Study to evaluate the need to regulate within the Framework of Regulation (EU) 305/2011 on the toxicity of smoke produced by construction products in fires. Final report, October 2017

The situation in the U.S.

- The Grenfell tower fire also impacts on the development of fire safety requirements in the U.S.
- The 2018 International Building Code (IBC) addresses Exterior Walls and Metal Composite Materials (MCM) in chapter 14*. For its next edition, changes considering the lessons learnt from the Grenfell tower fire will be included
- For buildings >40 feet (>12.2 m) Exterior Insulation Finish System (EIFS) containing foam plastic are tested to the large-scale test to NFPA 285



Source: Payette



Exterior Insulation Finish System (EIFS)

Source: Terraco

* <https://codes.iccsafe.org/content/IBC2018/chapter-14-exterior-walls>

Reaction-to-fire tests in building: Contribution of flame retardants

Flame retardants (FR) used in combustible construction products help to pass small, medium and large-scale reaction-to-fire tests

- **Small flame tests:** Met for virtually all FR building materials
Examples: EPS/XPS and PU foams, building interiors
- **Larger flame tests:** Met for many FR construction products
Examples: Thermal insulation systems, wall coverings, roofing
- **Radiant panel tests floorings:** Met for most FR construction products
Examples: Floor coverings, carpets, rugs
- **Heat release tests:** Met for many FR materials and construction products
Examples: Building interiors, coverings, thermal insulation systems
- **Large-scale façade tests:** Met for a number of FR construction products
Examples: Thermal insulation systems

6.2 Transportation

Fire Safety of Rail Vehicles EU Directives and Standardization

- Fire safety requirements part of the European Directive on interoperability of the trans-European high-speed rail system
- The European Standard EN 45545-2:2013, “Fire Protection on Rail Vehicles - Part 2: Requirement for fire behaviour of materials and components” is the basis for classification and testing
- After around 20 years of development, EN 45545 has become a European standard in March 2013
- EN 45545 referred to in railway directives taking over the new test methods and classification systems



Fire Safety of Rail Vehicles EU Directives and Standardization

EN 45545-2 requires heat fluxes of 25 and 50 kW/m² for

- **Flame propagation in radiant panel to ISO 5658-2**
CHF = Critical Heat Flux
- **Heat release in cone calorimeter to ISO 5660-1**
MAHRE = Maximum Average Rate of Heat Emission
- **Smoke/toxicity in single chamber smoke box to ISO 5659-2**
CIT = Conventional Index of Toxicity
VOF₄ = Smoke Obscuration Value within 4 min



Revision of EN 45545-2

Revision of EN 45545-2 completed in 2020

The main changes are:

- **Fire gas toxicity** (former Annex C) now **separate standard EN 17084-2018**. Only minor changes: Continuous smoke gas output measured every 20 s for calculating the Conventional Index of Toxicity CIT after 4 and 8 minutes
- **Fire testing seating** (former Annex B) now **separate standard EN 16989-2018**. Passenger seats tested with higher burner performance (21 instead of 7 kW) in the SBI test room to EN 13823; heat release determined and calculated as MAHRE (Maximum Average Rate of Heat Emission). **Flame height now considered**. Testing of vandalized and non-vandalized mandatory. Former cone and toxicity tests for seats obsolete

Fire Safety on Seagoing Vessels

- The International Maritime Organization **IMO** develops international regulations and standards for the safety of seagoing vessels. In 1996, introduction of the **Fire Test Procedures (FTP) Code**
- The FTP-Code contains **fire tests for flammability, heat release, smoke and toxicity** to meet fire safety requirements for materials and components used on ships



Fire Safety on Seagoing Vessels

Tests to the 2010 FTP-Code

FTP Code	Type of test	Referred test method	Similar test method
Part 1	Test for non-combustibility	ISO 1182:1990	-
Part 2	Test for smoke and Toxicity	ISO 5659-2	-
Part 3	Test for "A", "B" and "F" class divisions	IMO A.754(18)	ISO 834-1
Part 4	Test for fire door control systems	-	-
Part 5	Test for surface flammability (surface materials and primary deck coverings)	IMO A.653(16) IMO A.687(17)	ISO 5658-2
Part 7	Test for vertically supported textiles and films	IMO A.471(XII) IMO A.563(14)	ISO 6940/41
Part 8	Test for upholstered furniture	IMO A.652(16)	BS 5852-1/-2
Part 9	Test for bedding components	IMO A.688(17)	EN 597-1/-2
Part 10	Test for fire-restricting materials for high-speed craft	-	ISO 5660-1
Part 11	Test for fire-resisting divisions of high-speed craft	-	ISO 9705

6.3 E-mobility/E&E

Fire safety of conventional and electric vehicles

E-mobility is a megatrend where **zero-emission, battery-powered vehicles and interconnected, autonomous mobility** are revolutionizing transportation

Electric vehicles (EVs) use an electric motor powered by electricity from a battery that requires recharging

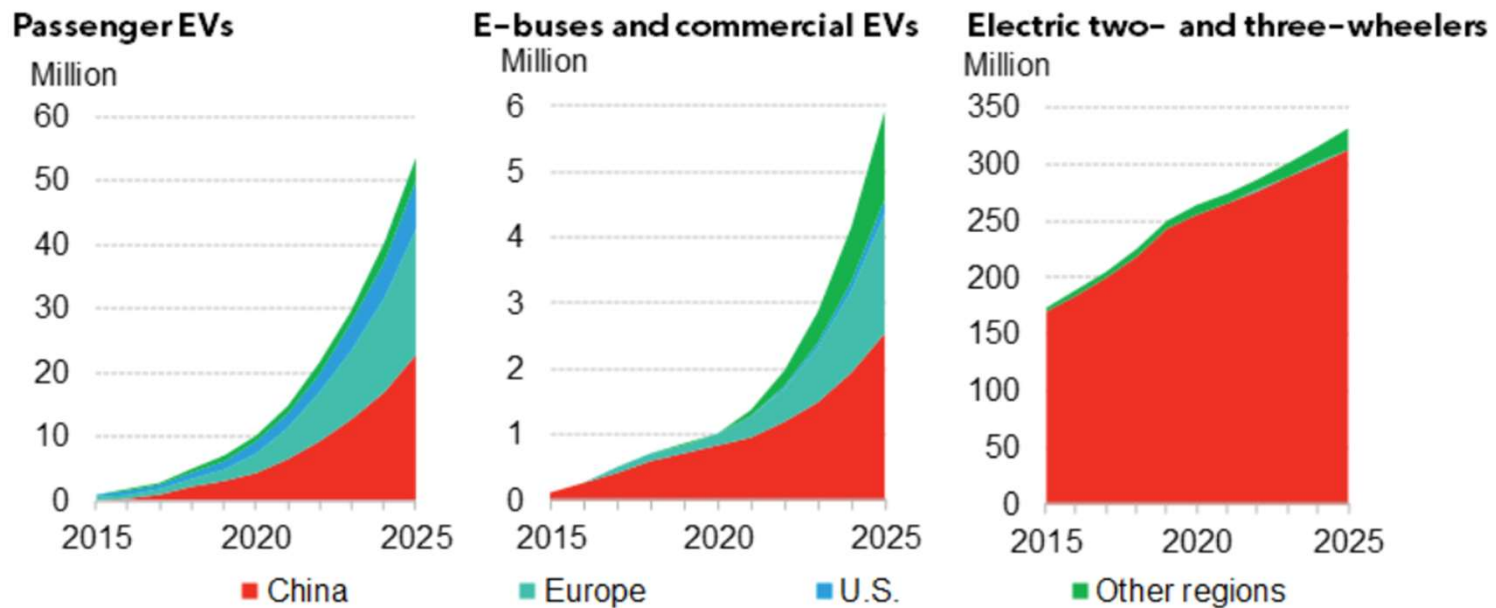
The **main electrical components** of an EV are the **electric powertrain** (battery, converter, traction motor), the controller, onboard **chargers and charge ports**



Source: Pixabay/cc0

Megatrend markets e-mobility

For e-mobility, a BNEF study estimates that **until 2025** the **global passenger e-vehicles** fleet will grow to over **50 million**, **e-buses** to around **6 million**, and **electrical two- and three-wheelers** to over **300 million**



Source: BNEF. Note: Two-wheelers includes mopeds, scooters and motorcycles, excludes e-bikes.

New technologies and fire safety

In these new, future-oriented technologies, it is essential to **consider** the impact of combustible materials and components on **fire safety**

The **quickly growing number of devices** used in e-mobility **requires high fire safety standards** to protect life and property



Fire statistics, recalls and potential fire hazards related to road vehicles

U.S. fire statistics show that most fires occur as structural fires, followed by highway vehicles fires. The **number of all fires and fire deaths, including that of structural fires and highway vehicle fires, decreased from 1980 to 2020**

Fires	Year	All	Structural	Highway vehicle
Number	1980	2,988,000	1,065,000	456,000
	2020	1,388,500	490,500	175,000
Deaths	1980	6,505	5,675	650
	2020	3,500	2,730	580

Fire statistics, recalls and potential fire hazards related to road vehicles

However, a recent NFPA study* shows that although a lot of progress has been made in the last 40 years “the success in taming fires has unfortunately led to **fire safety taking a back seat to other societal concerns that seem more pressing**”

- **Megatrends** with their exponentially growing new technologies may lead to “**increasing challenges to fire safety not yet appearing in the statistical data**”
- And this **applies to e-vehicles** using **lithium-ion batteries**.
- To prevent these technologies from becoming fire hazards, “**improved fire safety requirements and standards need to be developed/updated, and consumers educated on potential risks**”



* Ahrens, M.; Messerschmidt, B.: Fire safety in the United States since 1980. NFPA 2021 <https://go.nfpa.org/l/14662/2021-05-24/8hkgt5>

Electrical fires

In a study on **conventional vehicle fires***, it is shown that in the period **2013–2017** **mechanical failures or malfunctions** were the leading factors in highway vehicle fires (**47 %**), **followed by electrical failures or malfunctions (21 %)**

The share of **passenger e-vehicles** amounted to 12 million in **2020**, approx. **1% of the global fleet**. This is why e-vehicle fires have **not yet found their way into fire statistics**. But, due to the exponential growth of e-vehicles, this will **change in the future**, particularly because **Li-ion batteries fires** are extremely intensive, difficult to extinguish fires

In addition to fire statistics, **recalls** can **provide important information on fire safety issues** including road vehicles as shown in the following

* Ahrens, M.: Vehicle Fires. NFPA Research, March 2020



Fire safety requirements and tests used for conventional and e-vehicles

In the **conventional automotive** sector, **fire safety requirements for interiors** are **too low**, and excepted cables in buses, **E&E products are virtually not regulated**

Modern cars and e-vehicles in particular require higher fire safety, because the **fire hazard increases**

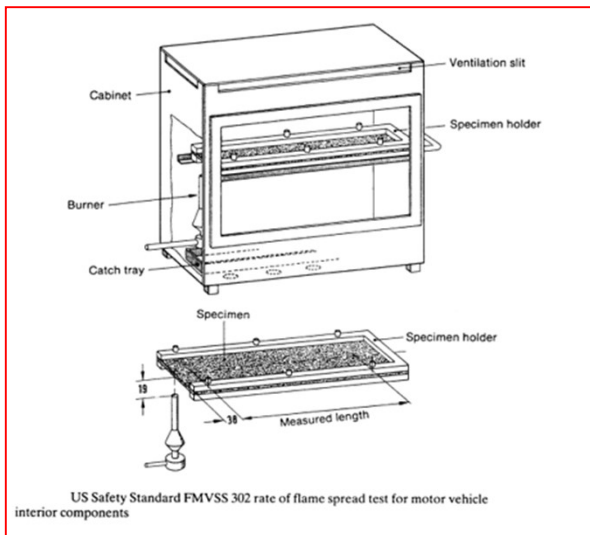
- For components such as the electric motor which can reach **voltages of 400 to 600 V**, versus 12 or 48 V for vehicles today
- Due to the **multitude of electrical motors as potential ignition sources**



Source: e2e.ti.com

Fire safety requirements: interiors

Like all road vehicles, e-vehicles must meet fire safety requirements for **car interiors** to **U.S. FMVSS 302** or **ISO 3795**



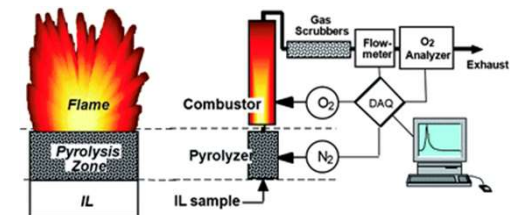
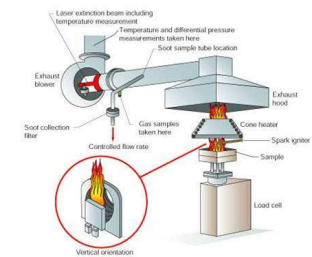
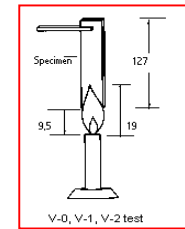
Source: FTT

These **requirements are old (1972) and rather low** and do not consider the fire safety needs of modern road vehicles. Studies are underway to find better alternatives

NHTSA sponsored study for improved FMVSS 302 flammability tests*

- Find alternative small-scale fire test method for which FMVSS 302 equivalent pass/fail criteria can be established

Test Method Designation	Title/Description
49 CFR 571.302	FMVSS No. 302-Horizontal burn rate test of 4x14 inch sample using a Bunsen burner – similar to ASTM D5132, SAE J369, ECE R.118 - Annex 6.
ASTM D3801-10	Standard test method for measuring the comparative burning characteristics of solid plastics in a vertical position. Similar to ECE R.118 –Annex 8, UL 94, and 14CFR 25 – Appendix F.
ASTM E1354-16a	Standard cone calorimeter test: Cone calorimeter test has an advantage over Bunsen burner type tests because the heat release rate can be related to real world vehicle fire scenarios. Previous research has demonstrated repeatability. Test parameters can be tuned to make equivalent to FMVSS No. 302.
ASTM D7309-13	Standard test method for determining flammability characteristics of plastics and other solid materials using microscale combustion calorimetry. Useful in testing small and non-standard size material.
ASTM E2574 / E2574M - 12a	Standard test method for fire testing of school bus seat assemblies. Maybe used for bus materials.



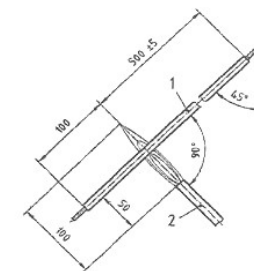
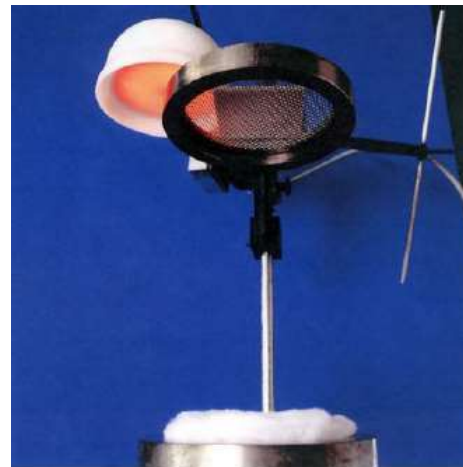
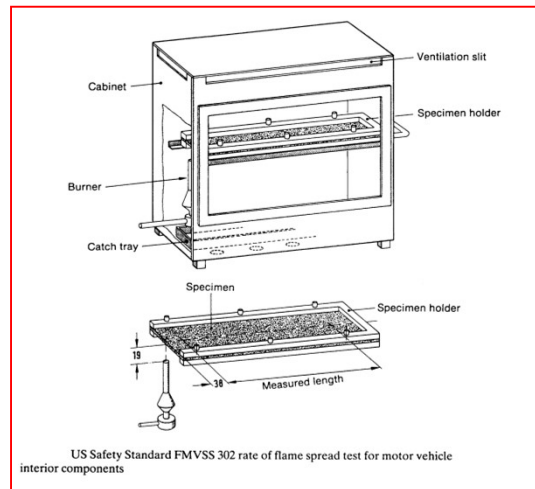
- MCC to ASTM D7309 found to be **most promising** in providing (heat release based) data related to the fire hazard of materials.
- Further work ongoing



* Huczek, J., Janssens, M., Cabiness, S., Friedman, K., Mattos, G., & Stephenson, R. (2021, April): Potential alternative methodology for evaluating flammability of interior automotive materials (Report No. DOT HS 812 091). National Highway Traffic Safety Administration

EU flammability tests for buses to UNECE Regulation 118

- **Interior materials**
Horizontal samples
to ISO 3795
- **All vertically oriented materials**
Vertical samples
to ISO 6940
- **Ceiling**
Drip test
to NF P 92-505
- **Single-core cables**
to ISO 6722



Key
1 Test sample
2 Bunsen burner

Figure 10 — Apparatus for resistance to flame propagation test

UNECE R 118 voluntary fire test

- On a **voluntary basis**, the stringent lateral flame propagation test to **ISO 5658-2** used for railways in EN 45545-2 and for ships in the FTP-Code can be performed



- **Materials that are approved by this test are considered to also fulfill the requirements for both the vertical burning rate test and the melting test, provided no burning drops are observed**

Fire safety requirements and tests used for e-vehicles

In addition, fire safety requirements and tests were developed to address **new fire safety challenges for**

- **electric powertrains and**
- **Li-ion batteries**

Fire and overheating requirements for enclosures, plugs, and sockets used in e-vehicles

- **charging stations**

have been introduced as well



Specific fire safety requirements for the electric powertrain

- **UNECE:** In the United Nations Economic Commission for Europe, WP 29 is responsible for the harmonization of vehicle regulations
- **WP 29** develops **regulations with technical requirements** for the assessment of safety and environmental performance of **Electric Vehicles (EV)**, Hybrid Electric Vehicles (HEV) and Fuel Cells Vehicles (FCV) laid down in the UNECE **Regulation 100** and 132 (e-powertrain, electric shock)
- In July 2013, an addendum to Regulation 100 concerning the approval of vehicles regarding specific requirements for the **electric power train** was introduced. In Annex 8E a **fire resistance test** is **mandatory**



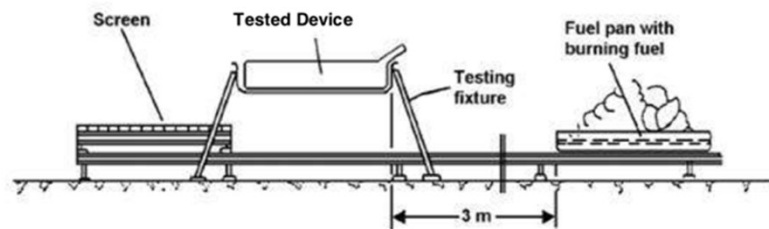
Electric power train: Li-ion battery



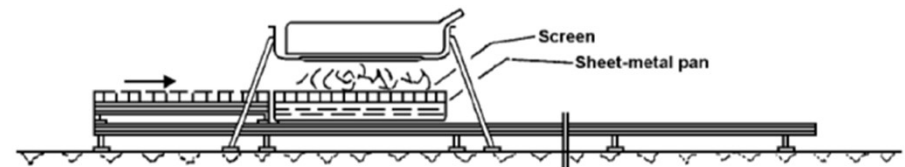
Test rig for electric power train

UNECE regulation No. 100 annex 8E fire resistance

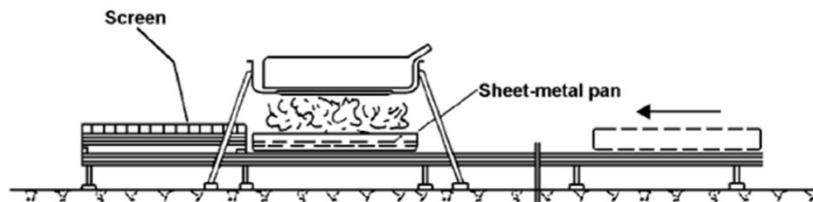
The purpose of this test is to verify the **resistance of the Rechargeable Energy Storage System (RESS) against exposure to fire** from outside of the vehicle. If this requirement is met, this will allow the driver and passengers enough time to leave the vehicle



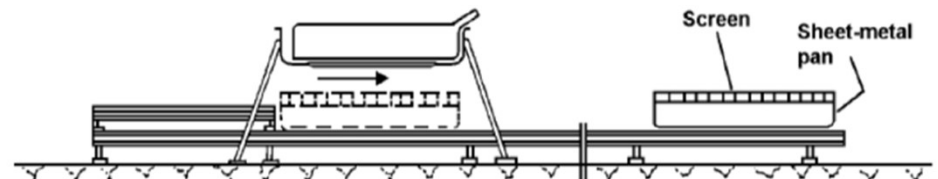
Phase A. Pre-heating (60 s)



Phase C. Indirect exposure to flame (60 s)



Phase B. Direct exposure to flame (70 s)



Phase D. End of test

Fire safety requirements for products used in chargers and charging stations

To ensure the **safety of electric vehicles charging stations**, fire safety requirements for plastic components such as **enclosures, plugs and sockets** have to be met with different UL and IEC standards

Different fire safety concepts in

- **Europe:** ignition and flammability using **glow wire ignition sources**
- **USA:** fire propagation using internal/external **open flame ignition sources**



Source: [electrivedrive.com](https://www.electrivedrive.com)



Source: [insideevs.com](https://www.insideevs.com)

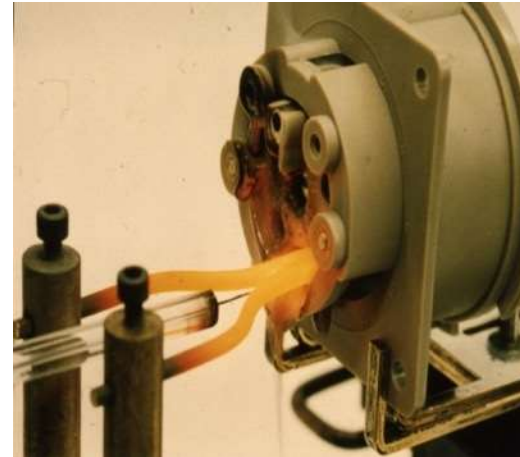
Glow wire tests

The most important **flammability and ignitability tests for appliances** are the glow wire tests

- IEC 60695-2-10 Apparatus and common test procedure
- IEC 60695-2-11 Flammability test for end products (GWEPT)
- IEC 60695-2-12 Flammability test for materials (GWFI)
- IEC 60695-2-13 Ignitability test for materials (GWIT)



Materials test setup

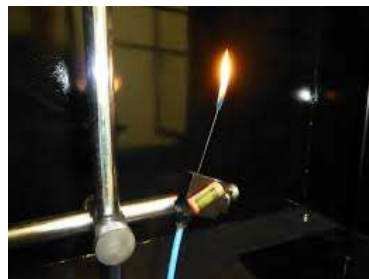


End products test setup

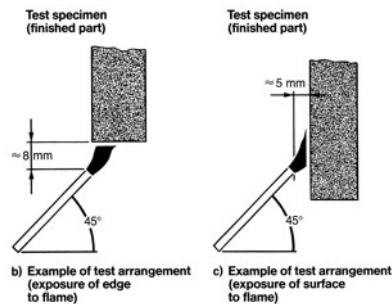
Small flame tests

The most important **open flame tests** for electrical equipment and electronics (E&E) are the small flame tests (needle flame, horizontal/vertical 50 W tests, UL 94 HB, V2, V1, V0)

Needle flame test IEC 60695-11-5



Source: cvzl.cz



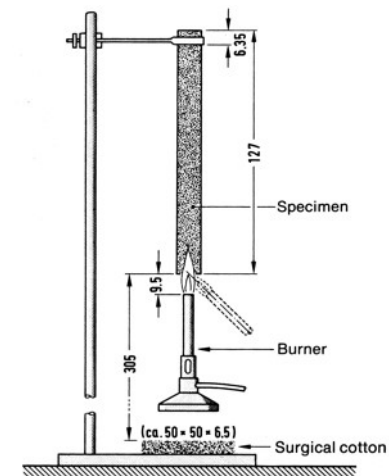
b) Example of test arrangement (exposure of edge to flame)

c) Example of test arrangement (exposure of surface to flame)

flammability tests (UL 94) 50 W vertical flame test method, IEC 60695-11-10



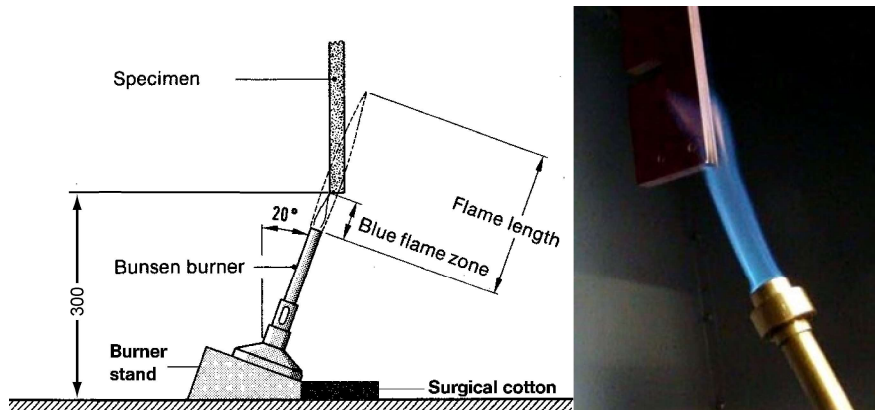
Source: UL.com



Larger flame tests

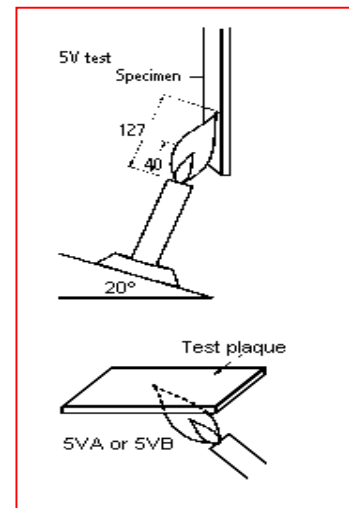
The most important larger flame tests for E&E equipment are the 500 W and UL 94 5VA and 5VB tests

500 W vertical flame test method IEC 60695-11-20



Source: KA Testing

UL 94 5VA or 5VB



Source: Korea.UL.com

Europe: Fire safety requirements for products in chargers and charging stations

Enclosures

- **IEC 61851-1** Electric vehicle conductive charging systems
Glow wire flammability index **GWFI 650°C**



Source: dellvallebox.com

Plugs and sockets

- **IEC 62196-1 and 2** Plugs, socket-outlets, vehicle connectors and vehicle inlets -
Conductive charging of electric vehicles
Glow wire flammability index **GWFI 650°C to 850°C**



Source: Distrelec.ch

USA: Fire safety requirements for products in chargers and charging stations

Enclosures

- **UL 2594** Electric vehicle charging stations: Permanent equipment **UL94 5V**
- **UL 2202** On-board battery chargers: Larger enclosures **UL 723** Steiner Tunnel or **ASTM E162** surface flammability test with a **flame spread rating of <200**



Source: firesafetysearch.com

UL 723



ASTM E162

Source: ftt.com

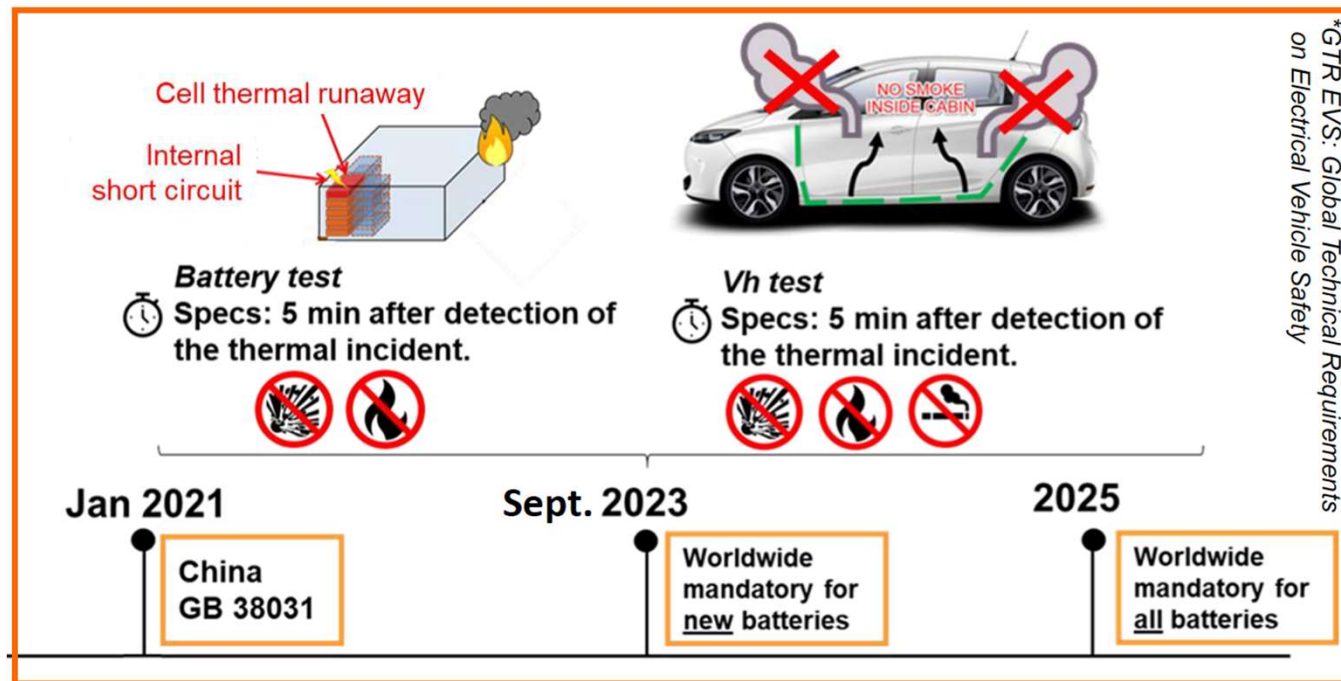
Plugs and sockets

- **UL 2251** charging inlets and plugs: at least **UL94 HB + HAI** (High-current arc ignition) **and HWI** (Hot wire ignition) for internal barrier or enclosures

Fire safety requirements for batteries

Battery standards generally address the **whole battery system**

- They focus on **mechanical, thermal and electrical abuse tests** and are part of the **roadmap requirements for Electrical Vehicle Safety**

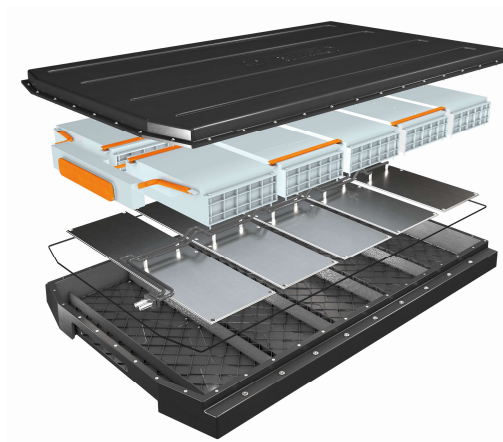


Source: Renault

Fire safety requirements for batteries

However, **materials and parts of batteries** are also concerned:

- **Plastics in electric vehicles' Li-ion batteries** enclosures, covers, end plates, cell holders, spacers and high-voltage connections usually must meet **UL 94 V0 or 5V**



Li-ion battery housing

(Source: Kautex Textron)

Passive fire safety of equipment used in conventional cars and e-mobility (1)

Passive **fire safety** needs are **met** with products often containing **flame retardants**

Modern flame retardants (FRs) used are **very efficient**, and **easy to process**.

The FRs used are mainly based on

- Organic/inorganic **phosphorus**
- Reactive/polymeric **brominated**
- **Nitrogen**, and
- **Inorganic compounds**

Depending on polymer and FR system used, **glow wire tests can be met up to GWIT 900°C and GWFI 960°C**, open flame **UL 94 tests up to Classes V0 and 5V**

Passive fire safety of equipment used in e-mobility (2)

- **Inherently flame retarded products** are used in specific cases, but they may be difficult to process and expensive

Thermal runaway prevention of single battery and battery module interiors with temperature peaks of up to 900°C with

- **Intumescent coatings**
- **Interlayers** such as **mica** (protect up to 1,500°C), or **aerogel** sheets (up to 600°C)
- **Ceramifying products** based on silicone (up to 1,200°C).



Intumescent coating

Source: jiosaerogel.com



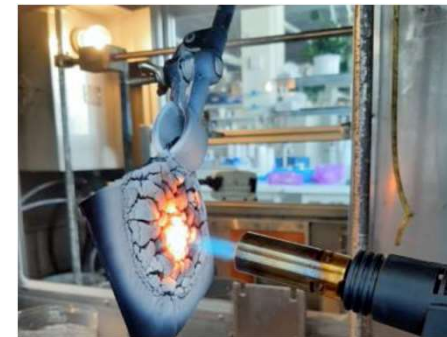
Mica sheets

Source: elmelin.com



Aerogel sheets

Source: aerchs.com



Ceramifying silicone product

Source: Wacker