Horizon 2020

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Deliverable D08.14

Fire risk assessment and establishment of requirements (material property performance and test method for evaluation) for combustible surfaces in ro-ro spaces

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Abstract

This report addresses the gap found in the fire regulations. Currently, there are no requirements for combustible interior surface materials for usage in ro-ro spaces. This issue has been addressed within the LASH FIRE project. An evaluation of fire test methods, now used in different sectors, was done to identify suitable methods for the interior surface materials. Two reaction-to-fire test methods were identified as relevant, the flame spread according to IMO FTP Code Part 5 and the smoke and toxicity according to IMO FTP Code Part 2. A test matrix was established, including approximately 30 combinations of resins, fibres, core materials and surface protections with end use as single laminates or sandwich panels. A comprehensive study on the reaction-to-fire performance was made and resulted in a lot of test data.

The general results for the samples showed that unprotected laminates and sandwich panels had the worse fire performance. However, this was also related to the type of resin as it strongly affects the fire behaviour. One type of surface protection was the intumescent integrated fabric, which did not have as good effect on the fire performance as expected. Best performance had the samples which were coated with intumescent coating. The coating formed a char layer which protected the material from pyrolysis and the fire growth. However, there was an exception regarding the sandwich panels. The core materials were affected by the heat source and either ignited or produced smoke and toxic gas species.

The fire test results were compared with the already established requirement levels for marine applications, given by the IMO FTP Code. Products and materials are divided into different categories related to the end-use. These categories are then given different requirements, based on their effect on the fire growth. For example, a wall material or ceiling material will contribute to the fire growth in a larger extent than a floor covering. Thus, the requirements are more stringent. The result from this study has been used to establish a suggestion of requirements for interior surface materials for ro-ro space materials.

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Content

1 Executive summary

This report present fire classification requirements and fire test methods relevant for ships and vehicles followed by a selection of fire test methods applicable for combustible surfaces in ro-ro spaces. A selection of relevant materials was made, and the materials were evaluated using the fire testing methods. The results were used to find relevant requirement levels for combustible surfaces in ro-ro spaces.

1.1 Problem definition

As the marine industry turns towards an increase in usage of lightweight constructions and materials, the usage of combustible materials, e.g., composite materials, increase. As a result, the fire risk is increased since these materials will contribute to the fire load and the fire development on board. However, for ro-ro spaces, there are no defined requirements for these materials. Evaluating the fire performance of these materials and define requirements and guidelines will keep the fire safety at a high level and facilitate implementation.

1.2 Method

A thorough literature study has been conducted to find fire classification requirements and fire test methods relevant for ships, vessels, and vehicles. An evaluation was made of these to find the most related requirements and test methods. A comprehensive list of material systems was presented within LASH FIRE Action 8C. In this task, a selection among them was made and their fire performance was evaluated using the selected fire test methods.

1.3 Results and achievements

Approximately 30 composite materials, designed from different combinations of resins, fibres, core materials and surface protections, were tested with regards to their reaction-to-fire behavior. Two test methods were used, the flame spread (IMO FTP Code Part 5) and the smoke and toxicity (IMO FTP Code Part 2). The fire testing resulted in a lot of test data and increased the knowledge of fire performance of composite materials. All test data can be found in two databases, the RISE Fire database and the E-LASS Material database.

The fire test results were compared with the already existing fire requirements for marine applications, given by the IMO FTP Code. Products and materials were divided into different categories, related to their end-use application. The requirements were set do different levels as the materials contribute to varying extent to the fire growth. After evaluation and analysis, it was seen that the exciting requirements were suitable also for interior surface materials for ro-ro spaces.

1.4 Contribution to LASH FIRE objectives

The specific objective of WP8 is to achieve a significant reduction of the most probable ignition sources and improved management of fire hazards in ro-ro spaces, including provision for automatic screening and risk-based loading support. At Action 8-C, this is achieved by determining reaction to fire property requirements for non-regulated used new materials in surfaces of ro-ro spaces.

1.5 Exploitation

The large amount of data is a good contribution to the knowledge of fire performance of composite materials. The results, the test data, will be published in two databases, the RISE Fire database (public available) as well as in the E-LASS Material database (public for all E-LASS members, free of charge to join the network).

The final results from the work within Action 8C and this deliverable can be used for future establishment of regulations and requirements for combustible surface materials in ro-ro spaces. Further, it may be used by ship designers, shipyards and ship operators to facilitate implementation as lightweight composite materials can contribute to the ship weight reduction and maintenance cost, thus, reduction of fuel consumption and CO_2 emissions.

2 List of symbols and abbreviations

PVC	Polyvinyl Chloride
PET	Polyethylene Terephthalate
HSC	High Speed Craft
FTP	Fire Test Procedures
IMO	International Maritime Organization
FRM	Fire Restricting Materials
FRD	Fire Resisting Divisions
TSI	Technical Specification of Interoperability
R-set	Requirement set
HL	Hazard Level
FAR	Federal Aviation Regulations
FTIR	Fourier Transform Infrared
CO	Carbon Monoxide
HCl	Hydrogen Chloride
HBr	Hydrogen Bromide
HF	Hydrogen Fluoride
HCN	Hydrogen cyanide
NO_x	Nitrogen Oxides
SO_2	Sulphur Dioxide
CFE	Critical Flux at Extinguishment
Q_{sb}	Heat for sustained burning
Q_p	Peak heat release
Q_t	Total heat release
MARHE	Maximum Average Rate of Heat Emission
SBI	Single Burning Item
HRR	Heat Release Rate
THR	Total Heat Release
FIGRA	FIre Growth Rate
SPR	Smoke Production Rate
TSP	Total Smoke Production
SMOGRA	SMoke Growth Rate
mv	mean value

3 Introduction

Main author of the chapter: Anna Sandinge, RISE.

The marine industry moves towards an increase in usage of lightweight materials. As the demands of a lighter vessel increases, conventional steel applications are replaced with lightweight applications. These are often made of composite materials, which are combustible. In case of a fire, the combustible materials will burn and contribute to the fire development on board. For yachts and high-speed craft (HSC) vessels, there are defined requirements for the usage of combustible materials with regards to fire. However, for combustible surfaces materials in ro-ro ships, there are no defined requirements. Evaluating the fire performance of these materials and define requirements and guidelines will keep the fire safety at a high level and facilitate implementation. Material systems for a wide range application in ro-ro spaces are investigated including currently used solutions on ro-ro ships as well as state-of-the-art solutions which are already well known in other industries and which could also be applied in the marine environment, for ro-ro cargo spaces.

3.1 Investigation of new material solutions

Material systems used in a wide range of applications in ro-ro spaces was identified in the work of task T08.16. It included currently used solutions on ro-ro ships as well as state-of-the-art solutions. These are already well known to other industries, and they could be applied in the marine environment, for ro-ro cargo spaces.

To further reduce the weight of ro-ro ships and to improve the fire safety, an evaluation of new material solutions and technologies for structural applications must be done, to replace conventional steel structures. To find these materials, several composite components and combinations were considered. Sandwich panels with laminate of resin and fibres in combination with a core material were identified. Core materials identified are for example PVC, PET, and Balsa. Commonly used fibres are glass, carbon, basalt, and hybrids. In addition, composite products with improved fire properties were identified, such as multiaxial fabrics with integrated fire protection for structural parts with fire retardant surface layer. Intumescent coatings have been used in the offshore oil and gas industry for more than 20 years and could potentially be used as a passive fire protection in the marine industry. It could be used as a replacement of the conventional insulation or in critical points, such as gaps at ro-ro ramps/hatches.

The findings in T08.16 were used for the materials selection in D08.14. For the selected material systems, relevant fire test was conducted to determine the reaction to fire property requirements.

4 Fire test methods for transportation vehicles

Main author of the chapter: Anna Sandinge, RISE.

In general, materials and products must be tested and validated with respect to their fire behaviour before entering the market. There are different fire classification standards for different end use applications. These can be categorized into mainly six groups: construction products and building elements, upholstered furniture and mattresses, marine applications, railway vehicles, aircraft and transportation such as buses, trucks and automotive. Classification standards and test methods are presented and discussed below. A selection among fire classification standards and fire test methods has been made with regards to the end use as a ro-ro surface material.

4.1 Introduction to fire technology

A short introduction to fire technology is given below, to better understand the fire behaviour and the relation to fire tests, test parameters and fire performance.

When dealing with fire, there are three main stages as shown in **Error! Reference source not found.**. The first stage is the ignition phase. Here, the material is ignited by an external ignition source and the material ignitability and flammability is evaluated. The second phase is the flaming phase, with the development of the fire from ignition, to flaming combustion and fire growth. Here, parameters such as flame spread, heat release rate and smoke production are measured. The third phase occur when the fire is fully developed. The heat penetration and the fire resistance of building elements such as floors or walls are evaluated.

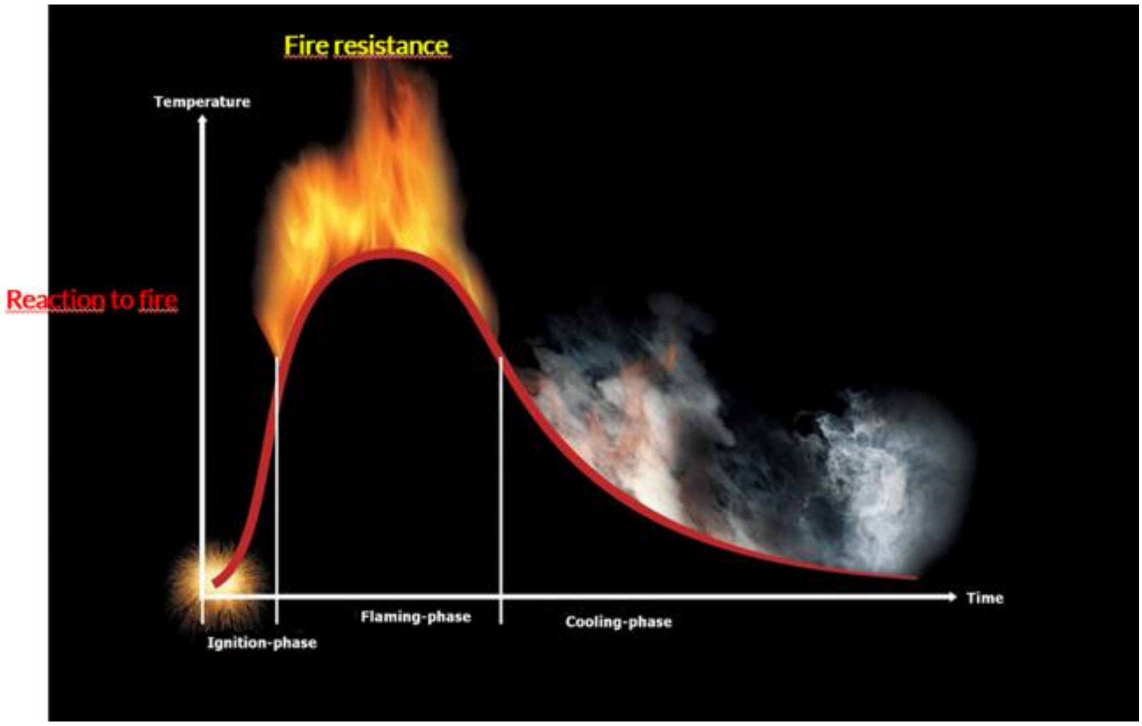

Figure 1 Schematic drawing of the main stages in a fire.

One important thing about fire testing is that one must be aware about the difference between ignitability testing and burning behaviour testing. Ignitability testing normally uses small ignition sources and the purpose is to see if a product can resist ignitability from a specific ignitions source (and only that source). If a product fulfils the ignitability requirements, it does not mean that the product is "safe" or could withstand other ignition sources. If using a larger ignition source or testing according to another test standard, the product might ignite and burn. Testing of burning behaviour is performed to see how the product behaves after ignition. Usually, the ignition sources used in these tests are larger and parameters such as heat release rate (heat production rate from the fire) and the total energy produced are measured. Smoke production can also be measured, Ref. [1] [2] [3].

4.2 Fire classification standards

There are different fire classification criteria and classification standards related to the end use of the product. Below are selected standards presented, related to transportation.

4.2.1 Classification of marine applications

Fire testing of marine applications is conducted according to the International code for application of Fire Test Procedures (FTP) Code 2010, given by the International Maritime Organization (IMO) [4]. The FTP Code contains several test methods and evaluates i.e., flame spread, heat release, combustibility, smoke generation, toxicity, and structural resistance to fire. In the FTP Code, there are tables listing applicable test methods and requirements for approval for specific applications or products.

The test methods in the FTP Code are given by separate appendices, and include the following:

- Part 1: Non-combustibility test
- Part 2: Smoke and toxicity test
- Part 3: Test for “A”, “B” and “F” class divisions
- Part 4: Test for fire door control systems
- Part 5: Test for surface flammability (flame spread)
- Part 7: Test for vertically supported textiles and films
- Part 8: Test for upholstered furniture
- Part 9: Test for bedding components
- Part 10: Test for fire-restricting materials (FRM) for high-speed craft
- Part 11: Test for fire-resisting divisions (FRD) of high-speed craft

4.2.2 Classification of railway vehicles

The European standard, EN 45545, is harmonised and has replaced the previous national standards of each European country. The standard applies to all railway vehicles included in the definition in EN 45545-1. The European Directive 2016/797 for railway however only applies to high-speed trains which are regulated by the Technical Specification of Interoperability, TSI LOC&PAS. This TSI refer only to EN 45545-2 for legal compliance. National regulations control all other types of railway vehicles which can mean a deviation from EN 45545.

There are several parts of the standard, all listed below:

- EN 45545-1 [5], Railway applications – Fire protection on railway vehicles – Part 1: General.
- EN 45545-2 [6], Railway applications – Fire protection on railway vehicles – Part 2: Requirements for fire behaviour of materials and components.
- EN 45545-3 [7], Railway applications – Fire protection on railway vehicles – Part 3: Fire resistance requirements for fire barriers.
- EN 45545-4, Railway applications – Fire protection on railway vehicles – Part 4: Fire safety requirements for rolling stock design.
- EN 45545-5, Railway applications – Fire protection on railway vehicles – Part 5: Fire safety requirements for electrical equipment including that of trolley buses, track guided buses and magnetic levitation vehicles.
- EN 45545-6, Railway applications – Fire protection on railway vehicles – Part 6: Fire control and management systems.

- EN 45545-7, Railway applications – Fire protection on railway vehicles – Part 7: Fire safety requirements for flammable liquid and flammable gas installations.

In EN 45545-2 [6], products and components used in trains are identified, and associated with specific requirements, R-sets. In each R-set, several fire test methods are listed, and the requirements are given for three different hazard levels, HL1, HL2 and HL3. The hazard levels are related to type of train and where it operates, such as in countryside or underground and in tunnels. The structure of a R-set is easier to understand by studying an example: The application of the tested product is a wall material of the external body shell of a train. This type of product has the product number EX1A (from Table 2 in EN 45545-2) and the requirement set is R7 which is given in Table 5 of EN 45545-2. This specific requirement set is shown in **Error! Reference source not found.** below. It can be seen from **Error! Reference source not found.** that the requirement set R7 is based on the results from three different test methods: ISO 5658-2 (flame spread), ISO 5660-1 (heat and smoke production) and EN ISO 5659-2 (smoke density and smoke toxicity).

Table 1 Requirement set R7, from Table 5 in EN 45545-2, here given as an example.

Requirement set R7 (used for)	Test method reference	Parameter and unit	Maximum or Minimum	HL1	HL2	HL3
(IN6B; IN12C; EX1A; EX1C; EX3; EX4; EX5; EX6A; X7; EX8; EL3C)	T02 ISO 5658-2	CFE kWm^{-2}	Minimum	20	20	20
	T03.01 ISO 5660-1: 50 kWm^{-2}	MARHE kWm^{-2}	Maximum	-	90	60
	T10.04 EN ISO 5659-2: 50 kWm^{-2}	Ds max. dimensionless	Maximum	-	600	300
	T11.01 EN ISO 5659-2: 50 kWm^{-2}	CIT_G dimensionless	Maximum	-	1.8	1.5

4.2.3 Classification of materials used in aircraft

A fire in an aircraft causes a significant threat to safety and life of the passengers since there is a large quantity of flammable fuel and the evacuation is limited. To reduce the risk, several approaches are required. One of them is to use materials and composite materials which do not add to the fire risk in terms of heat production, smoke production as well as smoke toxicity. These materials must pass the criteria of the national and international regulations given by the U.S. Federal Aviation Regulations (FAR). Test methods and requirements are related to the end use of the product. Products such as interior ceiling, wall panels, partitions and outer surfaces of galleys, large cabinets and storage compartments shall meet the requirement of the following tests (CS 25.853) [8]

- Vertical flame test
- Horizontal flame test
- Kerosene burner test
- Smoke density test

4.2.4 Classification of materials used in buses, trucks and automotive

Classification and fire testing of materials used in transportation vehicles, such as automotive, buses and trucks, are basically the same since it is based on the same fire requirements of the horizontal burning rate. The test method is ISO 3795 [9], describes the test method and equipment, or FMVSS

302, which also includes a requirement of the burning rate [9]. Commonly, the automotive manufacturers have developed their own test standard, based on the FMVSS 302, but with another requirement and in some cases another number of samples to be tested.

Besides the horizontal burning rate test, buses have additional requirements. The interior materials used in buses must fulfil several test methods described in the standard ECE Regulation 118 [10] provided by the UN. The standard contains the following annexes with test methods:

- Annex 6: Horizontal burning rate
- Annex 7: Melting behaviour
- Annex 8: Vertical burning rate
- Annex 9: Capability of materials to repeal fuel or lubricants (will not be dealt with here)

4.3 Fire test methods

There are numerous of fire test methods evaluating the fire performance of the material, product, or construction. The methods are developed to represent a burning behaviour similar to a real-life fire, but in a standardized procedure, to be able to repeat the test. As mentioned before, there are different test methods for each end use area. Table 2 presents a summary of fire test methods for materials used as interior surface materials or floor coverings, for five transportation vehicles, marine applications, railway vehicles, aircrafts, buses and automotive. As illustrated by the table, there are different fire test methods for the same test parameter. The level of required testing is higher for marine applications and aircrafts, due to the limitation of evacuating the vehicle. For automotives, there is only a requirement of the burning rate.

Table 2 Fire test methods valid for a specific product and end-use classification

Product	Test parameter	Marine application	Railway vehicle	Aircrafts	Buses	Automotive
Interior surface material	Ignitability	No test	No test	FAR/ JAR/ CS 25.853 b(5)	FMVSS 302	FMVSS 302
	Flame spread	IMO Part 5 (ISO 5658-2)	ISO 5658-2	FAR/JAR/CS 25.855	No test	No test
	Heat release	ISO 5660-1/ISO 9705-2 (FRM in HSC)	ISO 5660-1	FAR/JAR/CS 25.853 (d) (cabin compartment)	No test	No test
	Smoke density and smoke gas toxicity	IMO Part 2 (EN ISO 5659-2)	EN ISO 5659-2 + EN 17084	FAR/JAR/CS 25.853 (d) (cabin compartment) + BSS 7239/ ABD 0031 (cabin compartment)	No test	No test
Flooring	Flame spread	IMO Part 5 (ISO 5658-2)	EN ISO 9239-1	FAR Part 25 Appendix F Part VI	No test	No test
	Smoke density and smoke gas toxicity	IMO Part 2 (EN ISO 5659-2)	EN ISO 5659-2 + EN 17084		No test	No test

In the chapters blow, selected test methods, possibly relevant for ro-ro space surface materials, described in more detail. Information such as test procedure and test parameters are presented.

4.3.1 Non-combustibility

The non-combustibility fire test according to EN ISO 1182 [11] and IMO FTP Code Part 1 [4], evaluate if a material can be determined as non-combustible. The test is used as basis for classification of building products according to EN 13501-1 and of marine applications according to the FTP Code. The test is conducted in a cylindrical tube furnace at 750 °C with a cylinder-shaped specimen. During the test, the furnace temperature as well as the specimen temperature are measured continuously. The combustion of the specimen is registered as a rise in temperature in the oven as well as visible flames from the specimen. The mass loss of the specimen is also measured. All these parameters are used to determine if the material can be classified as non-combustible or not.

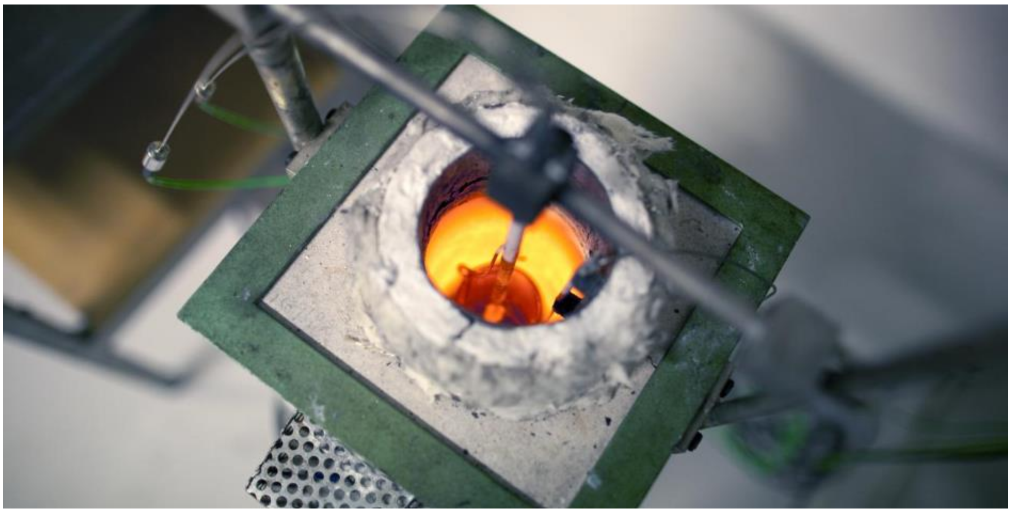

Figure 2 The cylindrical tube furnace according to EN ISO 1182.

4.3.2 Smoke generation and gas toxicity

Fire testing with the smoke chamber according to EN ISO 5659-2 [12] and IMO FTP Code Part 2 [4] measures the smoke generation from the material and the smoke density, i.e. the visibility through the smoke layer during a fire. The test methods are used for classification of building materials and marine products. The test is conducted in a sealed test chamber, the smoke box. The sample is placed horizontally in a specimen holder beneath a radiation cone with a fixed heat flux. When the sample is exposed to heat the pyrolysis at the material surface begins, followed by smoke production which is accumulated in the chamber. The specific optical density, i.e., the transparency, of the smoke is measured using a light source and a photocell.

In addition to the smoke density, a smoke toxicity analysis of the gases can be conducted. An FTIR-equipment is connected to the smoke chamber and the gas is then collected from the chamber. The following gases can be detected with the FTIR analysis; Carbon monoxide (CO), Hydrochloric acid (HCl), Hydrogen bromide (HBr), Hydrogen fluoride (HF), Hydrogen cyanide (HCN), Nitrous oxides (NO_x) and Sulphur dioxide (SO_2).

There are some differences between the tests according to EN ISO 5659-2, EN 45545-2 and IMO FTP Code Part 2. The number of tests is not the same and there are several heat flux-levels required by the FTP Code. There are also differences in the test duration and how to conduct the FTIR measurement.

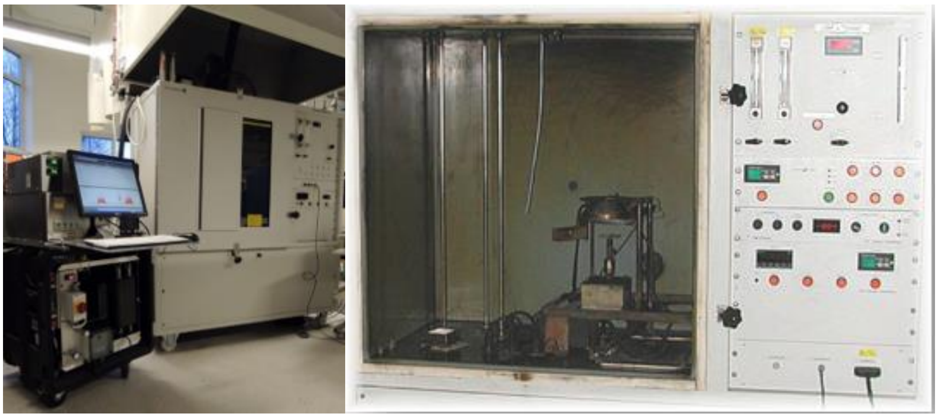

Figure 3 The smoke chamber with the additional FTIR equipment.

4.3.3 Spread of flame

The spread of flame test according to ISO 5658-2 [13] and IMO FTP Code Part 5 [4], evaluates the materials ability to resist a fire spread along its surface. The specimen is mounted in a specimen holder together with a substrate. The product and substrate should be mounted as in end use condition. The test specimen is vertically positioned during the test and exposed to heat by a radiation panel and a pilot flame. The time to ignition of the material is observed as well as the time it takes for the flame to reach each for the 50 mm marks along the specimen centre line. Other events during the fire test are time to flameout at the centre line, the burnt length in the surface and any occurrence of burning droplets.

The test methods, ISO 5658-2 and IMO FTP Code Part 5, are similar to each other, with a few exceptions. Output parameter from both methods is the CFE – Critical Flux at Extinguishment. This parameter is used as the classification parameter. The IMO FTP Code Part 5 method additionally calculates the heat release from temperature measurements of the fire gases collected in the exhaust duct. Additional classification parameters are heat for sustained burning (Q_{sb}), peak heat release rate (Q_p) and total heat release (Q_t).

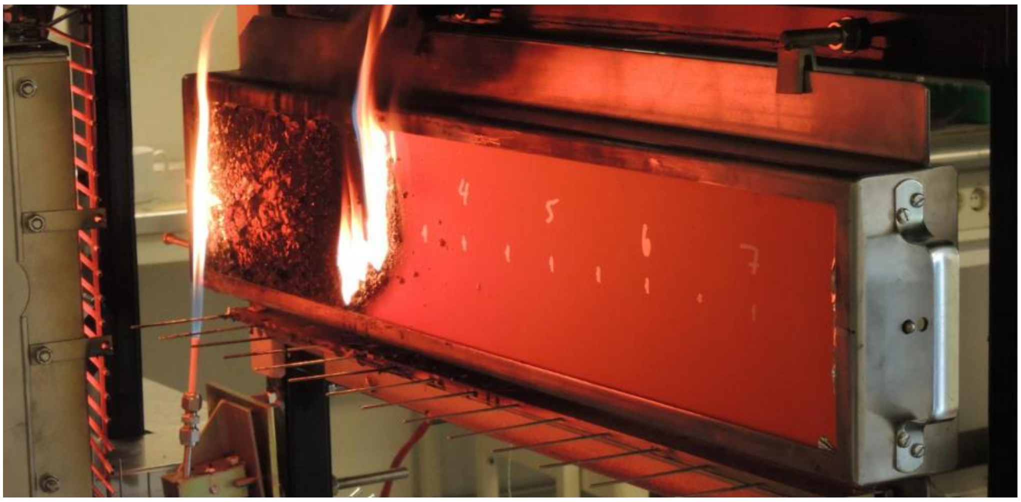

Figure 4 Specimen during fire test with the spread of flame equipment.

4.3.4 Cone calorimeter

Fire testing with the cone calorimeter, according to ISO 5660-1 [14], is a commonly used fire testing method to evaluate reaction-to-fire properties, both for classification according to EN 45545-2 (railway vehicles) and IMO FTP Code (marine applications), and for research purpose.

The test specimen is horizontally assembled in a specimen holder with a retainer frame, resulting in only surface exposure of the material. The specimen holder is positioned beneath the radiation cone with a pre-determined heat flux. When the test starts, the specimen surface is exposed to the heat radiation and pyrolysis of the material at the surface begins. The produced combustible gases are then ignited by a spark igniter. Emitted gases are collected in the exhaust duct and the heat release is calculated using the oxygen consumption method. Some of the output parameters are time to ignition, peak heat release rate, total health release rate, smoke production and mass loss. The classification criteria according to EN 45545-2 is the MARHE-value (Maximum Rate of Heat Emission) (kW/m^2).

Figure 5 The cone calorimeter equipment according to ISO 5660-1.

4.3.5 Single Burning Item

The Single Burning Item test (SBI) according to EN 13823 [15], is a reaction-to-fire test method to evaluate the fire performance of a building product, such as surface linings, wallpaper, coating systems, acoustic boards, wall panels, wooden planks, pipe insulation etc. **Error! Reference source not found.** shows a schematic drawing of the SBI test set-up. The material is assembled as a corner with a 30 kW gas burner in the corner. The size of the burner represents the size of a burning wastepaper bin. The test duration is 20 minutes and during this time the combustion gases are collected by a hood and exhaust system. The heat release rate and smoke production are measured using the oxygen consumption method. Output parameters are Heat Release Rate (HRR), Total Heat Release (THR) and FIre Growth RAte (FIGRA), Smoke Production Rate (SPR), Total Smoke Production (TSP) and SMOke Growth RAte (SMOGRA). During the test, the flame spread and burning droplets or particles are visually observed.

It is important that the mounting of the samples is as close as possible to the end use application. If the end-use of the product includes joints, vertical and horizontal, there should be joints during the SBI test. The substrate behind the product should also be the same as for the end-use installation. If the product is to be installed with an air gap, there should be an airgap during the test.

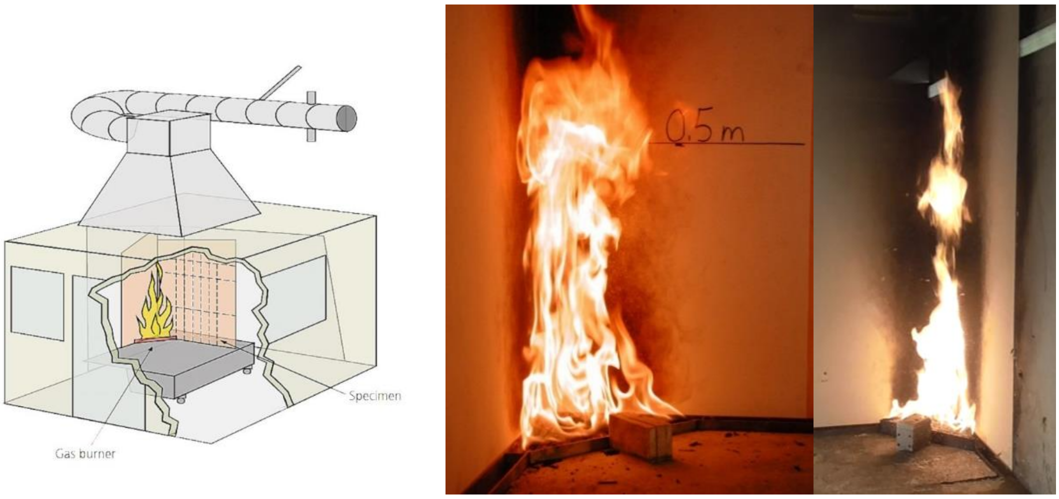

Figure 6 Schematic drawing of the SBI test set-up. A corner in the room is built of the material to be tested with a 30 kW burner in the corner.

The level of the output parameters from the SBI test, related to heat and smoke production, flame spread and burning droplets, is associated with a fire class according to EN 13501-1. The heat release is basis for the fire classes A2, B, C or D. The smoke production is associated with the smoke classes s1, s2 and s3. The presence of burning droplets is related to d0, d1 and d2.

4.3.6 Room corner test

The large-scale fire test, the room corner test, according to ISO 9705 [16] and IMO FTP Code Part 10 [4], measures the materials ability to withstand a flashover in the room. The product is mounted in the ceiling and on the walls, with exception for the wall with the door opening. In the inner corner, a propane gas burner is located. During the first 10 minutes of the test, the output from the burner is 100 kW. Then, during the next 10 minutes, the burner output is increased to 300 kW. The total test duration is 20 minutes. During the test, the heat release and the smoke production is measured in the exhaust duct using the oxygen consumption method. The occurrence of burning droplets is noted. If a flashover occurs before the end of 20 minutes, the fire is extinguished, and the product did not pass the test criteria.

The cone calorimeter, the SBI-test and the room corner all use the oxygen consumption method to measure the heat release rate and there is a correlation between these three test methods.

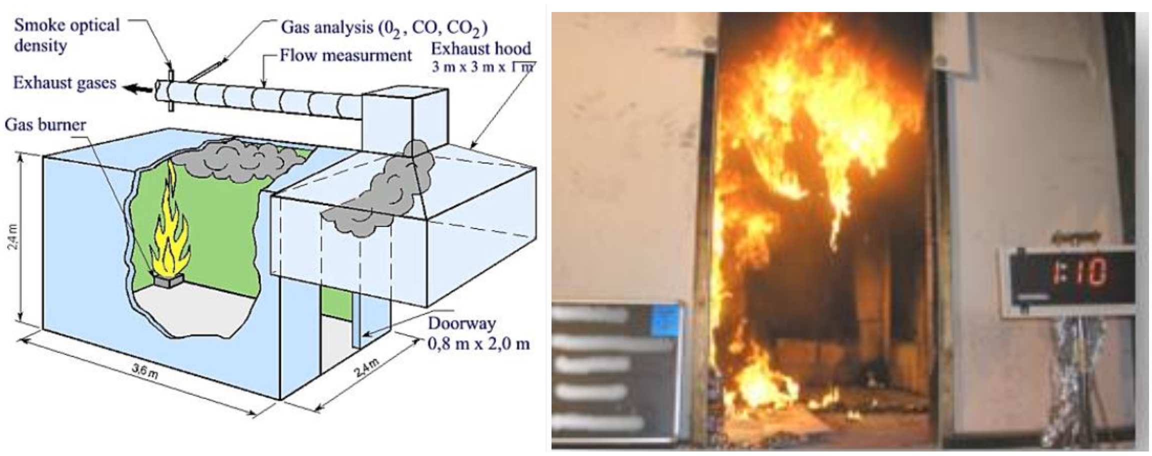

Figure 7 The room corner test equipment.

4.3.7 Burning behaviour of floor coverings

The burning behaviour of floor coverings is evaluated with the fire test method EN ISO 9239-1 [17] and it is used as a basis for classification according to EN 13501-1 and EN 45545-2. The fire test assesses the ability of the product to resist flames and heat from a radiant panel. During the test, the flame spread, smoke generation and the lowest radiant heat to sustain burning are measured. All types of floor coverings can be tested such as wood floor, plastic floor, rubber floor, linoleum floor etc.

During the test, a test specimen of the floor covering is placed horizontally. At one end of the specimen, a radiant panel is located and inclined at 30°. This inclination resulting in a decreasing exposure to a defined heat flux along the length of the specimen. At the same end, a pilot flame is located and applied to the specimen at the start of the test. After ignition of the material, the progression of the flame front horizontally along the specimen is noted, as well as the time for the flame front to spread defined distances. The smoke production is also measured using light transmission in the exhaust duct.

Figure 8 Floor covering during fire test according to EN ISO 9239-1.

4.3.8 Single-flame source test

There are several small flame tests, with both horizontal and vertical location of the specimen, and various sizes of flames. Below are the single-flame source test methods used for transportation vehicles presented.

4.3.8.1 Horizontal orientation

The horizontal burning rate is evaluated for materials used in buses, automotives and aircrafts, however, using different test procedures and equipment. Materials used in aircrafts are evaluated according to FAR 25, Appendix F [8]. Materials used in e.g., windows, are tested in the horizontal flame test with a flame exposure time of 15 s. The rate of flame spread across the specimen is used for classification.

The horizontal burning rate of materials used in buses and automotives is evaluated according to ISO 3795 [9], FMVSS 302 [18], Volvo STD 5031,19 (automotive), Volvo STD 104-0001 (trucks) and ECE Regulation 118, Annex 6 (buses) [9] [10]. Commonly, the automotive manufacturers have their own version of this standard. The fire test evaluates the burning rate of materials in the occupant compartment. The test is conducted inside a test chamber where the test specimen is mounted horizontally. The exposed side, at the end of the test specimen is subjected to a gas flame from underneath. The burnt distance and the time taken to burn this distance is measured during the test. The result, the burning rate, is expressed in mm/min.

Figure 9 Fire test of material in the equipment for horizontal burning rate, FMVSS 302.

4.3.8.2 Vertical orientation

The fire test method, ECE Regulation 118, Annex 8 [10], is used to determine the burning rate of vertically mounted products used internally in buses. The test specimen is mounted vertically in a metal frame. Across the specimen, three treads of cotton are mounted. The flame is applied at the bottom of the specimen and the time to breakage of the cotton treads is measured. The result, the burning rate, is expressed in mm/min.

Figure 10 Test equipment for test of vertical burning rate according to ECE Regulation 118, Annex 8.

The vertical burning test of materials used in aircrafts is described in FAR 25, Appendix F. The test method evaluates the flammability of the material by exposing the edge of the sample to a small flame, 38 mm high, from a Bunsen burner, with a temperature of 843 °C. Depending on the end-use application of the material, the exposure time is 12 s or 60 s. For the material to achieve the classification “self-extinguishing”, the material must show limited flame spread, after flaming time and burning droplets must extinguish after a given time.

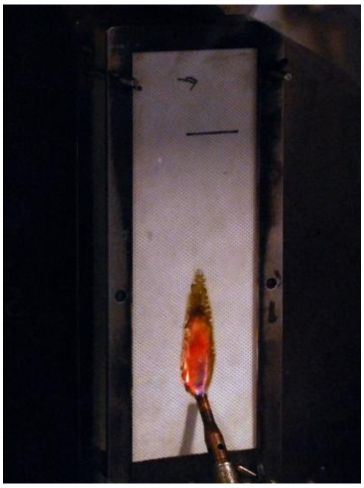

Figure 11 Surface exposure of a material according to EN ISO 11925-2

Fire testing according to EN ISO 11925-2 [19] is a small-scale reaction-to-fire test, where the ignitability of a product or material is measured when exposed to a small flame. The test is conducted inside a test chamber and the test specimen is mounted vertically. The small gas flame is applied at the specimen edge and at the surface, i.e., edge exposure and surface exposure. The time to ignition, any burning droplets and if the flame reaches the top marking of the specimen within a prescribed time period are noted during the test. The classification criteria is that the flame does not reach the top marking within a specified time. In addition, any burning droplets igniting an indicator below the specimen results in a d2 class for burning droplets. This test method is required for classification of building products according to EN 13501-1 and products used in railway applications according to EN 45545-2.

5 Selection of test standards related to surface materials in ro-ro spaces.

Main author of the chapter: Anna Sandinge, RISE

The usage of combustible materials is regulated by SOLAS Chapter II-2 Reg. 5, Reg 9 and thus not allowed for usage in ro-ro vessels. However, SOLAS Chapter II-2 Reg 17 gives a possibility to use combustible materials by addressing alternative design and arrangements deviation from the prescriptive requirements of Chapter II-2, given that the fire safety objectives and functional requirements are met. This means that an engineering analysis, evaluation, and approval of the alternative design shall be carried out in accordance with Reg 17, IMO Circulars MSC.1/Circ. 1455 and MSC/Circ. 1002 as amended by MSC.1/Circ. 1552. To demonstrate that composite materials (combustible materials) meet the fire safety objectives and the functional requirements can be complex and not guaranteed to success. IMO has developed an interim guideline for use of fibre reinforced plastic (FRP) elements within ship structures, the Fire safety issues, IMO Circular MSC.1/Circ. 1574.

The fire performance of combustible materials with end use as marine applications is evaluated in accordance with IMO FTP Code 2010. The materials, which were evaluated in this study, are intended to be used as surface materials in ro-ro spaces and not as a part of the structure contributing to the ship's global strength, as defined in IMO Circular MSC.1/Circ. 1574. This means that regarding fire performance, the focus will be on the surface behaviour. As describe in the previous chapter, relevant fire test methods for these materials are the spread of flame (Part 5) and the smoke and toxicity (Part 2). These test methods will be used for evaluation of the fire performance of a large range of composite materials. The results, the test data, can then be used as a basis for fire assessment, including assessments according SOLAS Chapter II-2 Reg 17, and included as a new appendix of IMO Circular MSC.1/Circ. 1574.

The spread of flame test, Part 5 of IMO FTP Code, evaluates the materials flame spread when exposed to an external heat source and pilot ignition flame. This is a good measure as it gives information of the ignitability of a material when exposed to heat from a close fire. The test will also evaluate if the material by itself will contribute to a spread of the fire. Besides this, the test also gives data of the heat release. The heat release is an important fire parameter as it describes the size of a fire. A high heat release indicates that a lot of energy is produced from the fire and thus the fire will be larger with a higher fire intensity. All these parameters together will give good knowledge of the materials fire performance with regards to ignitability, fire spread, and energy produced from a fire in the material. The Part 5 fire test method can be used for all surface materials, both in open and closed spaces.

The smoke and toxicity test, Part 2 of IMO FTP Code, evaluates the smoke production of the material in terms of smoke density, i.e., the visibility through the smoke layer. The test also evaluates the amount of toxic gases is the smoke. These parameters are crucial for passengers and crew in terms of a safe evacuation of the vessel. The Part 2 test method is most relevant for spaces where the smoke can accumulate and grow into a critical amount, i.e., most relevant for indoor used materials. For ro-ro ships, most spaces are large and open, thus it would take long time for the smoke to accumulate and create harmful amounts. However, there are closed spaces on a ro-ro vessel as well, thus it was decided to include the test in this study.

6 Material selection and sample preparation

Main author of the chapter: Anna Sandinge, RISE; Obrad Kuzmanovic, FLOW

A comprehensive identification and evaluation of materials and combinations of materials has been made within WP8, Action C.

Material systems for a wide range application in ro-ro spaces are investigated including currently used solutions on ro-ro ships as well as state-of-the-art solutions which are already well known in other industries and which could be also applied in the marine environment, in particular for ro-ro cargo spaces.

There are several interesting solutions which are already well known in other industry sectors, and which could be also widely used in the marine environment, in particular for ro-ro cargo spaces. Intumescent coatings, already widely used in offshore oil and gas industry for more than 20 years, could be one of the potential passive fire protection means as a replacement of the conventional insulation or to be used on critical points, such as gaps at ro-ro ramps/hatches, etc.

A step forward towards improving fire properties and reducing weight is investigating new materials and technologies for structural application on ro-ro ships, as to replace conventional steel structure arrangement.

Several composite components and combinations were considered, including core type (known materials as PVC, PET, Balsa, and other cores recently available on the market or under development), fibres (glass, carbon, basalt, hybrid, etc.) and composite products with improved fire properties such as multiaxial fabrics with integrated fire protection for structural parts with a fire-retardant surface layer a well as intumescent coating systems.

Results from previous EU funded R&D projects RAMSSES (CMT, BV, RISE and FLOW part of the project consortium) and FIBRESHIP (BV, VTT and CIMNE part of the project consortium) as well as other projects are considered, specifically for innovative types of composite materials (resins, cores, fibres, production technologies).

From these findings, a selection of materials has carefully been chosen for evaluation of fire performance.

6.1 Material solutions in ro-ro spaces (SoA)

Main author of the chapter: Obrad Kuzmanovic, FLOW

This section describes current state-of-the-art material solutions used in ro-ro spaces where design, production and operational aspects are given.

6.1.1 Surface protection

6.1.1.1 Typical coating layouts in ro-ro spaces

Typical painting schemes in ro-ro spaces, distinguished by ship location, paint type and dry film thickness, are shown in tables below. All layouts are based on application of epoxy/polyurethane coating systems. These paint systems can be approved for use as low flame spread surface materials, not generating excessive quantities of smoke or toxic products in fire.

There are several different epoxy coatings, each one of them made to meet certain requirements during service. Epoxy coatings have some general characteristics. The most important advantages are good water resistance, good adhesion to the substrate, good chemical resistance, very good alkali resistance, great resistance to mechanical damage, high durability, temperature resistant up to 120 °C (somewhat lower/ higher for certain systems), certain systems officially approved for potable water tanks and in contact with food, high solids content/low VOC possible. Limitations are poor UV resistance – chalks in sunlight, application and curing depends on the temperature, it may be difficult to overcoat cured epoxy, short maximum over coating intervals, two-component products and therefore require good mixing and may give increased wastage, moderate resistance to acids.

Epoxy can be modified using phenol, coal tar and hydrocarbon, reinforced with glass lakes etc. to give special properties, e.g. better chemical resistance, better penetration, better water resistance, impact and abrasion resistance etc. Among the most versatile coatings is epoxy mastic, due to its very good resistance to water. Also, contain high solids content which eliminate large quantities of solvent. However, a topcoat is required when exposed to UV-light, i.e. for weather decks, as well as for decorative purpose.

Polyurethanes are mainly used as topcoats in an epoxy paint system. Polyurethane coatings can be both one-component (moisture cured) or two- component. Two-component polyurethanes are among the most versatile coating types. They fill a vital niche for high-performance applications over metal, concrete, wood and plastic. These coatings show excellent colour and gloss retention for outdoor exposures. In addition, they are resistant to chemicals and solvents. Benefits are very good weather resistance, excellent gloss durability, very good chemical resistance, very good solvent resistance, while main limitation is that it is a two-component coating and it may cause skin irritation during application.

Table 3. Ro-Ro cargo ship painting scheme 1 (for heavy cargo)

Surface area	**Paint type**	**Dft (μm)**
Weather deck , deck in open ro-ro space	Abrasion resistant epoxy	100
	Abrasion resistant epoxy	150
	Polyurethane	80
Open/closed ro-ro space: Shell, walls and bulkheads, undersides of decks; Rampways under side; Hoistable deck under side	Abrasion resistant epoxy	100
	Polyurethane	80
Open/closed ro-ro space: Shell, walls and bulkheads, undersides of decks – under insulation	Abrasion resistant epoxy	100
Open/closed ro-ro space: Steel decks and platforms Hoistable deck upper side (“floor”)	Abrasion resistant epoxy	100
	Abrasion resistant epoxy	150

Table 4. Ro-Ro cargo multipurpose ship painting scheme 2 (container, various cargo and vehicle carrier)

Surface area	Paint type	Dft (µm)
Weather deck	Epoxy	150
	Epoxy	100
	Polyurethane	50
Open/closed ro-ro space: Shell, walls and bulkheads, undersides of decks; Rampways under side; Hoistable deck under side	Epoxy	130
	Polyurethane	50
Open/closed ro-ro space: Shell, walls and bulkheads, undersides of decks – under insulation	Epoxy	85
Open/closed ro-ro space: Steel decks and platforms Hoistable deck upper side ("floor")	Epoxy	120

Table 5. Vehicle carrier painting scheme 1

Surface area	Paint type	Dft (µm)
Weather deck	Epoxy	125
	Epoxy	125
	Polyurethane	50
Open/closed ro-ro space: Shell, walls and bulkheads, undersides of decks; Rampways under side; Hoistable deck under side	Epoxy	100
	Polyurethane	50
Open/closed ro-ro space: Shell, walls and bulkheads, undersides of decks – under insulation	Epoxy	100
Open/closed ro-ro space: Steel decks and platforms Hoistable deck upper side ("floor")	Epoxy	100
	Epoxy	100

Table 6. Vehicle carrier painting scheme 2

Surface area	Paint type	Dft (µm)
Weather deck	Epoxy	125
	Epoxy	125
	Polyurethane	50
Open/closed ro-ro space: Shell, walls and bulkheads, undersides of decks; Rampways under side; Hoistable deck under side	Epoxy	85
	Polyurethane	35
Open/closed ro-ro space: Shell, walls and bulkheads, undersides of decks – under insulation	Epoxy	85
Open/closed ro-ro space: Steel decks and platforms Hoistable deck upper side (“floor”)	Epoxy	125

Table 7. RoPax coating painting scheme

Surface area	Paint type	Dft (µm)
Weather deck	Epoxy	150
	Polyurethane	75
	Polyurethane	75
Open/closed ro-ro space: Shell, walls and bulkheads, undersides of decks; Rampways under side; Hoistable deck under side	Polyurethane	75
	Polyurethane	75
Open/closed ro-ro space: Shell, walls and bulkheads, undersides of decks – under insulation	Epoxy	100
Open/closed ro-ro space: Steel decks and platforms Hoistable deck upper side (“floor”)	Epoxy	100
	Epoxy	100

6.1.1.2 Anti-skid surfaces

Anti-skid coatings are low profile skid resistant surfaces, usually applied on steel ramps and decks, which contribute to the safe and efficient loading and discharging of vehicles and pedestrian traffic in both wet and dry conditions.

Anti-skid surfaces are a selection of high-grade abrasion resistant aggregates held together with a blend of specially formulated polyurethane or epoxy resins, designed to give strength, flexibility and long-life durability.

The resin systems are fully impervious and encapsulates the steel surface to give it corrosion protection, thereby extending the service life of the steel itself.

Aggregates are available in a variety of sizes, depending on the service conditions, and should be chemically inert and to have good impact crushing, abrasion and skid resistance.

Anti-skid surfaces are preferred by drivers of vehicles, for its smoother ride, unlike the vibrations and wheel spin they experience with the traditional metal anti-skid systems. The installation of such coating can save tractor unit owners less wear and tear on their vehicles as a direct result of the removal of these two conditions. Gear boxes and tyre service life is extended, not having to deal with loss of traction.

The product offers the key features mentioned above, which were seen as particularly important to vehicle carrier operators for the speedy, safe and efficient loading and discharging of their car carrying operations. There are quite a number of anti-skid coats and aggregates manufacturers, all of them already tested and certified according to IMO Resolution MSC 61(67): Annex 1, Part 5 Surface Flammability & Part 2 Smoke and Toxicity [4].

Figure 12. Surface with anti-skid system example

6.1.2 Ro-ro space structural material

Steel is the conventional and benchmark material used in shipbuilding, especially on larger vessels such as vehicle carriers, ro-ro cargo and ro-pax vessels. However, new material and design solutions are needed to achieve added values, such as reduced fuel consumption and increased payload. Unfortunately, despite numerous advantages, lightweight materials are still rarely used in large vessels' construction. This is mainly due to the SOLAS regulations issued by the International Maritime Organization (IMO), which required that commercial ships are built in steel until the MSC/Circ. 1002 was issued in 2002 giving the possibility for alternative designs. This regulation mandates a risk analysis to be performed, showing that the alternative design and construction is equivalent to steel. This process is long, expensive and the final decision of relevant authorities could still be negative. Still, ship owners, operators and builders are seeking solutions for improved sustainability, including lighter weight to reduce fuel use, greenhouse gas emissions and payload increase. Moreover, there is certain limited use of lightweight materials in ro-ro vessel's space, through implementation of composite materials, aluminium alloys and plywood.

6.1.2.1 Composite materials

Composite materials have proven themselves to be an attractive material choice when it comes to lightweight and freedom of design. Lightweight design by fibre reinforced composites has only been used in ro-ro cargo space in one case so far, the ULJANIK built vehicle carrier as first extensive shipping industry application of sandwich composites, [20]. Challenges encountered during implementation of composite materials were how to achieve required strength and stiffness, fire safety equivalent to steel and related costs.

The structure arrangement consists of a steel supporting grillage and composite sandwich panels. In general, the panels have GRP (Glass Reinforced Polymer) laminates and PVC (Polyvinyl Chloride) core, manufactured by vacuum infusion. The composite panel flexible connection to the supporting structure is designed. The panel system includes corresponding joints and outfitting elements (lashing devices, lifting elements etc.). A total of 1043 composite panels, of abt. 11 square meter each, have been arranged in current ship designs on relevant three car decks.

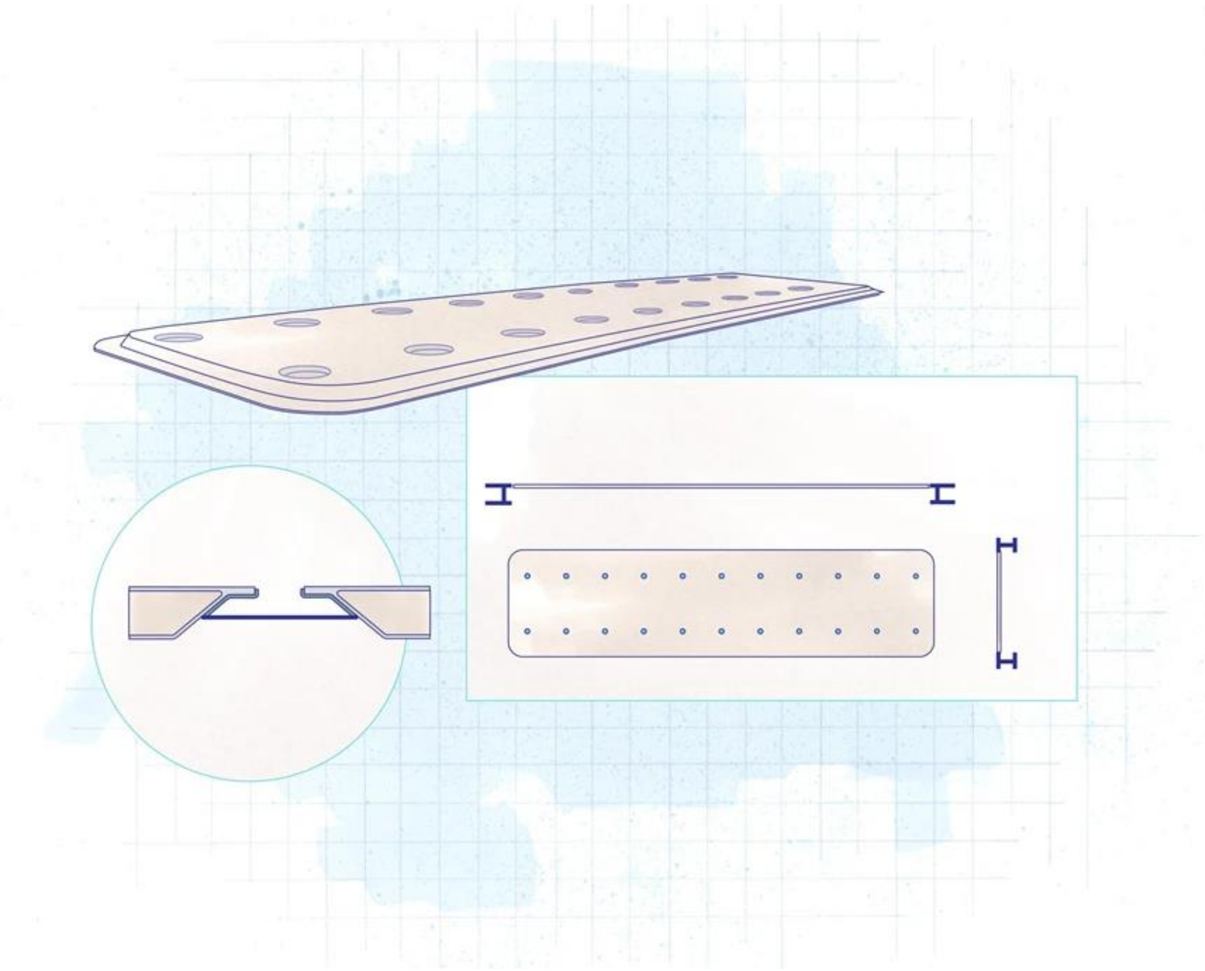

Figure 13. Car deck composite panel - sketch

Although, in this particular case, the ship does meet SOLAS fire safety requirements independent of the composite panels, a fire safety assessment was performed according to MSC/Circ. 1002 [21] to demonstrate that the alternative design (with composite decks) achieves fire safety equal to that of the conventional design (with steel decks). The fire safety assessment, conducted by RISE Fire Research AS (Boras, Sweden), revealed the composite deck disadvantages that included the potential for greater linear (same deck) fire growth rate, more compromised panel structural integrity, and toxic smoke due to hydrochloride creation from burning PVC. But the panels also demonstrated delayed deck-to-deck fire spread, due to the panels' insulating effects and the closed lashing holes. Additionally, the composite panels, unlike steel plates, insulate crew members from the heat of a below-deck fire, so escape routes can cross panels on overhead decks.

To make composite decks economically feasible, thorough investigation must be performed to select optimal sandwich materials and fabrication process that results in a production cost equal or at least similar to that of traditional steel decks. For the panel laminates, polyester, vinyl ester and epoxy resin systems were considered. Polyester resin was chosen for its cost and its properties favourable to vacuum infusion, and the panel fabrication method, also chosen for its cost-efficiency. Further, using well-established materials and simple geometries in the floor panels enabled shorter lead times as well as improved manufacturing reliability and quality.

Figure 14. Car deck composite panels

Because the floor panels reduce weight in the ship's uppermost decks, weight savings are doubly beneficial. First, the three composite decks are 25% lighter than three steel decks, saving 230 tons. Second, the lighter upper decks lower the ship's vertical centre of gravity (VCG). Therefore, less ballast is needed to ensure the ship's stability. Alternatively, for the same fuel consumption as a vehicle carrier with all-steel decks, the vessel may increase its payload by as much as 805 tons. The composite decks also will reduce maintenance costs because they do not corrode. Environmental benefits from the fuel savings include reduced fuel oil consumption and carbon dioxide emissions for 4.5 % or 2.1 t/day of fuel oil.

A step forward towards improving fire properties, reducing weight, production cost and lead time will be investigating new materials and technologies as well as replacing steel supporting structure with composites. Further development on similar lightweight structures is continued by FLOW ship design team within the EU funded project RAMSSES, where pultruded FRP are investigated.

6.1.2.2 Wood

Lightweight liftable and hoistable car deck panels have been developed, which incorporate plywood in their construction to reduce their weight considerably compared with steel equivalents. The panels can accommodate car lashing fittings. The individual panel configuration options give operator the flexibility to adjust to different cargo on different routes. The car deck panels feature a lightweight open beam construction with a plywood top plate to minimise their weight and therefore their impact on ship stability. The developed lashing profile is also a very special concept. The lashing is not attached to the plywood panel itself, but to the steel secondary stiffeners, which also act as a support for the plywood panels. This patented lightweight car deck concept meets environmental protection in several ways:

- Compared with steel the panels have a lower cost and lower weight with the same durability and lifetime.
- Lighter decks improve vessel efficiency in terms of payload and flexibility of operations.
- Lighter decks and ships allow increased speed or reduced fuel consumption.
- Stability benefits are gained by reducing weight high up in the vessel’s structure.

Figure 15. Plywood car deck panels

6.1.2.3 Aluminium

Aluminum alloys for use in marine applications are normally of the 5xxx series (with magnesium as alloying element) or, for locations such as decks that are not in direct, continuous contact with sea water, the 6xxx series (with magnesium and silicon). Plates are normally strain hardened (cold worked), giving an “H” temper designation. Stiffeners and deck plating are generally extruded. Wrought aluminum alloys have a high strength/weight ratio compared to steel. Aluminum alloy structures generally have higher stiffness than corresponding FRP structures. Many grades are weldable, and many are also extrudable. Aluminum alloys, if chosen correctly, have a good corrosion resistance. The main disadvantage of aluminum is the severe softening of the heat affected zone (HAZ) that occurs during welding. This reduces both the static strength and the fatigue life. Aluminum alloys are also relatively expensive to weld. The combination of a high required heat input and a high coefficient of expansion leads to large distortions and shrinkage during welding. If the wrong alloy is selected for a given purpose, corrosion resistance may be poor. Aluminum alloys have a fairly low melting point (around 650°C) and they soften at temperatures considerably below this, so that aluminum structures generally require extensive fire insulation. The tearing resistance of aluminum is relatively poor; however, this disadvantage is not reflected in the required scantlings of ships because the prescribed damaged stability cases take no account of the difference in tearing resistance of the various materials.

However, there has been no aluminum alloys applications as structural material in ro-ro space, (HSC are not considered) due to too expensive design, despite their widespread use in outfitting equipment (railings, smaller ramps, gangways etc.)

6.1.3 Insulation

The purpose of passive fire protection is to raise the fire resistance of the structure, to protect the structure against the effects of fire, to reduce the fire spread through secondary ignition, to limit the movement of flame and smoke and to minimize the danger of fire-induced collapse or structural distortion.

Passive fire protection in marine industry is traditionally based on glass or mineral wool (stone wool) products, which cannot burn, and which can stand temperatures up to 1000°C without melting. The fibers are usually bonded with appropriate binding agent, which evaporates on much lower temperatures, generating smoke in a fire. However, the fibers remain intact thanks to their inbuilt cohesiveness and layering, ensuring that the material will retain its rigidity and protect the material beneath it from fire. Mineral or glass wool usually come in form of blankets or slabs, with or without protective covering, such as aluminum foils, glass cloth or similar, for areas exposed to weather or potential physical damage. The insulation is typically held in place by steel pins of appropriate diameter. There are large number of marine insulation manufacturers in the world.

The appropriate fire class division (A, B or others) is always obtained with a combination of thickness and characteristics of insulating material as well as a type of material being insulated.

6.1.3.1 Ceramic fiber insulation

There are also insulations based on thermal and pure ceramics fibers, a range of advanced fire protection materials. Ceramic fibers are usually a combination of high purity raw materials like aluminum powder, pure silica sand and zircon sand. It is usually applied on offshore objects, due to very good thermal resistance (1200°C for extended time period – hydrocarbon fire protection). These materials do not contain any chemical binder and therefore does not generate smoke in a fire, it is a non-combustible and non-toxic material. Provides not only fire insulation, but also excellent thermal and acoustic insulation. Moreover, thermal ceramics is lightweight material, with typical weight saving of 30% compared to traditional materials but the investment cost is higher compared to the cost of conventional glass or mineral wool products applications. Finally, it contains low bio-persistence fibers, so is exonerated from any carcinogenic classifications.

6.1.3.2 Spray-on insulation

Installing traditional insulation on marine structures is labor intensive and thus expensive, while insulation's long-term performance is typically reduced or greatly compromised by wet working conditions or mechanical damage. Conventional techniques with prefabricated insulation elements have a number of built-in limitations; weak points that can seriously impair the efficiency and economies of fire protective shield. The total cost for a completely insulated surface using spray-on insulation should therefore be lower than with conventional techniques. It also eliminates the need for mechanical fasteners and manual cutting of pre-fabricated standard sized insulation elements, which results in around 20-30% of wasted material. Moreover, the insulation layer is seamless as there is no gaps or cracks like in joints between pre-fabricated elements. The spray-on insulation is easily applied onto the flat, curved, uneven surfaces, inside ducts, around corners and on already installed equipment or structures, electrical or piping fixtures.

Figure 16. Sprayed-on insulation

Basically, it is a self-adhesive glass or stone wool (depending on level of insulation needed), sprayed directly onto a surface. It is used in combination with a waterborne two-component binder system, which is entirely free of additives such as solvents, asbestos, cement or fusible silicates. If fire protection is needed, the fibers are manufactured from diabase or basalt, to withstand more than 1100°C. The surface can be coated with aluminum foil or sprayed with vinyl coating, fire retardant, nontoxic and smokeless surface, which can be used where original insulation is exposed to high-pressure cleaning, oil vapor or similar, such as storages, engine room, machinery room etc. If applied in ro-ro spaces, the surface is usually protected with metallic sheets.

This type of insulation requires special equipment, such as special coating machine and spray gun with 3-way nozzle. Spray-on insulation must always be applied by a specially trained and licensed applicator with documented skills and experience, to ensure the right quality of the insulation and that the insulation complies with the certificates issued by relevant authority.

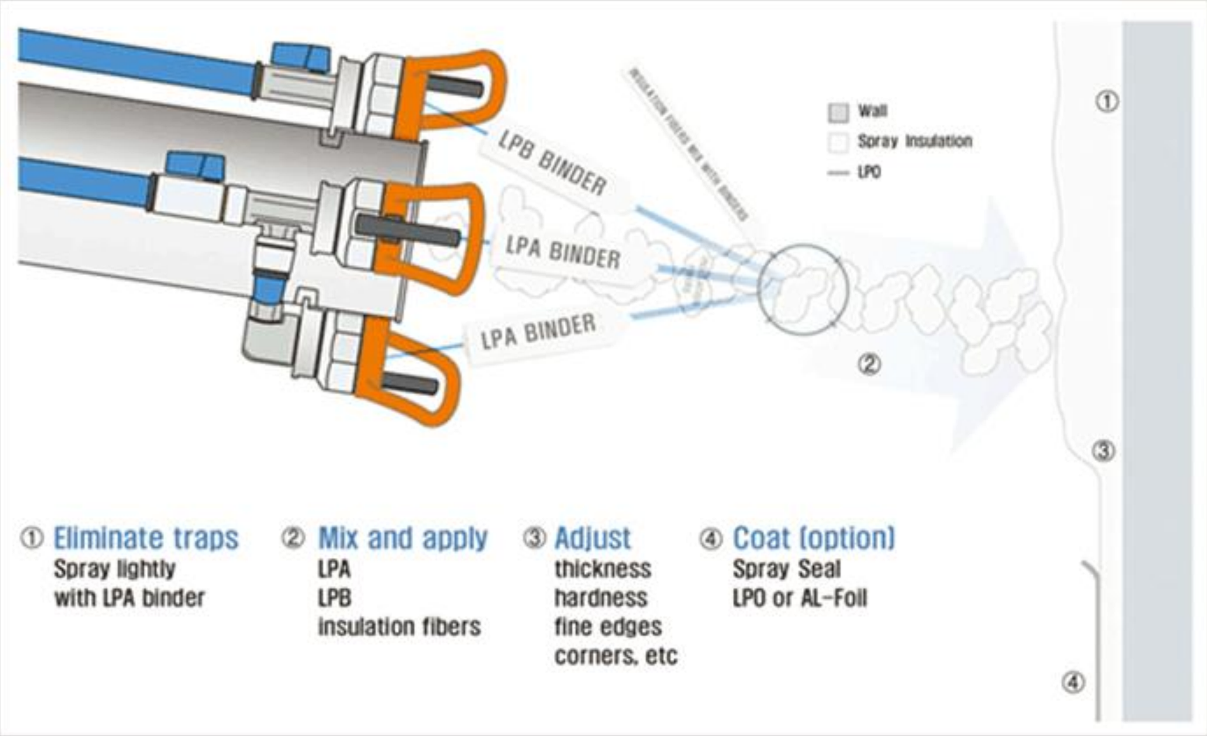

Figure 17. Spray-gun with 3-way nozzle

This particular spray-on insulation system is very successful in the South Korean market and shipyards, resulting in a large number of major contracts with world leading ship owners and operators.

6.2 New material solutions in ro-ro spaces

Main author of the chapter: Obrad Kuzmanovic, FLOW

This chapter provides investigation of state-of-the-art solutions which are already well known in civil and/or offshore objects and which could be also applied in the marine environment, in particular for ro-ro cargo spaces. The goal of this task is to determine theirs reaction to fire requirements which can occur in ro-ro spaces. Therefore, this report will provide a list of possible new material solutions and development and provisions of selected samples for fire testing.

New materials should have as less environmentally harmful and toxic substances as possible, as well as their ignition products (burnt remnants, fumes). Further, it should be lighter than conventional solutions, thus reducing the fuel consumption and connected Greenhouse gases emissions. Finally, new solutions should be maintenance friendly, which shall also be beneficial for environmental protection.

There are several interesting solutions which are already well known in the civil and/or offshore objects and which could be also widely used in the marine environment, in particular for ro-ro cargo spaces.

Intumescent coatings, already widely used in offshore oil and gas industry for more than 20 years, could be one of the potential passive fire protection means as a replacement of the conventional insulation or to be used on critical points, such as gaps at ro-ro ramps/hatches, etc. This could be promising material as ro-ro cargo space gastight deck coatings, despite poor thermal and acoustic insulation. Other alternatives will be investigated as well.

A step forward towards improving fire properties and reducing weight will be investigating new materials and technologies for structural application on ro-ro ships, as to replace conventional steel structure arrangement.

Several composite components and combinations may be considered, including core type (known materials as PVC, PET, Balsa, and other cores recently available on the market or under development), fibres (glass, carbon, basalt, hybrid, etc.) and composite products with improved fire properties such as Saertex Leo (by Saertex GmbH) , the multiaxial fabric with integrated fire protection for structural parts with a fire-retardant surface layer.

Production technology (vacuum infusion, pultrusion, prepreg, etc.) may have effect on the composite component fire properties (mainly due to the amount of resin) as well as on cost and production lead time. Further, this may also be considered.

Innovative types of composite materials (resins, cores, fibres, production technologies) are currently under development at EU funded R&D projects RAMSSES (CMT, BV, RISE and FLOW part of the project consortium) and FIBRESHIP (BV, VTT and CIMNE part of the project consortium).

6.2.1 Surface protection

There are several interesting surface protection systems used widely in other domains (buildings, offshore industry) which could be evaluated for application within ro-ro space. Anti-skid coatings, already widely used in such spaces, will be also tested with focus on flammability and fire growth potential, as the goal of this task is to determine the reaction to fire requirements for non-regulated surface materials.

6.2.1.1 Intumescent coating systems

Intumescent coatings are reactive coatings used to minimise the effects of a fire. Applied to structural steel, they swell to form a layer of inorganic carbonaceous char when exposed to temperatures above 250°C. This insulates the steel from the heat, enabling it to maintain its load-bearing capacity for longer. Under normal circumstances the coatings are inert but when subjected to elevated temperatures the coating develops a thick char that provides a higher level of insulation than the coating system in its un-reacted state. The level of protection required from a coating is dependent on the system being protected. For structural steel members, the systems may be specified to ensure that steel temperatures remain below the temperature at which structural failure may occur. This can give time for the firefighting measures and/or eventual evacuation of personnel to be implemented.

The paint is applied, with a brush and roller or spray, and looks much like any other paint coating when dry. The key feature of Intumescent coatings is that in the event of a fire the coating reacts to high temperatures and swells (similar to expanding foam) by up to 100 times, forming a hard char insulating the structural steel members from damage. Usually Intumescent coatings will start to react and expand at a temperature of 200°C, far below what would cause damage to the steel structure.

Figure 18. Steel beam coated with intumescent coating – under normal temperature and swelled during the fire

There are generally two basic types of intumescent coatings: single component acrylic/vinyl/polyvinyl acetate coatings and high-build plural component epoxy coatings. Furthermore, single component coatings may be solvent- or water-based and are applied in several coats. Water-based intumescent coatings are a generally eco-friendlier, and less-chemically smelling option. They are the least expensive and produce less odour, however, these coatings are less tolerant to humidity and low temperatures and therefore may take longer to completely cure in such environments. Solvent-based coatings usually used in semi-exposed environments and are tested against weather and temperature variations. Solvent-based coatings tend to be more resistant to weather conditions as well as temperature changes and humidity. They also dry faster and have a smoother finish. Epoxy-based intumescent is typically used in harsher environments such as the offshore marine industries or the chemical industry because these coatings provide excellent hydrocarbon fire protection. Epoxy-based intumescent comes in two-parts which when combined, forms a very thick and durable film that insulates the steel member and is highly resistant to corrosion.

Epoxy intumescent coating systems for fire protection have become more accepted and more commonly used in recent years due to continued improvement in formulation, application and performance. These coatings are used extensively in the petrochemical, offshore and marine markets, therefore could be also evaluated for use within ro-ro spaces.

Epoxy intumescent coatings have already been shown to be suitable by testing and independent third party approval for fire protection and offers a variety of versatile, durable, attractive, low thickness and low weight coatings for a wide variety of structures.

In the offshore and petrochemical industries epoxy intumescent coatings have been already widely used to provide fire protection to steel structures (for example on liquid natural gas carriers, oil drilling ships, floating oil and gas production vessels, oil tankers etc.). In such applications, fires resulting from the ignition of hydrocarbons can be substantially more severe in terms of temperature rise and incidental heat flux when compared with fires involving traditional, cellulosic building materials. The hydrocarbon fires could also occur in vehicles and special category spaces.

Epoxy coatings have been used successfully for decades to provide corrosion protection in challenging environmental conditions, typically offshore applications, petrochemical industry on shore and in marine environment. In terms of expected durability, claims are made (i.e. life to first maintenance) that up to 25 years or more can be achieved with careful specification and application controls. Such coatings, combining durability, corrosion resistance and fire protection have led to these type of product being used extensively for fire protection in the petrochemical, offshore and marine industry.

There are a number of factors to consider when specifying intumescent coating systems, including both fire duration and durability, to ensure that the system is fit for purpose in the event of a fire.

When intumescent coating systems are specified, 'fire duration' (i.e. the amount of time that the system will enable the steel to maintain its load-bearing capacity during a fire) is often the key consideration. Typically, fire duration ranges from 30 minutes to 120 minutes.

However, another key consideration – durability – cannot be overlooked. Durability is the ability of the reactive coating system to maintain an adequate level of fire protection after exposure to environmental conditions, either during the construction phase or during end-use. It is very important that durability is predicted correctly, as premature weathering or aging of the coating system may have a negative effect on the intumescent coating's fire protection properties.

Both fire duration and durability should be considered when specifying the full system.

Intumescent coating systems usually comprise several layers of different paints: a two-coat system (primer + intumescent) may be sufficient for low corrosive environments; a three-coat system (primer + intumescent + topcoat) may be preferred for more corrosive environments.

During its lifetime, an intumescent coating system may be subject to a variety of environmental conditions that affect its performance. The durability of the coating system depends on its ability to withstand these conditions, specifically the adverse effect of weathering and corrosion provoked by water, humidity, pollution, temperature changes and UV light.

For an intumescent coating system, there are two particularly important deterioration effects.

As with most coating systems, atmospheric weathering conditions can cause corrosion at the interface between the primer and the substrate, which may shorten the lifetime of the coating system. Due to their reactive nature, intumescent coatings are rather sensitive to water and humidity. Over-exposure to humidity can affect the coating's char-forming properties, resulting in a shorter fire duration. Therefore, a topcoat is often specified to act as a sealer coat and prevent moisture reaching the intumescent coating. The topcoat must be able to withstand exposure to atmospheric elements, such as UV light, temperature variations and rain. Also, in fire scenario, it must allow the intumescent coating to react and must not prohibit expansion. Therefore, all topcoats must be tested in fire conditions prior to approval.

To conclude, a number of factors need to be considered when selecting an intumescent coating system, from coating application conditions to required fire duration. It is also essential that performance in the end-use environment is considered.

6.2.1.1.1 Intumescent coating

An investigation of available intumescent coating system on the market has been made and the results are presented in Table 8.

Table 8 List with coating systems function as Intumescent coating available on the market.

Supplier	Coating	Type	Description	Outdoor use
A	1	Intumescent water based	Used as internal wall and ceiling lining on wood. Always use with topcoat TOP 1FR.	No
	2	Intumescent water based	Used as internal wall and ceiling lining on wood.	No
	3	Intumescent water based	Used as wall and ceiling lining on wood, as a fire sealing of cable and pipe penetrations between fire compartments. Used indoors or in conjunction with approved topcoat outdoors under roof.	With topcoat, under roof
	4	Intumescent water based	Used indoors as a part of a system for fire insulation of steel, timber and concrete structures.	No
	5	Intumescent water based	Used indoor on structural steelwork.	No
	6	Intumescent water based	Used as internal wall and ceiling lining on wood.	No
	7	Fire seal system, water based	water-based, containing glass fibres, fire sealing of cable and pipe penetrations, fire protection of cables	No
B	1	Intumescent water based	Used on wood substrate, indoors and outdoors.	Yes
	2	Intumescent water based	Used on wood substrate.	No
C	1	Intumescent epoxy based	Flexible coating system offering low thickness, reduced weight, faster application and durability. Also resistant to abrasion, vibration, impact.	Yes
	2	Intumescent epoxy based	Provides resistance to abrasion, impact.	Yes
D	1	Intumescent epoxy based	Used on internally or externally exposed structural steel.	Yes
	2	Intumescent water based	Fast drying and tough water based fire protection coating for interior structural steel work.	Yes
	3	Intumescent water or solvent based	Water (100) or solvent-based (200) for interior (100) or exterior use (200).	Yes
	4	-	Used on wood. Should not be used in areas of high humidity, heat sources or on surfaces where significant physical impact is likely such as floors, stairs etc.	No*

Supplier	Coating	Type	Description	Outdoor use
	5	Intumescent water based	For interior use on wood.	No*
	6	Intumescent solvent based	Interior usage on concrete.	No*
E	1	Intumescent	Used on interior surfaces and on cables.	No
	2	Intumescent	Used on wood.	No
	3	Intumescent water based	For indoor use. Approved product to protect structural steel (columns, beams and truss).	No
F	1	Intumescent	A composite system with several layers.	-
G	1	Intumescent water based	Clear waterborne interior intumescent varnish for structural timber beams which is easy to use and quick drying.	No
	2	Intumescent water based	Water born intumescent coating for steelwork fire protection and decoration.	No*
H	1	intumescent water based	For structural steelwork providing up to 60 minutes fire protection.	-
I	1	Water based	Used as coating for walls and ceilings.	No
	2	Intumescent water based	For timber, plywood and MDF.	No
J	1	Intumescent epoxy based	-	Yes
	2	Intumescent water based	Designed for on-site application to structural steel.	No
	3	Intumescent solvent based	Designed to provide fire protection to structural steelwork for up to 60 minutes.	No*
K	1	Intumescent water based	Designed for hollow section steelwork	No*
	2	Intumescent water based	Water Based Intumescent Coating designed for I Section Steelwork	No*
L	1 2 3	Intumescent solvent based	For structural steel, interior and exterior versions.	No*
	4a, 4b, 4c, 4d	Intumescent water based	Designed for internal section steelwork.	No
	5	Intumescent methacrylate and epoxy based	For structural steel, decks and bulkheads.	Yes
M	1	Intumescent water based	Can be applied to most substrates, used in construction and transportation, used among others for composites.	No*

Supplier	Coating	Type	Description	Outdoor use
	2	Intumescent	For wood substrates. Can be used in exterior applications, if covered by the Firefree Exterior Topcoat.	No*
	3	Topcoat for FFA	Used on structures such as walls, sidings, eaves, soffits, building projections and under-floor areas.	Yes
N	1	Various	Resins and gelcoats that can be combined.	Yes
O	2	Intumescent acrylic based	For internal and semi-exposed steelwork for on-site application	No
	3	Intumescent water based	Suitable for internal use on structural steelwork.	No
	4	Intumescent	For external structural steelwork with early weather protection.	No*
	5	Intumescent	Same as SC901.	No*
P	1	Intumescent	For interior and exterior timber surfaces.	Yes
	2	-	Flame retardant coating for exterior surfaces.	Yes
Q	3	Intumescent	For timber and wood related surfaces.	Yes
	4	-	Clear fire protection coating for wood and timber.	Yes
R	1	Intumescent	-	-
	2	Intumescent epoxy based	-	Yes
S	1	Intumescent water and solvent based	Protection of structural steel.	Yes, in low humidity

* Could function outdoor with an additional top coat according to supplier.

6.2.1.1.2 Intumescent mats

An investigation of available intumescent mats on the market has been made and the results are presented in Table 9.

Table 9 List with intumescent mats available on the market.

Supplier	Coating	Type	Description	Outdoor use
A	1	Intumescent mat	-	-
B	1	Intumescent mat	Available in a range of sizes, thicknesses and shapes with various expansion rates. Flexible & rigid sheets, papers, grilles and vacuum formed shapes. Thickness 0.5 to 6mm. Expansion 20 to 60 times.	Yes
C	1	Intumescent mat	These intumescent mats are infused with resin and integrated into a composite structure to impart integrated resistance to burn through, flame spread and also provide insulation from the heat of combustion.	Yes
D	1	Intumescent mat		-

6.2.1.1.3 Fire retardant paint systems

Non-intumescent fire-retardant coatings (application by spray, brush, roller or towel), already commercialized, are listed in table below.

Table 10 Non-intumescent fire-retardant systems available on the market.

Supplier	Coating	Type	Description	Outdoor use
A	1	Ceramic shield	Developed for GRP composite panels, indoor and outdoor.	Yes
B	1	Silicate	For indoor use on concrete, plaster board. Not marketed as fire protection but is non-flammable.	No
C	1	Silicate	For cementitious absorbent surfaces but can also be used on interior wood.	No
D	1	-	For indoor and outdoor use, cable, pipe or combined penetration sealings.	Yes
E	1	Water borne	For walls and ceilings	No
F	1	Fire-retardant erosion coating	PUR based coating for erosion, that is available in a fire-retardant version	No

6.2.2 Insulation

Insulation solutions, which are already commercialized, are listed in table below.

Table 11 Insulation solutions available on the market.

Supplier	System	Type	Description	Outdoor use
A	1	Stone or glass wool	A self-adhesive glass or stone wool, sprayed directly onto surface.	Yes
B	1	High purity raw materials -alumina powder, pure silica sand, zircon sand	For indoor/outdoor use in offshore and petrochemical industry, as well as fire protection systems.	Yes
C	1	Insulfrax made from calcia, magnesia and silicy	Passive fire protection systems for all marine and offshore industry	Yes
D	1	Thermal Ceramics	All passive fire protection systems for marine and offshore industry	Yes

6.2.3 New ro-ro space structural material

A step forward towards improving fire properties and reducing weight is to investigate new material solution and technologies for structural application on ro-ro ships, as to replace conventional steel structure arrangement and surface material solutions.

6.2.3.1 Composite materials

Several composite components and combinations may be considered, including core type (known materials as PVC, PET, Balsa, and other cores recently available on the market or under development), fibres (glass, carbon, basalt, hybrid, etc.) and composite products with improved fire properties, the multiaxial fabric with integrated fire protection for structural parts with a fire-retardant surface layer.

Production technology (vacuum infusion, pultrusion, prepreg, etc.) may have effect on the composite component fire properties (mainly due to the amount of resin) as well as on cost and production lead time.

6.2.3.1.1 Ongoing developments

Innovative types of composite materials (resins, cores, fibres, production technologies) are currently under development at several R&D projects, such as EU funded R&D projects RAMSSES and FIBRESHIP.

A summary of material systems combinations is presented in the Table 12.

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Table 12. Composite material systems

Type of product	Coating	Laminate	Core	Comment
Laminate	Intumescent coating	Phenol and vinylester	-	For maritime application
Sandwich	-	PFA/Glass	Silicate board	Bulkhead
Sandwich	-	PFA/Glass	Balsa	Bulkhead
Sandwich	-	PFA/Glass	PVC	Bulkhead
Sandwich	-	1. CaSi board 2. PFA/Glass	PET	Bulkhead
Sandwich	-	PFA/Glass	1. Balsa 2. PET 3. Balsa	Bulkhead
Sandwich	intumescent system integrated in fibres	PFA/Glass	Balsa	Bulkhead
Sandwich	intumescent system integrated in fibres	1. Epoxy/Glass 2. Cork	PIR	Bulkhead
Deck profile	-	Polyester/Glass	-	
Sandwich	Intumescent coating	Polyester/Glass	Balsa	Bulkhead
Sandwich	intumescent system integrated in fibres	Vinylester/Glass	PIR	Bulkhead
Sandwich	intumescent system integrated in fibres	Epoxy/Carbon	Balsa	Bulkhead
Laminate	-	Phenolic/Basalt	-	
Laminate	-	Epoxy/Basalt	-	Developed for railway vehicles
Laminate	-	Benzoxazine/Basalt	-	Developed for railway vehicles
Laminate	-	Benzoxazine/Glass	-	Developed for railway vehicles

6.3 Material selection for fire testing and development of samples

Main author of the chapter: Anna Sandinge, RISE

Development of samples, according to material systems investigation results described at Chapters 6.1 and 6.2 required for fire risk and new requirements assessment and testing was performed.

The results combined with the expertise of the partners involved and the knowledge obtained from other industrial fields was used to identify and select a comprehensive list of materials for the fire performance evaluation. The selection was based on the availability of data in terms of reaction-to-fire properties and the knowledge-based opinion on potential material systems that could be used within ro-ro spaces. Other critical parameters such as mechanical properties, manufacturing processes, cost and skillfulness at ship operators and shipyards was considered but not critical for the material selection. The results showed that non-intumescent fire-retardant paints (application by spray, brush, roller or towel) are already commercialized with relevant data available. Further, insulation will not be further considered, as the various fire class solutions have been already certified and commercialized, such as ceramic fibre and spray-on insulation. Finally, composite materials, such as single laminates and sandwich panels, and relevant intumescent system were identified to be the most promising materials for further evaluation.

A test matrix was developed with more than 30 material layouts to be tested. The specimens were made as composite materials including intumescent systems, developed for the small-scale fire tests. The samples were monolithic laminates made of fibre reinforced plastics and sandwich panels. Glass and basalt were used as fibres. Three resins were selected: polyester, epoxy, and Poly Furfuryl Alcohol (PFA). Four core materials were used for the sandwich panels: balsa, PVC, PET, and PIR. Different surface protections were also used in terms of intumescent systems: integrated intumescent system in the fibres, intumescent gelcoat, and intumescent coating.

All samples were manufactured using vacuum as production technology. Photos of a representative specimen of each sample is shown in Annex A.

Table 13 show the composition of all samples including the resin and fibres used in the laminates and the material used as core in the sandwich panels.

In Table 13 there are missing samples in the number series. At an early phase of sample identification and development of test matrix, all samples were given an identification number. During sample production, unexpected problems occurred, and a few samples were removed from the test matrix. However, at this stage, it was not possible to change the identification number. Thus, a few numbers are missing in the number series.

Table 13 Presentation of samples used for the study including materials in laminate and core.

Material						
No	Coating	Laminate			Core	
		Resin	Fibre			
Monolithic						
1	-	Polyester	Glass	3x1200 g/m^2	-	-
2	Intumescent coating	Polyester	Glass	3x1200 g/m^2	-	-
3	Intumescent integrated in fabrics	Epoxy	Glass	2x1200 g/m^2 1xINT1200 g/m^2	-	-
4	Intumescent gelcoat	Polyester	Glass	3x1200 g/m^2	-	-
7	-	Epoxy	Basalt	5x620 g/m^2	-	-
8	Intumescent coating	Epoxy	Basalt	5x620 g/m^2		
9	Intumescent integrated in fabrics	Polyester	Basalt	4x620 g/m^2 1xINT620 g/m^2	-	-
10	-	PFA	Glass	3x1200 g/m^2	-	-
11	-	PFA	Basalt	5x630 g/m^2	-	-
12	Intumescent coating	PFA	Basalt	5x630 g/m^2	-	-
13	Intumescent integrated in fabrics	PFA	Basalt	4x630 g/m^2 1xINT630 g/m^2	-	-
Sandwich						
14	-	Upper laminate			PVC	80 kg/m^3, 40 mm
		Polyester	Glass	3x1200 g/m^2		
		Lower laminate				
		Polyester	Glass	3x1200 g/m^2		
15	Intumescent coating	Upper laminate			PVC	80 kg/m^3, 40 mm
		Polyester	Glass	3x1200 g/m^2		
		Lower laminate*				
		Polyester	Glass	3x1200 g/m^2		

Material						
No	**Coating**	**Laminate**			**Core**	
		Resin	**Fibre**			
16	Intumescent integrated in fabrics	Upper laminate Epoxy Lower laminate** Epoxy	 Glass Glass	 3x1200 g/m² 2x1200 g/m² 1xINT630 g/m²	PVC	80 kg/m³, 40 mm
17	Intumescent gelcoat	Upper laminate Polyester Lower laminate*** Polyester	 Glass Glass	 3x1200 g/m² 3x1200 g/m²	PVC	80 kg/m³, 40 mm
18	-	Upper laminate Polyester Lower laminate Polyester	 Glass Glass	 3x1200 g/m² 3x1200 g/m²	Balsa	120 kg/m³, 40 mm
19	Intumescent coating	Upper laminate Polyester Lower laminate* Polyester	 Glass Glass	 3x1200 g/m² 3x1200 g/m²	Balsa	120 kg/m³, 40 mm
20	Intumescent integrated in fabrics	Upper laminate Epoxy Lower laminate** Epoxy	 Glass Glass	 3x1200 g/m² 2x1200 g/m² 1xINT630 g/m²	Balsa	100 kg/m³, 40 mm
21	Intumescent gelcoat	Upper laminate Polyester Lower laminate*** Polyester	 Glass Glass	 3x1200 g/m² 3x1200 g/m²	Balsa	120 kg/m³, 40 mm

Material						
No	Coating	Laminate			Core	
		Resin	Fibre			
22	Intumescent coating	Upper laminate			PET	100 kg/m³, 40 mm
		Polyester	Glass	3x1200 g/m²		
		Lower laminate*				
		Polyester	Glass	3x1200 g/m²		
24	Intumescent coating	Upper laminate			PIR	? kg/m³, 2x20 mm
		Polyester	Glass	3x1200 g/m²		
		Lower laminate*				
		Polyester	Glass	3x1200 g/m²		
25	-	Upper laminate			Balsa	120 kg/m³, 40 mm
		PFA	Glass	3x1200 g/m²		
		Lower laminate				
		PFA	Glass	3x1200 g/m²		
26	Intumescent coating	Upper laminate			Balsa	120 kg/m³, 40 mm
		PFA	Glass	3x1200 g/m²		
		Lower laminate*				
		PFA	Glass	3x1200 g/m²		
27	Intumescent coating	Upper laminate			PVC	80 kg/m³, 40 mm
		Polyester	Basalt	5x620 g/m²		
		Lower laminate*				
		Polyester	Basalt	5x620 g/m²		
28	Intumescent coating	Upper laminate			Balsa	120 kg/m³, 40 mm
		Polyester	Basalt	5x620 g/m²		
		Lower laminate*				
		Polyester	Basalt	5x620 g/m²		

Material							
No	Coating	Laminate				Core	
			Resin	Fibre			
29	Intumescent coating	Upper laminate	Polyester	Basalt	5x620 g/m²	PET	100 kg/m³, 40 mm
		Lower laminate*	Polyester	Basalt	5x620 g/m²		
32	Intumescent coating	Upper laminate	PFA	Basalt	5x630 g/m²	PVC	80 kg/m³, 40 mm
		Lower laminate*	PFA	Basalt	5x630 g/m²		
34	-	Upper laminate	PFA	Basalt	5x630 g/m²	Balsa	120 kg/m³, 40 mm
		Lower laminate	PFA	Basalt	5x630 g/m²		
35	Intumescent coating	Upper laminate	PFA	Basalt	5x630 g/m²	Balsa	120 kg/m³, 40 mm
		Lower laminate*	PFA	Basalt	5x630 g/m²		
36	Intumescent integrated in fabrics	Upper laminate	PFA	Basalt	5x630 g/m²	Balsa	120 kg/m³, 40 mm
		Lower laminate**	PFA	Basalt	4x630 g/m² 1xINT630 g/m²		

* Intumescent coating on lower laminate only, i.e., the exposed side during the fire test.
** Intumescent integrated fabric system on lower laminate only, i.e., the exposed side during the fire test.
*** Gelcoat on lower laminate only, i.e., the exposed side during the fire test.

The samples were stored in a condition climate of 23°C and 50% relative humidity according to the test standard IMO FTP Code 2010, Part 5 and Part 2. Before testing, the samples were measured and weighed for calculation of area weight and density. The measured data is presented in Table 14 and show the results for the complete system, i.e., the laminate, core and intumescent system accordingly.

Table 14 Measured data for the tested samples, before fire testing.

Material No	Size (mm x mm)	Weight (g)	Area weight (kg/m^2)	Thickness (mm)	Density (kg/m^3)
1	796 x 155	575.4	4.66	2.63	1777
2	798 x 155	646.9	5.23	2.90	1807
3	796 x 155	624.3	1.82	2.94	622.6
4	800 x 155	660.6	5.33	3.24	1644
7	796 x 155	502.0	4.07	2.29	1781
8	797 x 156	581.2	4.67	2.70	1731
9	796 x 155	708.4	5.71	3.65	1564
10	795 x 154	532.5	4.34	2.27	1931
11	797 x 155	477.0	3.86	2.22	1739
12	798 x 155	556.7	4.50	2.53	1783
13	799 x 155	627.8	5.07	3.45	1469
14	796 x 155	1895	15.4	44.8	343.2
15	799 x 156	1963	15.7	45.0	349.5
16	796 x 155	1830	14.8	44.1	336.7
17	799 x 155	1962	15.8	45.3	349.7
18	796 x 155	2371	19.2	42.8	450.6
19	800 x 155	2502	20.2	43.1	468.5
20	796 x 155	2566	20.8	42.7	487.7
21	798 x 155	2407	19.5	42.9	453.3
22	799 x 156	2305	18.5	45.0	411.6
24	783 x 155	2385	19.7	45.4	432.9
25	795 x 150	1818	15.2	42.5	358.9
26	796 x 150	1911	16.0	42.7	375.0
27	798 x 156	1909	15.3	44.4	345.5
28	798 x 155	2400	19.4	42.4	457.3
29	799 x 156	2200	17.7	44.7	395.0
32	799 x 155	1862	15.0	45.3	332.1
34	797 x 155	2124	17.2	55.2	311.4
35	799 x 155	2120	17.1	56.1	305.2
36	798 x 155	2277	18.4	56.8	324.1

7 Fire testing

Main author of the chapter: Anna Sandinge, RISE

An evaluation of the selected materials was conducted using two test methods according to IMO FTP Code 2010. The flame spread was evaluated according to IMO FTP Code 2010 Part 5 and the smoke and toxicity was evaluated according to Part 2. The test procedure and test results are detailed below.

All test data can be found at RISE Fire database (https://www.ri.se/en/what-we-do/services/rise-fire-database) and at E-LASS Material database (https://e-lass.eu/).

7.1 Spread of flame – IMO FTP Code Part 5

Fire testing was conducted according to IMO FTP Code 2010, Part 5, the spread of flame test. The spread of flame test evaluates the materials ability to resist a fire spread along its surface.

7.1.1 Test procedure

The specimen was mounted in a specimen holder with the sample size of 795x155 mm. The test specimen was vertically positioned during the test and exposed to heat by a radiation panel and a pilot flame at the left side of the sample, see Figure 19. The time to ignition of the material was observed as well as the time it takes for the flame to reach each for the 50 mm marks along the specimen centre line. Other events during the fire test were time to flameout at the centre line, the burnt length in the surface and any occurrence of burning droplets.

Output parameters from the tests are the CFE – Critical Flux at Extinguishment, the heat release from temperature measurements of the fire gases collected in the exhaust duct, heat for sustained burning (Q_{sb}), peak heat release rate (Q_p) and total heat release (Q_t).

Single test was conducted instead of three as stipulated in the standard.

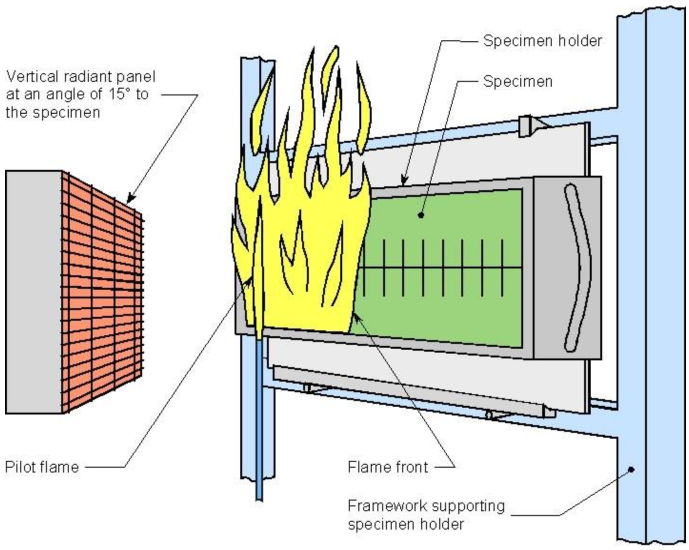

Figure 19 Schematic drawing of the spread of flame test equipment.

7.1.2 Test results and discussion

A summary of the test results is presented in Table 15, detailed test results can be found in Annex B.

Table 15 Summary of test results Part 5, Spread of flame.

Material		Type	CFE (kW/m²)	Q_{sb} (MJ/m²)	Q_p (kW)	Q_t (MJ)	Burning droplets
Requirement IMO FTP Part 5, bulkheads			**>20.0**	**>1.5**	**<4.0**	**<0.7**	**No**
Requirement IMO FTP Part 5, floorings			**>7.0**	**>0.25**	**<10.0**	**<2.0**	**< 10**
1	Glass/Polyester	Laminate	9	2.5	3.3	1.1	No
2	Glass/Polyester/Intumescent coating	Laminate	48	-*	0.4	0.1	No
3	Glass/Epoxy/Intumescent integrated fabric	Laminate	31	16.1	1.9	1.0	No
4	Glass/Polyester/Intumescent gelcoat	Laminate	25	7.0	1.4	0.8	No
7	Basalt/Epoxy	Laminate	14	2.0	3.4	0.9	No
8	Basalt/Epoxy/Intumescent coating	Laminate	48	-*	0.3	0.1	No
9	Basalt/Polyester/Intumescent integrated fabric	Laminate	48	-*	0.9	0.8	No
10	Glass/PFA	Laminate	44	3.6	0.7	0.2	No
11	Basalt/PFA	Laminate	48	-*	0.6	0.1	No
12	Basalt/PFA/Intumescent coating	Laminate	48	-*	0.0	0.0	No
13	Basalt/PFA/Intumescent integrated fabric	Laminate	32	2.7	0.8	0.1	No
14	PVC/Glass/Polyester	Sandwich	6	2.5	3.5	1.8	No
15	PVC/Glass/Polyester/Intumescent coating	Sandwich	39	7.0	2.5	1.2	No
16	PVC/Glass/Epoxy/Intumescent integrated fabric	Sandwich	22	9.7	2.5	1.1	No
17	PVC/Glass/Epoxy/Intumescent gelcoat	Sandwich	24	5.2	3.7	2.0	No
18	Balsa/Glass/Polyester	Sandwich	8	2.9	5.9	3.0	No
19	Balsa/Glass/Polyester/Intumescent coating	Sandwich	48	-*	0.4	0.4	No
20	Balsa/Glass/Epoxy/Intumescent integrated fabric	Sandwich	25	12.2	2.4	3.2	No
21	Balsa/Glass/Polyester/Intumescent gelcoat	Sandwich	18	4.3	4.2	3.3	No
22	PET/Glass/Polyester/Intumescent coating	Sandwich	46	-*	2.1	3.8	No
24	PIR/Glass/Polyester/Intumescent coating	Sandwich	43	16.7	0.7	0.7	No
25	Balsa/Glass/PFA	Sandwich	25	4.0	2.6	0.9	No
26	Balsa/Glass/PFA/Intumescent coating	Sandwich	48	-*	0.7	0.2	No
27	PVC/Basalt/Polyester/Intumescent coating	Sandwich	43	2.4	0.7	1.0	No
28	Balsa/Basalt/Polyester/Intumescent coating	Sandwich	43	3.0	2.2	3.4	No
29	PET/Basalt/Polyester/Intumescent coating	Sandwich	39	2.6	3.1	2.8	No
32	PVC/Basalt/PFA/Intumescent coating	Sandwich	7	4.0	5.2	3.9	No
34	Balsa/Basalt/PFA	Sandwich	17	3.3	3.0	0.8	No
35	Balsa/Basalt/PFA/Intumescent coating	Sandwich	48	-*	0.0	0.0	No
36	Balsa/Basalt/PFA/Intumescent coating	Sandwich	32	2.8	0.3	0.0	No

* Not calculated since the flame front did not reach the 175 mm mark.

The fire performance of the tested samples shows a large difference in the reaction-to-fire properties. When comparing the results with the requirements given by the IMO FTP Code, valid for marine applications, it can be seen that only a few of the materials does not fulfil the requirement of Critical Flux at Extinguishment (CFE). Common for these materials is that they have an unprotected surface, with the pure laminate exposed to the heat source. After ignition, there is a too long fire spread in the material. It can also be seen from the total heat release (Q_t) of this samples that the materials burn well, and they do not fulfil the requirements.

The most critical parameter for the tested samples was the total heat release (Q_t). Only a few of them fulfilled the requirement for bulkheads, as given in IMO FTP Code. A general observation from the tests was that in many of the test, the fire spread was limited, but the materials kept burning at the exposed edge. After some time of burning in the exposed laminate, there was an ignition in the core material. As they are combustible, some more than others, they kept burning and as a result the total heat release through the test was too high.

The laminate samples coated with the intumescent coating showed excellent results with a high CFE and heat for sustained burning (Q_{sb}) and low Q_t and peak heat release (Q_p). They all had a limited time when there was burning in the material and the coating protected the material behind as it formed a protective char layer. The sandwich panels with the same intumescent coating, generally, showed a very good CFE, but the Q_t was higher. For the end use of the product as a bulkhead, the Q_t was too high. If the end use of the product is a flooring, the Q_t is ok. The higher Q_t is most probably related to ignition and burning in the core materials.

7.2 Smoke density and smoke toxicity

Fire testing was conducted according to IMO FTP Code 2010, Part 2, smoke and toxicity. The test evaluates the smoke production from the material as smoke density, the visibility through the smoke, as well as the toxicity in terms of amount (ppm) toxic gas specie in the smoke.

7.2.1 Test procedure

The fire test was conducted according to IMO FTP Code Part 2.

Duplicate tests were conducted using a heat flux level of 50 kW/m^2, without the pilot flame. The test duration was 20 min. The smoke density was continuously measured through the test and expressed as D_s. In addition, the smoke gas toxicity was measured using a FTIR equipment. The sampling probe was as described in the standard, located for sampling the gas from the centre of the chamber. The gas was continuously collected from the chamber during the test and the content of the toxic gas species were measured during the full test time. The sampling flow rate was 1.5 l/min.

7.2.2 Test results and discussion

A summary of the test results is presented in Table 16, detailed test results can be found in Annex C.

Table 16 Summary of test results Part 2, Smoke and toxicity.

Material		$D_{s,max}$	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
Requirement IMO FTP Part 2, bulkheads		200	1450	140	600	600	600	120	350
Requirement IMO FTP Part 2, floorings		400	1450	140	600	600	600	200	350
1	Glass/Polyester	566	208	<3	<5	<10	<5	<10	<20
2	Glass/Polyester/Intumescent coating	117	569	31	<5	<10	<5	<10	<20
3	Glass/Epoxy/Intumescent integrated fabric	505	1423	107	16	<10	<5	<10	<20
4	Glass/Polyester/Intumescent gelcoat	558	761	12	<5	<10	<5	<10	50
7	Basalt/Epoxy	482	369	<3	<5	<10	<5	<10	<20
8	Basalt/Epoxy/Intumescent coating	96	525	31	<5	<10	<5	<10	<20
9	Basalt/Polyester/Intumescent integrated fabric	960	1838	63	<5	<10	<5	59	<20
10	Glass/PFA	47	742	6	<5	<10	<5	<10	<20
11	Basalt/PFA	67	323	8	<5	<10	<5	60	<20
12	Basalt/PFA/Intumescent coating	42	262	33	<5	<10	<5	<10	<20
13	Basalt/PFA/Intumescent integrated fabric	135	950	49	<5	<10	<5	<10	<20
14	PVC/Glass/Polyester	1320	1368	29	1207	<10	<5	<10	60
15	PVC/Glass/Polyester/Intumescent coating	503	1516	47	953	<10	<5	<10	40
16	PVC/Glass/Epoxy/Intumescent integrated fabric	754	3628	216	1592	<10	<5	19	<20
17	PVC/Glass/Epoxy/Intumescent gelcoat	1320	1072	38	792	<10	<5	<10	102
18	Balsa/Glass/Polyester	1021	1147	6	<5	<10	<5	<10	<20
19	Balsa/Glass/Polyester/Intumescent coating	340	1154	34	<5	<10	<5	<10	<20
20	Balsa/Glass/Epoxy/Intumescent integrated fabric	649	4914	214	12	<10	<5	<10	<20
21	Balsa/Glass/Polyester/Intumescent gelcoat	828	929	12	<5	<10	<5	<10	74
22	PET/Glass/Polyester/Intumescent coating	199	808	34	<5	<10	<5	<10	<20
24	PIR/Glass/Polyester/Intumescent coating	386	962	28	<5	<10	<5	<10	<20
25	Balsa/Glass/PFA	42	140	<3	<5	<10	<5	<10	<20
26	Balsa/Glass/PFA/Intumescent coating	197	1340	45	<5	<10	<5	<10	30
27	PVC/Basalt/Polyester/Intumescent coating	517	1151	41	557	<10	<5	<10	<20
28	Balsa/Basalt/Polyester/Intumescent coating	238	1020	35	<5	<10	<5	<10	<20
29	PET/Basalt/Polyester/Intumescent coating	170	721	32	<5	<10	<5	<10	<20
32	PVC/Basalt/PFA/Intumescent coating	1320	1215	17	14	<10	<5	<10	75
34	Balsa/Basalt/PFA	248	1193	14	<5	<10	<5	22	<20
35	Balsa/Basalt/PFA/Intumescent coating	208	1691	41	<5	<10	<5	<10	<20
36	Balsa/Basalt/PFA/Intumescent coating	253	2170	61	<5	<10	<5	<10	<20

The fire performance evaluated with the smoke chamber, i.e., the smoke density and the smoke toxicity show that type of resin, core material as well as surface protection have a direct impact on the results. The single laminate with polyester and epoxy shows a smoke density of 480 – 570, i.e., a high value. Roughly, a $D_{s,\,max}$ above 500 is high and the visibility for a human through the smoke layer is limited. However, the smoke toxicity for these laminates is ok. The laminates with PFA as resin show good fire performance with a low $D_{s,\,max}$ and low concentrations of toxic gas species. The sandwich panels with PFA in the laminate also show good fire performance.

Generally, for the sandwich panels with untreated surface, there was a high smoke density and a higher concentration of toxic gas species than for the laminates. This is related to the core materials and their contribution to smoke production as the materials pyrolysis. All samples with PVC in the core show a very high concentration of HCl in the smoke.

None of the samples with the intumescent integrated fabric fulfilled the requirements of IMO FTP Code Part 2. The $D_{s,\ max}$ was too high, and they had the highest concentration of CO.

The single laminates coated with intumescent coating showed good results, both with regards to the smoke density and the smoke toxicity. For the intumescent coating coated sandwich panels, the results differed. The difference in the results can be correlated to the core material. The protection of the coating is not good enough to protect the samples as the core material will pyrolyze and add to the smoke production and smoke gas toxicity.

8 Establishment of requirements

Main author of the chapter: Anna Sandinge, RISE

The samples presented in the comprehensive test matrix were evaluated with regards to their reaction-to-fire performance according to two test methos, IMO FTP Code Part 5, surface flammability, and IMO FTP Code Part 2, smoke and toxicity. In the surface flammability test, the samples showed a large difference in the fire performance. Generally, samples with unprotected surface, exposed to the heat source, showed worse fire behaviour. Best results were seen for the samples coated with intumescent coating. Noticeable was that most of the samples had a high total heat release. In many of the cases, this can be correlated with the pyrolysis and burning in the core materials.

Also, in the smoke and toxicity test it was shown that type of resin, fibres, core material and surface protection effect the result. The samples coated with intumescent coating showed the best fire performance. The resin and the core material had a direct impact on the smoke density and smoke toxicity, resulting in a worse fire behaviour.

These lightweight composite materials are to replace the conventional steel structures and the safety on board must be kept at a high level. These combustible materials will burn when exposed to a fire. However, the current regulation for marine applications allows these materials as long as they fulfil the requirements. Test methods, fire test parameters and requirements are carefully selected to maintain the fire safety on board. Comparing the test results in this study with the requirements for marine applications according to IMO FTP Code show that the requirements can be used for interior surface materials for ro-ro spaces as well. There are different requirements depending on type of product and where it is located. Here, the focus has been on two categories of materials, the bulkhead, wall and ceiling linings and the floor coverings. The selected materials within the LASH FIRE project are to be used as interior surface materials and corresponds well to the categories in the IMO FTP Code.

8.1 Discussion of surface flammability requirements

The test parameter Critical Flux at Extinguishment (CFE) is a measure of the burnt length of the flame front given in kW/m^2. The energy is related to the heat exposure from the radiation panel and the heat at the sample surface decreases with increasing distance. Figure 20 show the test set up during calibration of the heat flux. The heat flux is measured at pre-decided distances, presented in Table 17. These indicates that if you have a CFE value of 20, the burnt distance is somewhere between 350 and 400 mm. At this location, the heat from the ignition panel is lower and for the flame front to move forward at the surface, the heat evolved from the samples must be high enough to pyrolysis the materials and ignite. If you have a good material with regards to fire performance, there will be no further flame spread in the material. If the material is easily ignited, the flame front will continue along the sample as it heats up the material. So, an ignition in the material is ok, as long as it doesn’t spread too far.

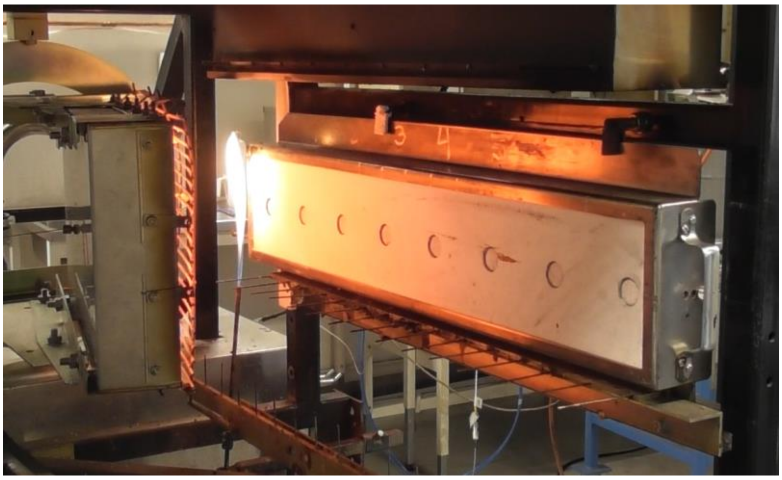

Figure 20 The spread of flame equipment with the specimen for calibration. The heat flux is measured in pre-decided spots along the specimen.

Table 17 Standardization of heat flux along the calibration board

Position (mm)	Heat flux (kW/m²)
0	49.5
50	50.5
100	49.5
150	47.1
200	43.1
250	37.8
300	30.9
350	23.9
400	18.2
450	13.2
500	9.2
550	6.2
600	4.3
650	3.1
700	2.2
750	1.5

The other parameters given by the IMO FTP Code are related to the heat release. As seen from the LASH FIRE test results, an ignition and slowly burning in the surface is acceptable. The heat release will be at a low level. But for some of the samples with a core material, the fire intensity increased as soon as there was pyrolysis and burning from the core. Thus, the total heat release (Q_t) was high. Also, the parameter Q_{sb}, average heat for sustained burning, was high. Previous test results have shown that this parameter will be high when there is intense burning in the core. The fire spread in the surface might not be high, but the core will burn and thus there will be a heat release. The standardized test sample is a cut out from the end use product. This results in exposed core material at the edges of the samples. In real life, as end use, the edges will not be exposed. They will be covered in the construction. In the RAMSSES project this was evaluated and a specimen with protected edges was developed. The fire testing with these samples showed that there was no burning from the edges and a more correct real fire scenario was achieved. This should be considered when evaluating the LASH FIRE results, as many of the samples with a core material, showed burning from the edges and the core.

A wide range of products has been tested and their fire performance has been evaluated with regards to the existing fire requirements according to IMO FTP Code Part 5. Table 18 summarizes what requirement the samples fulfil with a simple yes or no. Generally, only the samples with intumescent coating can be used as a bulkhead or ceiling material. Both these end-use products are heavily exposed during a fire. The accumulation of smoke and hot gases at the ceiling (smoke gas layer) increases the demands on the materials used. The products are located at a rather protected area with regards to wear. Thus, a protective covering with an intumescent coating can be used. For other parts in the ship, such as decks, exposed from wear and tear during loading of the cargo, the solution with intumescent coating is not applicable. In addition to this, the exposure from the hot smoke gas layer is lower. According to IMO FTP Code Part 5, the requirements for products used as floor coverings are lower. Table 18, show that only nine of the LASH FIRE samples will not fulfil the requirements, where most of them fails due to a too high Q_t. As discussed earlier, this is related to burning in the core materials at the edge of the sample. The end use product would not have these edges as they will be protected. So, with this in mind, two products did not fulfil the requirements as they had a too low CFE, i.e., the flame spread was too long. Within the LASH FIRE samples, there are several of products which have an unprotected surface, thus not sensitive to wear, which can be used for floorings.

Table 18 Summary of all samples indicating the fulfilment of requirements according to IMO FTP Code Part 5.

Material		Fulfilling the requirements of IMO FTP Code Part 5	
		Bulkhead, surface linings	Floor coverings
1	Glass/Polyester	No	Yes
2	Glass/Polyester/Intumescent coating	Yes	Yes
3	Glass/Epoxy/Intumescent integrated fabric	No	Yes
4	Glass/Polyester/Intumescent gelcoat	No	Yes
7	Basalt/Epoxy	No	Yes
8	Basalt/Epoxy/Intumescent coating	Yes	Yes
9	Basalt/Polyester/Intumescent integrated fabric	No	Yes
10	Glass/PFA	Yes	Yes
11	Basalt/PFA	Yes	Yes
12	Basalt/PFA/Intumescent coating	Yes	Yes
13	Basalt/PFA/Intumescent integrated fabric	Yes	Yes
14	PVC/Glass/Polyester	No	No
15	PVC/Glass/Polyester/Intumescent coating	No	Yes
16	PVC/Glass/Epoxy/Intumescent integrated fabric	No	Yes
17	PVC/Glass/Epoxy/Intumescent gelcoat	No	No
18	Balsa/Glass/Polyester	No	No
19	Balsa/Glass/Polyester/Intumescent coating	Yes	Yes
20	Balsa/Glass/Epoxy/Intumescent integrated fabric	No	No
21	Balsa/Glass/Polyester/Intumescent gelcoat	No	No
22	PET/Glass/Polyester/Intumescent coating	No	No
24	PIR/Glass/Polyester/Intumescent coating	No	Yes
25	Balsa/Glass/PFA	No	Yes
26	Balsa/Glass/PFA/Intumescent coating	Yes	Yes
27	PVC/Basalt/Polyester/Intumescent coating	No	Yes
28	Balsa/Basalt/Polyester/Intumescent coating	No	No
29	PET/Basalt/Polyester/Intumescent coating	No	No
32	PVC/Basalt/PFA/Intumescent coating	No	No
34	Balsa/Basalt/PFA	No	Yes
35	Balsa/Basalt/PFA/Intumescent coating	Yes	Yes
36	Balsa/Basalt/PFA/Intumescent coating	Yes	Yes

8.2 Discussion of smoke and toxicity requirements

The smoke and toxicity are crucial for the ability of manual fire extinguishment as well as evacuation of the vessel. The smoke can interfere with the visibility and contain harmful substances which can be toxic. Generally, for ro-ro spaces, a manual fire extinguishment is very rare and during voyage, no persons are located in the ro-ro space. Thus, the risk with smoke and toxicity is limited. However, these parameters were evaluated within LASH FIRE, since the products can be used in areas where these parameters are critical.

The test parameter $D_{s,max}$, smoke density, is a direct measurement of the visibility through the smoke as it measures the light transmission. A higher value indicates a darker and thicker smoke. Roughly, if the value is at a level of 500, the smoke is dark and very hard to navigate through. Even a lighter smoke can be hard to navigate through.

The gas species produced in a fire can roughly be divided into two groups related to their toxic effect on humans. The first group, with a suffocating effect, includes Carbon monoxide (CO) and Hydrogen cyanide (HCN). These gas species have a dose related effect which cause a decrease in the oxygen supplied to the body, resulting in fast incapacitation and ultimately death. HCN is approximately 25 times more toxic compared to CO [22]. However, to assess the relative effect of these gases for various exposure times, one needs to consider the fractional effective dose (FED) equations available in ISO 13571 [23]. The second group of toxic gas species are the irritants, Hydrochloric acid (HCl), Hydrogen bromide (HBr), Hydrogen fluoride (HF), Nitrous oxides (NO_x) and Sulphur dioxide (SO_2). They cause irritations in the respiratory system resulting in incapacitation, lung damages and oedema. The toxicity varies, i.e., the required concentration and exposure time until health effects of humans occur is different. Table 19 presents the critical gas specie concentrations, in ppm, when exposed for 10 minutes. The concentrations are related to three levels of toxicity according to the Acute Exposure Guideline Levels (AEGL) [24]. The reference to the AEGL exposure levels here, is made to briefly compare the toxicity of important fire gases. There are three AEGL- levels with the following definitions of toxic effect on humans:

- AEGL-1: Notable discomfort, irritation, asymptomatic non-sensory effects, not disabling, transient and reversible.
- AEGL-2: Irreversible or other serious long-lasting adverse health effects or an impaired ability to escape.
- AEGL-3: Life-threatening adverse health effects or death.

Table 19 Critical gas specie concentration (ppm) with an exposure time of 10 min for the three AEGL levels.

	CO (ppm) [25]	**HCN (ppm)** [26]	**HCl (ppm)** [27]	**HBr (ppm)** [28]	**NO_2 (ppm)** [29]
AEGL-1	-	2.5	1.8	1.0	0.5
AEGL-2	420	17	100	250	20
AEGL-3	1700	27	620	740	34

AEGL-2 is the most relevant from an evacuation point of view. At these levels, the smoke toxicity will affect the human and reduce the ability to safely evacuate. The critical concentrations given in Table 19, show that both HCN and NO_2 have a toxic effect already at low concentrations. These concentrations are often reached in a fire.

8.3 Requirements for interior surface materials in ro-ro spaces

When designing requirements, it is important to have good knowledge of the end use products as well as the construction and application. The requirement level can be different depending on product, location, and application. Since ro-ro spaces can have different design and areas of application, three main categories of ro-ro ship types have been identified, according to D05.1 Definition of generic ships: the ro-pax vessel, ro-ro cargo and the vehicle carrier. The type of cargo as well as accessibility of crew and passengers within the ro-ro space differs for each of the ro-ro ship type. Suggestions of surface material requirement levels for each ro-ro ship type as well as application area are presented below. The interior materials used for internal spaces and boundaries should pass those requirements in order to be allowed for installation. However, there is still the possibility to perform the alternative design assessment (SOLAS Chapter II-2 Reg 17).

Further, it is to be noted that at ro-ro space internal decks (nor gastight or watertight) lashing openings may be arranged on the deck, which could cause fire spread between the decks. Such arrangement is typical for vehicle carriers where the amount of openings is considerable (typical spacing between the openings may vary from 0.6 to 1.0 m, typical opening diameter is abt. 5 cm). This has not been considered within the LASH FIRE project.

8.3.1 Ro-pax vessel

On ro-pax ships, the requirement should be stringent since passengers are allowed on board as well as within a ro-ro space during loading and unloading operations in ports. The fire spread should be limited, and the smoke production and the toxic gas concentrations should be at a low level in order to have as safe as possible evacuation. In addition to this, manual firefighting teams are used for extinguishing fires. For this to be possible, the fire development must be controlled as well as the smoke production. Two product groups have been identified, which have different levels of the requirement parameters. Table 20 presents the suggested requirements for the two product groups using two relevant test methods, the flame spread according to IMO FTP Code Part 5 and the smoke and toxicity according to IMO FTP Code Part 2. The requirements are higher for bulkheads and ceilings in the boundaries of the ro-ro space than for the floor coverings. For the interior surfaces within the ro-ro space (ceilings at the deck, i.e., area below deck), the requirements can be lower. For these decks the recommendation is that the ceiling (not a boundary) should have higher requirements than floorings but can be lower than the requirements for the bulkhead and ceiling according to IMO FTP Code Part 5. The requirement levels need to be further evaluated and assessed with larger fire tests to validate the relation to flame spread in a large fire.

Table 20 Suggestion of requirements for interior surface materials in ro-ro spaces.

Test parameter		Bulkhead, surface linings, ceiling	Floor coverings
IMO FTP Code Part 5, surface flammability			
Critical Flux at Extinguishment	CFE (kW/m^2)	> 20.0	> 7.0
Average heat for sustained burning	Q_{sb} (MJ/m^2)	> 1.5	> 0.25
Peak heat release	Q_p (kW)	< 4.0	< 10.0
Total heat release	Q_t (MJ)	<0.7	< 2.0
Burning droplets		No	Not more than 10
IMO FTP Code Part 2, smoke and toxicity			
Maximum smoke density	$D_{s,\,max}$	200	400
Carbon monoxide	CO	1450	1450
Hydrogen cyanide	HCN (ppm)	140	140
Hydrogen chloride	HCl (ppm)	600	600
Hydrogen bromide	HBr (ppm)	600	600
Hydrogen fluoride	HF (ppm)	600	600
Sulphur dioxide	SO_2 (ppm)	120	200
Nitrogen oxides	NO_x (ppm)	350	350

8.3.2 Ro-ro cargo

On the ro-ro cargo ship, generally no passengers are allowed within the ro-ro space, but there are manual firefighting teams, which can enter the ro-ro space in case of fire. It seems reasonable to keep the fire safety at a high level with a limited flame spread in the surface material. This will give the firefighting team the possibility to extinguish a small fire before there is a rapid fire development and flashover. Thus, the requirements for bulkheads, surface linings, ceilings and floor coverings given by IMO FTP Code Part 5 can be adapted. In addition, internal decks, not part of the boundaries of the ro-ro deck, could have lower flame spread requirements than bulkheads, ceilings and internal surfaces. However, the levels must be further evaluated and assessed with larger fire tests to validate the fire growth and fire spread in a large-scale fire test.

The relevance of a smoke and toxicity requirement can be discussed. Since there are no passengers on board, the time for evacuation is not as critical as for ro-pax ships. The firefighting team will only be allowed to enter the ro-ro space as long as the fire is rather small and as a complement to automatic fire extinguishing systems. Based on this, the recommendation is that the smoke and toxicity test shall not be considered as mandatory.

8.3.3 Vehicle carriers

On vehicle carriers, no passengers are allowed, and according to the experience, manual firefighting team will almost never enter the ro-ro space during a fire, to reduce the time of activation of the CO_2 fire extinguishing system. Furter, the ro-ro space consists of several decks where the cars are stowed tightly, making the accessibility difficult.

According to rules and regulations, the boundaries of a ro-ro space must fulfill the fire integrity requirements, which is not the case for the decks within a ro-ro space. The recommendation is that all areas shall fulfil the requirement according to IMO FTP Code Part 5, except the ceiling at the decks (area below deck) within a ro-ro space, not forming a boundary. For these decks the recommendation is that the ceiling should have higher requirements than flooring, but these can be lower than the requirements for the bulkhead and ceiling according to IMO FTP Code Part 5. The requirement levels need to be further evaluated and assessed with larger fire tests to validate the relation to flame spread in a large fire.

9 Conclusion

Main author of the chapter: Anna Sandinge, RISE

The industry and shipyard have identified a gap in the exciting fire regulations. There are currently no fire requirements for interior surface materials for ro-ro spaces. As steel parts are replaced with lightweight materials, such as composite materials, it is important to keep the fire safety at a high level. A comprehensive study was conducted within the LASH FIRE project to identify relevant test methods and establish fire requirements. Initially, an evaluation of current available fire test methods was made. The study included different sectors to find suitable methods. The evaluation of the test methods concluded that mainly two fire test methods are relevant for interior surface materials for ro-ro spaces, the surface flammability, IMO FTP Code Part 5, and the smoke and toxicity test, IMO FTP Code Part 2. The Part 5 test is an important test method since it evaluates the surface flammability as well as the heat release from the material. These are critical fire parameters which must be controlled to keep the fire safety at a high level. The Part 2 test evaluate the smoke production in terms of smoke density and smoke toxicity. Both these are important fire test parameters as they affect the ability of manual firefighting and evacuation. With a high smoke density, the visibility in the room or space will be very limited and it will be hard to orientate during an evacuation or firefighting action. The smoke toxicity should also be kept at a low level since high concentrations of the gas species will cause toxification and prevent passengers to evacuate.

A test matrix with approximately 30 combinations of resin, fibre, core materials and different techniques for surface protection, was established. The samples were fire tested. As a result, a lot of test data was produced. The results have increased the knowledge regarding reaction-to-fire performance of composite materials and sandwich panels. All test data available in two databases, RISE Fire database (https://www.ri.se/en/what-we-do/services/rise-fire-database) and at E-LASS Material database (https://e-lass.eu/). The fire testing, analysis and evaluation of the large number of samples show that there is a difference between the materials, resins, fibres, cores, and surface protections. The material design has a big impact on the fire safety. The results were compared with the requirements given by IMO FTP Code 2010, and requirement levels were designed for three types of ro-ro vessels, the ro-pax, ro-ro cargo and vehicle carrier. The requirements are summarized in Table 21 and

Table 22.

Table 21 Summary of designed requirements using the flame spread method.

Flame spread according to IMO FTP Code Part 5

Type of vessel	Type of product	CFE (kW/m^2)	Q_{sb} (MJ/m^2)	Q_p (kW)	Q_t (MJ)	Burning droplets
Ro-pax	Bulkhead, interior surface, ceiling	> 20.0	> 1.5	< 4.0	<0.7	No
	Floorings	> 7.0	> 0.25	< 10.0	<2.0	<10
	Ceilings within ro-ro space	A validation with large scale fire tests is required to set the requirements.				
Ro-ro cargo	Bulkhead, interior surface, ceiling	> 20.0	> 1.5	< 4.0	<0.7	No
	Floorings	> 7.0	> 0.25	< 10.0	<2.0	<10
	Ceilings within ro-ro space	A validation with large scale fire tests is required to set the requirements.				
Vehicle carrier	Bulkhead, interior surface	> 20.0	> 1.5	< 4.0	<0.7	No
	Floorings	> 7.0	> 0.25	< 10.0	<2.0	<10
	Ceilings within ro-ro space	A validation with large scale fire tests is required to set the requirements.				

Table 22 Summary of designed requirements for smoke and toxicity

Smoke and toxicity according to IMO FTP Code Part 2										
Type of vessel	Type of product	$D_{s, max}$	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
Ro-pax	Bulkhead, interior surface	200	1450	140	600	600	600	120	350
	Floor coverings	400	1450	140	600	600	600	200	350
Ro-ro caego	All products	Not applicabe							
Vehicle carrier	All products	Not applicable							

It is important to have in mind that these conclusions and recommendations of test methods and requirements are only valid for interior surface materials in the ro-ro space. Other parts of the ro-ro ship, which could be designed with lightweight materials, must be evaluated separately with other test methods to determine the fire development (the fire growth when exposed to a large fire) and the fire resistance (fire spread through a construction).

10 Indexes

10.1 Index of tables

10.2 Index of figures

11 References

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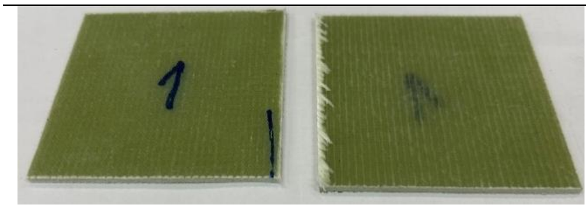
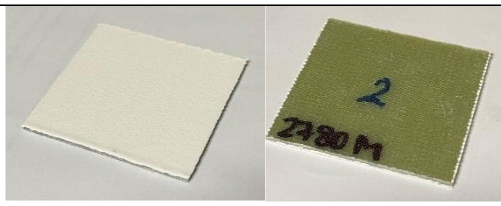
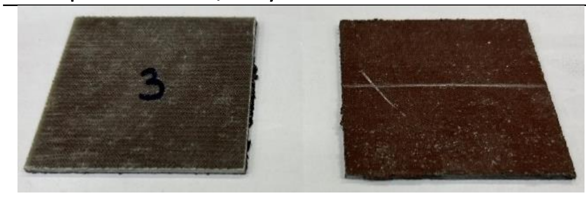
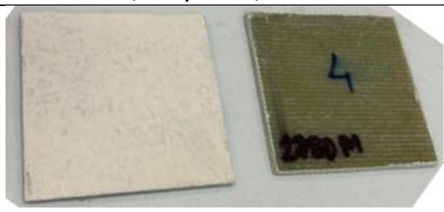
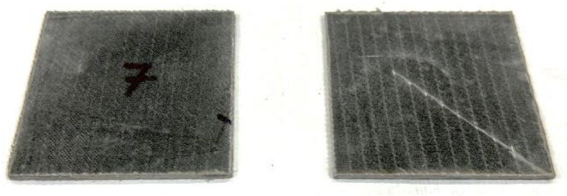
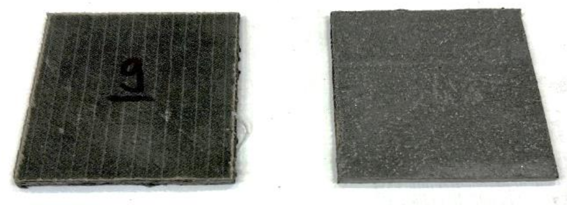
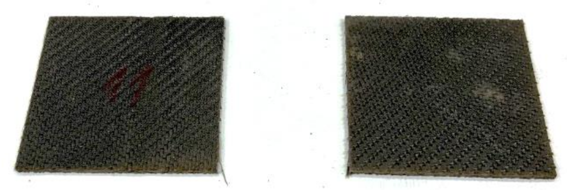
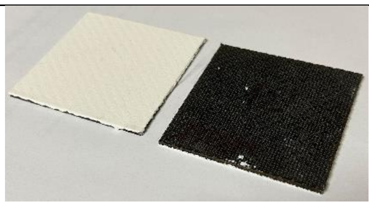
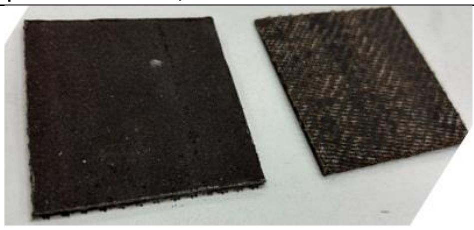
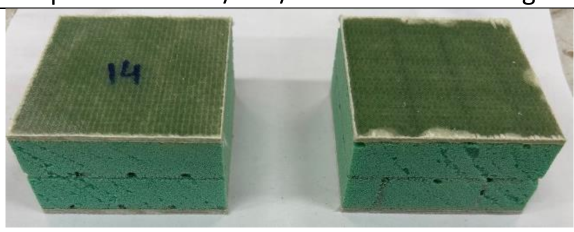
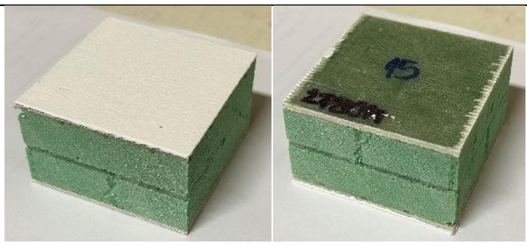
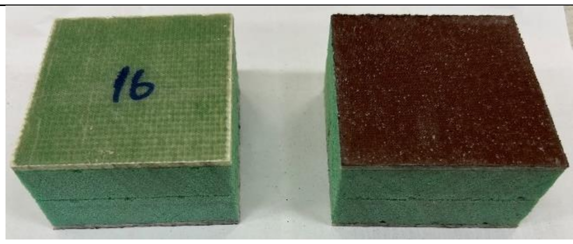
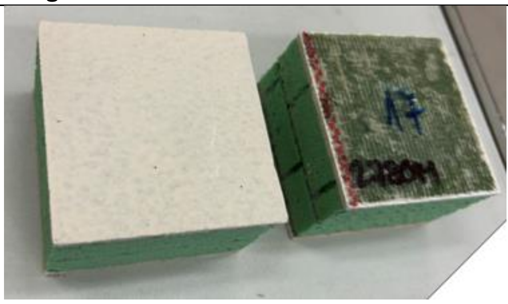
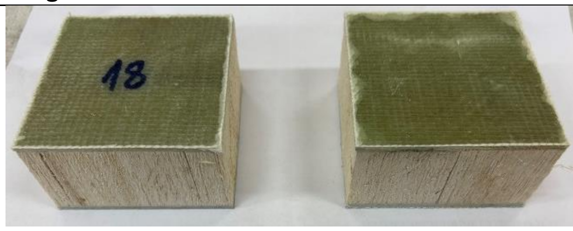
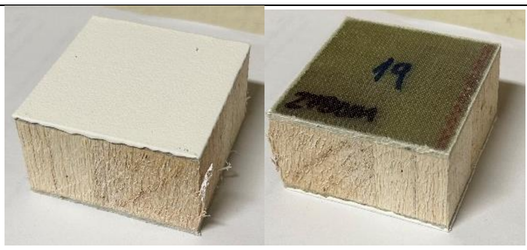
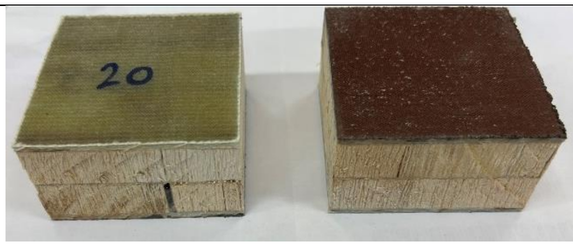
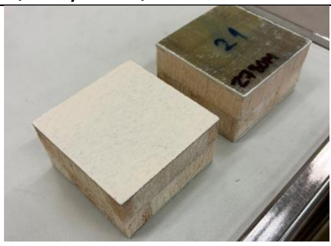
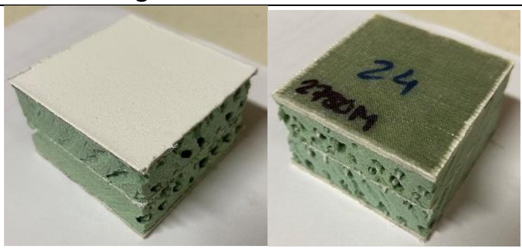
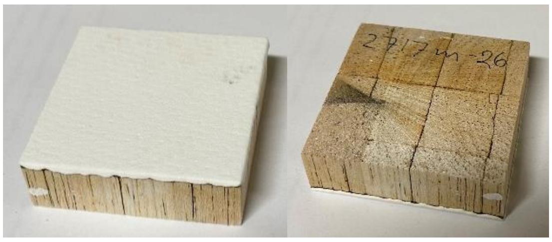
12 ANNEXES

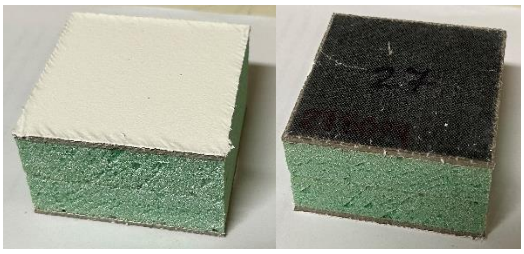
12.1 ANNEX A – Photos of representative specimen of each sample

 Sample 1 – Glass/Polyester	 Sample 2 – Glass/Polyester/Intumescent coating
 Sample 3 – Glass/Epoxy/Intumescent integrated fabric	 Sample 4 – Glass/Polyester/Intumescent gelcoat
 Sample 7 – Basalt/Epoxy	Not recorded Sample 8 – Basalt/Epoxy/Intumescent coating
 Sample 9 – Basalt/Polyester/Intumescent integrated fabric	Not recorded Sample 10 – Glass/PFA
 Sample 11 – Basalt/PFA	 Sample 12 – Basalt/PFA/Intumescent coating
 Sample 13 – Basalt/PFA/Intumescent integrated fabric	 Sample 14 – PVC/Glass/Polyester

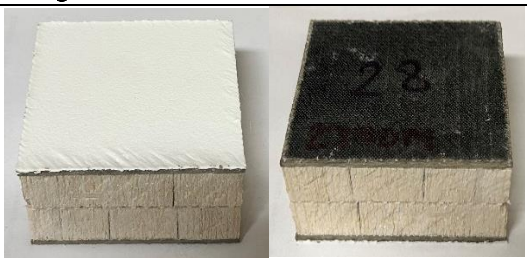
 Sample 15 – PVC/Glass/Polyester/Intumescent coating	 Sample 16 – PVC/Glass/Epoxy/Intumescent integrated fabric
 Sample 17 – PVC/Glass/Polyester/Intumescent gelcoat	 Sample 18 – Balsa/Glass/Polyester
 Sample 19 – Balsa/Glass/Polyester/Intumescent coating	 Sample 20 – Balsa/Glass/Epoxy/Intumescent integrated fabric
 Sample 21 – Balsa/Glass/Polyester/ Intumescent gelcoat	 Sample 22 – PET/Glass/Polyester/Intumescent coating
 Sample 24 – PIR/Glass/Polyester/Intumescent coating	Not recorded Sample 25 – Balsa/Glass/PFA



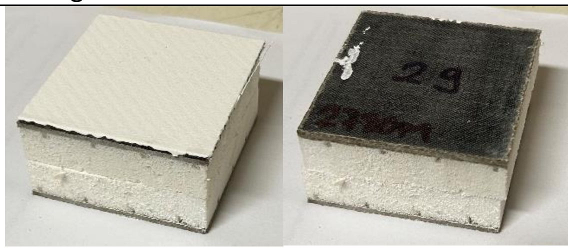
Sample 26 – Balsa/Glass/PFA/Intumescent coating



Sample 27 – PVC/Basalt/Polyester/Intumescent coating



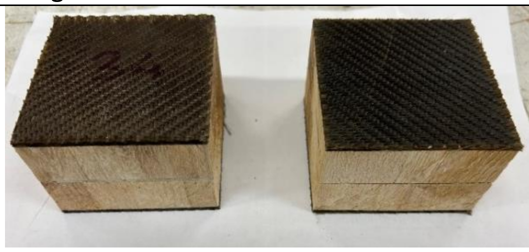
Sample 28 – Balsa/Basalt/Polyester/Intumescent coating



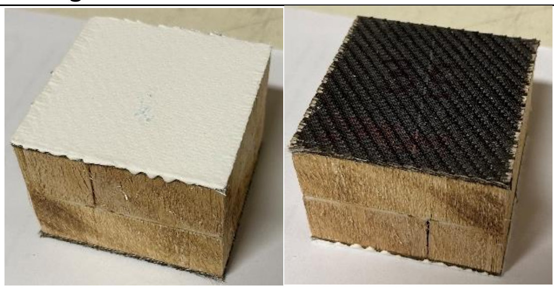
Sample 29 – PET/Basalt/Polyester/Intumescent coating

Not recorded

Sample 32 – PVC/Basalt/PFA/Intumescent coating



Sample 34 – Balsa/Basalt/PFA



Sample 35 – Balsa/Basalt/PFA/Intumescent coating

Not recorded

Sample 36 – Balsa/Basalt/PFA/Intumescent coating

12.2 ANNEX B – Test results IMO Part 5, Spread of flame

Below are the test results detailed of all tested samples according to IMO FTP Code Part 5, Spread of flame. The results are presented for each sample separately.

12.2.1 Sample 1 – Glass/polyester

Sample description

Single laminate of glass fibre reinforced polyester with nominal thickness 2.6 mm.

Test results

Test parameter	**Test result**
CFE (kW/m^2)	9
Q_{sb} (MJ/m^2)	2.5
Q_p (kW)	3.3
Q_t (MJ)	1.1
Burning droplets	No
Time to ignition (s)	13
Time to flameout (s)	780
Flame front went out (mm)	500
Flame front went out (s)	477
Events	**Time (s)**
	- Not recorded

Photos

30 s of test time

1 min of test time

2 min of test time

5 min of test time

7 min of test time

10 min of test time

12.2.2 Sample 2 – Glass/Polyester/Intumescent Coating

<u>Sample description</u>

Single laminate of glass fibre reinforced polyester coated with intumescent coating. Nominal thickness of laminate was 2.9 mm.

<u>Test results</u>

Test parameter	Test result	
CFE (kW/m^2)	48	
Q_{sb} (MJ/m^2)	-*	
Q_p (kW)	0.4	
Q_t (MJ)	0.1	
Burning droplets	No	
Time to ignition (s)	25	
Time to flameout (s)	90	
Flame front went out (mm)	-**	
Flame front went out (s)	Not recorded	
Events	**Time (s)**	
	9	Bubbles at the surface.
	12	Flakes of coating fell from the surface as they became warm due to bad adhesion to laminate.
	46	Charring.
	78	Cracks in the surface.
	257	Intumescence in the coating layer.

* Not recorded since the flame front did not reach the 175 mm mark.

** Flame front did not reach the 50 mm mark.

<u>Photos</u>

No video was recorded during the test. No photos were taken.

12.2.3 Sample 3 – Glass/Epoxy/Intumescent integrated fabric

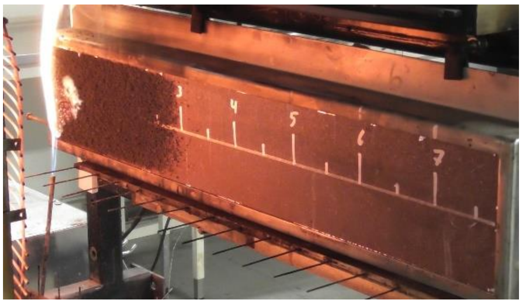
Sample description

Single laminate of glass fibre reinforced epoxy with intumescent integrated fabric, nominal thickness was 2.9 mm.

Test results

Test parameter	Test result	
CFE (kW/m^2)	31	
Q_{sb} (MJ/m^2)	16	
Q_p (kW)	1.9	
Q_t (MJ)	1.0	
Burning droplets	No	
Time to ignition (s)	10	
Time to flameout (s)	952	
Flame front went out (mm)	300	
Flame front went out (s)	483	
Events	**Time (s)**	
	11	Charring in the surface layer.
	23	Flashing at the surface.
	31	Intumescence of the coating.

Photos



30 s of test time

1 min of test time

2 min of test time

5 min of test time

7 min of test time

10 min of test time

12.2.4 Sample 4 – Glass/Epoxy/Intumescent integrated fabric/Gelcoat

Sample description

Single laminate with glass fibre reinforced polyester, surface treated with an intumescent gelcoat. Nominal thickness of laminate was 3.2 mm.

Test results

Test parameter	**Test result**	
CFE (kW/m^2)	25	
Q_{sb} (MJ/m^2)	7.0	
Q_p (kW)	1.4	
Q_t (MJ)	0.8	
Burning droplets	No	
Time to ignition (s)	50	
Time to flameout (s)	1457	
Flame front went out (mm)	340	
Flame front went out (s)	520	
Events	**Time (s)**	
	44	Bubbles in the coating.
	47	Flashing at the surface.
	57	Intumescence of the coating.
	74	Charring at the surface.

Photos

No video was recorded during the test. No photos were taken.

12.2.5 Sample 7 – Basalt/Epoxy

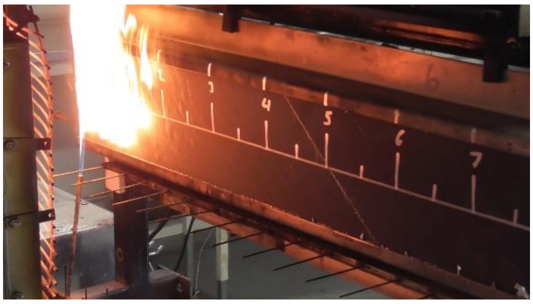
Sample description

Single laminate with basalt fibre reinforced epoxy with a nominal thickness of 2.3 mm.

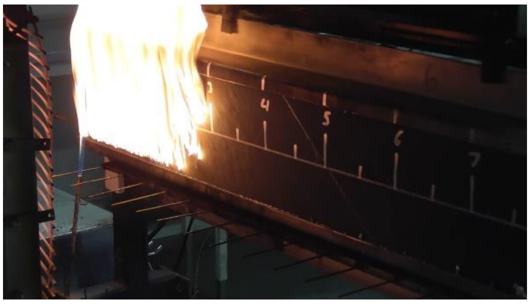
Test results

Test parameter	Test result	
CFE (kW/m^2)	14	
Q_{sb} (MJ/m^2)	2.0	
Q_p (kW)	3.4	
Q_t (MJ)	0.9	
Burning droplets	No	
Time to ignition (s)	10	
Time to flameout (s)	386	
Flame front went out (mm)	440	
Flame front went out (s)	356	
Events	**Time (s)**	
	19	Bubbles in the laminate.
	352	Flashing at the surface.

Photos



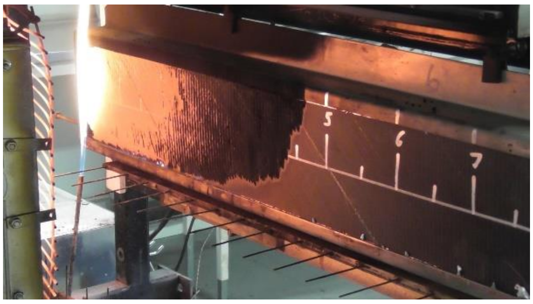
30 s of test time



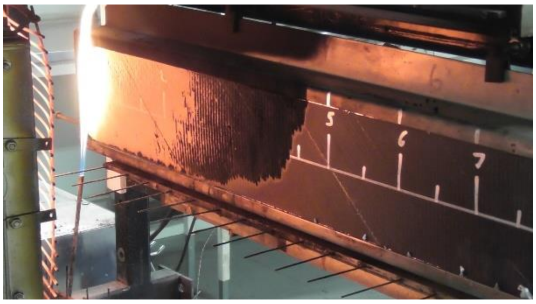
1 min of test time

2 min of test time

5 min of test time



7 min of test time



10 min of test time

12.2.6 Sample 8 – Basalt/Epoxy/Intumescent coating

Sample description

Single laminate of basalt fibre reinforced epoxy coated with intumescent coating. Nominal thickness of laminate was 2.7 mm.

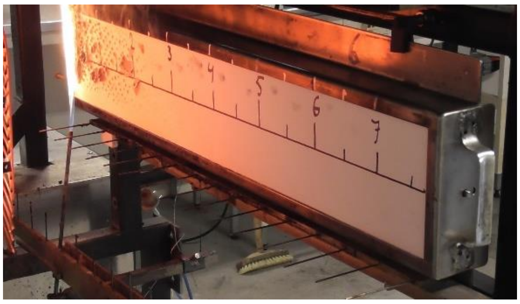
Test results

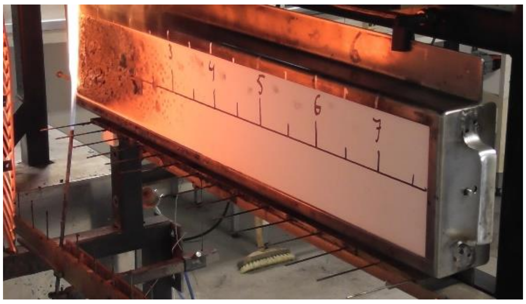
Test parameter	Test result	
CFE (kW/m^2)	48	
Q_{sb} (MJ/m^2)	-*	
Q_p (kW)	0.3	
Q_t (MJ)	0.1	
Burning droplets	No	
Time to ignition (s)	46	
Time to flameout (s)	233	
Flame front went out (mm)	-**	
Flame front went out (s)	Not recorded	
Events	**Time (s)**	
	7	Bubbles in the coating.
	31	Charring.
	33	Flakes of coating fell from the surface as they became warm due to bad adhesion to laminate.
	53	Cracks in surface.
	186	Flashing at surface.

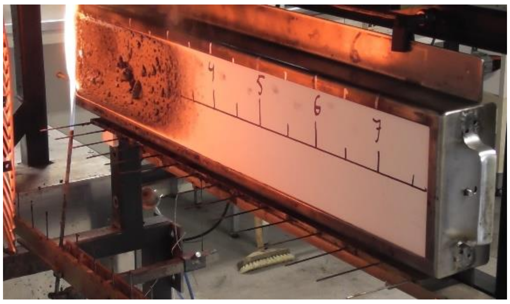
* Not recorded since the flame front did not reach the 175 mm mark.

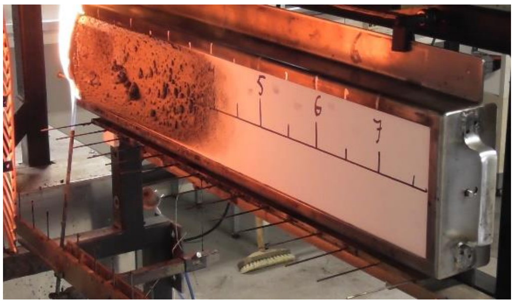
** Flame front did not reach the 50 mm mark.

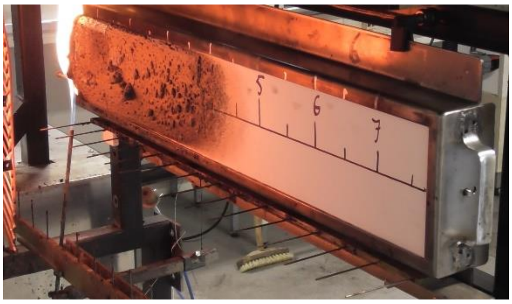
Photos


30 s of test time

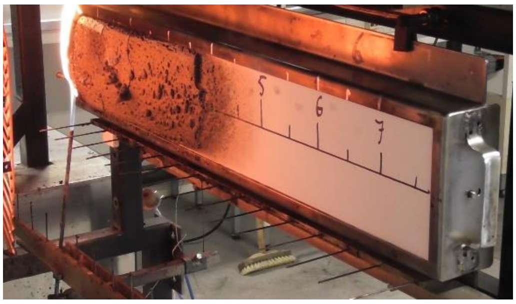

1 min of test time


2 min of test time


5 min of test time



7 min of test time



10 min of test time

12.2.7 Sample 9 – Basalt/Polyester/Intumescent integrated fabric

Sample description

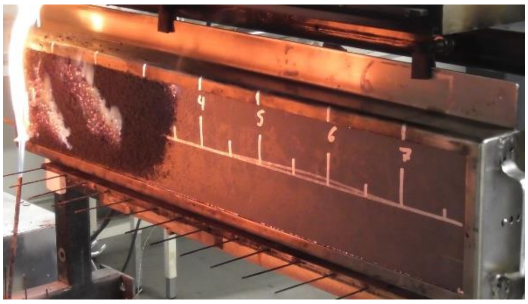
Single laminate of basalt fibre reinforced polyester with intumescent integrated fabric, nominal thickness was 3.7 mm.

Test results

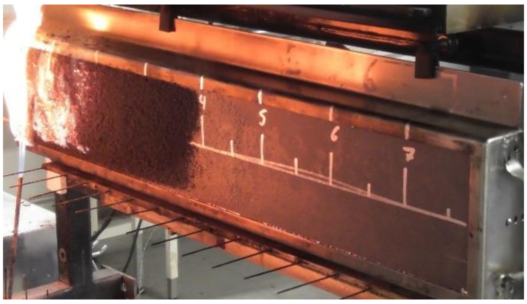
Test parameter	Test result	
CFE (kW/m^2)	48	
Q_{sb} (MJ/m^2)	-*	
Q_p (kW)	0.9	
Q_t (MJ)	0.8	
Burning droplets	No	
Time to ignition (s)	8	
Time to flameout (s)	1655	
Flame front went out (mm)	150	
Flame front went out (s)	1000	
Events	**Time (s)**	
	8	Charring.
	11	Intumescence of the fabric.
	15	Flashing at the surface.
	145	Flashing.

* Not recorded since the flame front did not reach the 175 mm mark.

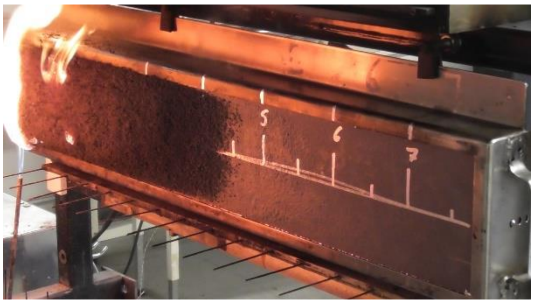
Photos



30 s of test time



1 min of test time



2 min of test time

5 min of test time

7 min of test time

10 min of test time

12.2.8 Sample 10 – Glass/PFA

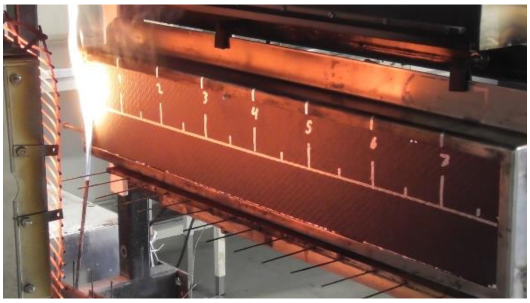
Sample description

Single laminate with glass fibre reinforced PFA with a nominal thickness of 2.3 mm.

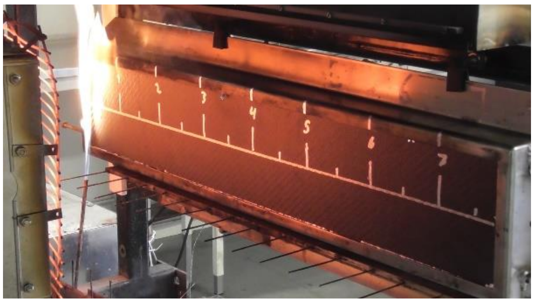
Test results

Test parameter	Test result	
CFE (kW/m^2)	44	
Q_{sb} (MJ/m^2)	3.6	
Q_p (kW)	0.7	
Q_t (MJ)	0.2	
Burning droplets	No	
Time to ignition (s)	60	
Time to flameout (s)	109	
Flame front went out (mm)	200	
Flame front went out (s)	89	
Events	**Time (s)**	
	70	Flashing and charring at the surface.

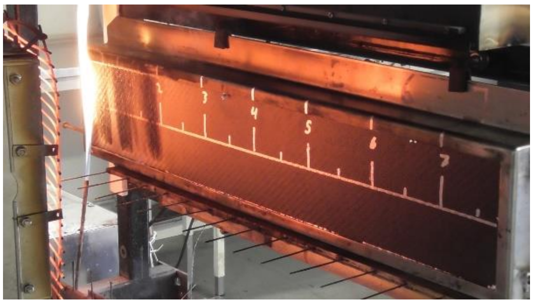
Photos



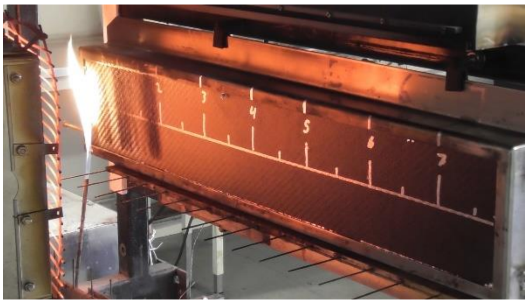
30 s of test time



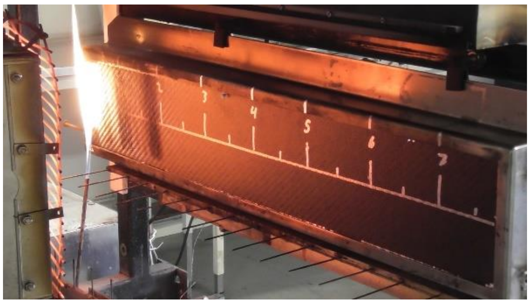
1 min of test time



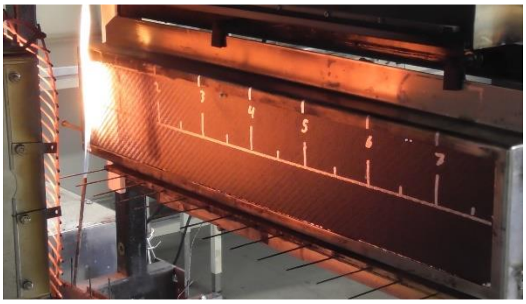
2 min of test time



5 min of test time



7 min of test time



10 min of test time

12.2.9 Sample 11 – Basalt/PFA

Sample description

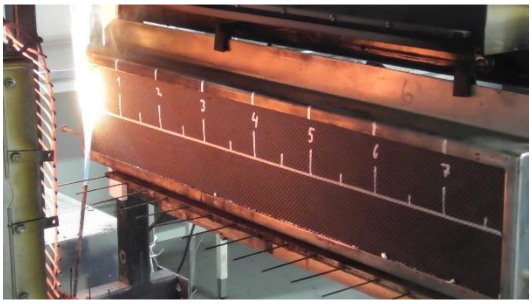
Single laminate with basalt fibre reinforced PFA with a nominal thickness of 2.2 mm.

Test results

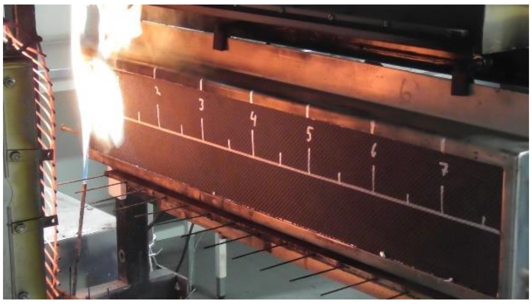
Test parameter	Test result	
CFE (kW/m^2)	48	
Q_{sb} (MJ/m^2)	-*	
Q_p (kW)	0.6	
Q_t (MJ)	0.1	
Burning droplets	No	
Time to ignition (s)	36	
Time to flameout (s)	91	
Flame front went out (mm)	150	
Flame front went out (s)	62	
Events	**Time (s)**	
	80	Flashing at surface.
	81	Charring.

* Not recorded since the flame front did not reach the 175 mm mark.

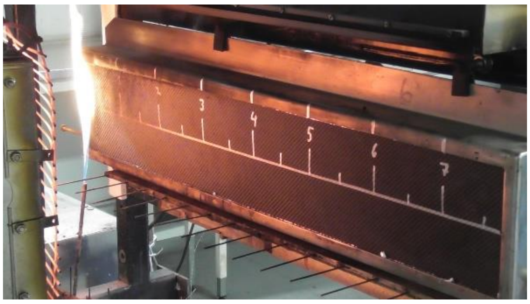
Photos



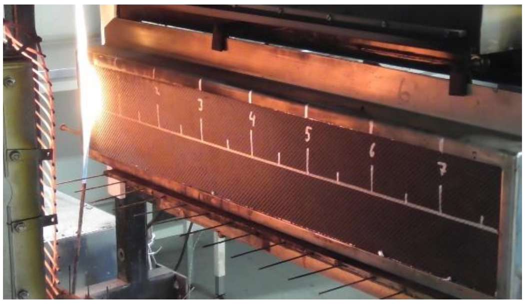
30 s of test time



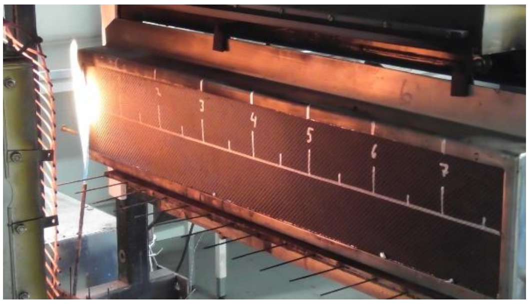
1 min of test time



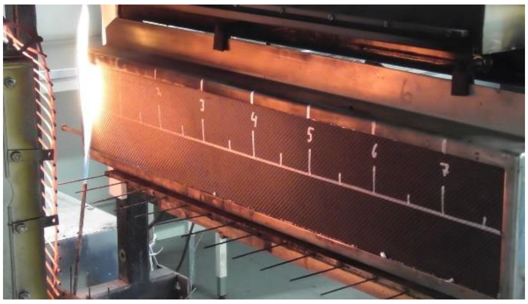
2 min of test time



5 min of test time



7 min of test time



10 min of test time

12.2.10 Sample 12 – Basalt/PFA/Intumescent coating

Sample description

Single laminate of basalt fibre reinforced PFA coated with intumescent coating. Nominal thickness of laminate was 2.5 mm.

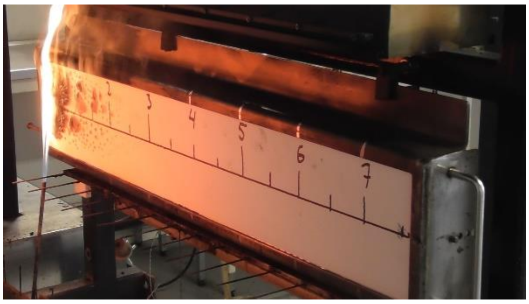
Test results

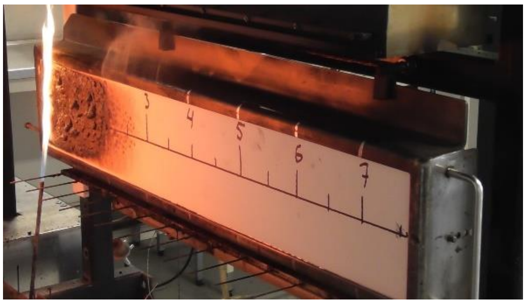
Test parameter	Test result	
CFE (kW/m^2)	48	
Q_{sb} (MJ/m^2)	-*	
Q_p (kW)	0.0	
Q_t (MJ)	0.0	
Burning droplets	No	
Time to ignition (s)	22	
Time to flameout (s)	123	
Flame front went out (mm)	-**	
Flame front went out (s)	Not recorded	
Events	**Time (s)**	
	9	Bubbles in the coating.
	47	Charring.
	419	Intumescence in coating.

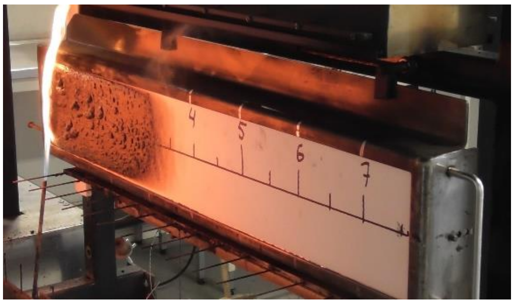
* Not recorded since the flame front did not reach the 175 mm mark.

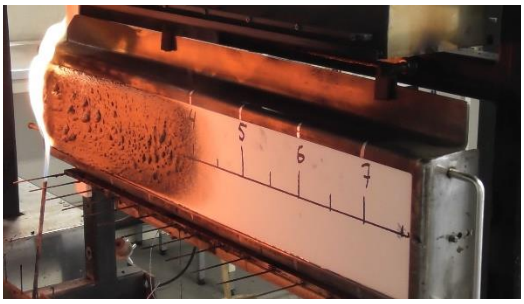
** Flame front did not reach the 50 mm mark.

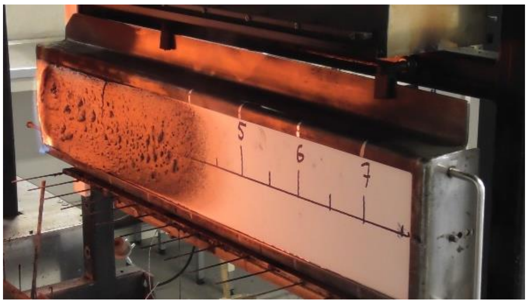
Photos


30 s of test time

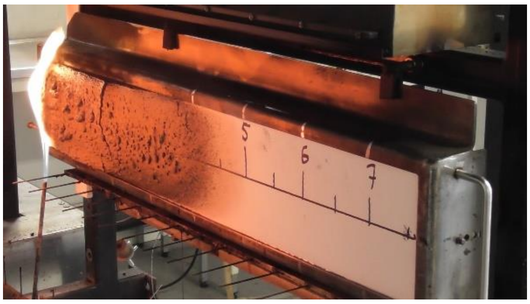

1 min of test time


2 min of test time


5 min of test time



7 min of test time



10 min of test time

12.2.11 Sample 13 – Basalt/PFA/Intumescent integrated fabric

Sample description

Single laminate of basalt fibre reinforced PFA with intumescent integrated fabric, nominal thickness was 3.5 mm.

Test results

Test parameter	Test result	
CFE (kW/m^2)	32	
Q_{sb} (MJ/m^2)	2.7	
Q_p (kW)	0.8	
Q_t (MJ)	0.1	
Burning droplets	No	
Time to ignition (s)	26	
Time to flameout (s)	184	
Flame front went out (mm)	300	
Flame front went out (s)	82	
Events	**Time (s)**	
	7	Bubbles and intumescence in the coating.
	10	Flashing at the surface.

Photos

No video was recorded during the test. No photos were taken.

12.2.12 Sample 14 – PVC/Glass/Polyester

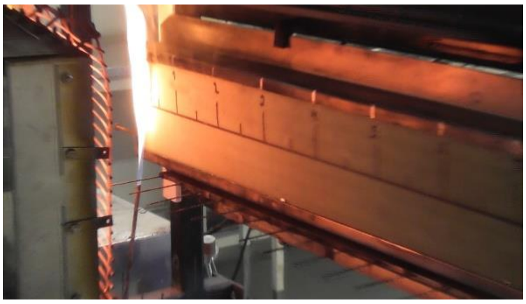
Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of PVC, and lower laminate of polyester reinforced with glass fibres. Nominal thickness of panel was 44.8 mm.

Test results

Test parameter	Test result	
CFE (kW/m^2)	6	
Q_{sb} (MJ/m^2)	2.5	
Q_p (kW)	3.5	
Q_t (MJ)	1.8	
Burning droplets	No	
Time to ignition (s)	13	
Time to flameout (s)	1043	
Flame front went out (mm)	570	
Flame front went out (s)	1043	
Events	**Time (s)**	
	44	Flashing.
	1037	Burning from rear side of specimen.

Photos



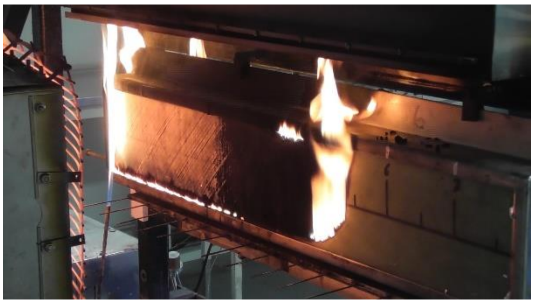
30 s of test time

1 min of test time

2 min of test time

5 min of test time

7 min of test time



10 min of test time

12.2.13 Sample 15 – PVC/Glass/Polyester/Intumescent coating

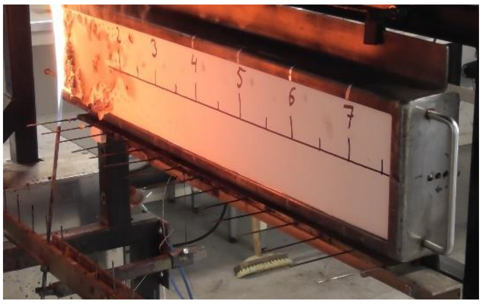
Sample description

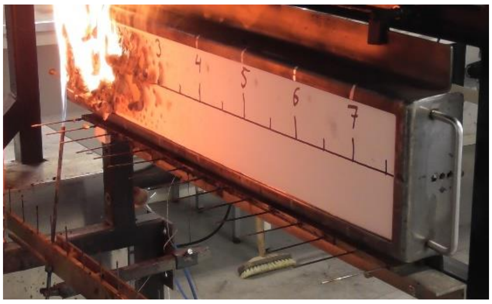
Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of PVC, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 44.8 mm.

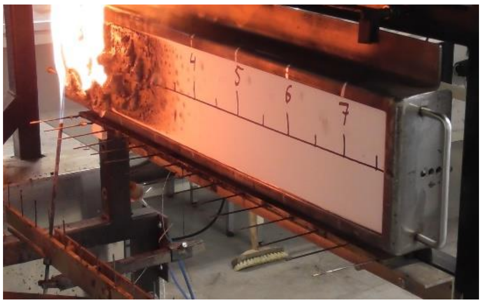
Test results

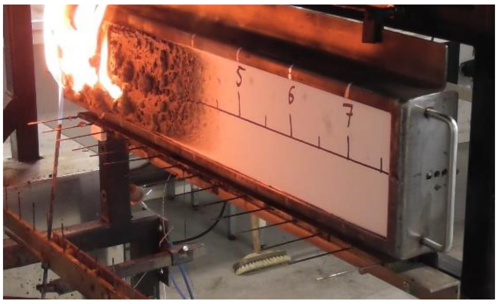
Test parameter	**Test result**	
CFE (kW/m^2)	39	
Q_{sb} (MJ/m^2)	7	
Q_p (kW)	2.5	
Q_t (MJ)	1.2	
Burning droplets	No	
Time to ignition (s)	14	
Time to flameout (s)	2400	
Flame front went out (mm)	250	
Flame front went out (s)	275	
Events	**Time (s)**	
	5	Bubbles in the coating.
	15	Charring.
	1918	Intumescence of coating.

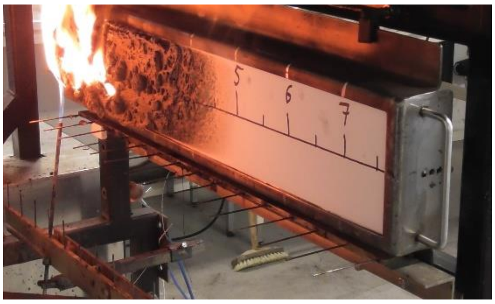
Photos

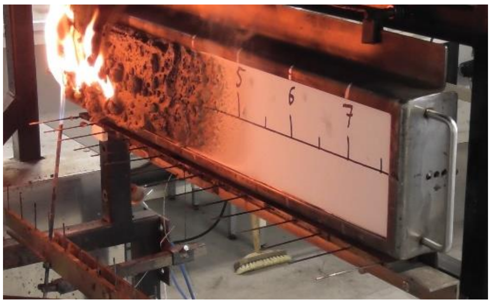

30 s of test time


1 min of test time


2 min of test time


5 min of test time


7 min of test time


10 min of test time

12.2.14 Sample 16 – PVC/Glass/Epoxy/Intumescent integrated fabric

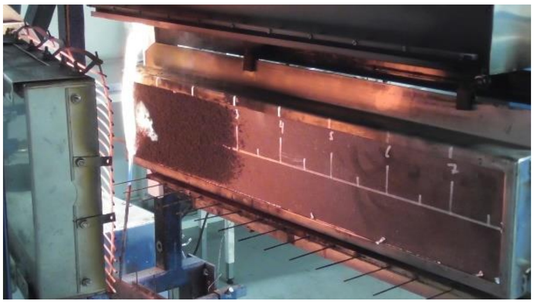
Sample description

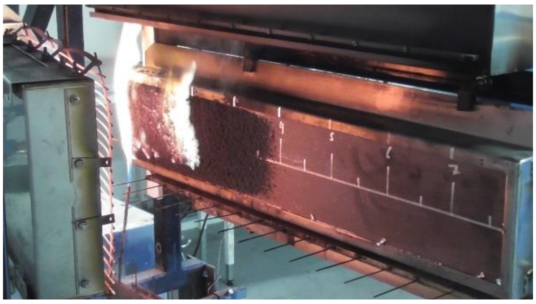
Sandwich panel with upper laminate of epoxy reinforced with glass fibres, core of PVC, and lower laminate of epoxy reinforced with glass fibres. An intumescent fabric was integrated in the lower laminate. Nominal thickness of panel was 44.1 mm.

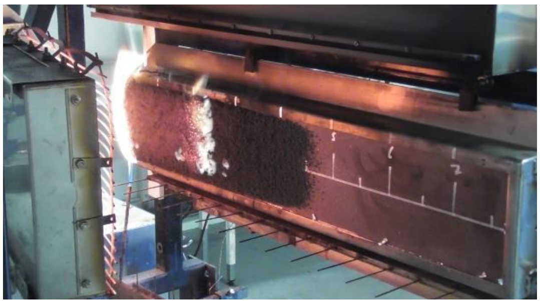
Test results

Test parameter	Test result	
CFE (kW/m^2)	22	
Q_{sb} (MJ/m^2)	9.7	
Q_p (kW)	2.5	
Q_t (MJ)	1.1	
Burning droplets	No	
Time to ignition (s)	23	
Time to flameout (s)	750	
Flame front went out (mm)	380	
Flame front went out (s)	340	
Events	**Time (s)**	
	4	Charring.
	9	Flashing.
	25	Intumescence.
	737	Burning from rear side of specimen.

Photos


30 s of test time


1 min of test time


2 min of test time


5 min of test time


7 min of test time


10 min of test time

12.2.15 Sample 17 – PVC/Glass/Epoxy/Gelcoat

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of PVC, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with a gelcoat. Nominal thickness of panel was 45.3 mm.

Test results

Test parameter	**Test result**	
CFE (kW/m^2)	24	
Q_{sb} (MJ/m^2)	5.2	
Q_p (kW)	3.7	
Q_t (MJ)	2.0	
Burning droplets	No	
Time to ignition (s)	68	
Time to flameout (s)	1387	
Flame front went out (mm)	350	
Flame front went out (s)	330	
Events	**Time (s)**	
	50	Bubbles in the coating.
	55	Melting of surface material.
	99	Intumescence of coating.
	1398	Flashing at surface.

Photos

No video was recorded during the test. No photos were taken.

12.2.16 Sample 18 – Balsa/Glass/Polyester

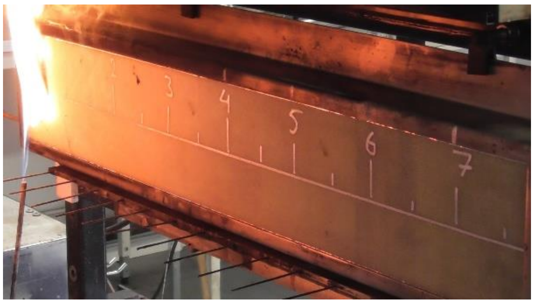
Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of balsa, and lower laminate of polyester reinforced with glass fibres. Nominal thickness of panel was 42.8 mm.

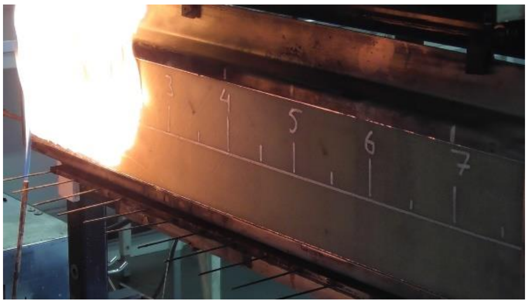
Test results

Test parameter	Test result
CFE (kW/m^2)	8
Q_{sb} (MJ/m^2)	2.9
Q_p (kW)	5.9
Q_t (MJ)	3.0
Burning droplets	No
Time to ignition (s)	12
Time to flameout (s)	1173
Flame front went out (mm)	530
Flame front went out (s)	500
Events	**Time (s)**
	- Not recorded

Photos



30 s of test time



1 min of test time

2 min of test time

5 min of test time

7 min of test time

10 min of test time

12.2.17 Sample 19 – Balsa/Glass/Polyester/Intumescent coating

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of balsa, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 43.1 mm.

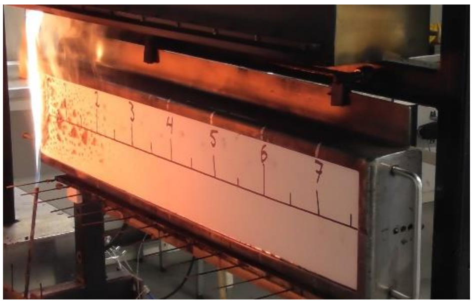
Test results

Test parameter	Test result	
CFE (kW/m^2)	48	
Q_{sb} (MJ/m^2)	-*	
Q_p (kW)	0.4	
Q_t (MJ)	0.4	
Burning droplets	No	
Time to ignition (s)	93	
Time to flameout (s)	Not recorded	
Flame front went out (mm)	-**	
Flame front went out (s)	Not recorded	
Events	**Time (s)**	
	18	Bubbles and intumescence in coating.
	65	Burning from core behind the laminate.

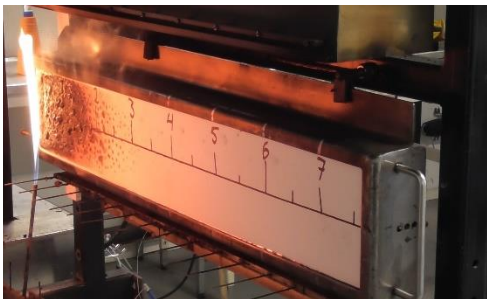
* Not recorded since the flame front did not reach the 175 mm mark.

** Flame front did not reach the 50 mm mark.

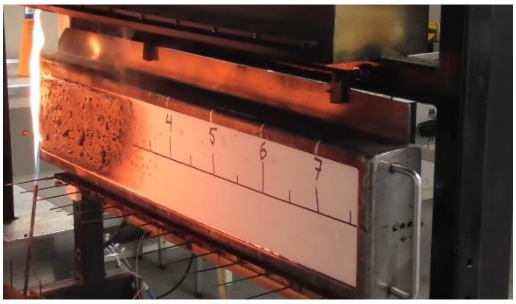
Photos



30 s of test time



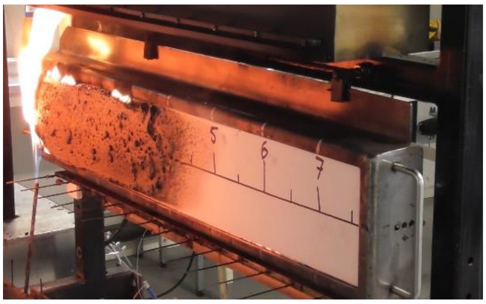
1 min of test time



2 min of test time

5 min of test time

7 min of test time



10 min of test time

12.2.18 Sample 20 – Balsa/Glass/Epoxy/Intumescent integrated fabric

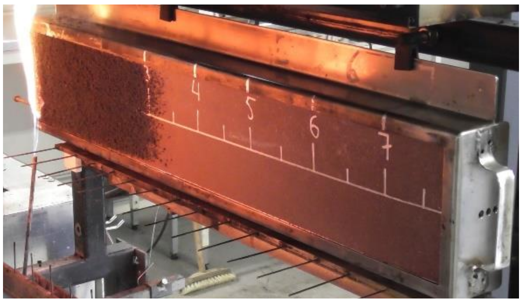
Sample description

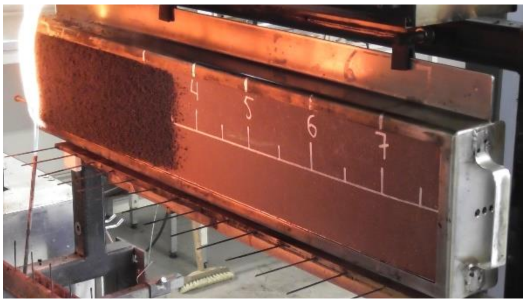
Sandwich panel with upper laminate of epoxy reinforced with glass fibres, core of balsa, and lower laminate of epoxy reinforced with glass fibres. An intumescent fabric was integrated in the lower laminate. Nominal thickness of panel was 42.7 mm.

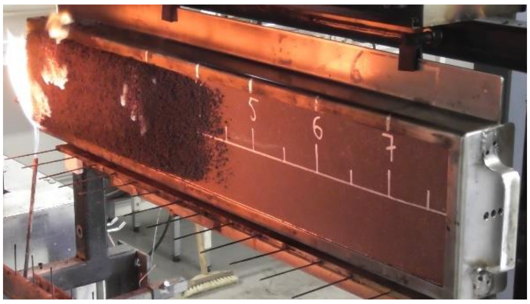
Test results

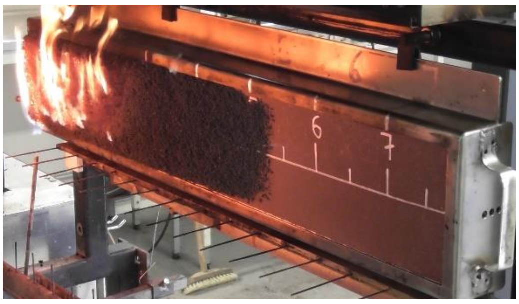
Test parameter	Test result	
CFE (kW/m^2)	25	
Q_{sb} (MJ/m^2)	12	
Q_p (kW)	2.4	
Q_t (MJ)	3.2	
Burning droplets	No	
Time to ignition (s)	12	
Time to flameout (s)	2400	
Flame front went out (mm)	350	
Flame front went out (s)	509	
Events	**Time (s)**	
	6	Intumescence
	1864	Burning from rear side of sample.

Photos


30 s of test time


1 min of test time


2 min of test time


5 min of test time


7 min of test time


10 min of test time

12.2.19 Sample 21 – Balsa/Glass/Polyester/Gelcoat

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of balsa, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with a gelcoat. Nominal thickness of panel was 42.9 mm.

Test results

Test parameter	**Test result**	
CFE (kW/m^2)	18	
Q_{sb} (MJ/m^2)	4.3	
Q_p (kW)	4.2	
Q_t (MJ)	3.3	
Burning droplets	No	
Time to ignition (s)	68	
Time to flameout (s)	1884	
Flame front went out (mm)	400	
Flame front went out (s)	779	
Events	**Time (s)**	
	43	Bubbles in the coating.
	51	Flashing in the surface.
	64	Intumescence in the coating.

Photos

No video was recorded during the test. No photos were taken.

12.2.20 Sample 22 – PET/Glass/Polyester/Intumescent coating

Sample description

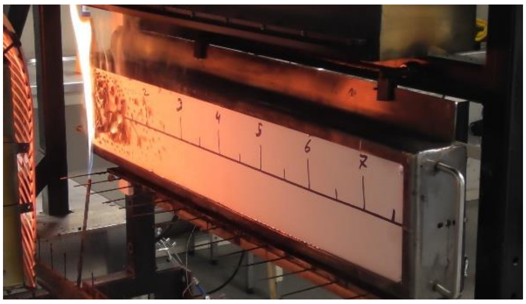
Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of PET, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 45.0 mm.

Test results

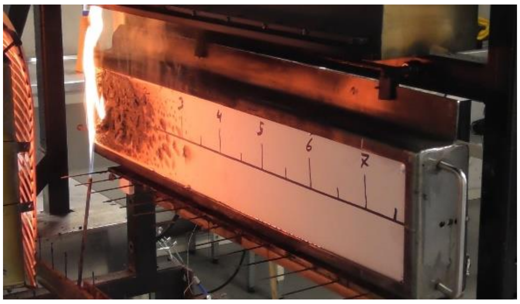
Test parameter	Test result	
CFE (kW/m^2)	46	
Q_{sb} (MJ/m^2)	-*	
Q_p (kW)	2.1	
Q_t (MJ)	3.8	
Burning droplets	No	
Time to ignition (s)	20	
Time to flameout (s)	Not recorded	
Flame front went out (mm)	150	
Flame front went out (s)	122	
Events	**Time (s)**	
	8	Bubbles
	22	Intumescence
	25	Flakes of coating fell from the surface as they became warm due to bad adhesion to laminate.
	586	Melting of material
	1158	Burning from rear side of sample.

* Not recorded since the flame front did not reach the 175 mm mark.

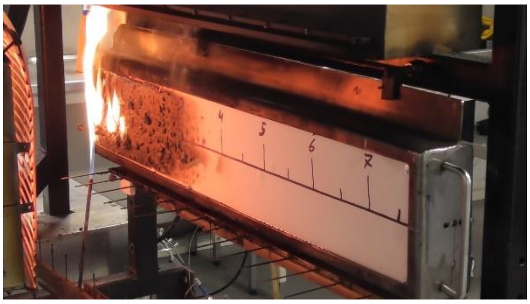
Photos



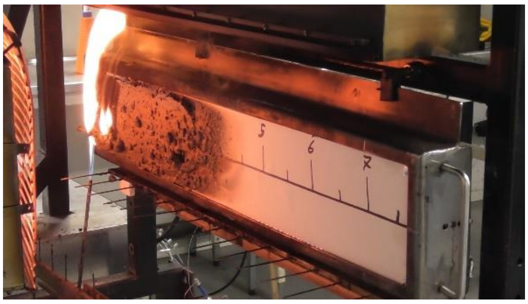
30 s of test time



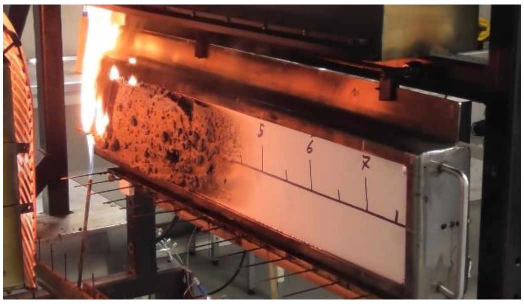
1 min of test time



2 min of test time



5 min of test time



7 min of test time

10 min of test time

12.2.21 Sample 24 – PIR/Glass/Polyester/Intumescent coating

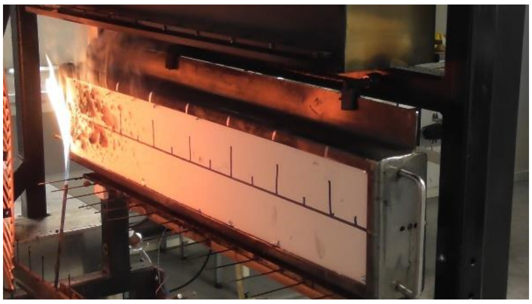
Sample description

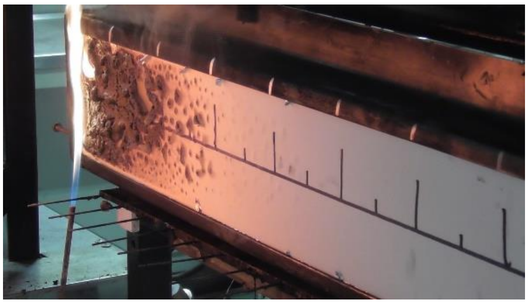
Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of PIR, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 45.4 mm.

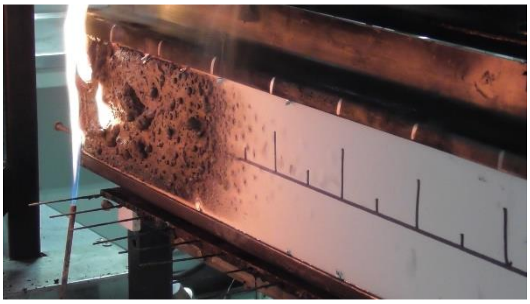
Test results

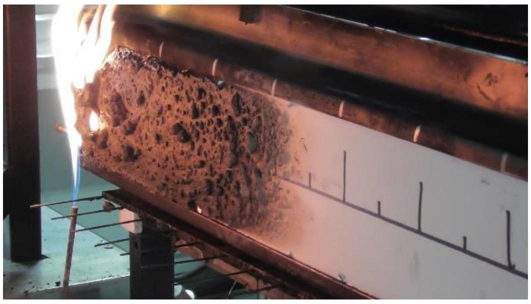
Test parameter	**Test result**	
CFE (kW/m^2)	43	
Q_{sb} (MJ/m^2)	17	
Q_p (kW)	0.7	
Q_t (MJ)	0.7	
Burning droplets	No	
Time to ignition (s)	25	
Time to flameout (s)	Not recorded	
Flame front went out (mm)	200	
Flame front went out (s)	1596	
Events	**Time (s)**	
	7	Bubbles.
	19	Melting.
	24	Intumescence.

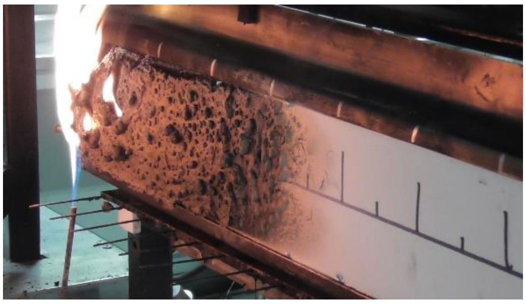
Photos

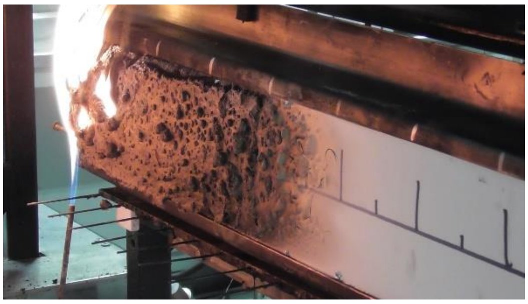

30 s of test time


1 min of test time


2 min of test time


5 min of test time


7 min of test time


10 min of test time

12.2.22 Sample 25 – Balsa/Glass/PFA

Sample description

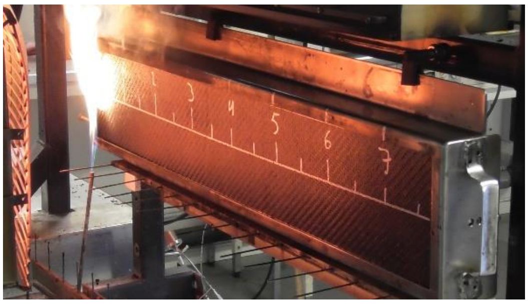
Sandwich panel with upper laminate of PFA reinforced with glass fibres, core of balsa, and lower laminate of PFA reinforced with glass fibres. Nominal thickness of panel was 42.5 mm.

Test results

Test parameter	Test result	
CFE (kW/m^2)	25	
Q_{sb} (MJ/m^2)	4.0	
Q_p (kW)	2.6	
Q_t (MJ)	0.9	
Burning droplets	No	
Time to ignition (s)	29	
Time to flameout (s)	580	
Flame front went out (mm)	350	
Flame front went out (s)	193	
Events	**Time (s)**	
	90	Smoke production from specimen at right end.

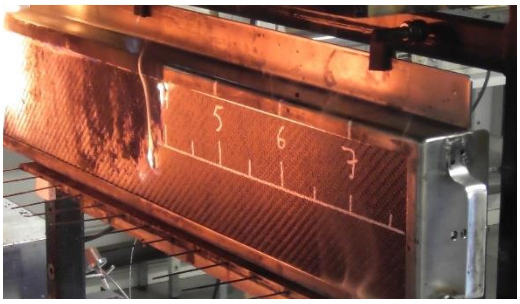
Photos

30 s of test time

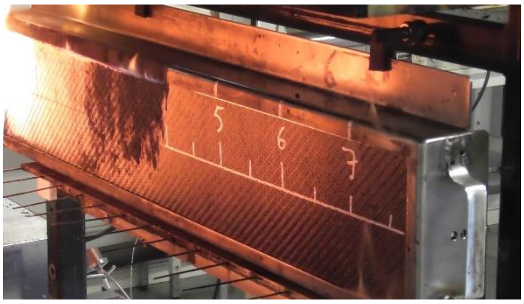


1 min of test time

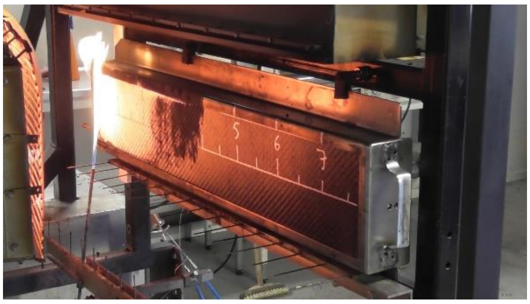
2 min of test time



5 min of test time



7 min of test time



10 min of test time

12.2.23 Sample 26 – Balsa/Glass/PFA/Intumescent coating

Sample description

Sandwich panel with upper laminate of PFA reinforced with glass fibres, core of balsa, and lower laminate of PFA reinforced with glass fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 42.7 mm.

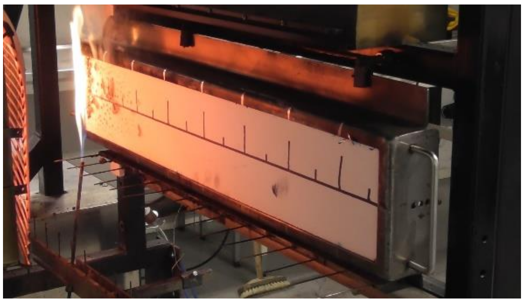
Test results

Test parameter	Test result	
CFE (kW/m^2)	48	
Q_{sb} (MJ/m^2)	-*	
Q_p (kW)	0.7	
Q_t (MJ)	0.2	
Burning droplets	No	
Time to ignition (s)	42	
Time to flameout (s)	248	
Flame front went out (mm)	-**	
Flame front went out (s)	Not recorded	
Events	**Time (s)**	
	10	Bubbles.
	27	Intumescence.
	145	Charring.

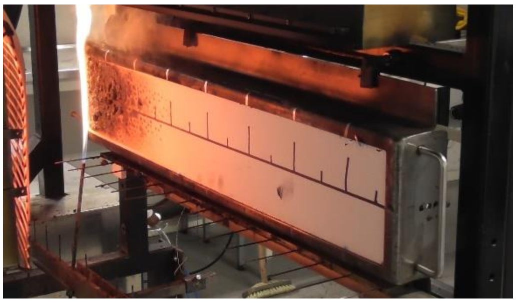
* Not recorded since the flame front did not reach the 175 mm mark.

** Flame front did not reach the 50 mm mark.

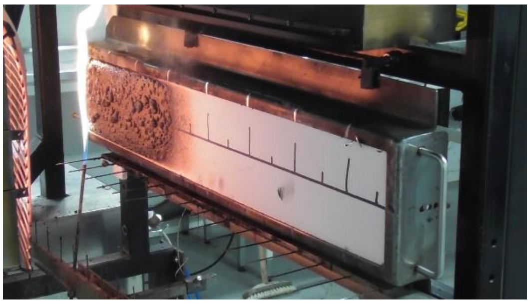
Photos



30 s of test time

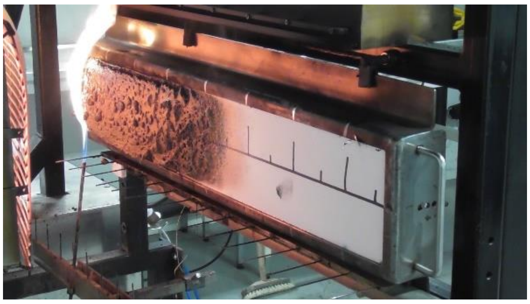


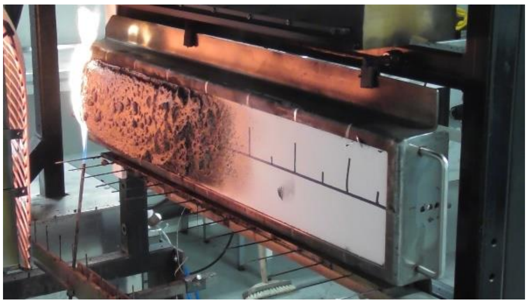
1 min of test time



2 min of test time

5 min of test time


7 min of test time


10 min of test time

12.2.24 Sample 27 – PVC/Basalt/Polyester/Intumescent coating

Sample description

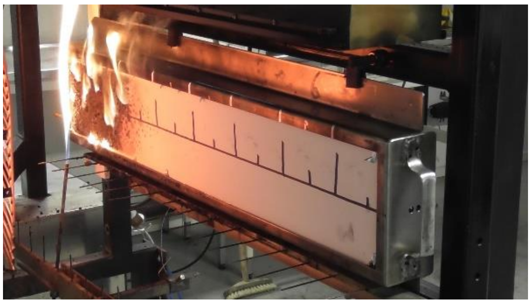
Sandwich panel with upper laminate of polyester reinforced with basalt fibres, core of PVC, and lower laminate of polyester reinforced with basalt fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 44.4 mm.

Test results

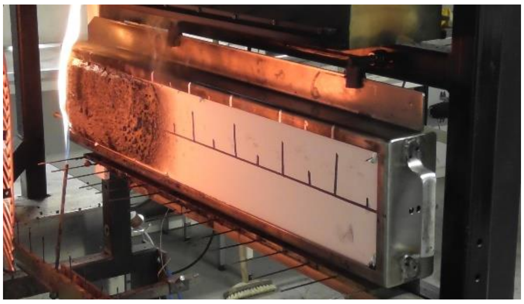
Test parameter	Test result	
CFE (kW/m^2)	43	
Q_{sb} (MJ/m^2)	2.4	
Q_p (kW)	0.7	
Q_t (MJ)	1.0	
Burning droplets	No	
Time to ignition (s)	46	
Time to flameout (s)	1084	
Flame front went out (mm)	200	
Flame front went out (s)	61	
Events	**Time (s)**	
	8	Bubbles.
	54	Intumescence.
	123	Charring.
	402	Burning from rear side of specimen.

Photos

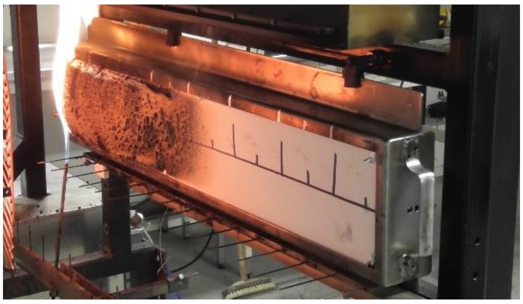
30 s of test time



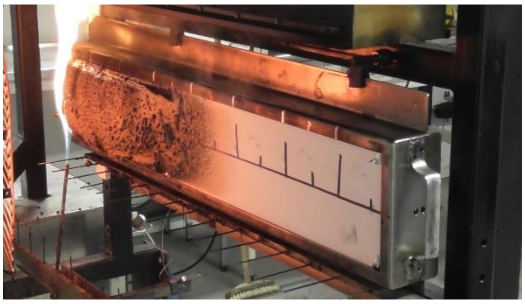
1 min of test time



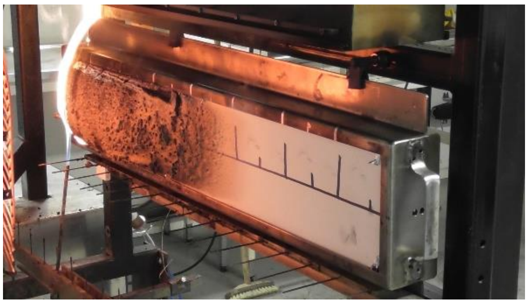
2 min of test time



5 min of test time



7 min of test time



10 min of test time

12.2.25 Sample 28 – Balsa/Basalt/Polyester/Intumescent coating

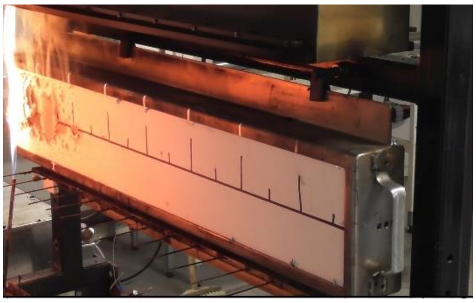
Sample description

Sandwich panel with upper laminate of polyester reinforced with basalt fibres, core of balsa, and lower laminate of polyester reinforced with basalt fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 42.4 mm.

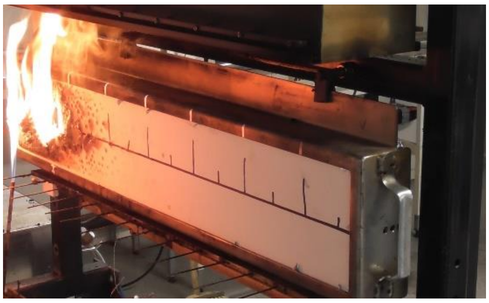
Test results

Test parameter	**Test result**	
CFE (kW/m^2)	43	
Q_{sb} (MJ/m^2)	3.0	
Q_p (kW)	2.2	
Q_t (MJ)	3.4	
Burning droplets	No	
Time to ignition (s)	43	
Time to flameout (s)	Not recorded	
Flame front went out (mm)	200	
Flame front went out (s)	88	
Events	**Time (s)**	
	8	Bubbles.
	22	Flakes of coating fell from the surface as they became warm due to bad adhesion to laminate.
	54	Intumescence.
	206	Burning from rear side of specimen.

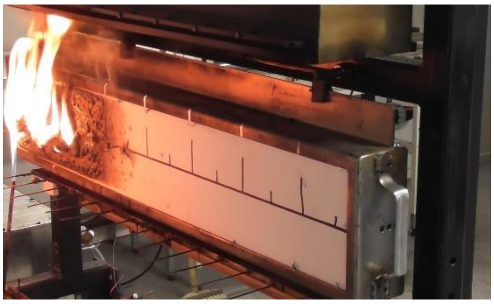
Photos



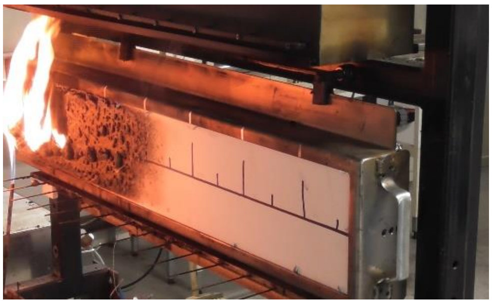
30 s of test time



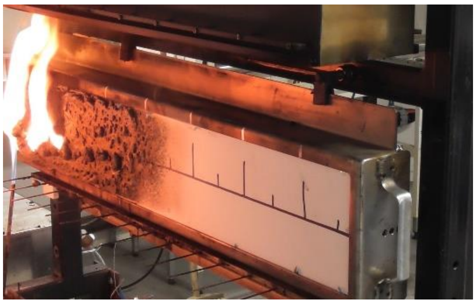
1 min of test time



2 min of test time



5 min of test time


7 min of test time


10 min of test time

12.2.26 Sample 29 – PET/Basalt/Polyester/Intumescent coating

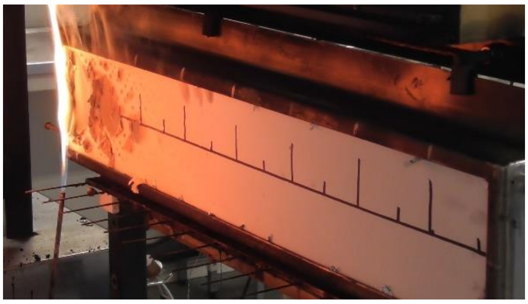
Sample description

Sandwich panel with upper laminate of polyester reinforced with basalt fibres, core of PET, and lower laminate of polyester reinforced with basalt fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 44.7 mm.

Test results

Test parameter	Test result	
CFE (kW/m^2)	39	
Q_{sb} (MJ/m^2)	2.6	
Q_p (kW)	3.1	
Q_t (MJ)	2.8	
Burning droplets	No	
Time to ignition (s)	26	
Time to flameout (s)	Not recorded	
Flame front went out (mm)	250	
Flame front went out (s)	70	
Events	**Time (s)**	
	9	Bubbles.
	10	Flakes of coating fell from the surface as they became warm due to bad adhesion to laminate.
	18	Intumescence.
	24	Burning from rear side of specimen.
	980	Melting.

Photos



30 s of test time

1 min of test time

2 min of test time

5 min of test time


7 min of test time


10 min of test time

12.2.27 Sample 32 – PVC/Basalt/PFA/Intumescent coating

Sample description

Sandwich panel with upper laminate of PFA reinforced with basalt fibres, core of PVC, and lower laminate of PFA reinforced with basalt fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 45.3 mm.

Test results

Test parameter	**Test result**	
CFE (kW/m^2)	7.0	
Q_{sb} (MJ/m^2)	4.0	
Q_p (kW)	5.2	
Q_t (MJ)	3.9	
Burning droplets	No	
Time to ignition (s)	66	
Time to flameout (s)	1524	
Flame front went out (mm)	550	
Flame front went out (s)	1296	
Events	**Time (s)**	
	63	Flashing at the surface.

Photos

No video was recorded during the test. No photos were taken.

12.2.28 Sample 34 – Balsa/Basalt/PFA

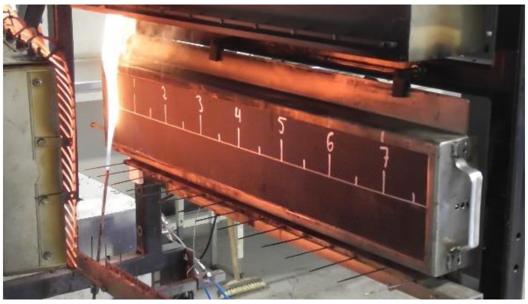
<u>Sample description</u>

Sandwich panel with upper laminate of PFA reinforced with basalt fibres, core of balsa, and lower laminate of PFA reinforced with basalt fibres. Nominal thickness of panel was 55.2 mm.

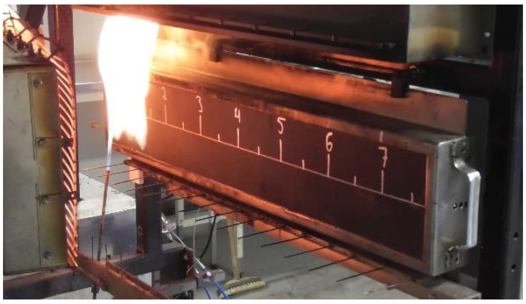
<u>Test results</u>

Test parameter	**Test result**	
CFE (kW/m^2)	17	
Q_{sb} (MJ/m^2)	3.3	
Q_p (kW)	3.0	
Q_t (MJ)	0.8	
Burning droplets	No	
Time to ignition (s)	28	
Time to flameout (s)	565	
Flame front went out (mm)	420	
Flame front went out (s)	340	
Events	**Time (s)**	
	74	Flashing in surface.
	346	Flashing at flame front.

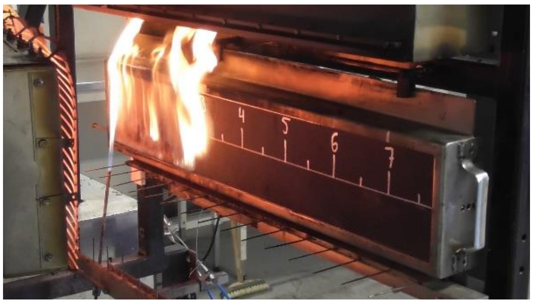
<u>Photos</u>



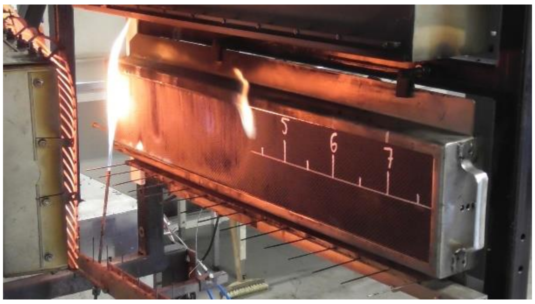
30 s of test time



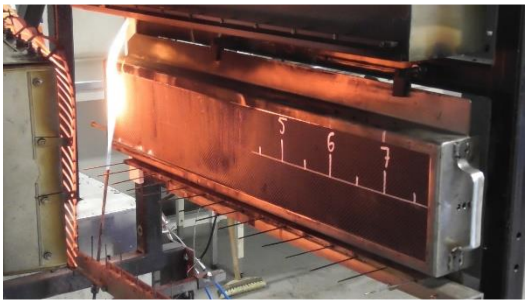
1 min of test time



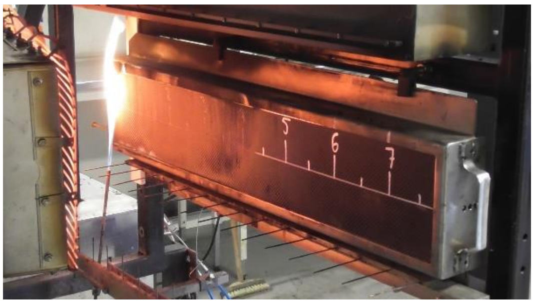
2 min of test time



5 min of test time



7 min of test time



10 min of test time

12.2.29 Sample 35 – Balsa/Basalt/PFA/Intumescent coating

Sample description

Sandwich panel with upper laminate of PFA reinforced with basalt fibres, core of balsa, and lower laminate of PFA reinforced with basalt fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 56.1 mm.

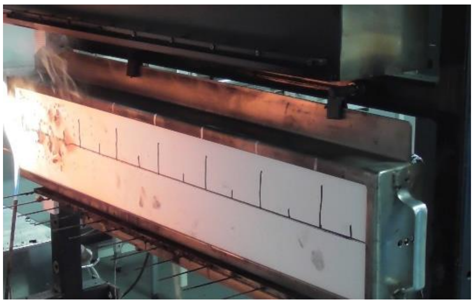
Test results

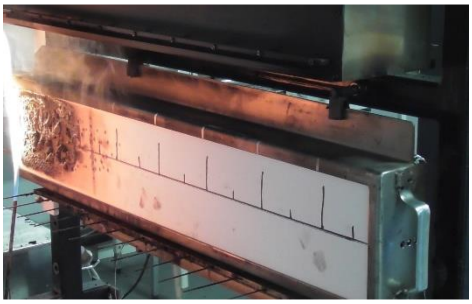
Test parameter	Test result	
CFE (kW/m^2)	48	
Q_{sb} (MJ/m^2)	-*	
Q_p (kW)	0.0	
Q_t (MJ)	0.0	
Burning droplets	No	
Time to ignition (s)	40	
Time to flameout (s)	74	
Flame front went out (mm)	-**	
Flame front went out (s)	-	
Events	**Time (s)**	
	7	Bubbles.
	8	Charring.
	28	Intumescence.
	30	Flakes of coating fell from the surface as they became warm due to bad adhesion to laminate.

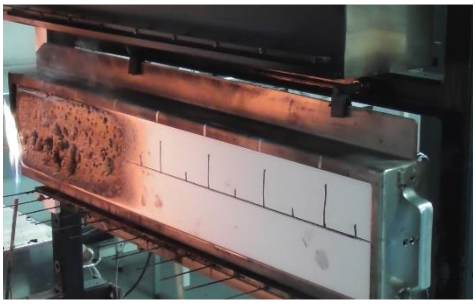
* Not recorded since the flame front did not reach the 175 mm mark.

** Flame front did not reach the 50 mm mark.

Photos

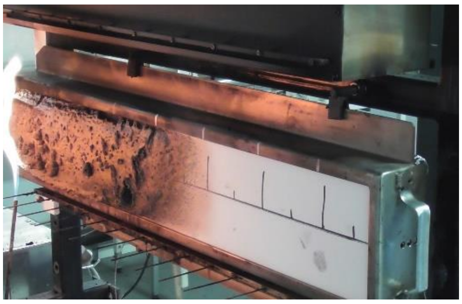

30 s of test time


1 min of test time


2 min of test time


5 min of test time


7 min of test time


10 min of test time

12.2.30 Sample 36 – Balsa/Basalt/PFA/Intumescent integrated fabric

Sample description

Sandwich panel with upper laminate of PFA reinforced with basalt fibres, core of balsa, and lower laminate of PFA reinforced with basalt fibres. An intumescent fabric was integrated in the lower laminate. Nominal thickness of panel was 56.9 mm.

Test results

Test parameter	Test result	
CFE (kW/m^2)	32	
Q_{sb} (MJ/m^2)	2.8	
Q_p (kW)	0.3	
Q_t (MJ)	0.0	
Burning droplets	No	
Time to ignition (s)	54	
Time to flameout (s)	161	
Flame front went out (mm)	300	
Flame front went out (s)	83	
Events	**Time (s)**	
	10	Intumescence in the coating.
	21	Flashing at the surface.
	35	Ash falls from the specimen.

Photos

No video was recorded during the test. No photos were taken.

12.3 ANNEX C – Test results IMO Part 2, Smoke and toxicity

Below are the test results detailed of all tested samples according to IMO FTP Code Part 2, Smoke and toxicity. The results are presented for each sample separately.

12.3.1 Sample 1 – Glass/polyester

Sample description

Single laminate of glass fibre reinforced polyester with nominal thickness 2.6 mm.

Test results

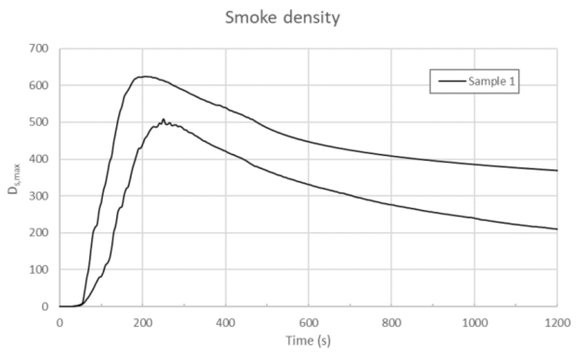
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

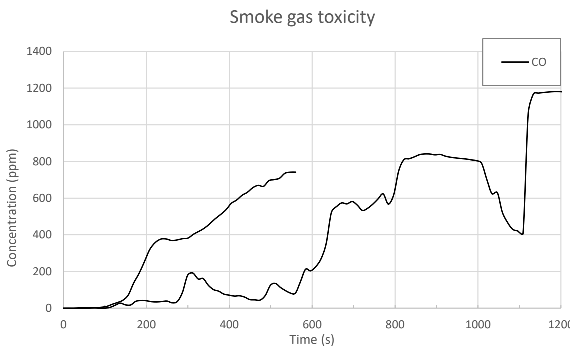
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
1	Glass/polyester	A	NI	-	624	205
		B	119	373	509	250
		mv	-	-	566	228

The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
1	Glass/polyester	A	205	36	<3	<5	<10	<5	<10	<20
		B	250	379	<3	<5	<10	<5	<10	<20
		mv	228	208	<3	<5	<10	<5	<10	<20

Graphs





12.3.2 Sample 2 – Glass/Polyester/Intumescent Coating

Sample description

Single laminate of glass fibre reinforced polyester coated with intumescent coating. Nominal thickness of laminate was 2.9 mm.

Test results

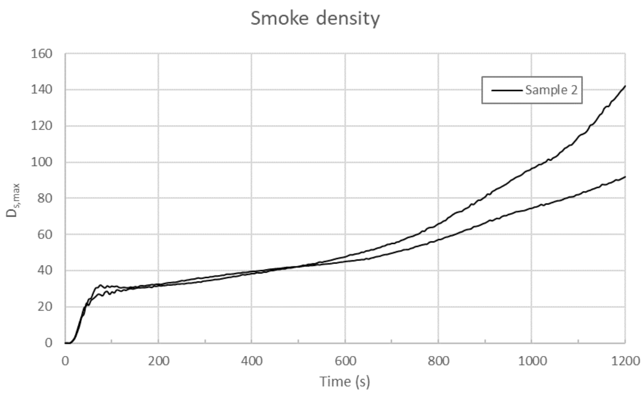
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

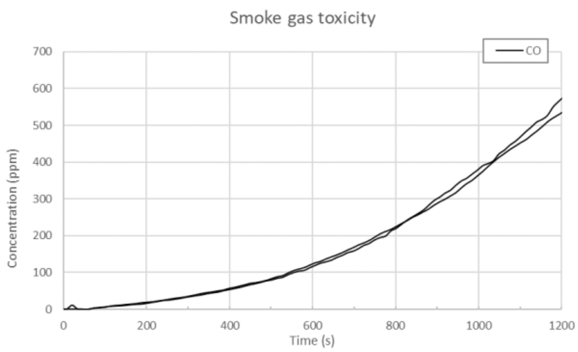
Material		Test	t ignition (s)	t extinguishment (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
2	Glass/Polyester/Intumescent Coating	A	NI	-	142	1200
		B	862	1200	92	1200
		mv	-	-	117	1200

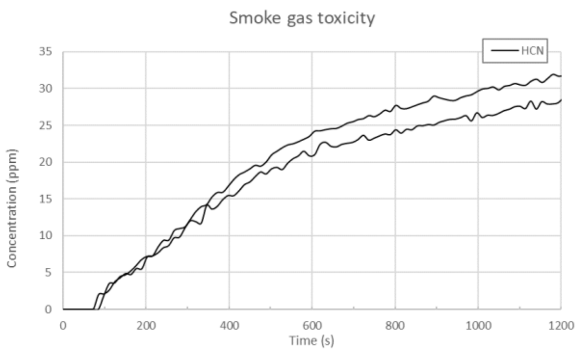
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
2	Glass/Polyester/Intumescent Coating	A	1200	578	29	<5	<10	<5	<10	<20
		B	1200	559	32	<5	<10	<5	<10	<20
		mv	1200	569	31	<5	<10	<5	<10	<20

Graphs







12.3.3 Sample 3 – Glass/Epoxy/Intumescent integrated fabric

Sample description

Single laminate of glass fibre reinforced epoxy with intumescent integrated fabric, nominal thickness was 2.9 mm.

Test results

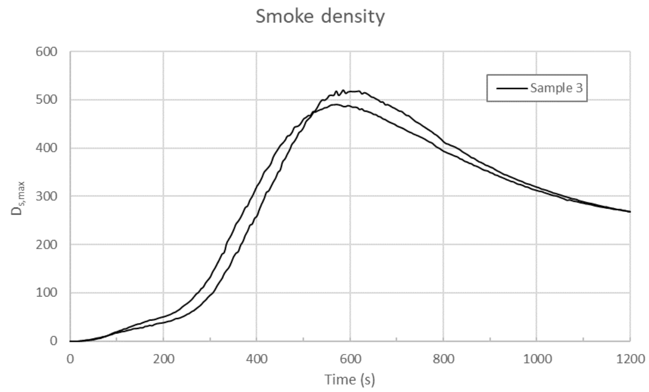
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

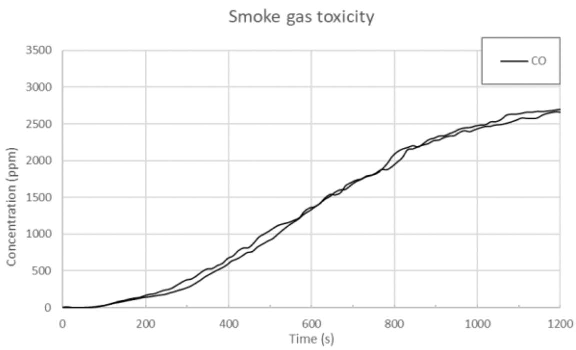
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
3	Glass/Epoxy/Int. Fabric	A	NI	-	490	570
		B	NI	-	520	585
		mv	-	-	505	578

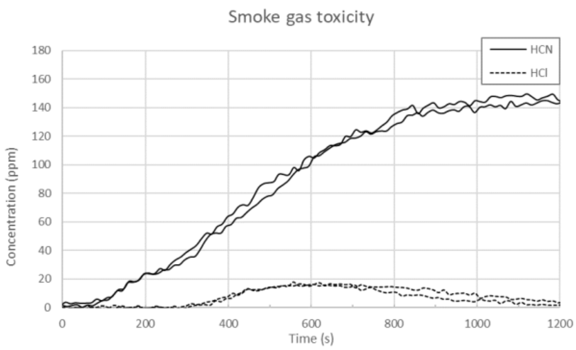
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
3	Glass/Epoxy/Int. Fabric	A	570	1374	105	16	<10	<5	<10	<20
		B	585	1472	109	16	<10	<5	<10	<20
		mv	578	1423	107	16	<10	<5	<10	<20

Graphs







12.3.4 Sample 4 – Glass/Polyester/Intumescent gelcoat

Sample description

Single laminate with glass fibre reinforced polyester, surface treated with an intumescent gelcoat. Nominal thickness of laminate was 3.2 mm.

Test results

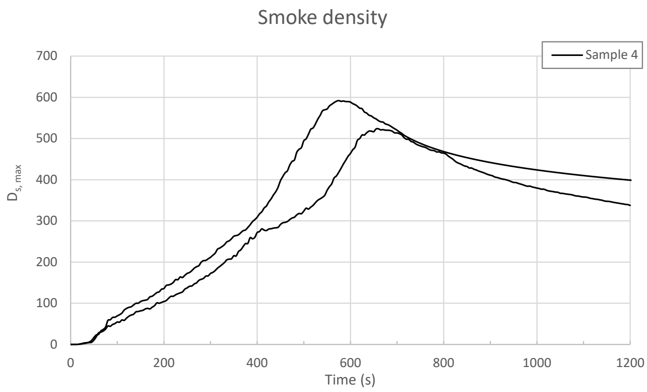
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

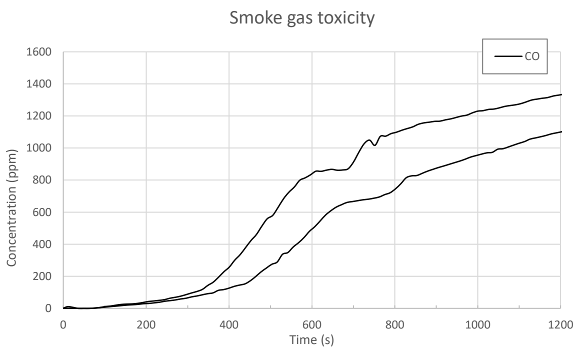
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
4	Glass/Polyester/Intumescent gelcoat	A	404	793	523	660
		B	385	696	592	575
		mv	395	745	558	618

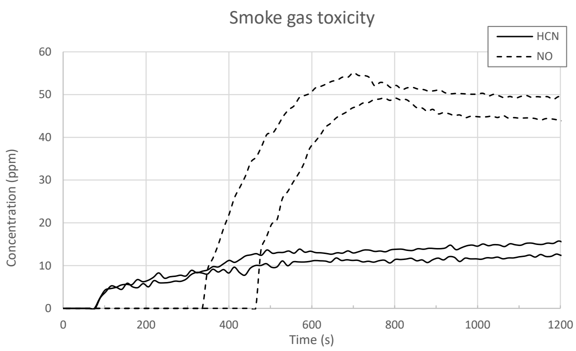
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material	Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
Glass/Polyester/Intumescent gelcoat	A	660	666	11	<5	<10	<5	<10	47
	B	575	856	13	<5	<10	<5	<10	52
	mv	618	761	12	<5	<10	<5	<10	50

Graphs







12.3.5 Sample 7 – Basalt/Epoxy

Sample description

Single laminate with basalt fibre reinforced epoxy with a nominal thickness of 2.3 mm.

Test results

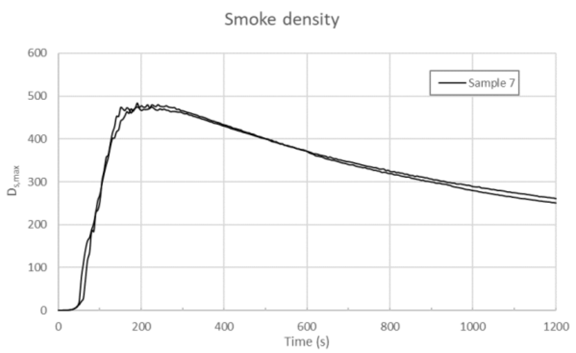
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

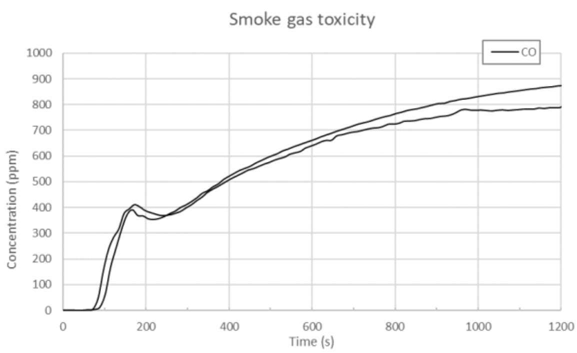
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
7	Basalt/Epoxy	A	47	394	480	240
		B	59	429	483	190
		mv	53	412	482	215

The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
7	Basalt/Epoxy	A	240	385	<3	<5	<10	<5	<10	<20
		B	190	353	<3	<5	<10	<5	<10	<20
		mv	215	369	<3	<5	<10	<5	<10	<20

Graphs





12.3.6 Sample 8 – Basalt/Epoxy/Intumescent coating

Sample description

Single laminate of basalt fibre reinforced epoxy coated with intumescent coating. Nominal thickness of laminate was 2.7 mm.

Test results

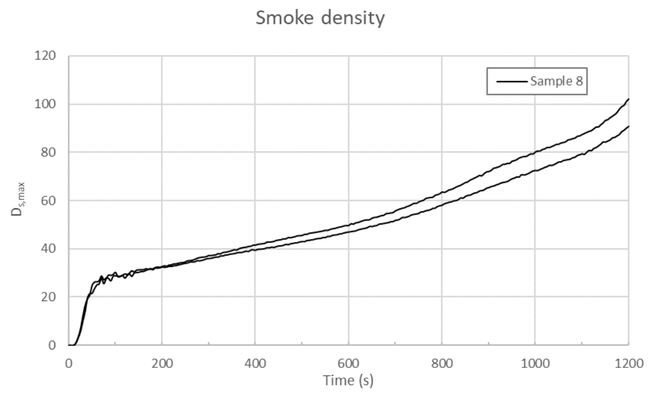
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

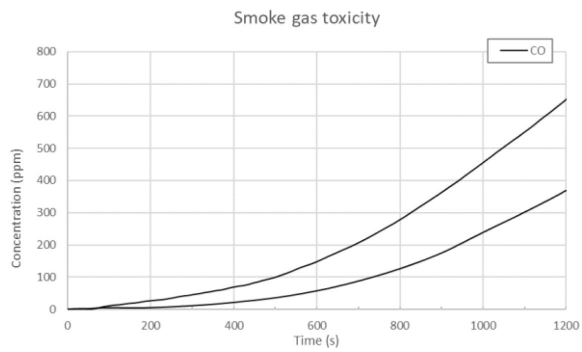
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
8	Basalt/Epoxy/Intumescent coating	A	NI	-	102	1200
		B	NI	-	91	1200
		mv	-	-	96	1200

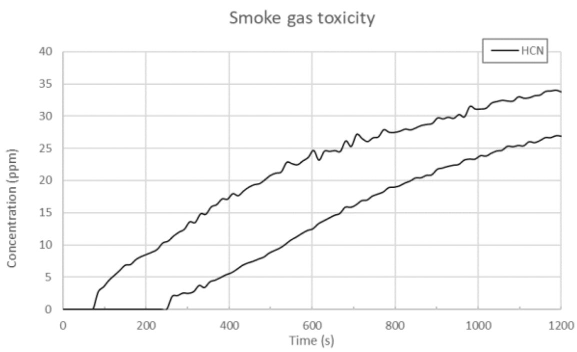
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
8	Basalt/Epoxy/Intumescent coating	A	1200	407	27	<5	<10	<5	<10	<20
		B	1200	640	34	<5	<10	<5	<10	<20
		mv	1200	524	31	<5	<10	<5	<10	<20

Graphs







12.3.7 Sample 9 – Basalt/Polyester/Intumescent integrated fabric

Sample description

Single laminate of basalt fibre reinforced polyester with intumescent integrated fabric, nominal thickness was 3.7 mm.

Test results

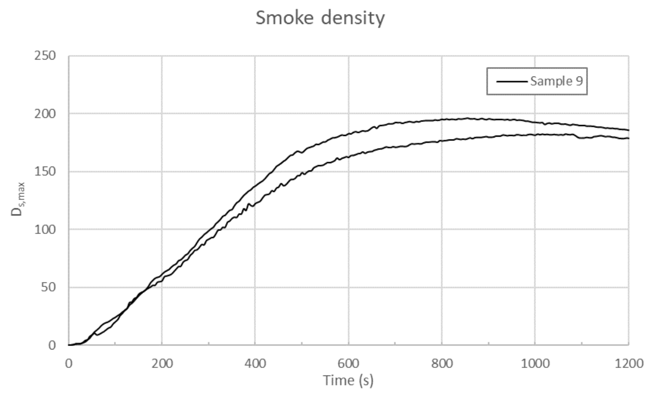
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

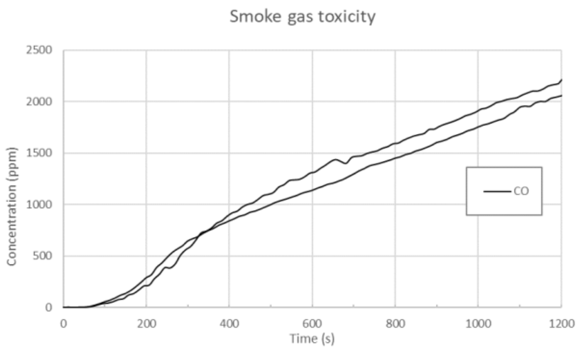
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
9	Basalt/Polyester/Intumescent integrated fabric	A	32	189	182	1065
		B	26	245	196	855
		mv	29	217	189	960

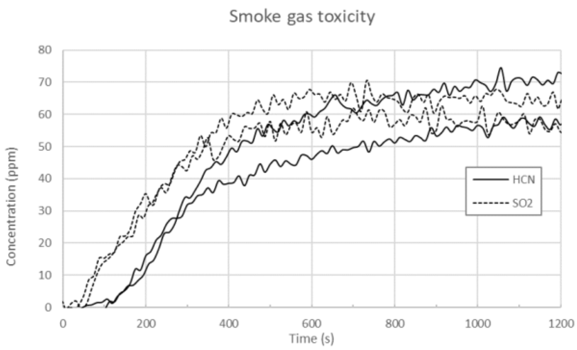
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
9	Basalt/Polyester/Intumescent integrated fabric	A	1065	1944	58	<5	<10	<5	58	<20
		B	855	1731	68	<5	<10	<5	60	<20
		mv	960	1838	63	<5	<10	<5	59	<20

Graphs







12.3.8 Sample 10 – Glass/PFA

Sample description

Single laminate with glass fibre reinforced PFA with a nominal thickness of 2.3 mm.

Test results

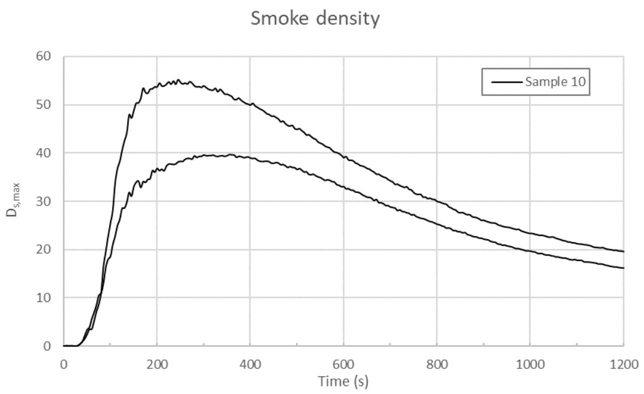
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

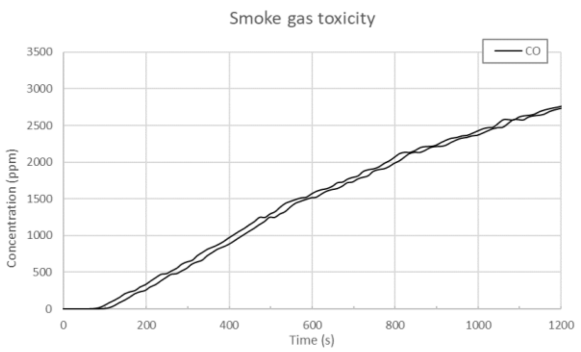
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
10	Glass/PFA	A	NI	-	55	245
		B	NI	-	40	355
		mv	-	-	47	300

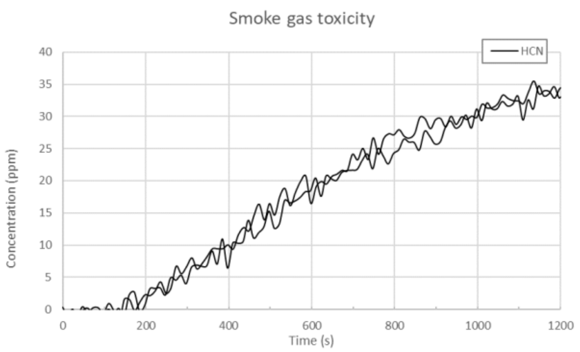
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
10	Glass/PFA	A	245	611	6	<5	<10	<5	<10	<20
		B	355	873	6	<5	<10	<5	<10	<20
		mv	300	742	6	<5	<10	<5	<10	<20

Graphs







12.3.9 Sample 11 – Basalt/PFA

Sample description

Single laminate with basalt fibre reinforced PFA with a nominal thickness of 2.2 mm.

Test results

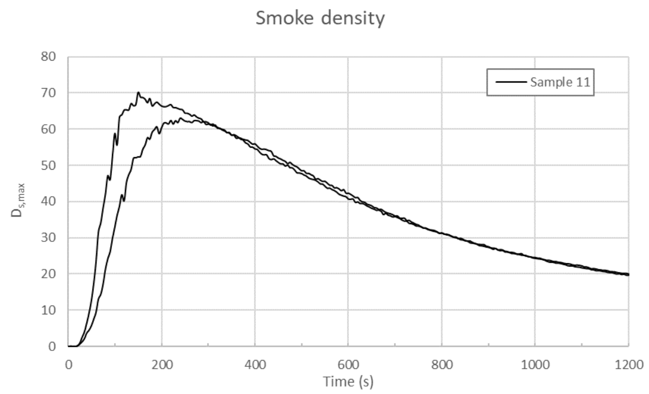
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

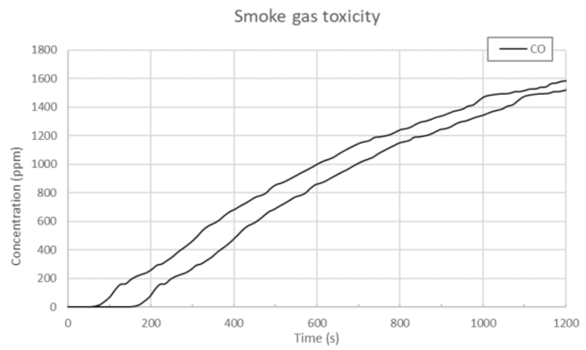
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
11	Basalt/PFA	A	NI	-	63	240
		B	NI	-	70	150
		mv	-	-	67	195

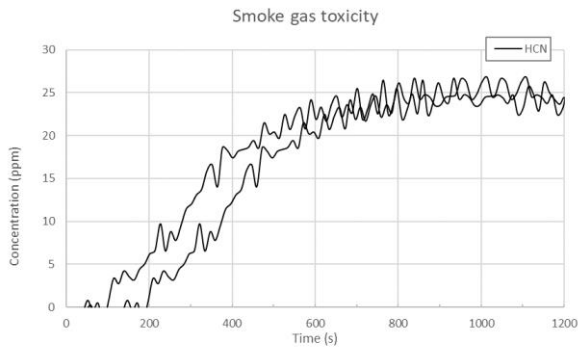
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
11	Basalt/PFA	A	240	382	8	<5	<10	<5	60	<20
		B	150	263	8	<5	<10	<5	60	<20
		mv	195	323	8	<5	<10	<5	60	<20

Graphs







12.3.10 Sample 12 – Basalt/PFA/Intumescent coating

Sample description

Single laminate of basalt fibre reinforced PFA coated with intumescent coating. Nominal thickness of laminate was 2.5 mm.

Test results

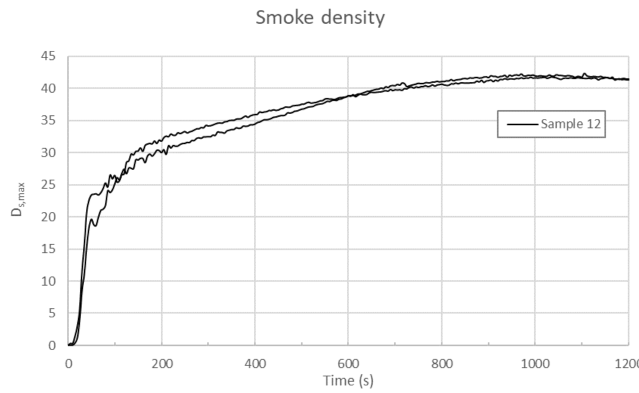
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

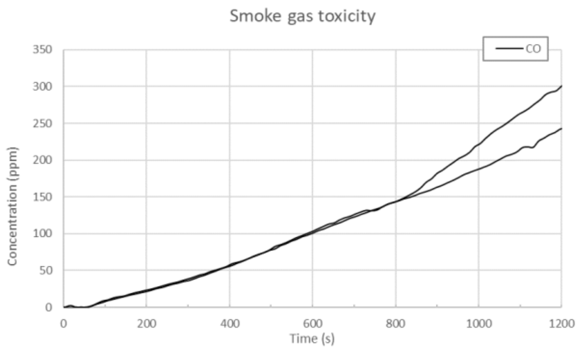
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
12	Basalt/PFA/Intumescent coating	A	NI	-	42	1035
		B	NI	-	42	1105
		mv	-	-	42	1070

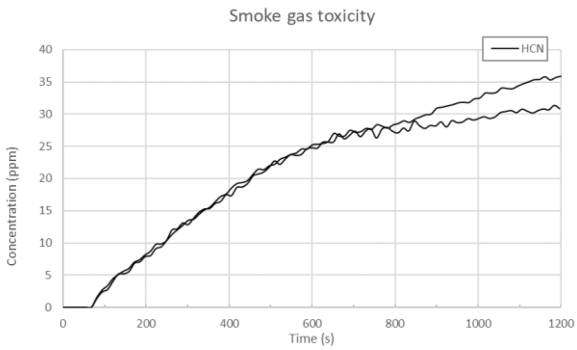
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
12	Basalt/PFA/Intumescent coating	A	1035	305	36	<5	<10	<5	<10	<20
		B	1105	218	30	<5	<10	<5	<10	<20
		mv	1070	262	33	<5	<10	<5	<10	<20

Graphs







12.3.11 Sample 13 – Basalt/PFA/Intumescent integrated fabric

Sample description

Single laminate of basalt fibre reinforced PFA with intumescent integrated fabric, nominal thickness was 3.5 mm.

Test results

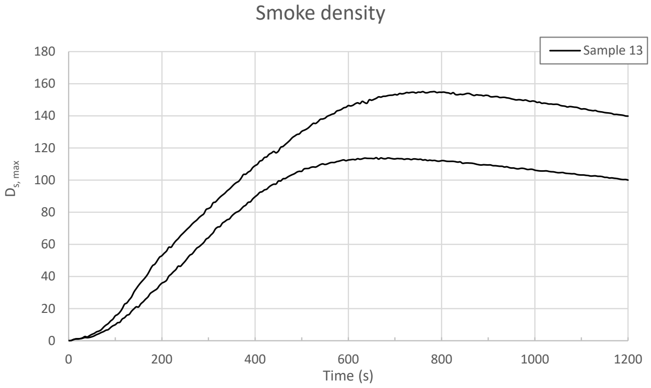
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

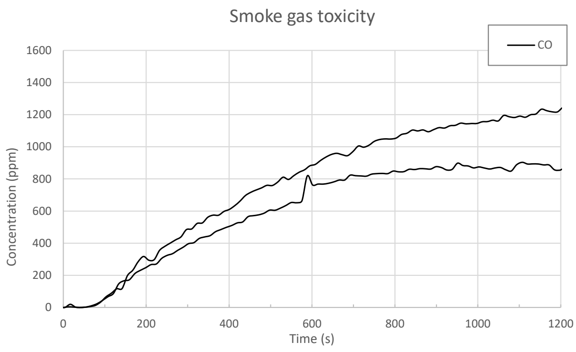
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
13	Basalt/PFA/Intumescent integrated fabric	A	NI	-	155	785
		B	40	62	114	660
		mv	-	-	135	723

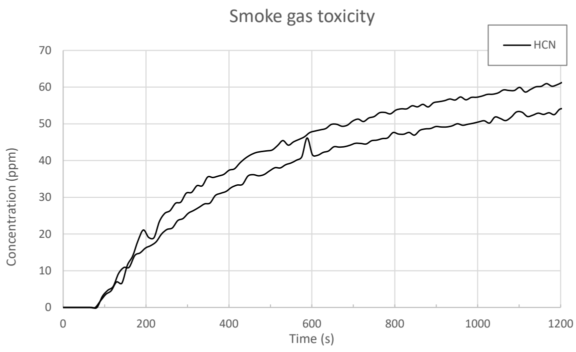
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
13	Basalt/PFA/Intumescent integrated fabric	A	785	1077	54	<5	<10	<5	<10	<20
		B	660	823	44	<5	<10	<5	<10	<20
		mv	723	950	49	<5	<10	<5	<10	<20

Graphs







12.3.12 Sample 14 – PVC/Glass/Polyester

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of PVC, and lower laminate of polyester reinforced with glass fibres. Nominal thickness of panel was 44.8 mm.

Test results

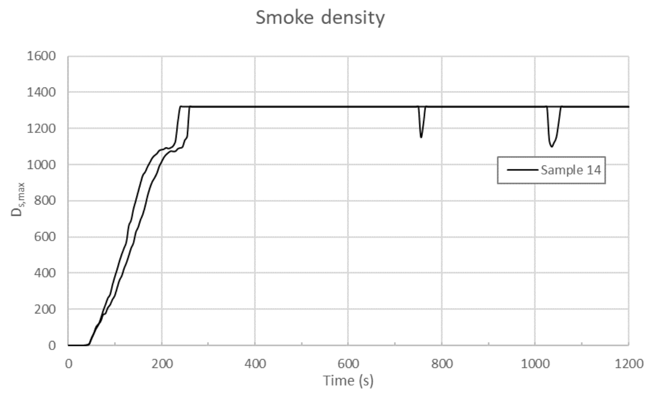
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

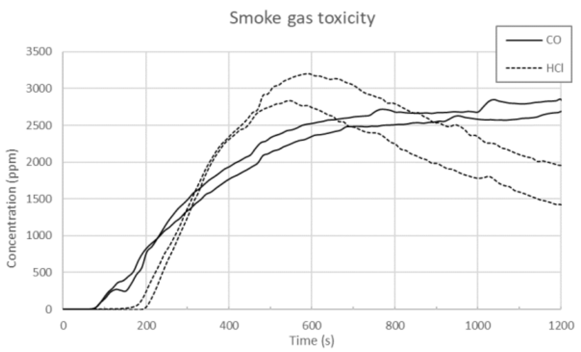
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
14	PVC/Glass/Polyester	A	43	1184	1320	260
		B	43	1160	1320	240
		mv	43	1172	1320	250

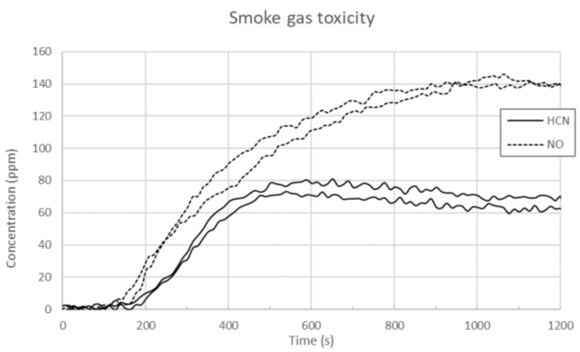
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
14	PVC/Glass/Polyester	A	260	1498	31	1275	<10	<5	<10	65
		B	240	1237	26	1138	<10	<5	<10	54
		mv	250	1368	29	1207	<10	<5	<10	60

Graphs







12.3.13 Sample 15 – PVC/Glass/Polyester/Intumescent coating

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of PVC, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 44.8 mm.

Test results

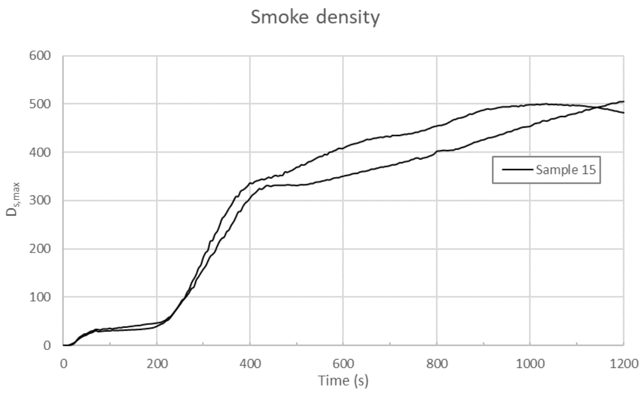
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

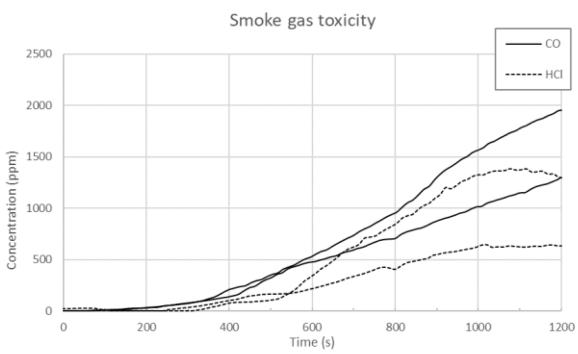
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
15	PVC/Glass/Polyester/Intumescent coating	A	408	1200	506	1200
		B	330	1200	500	1035
		mv	369	1200	503	1118

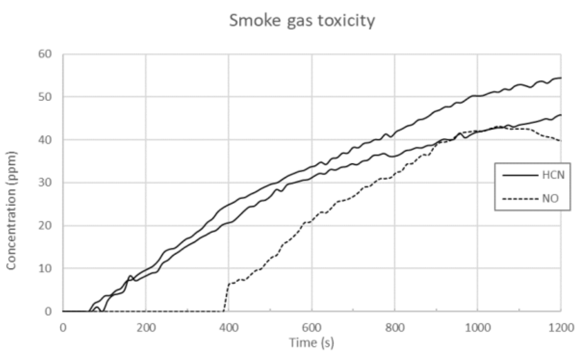
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
15	PVC/Glass/Polyester/Intumescent coating	A	1200	1077	39	617	<10	<5	<10	<20
		B	1035	1954	55	1289	<10	<5	<10	40
		mv	1118	1516	47	953	<10	<5	<10	40

Graphs







12.3.14 Sample 16 – PVC/Glass/Epoxy/Intumescent integrated fabric

Sample description

Sandwich panel with upper laminate of epoxy reinforced with glass fibres, core of PVC, and lower laminate of epoxy reinforced with glass fibres. An intumescent fabric was integrated in the lower laminate. Nominal thickness of panel was 44.1 mm.

Test results

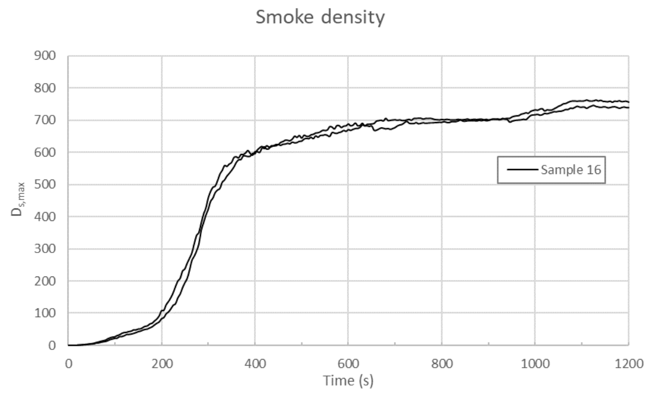
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

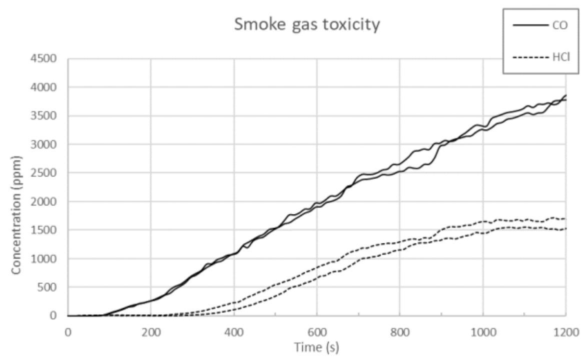
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
16	PVC/Glass/Epoxy/Intumescent integrated fabric	A	NI	-	763	1110
		B	NI	-	746	1125
		mv	-	-	754	1118

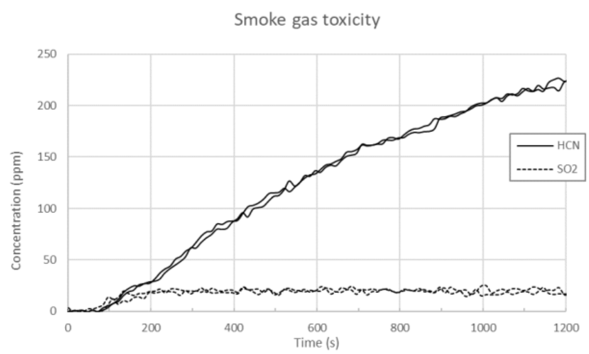
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
16	PVC/Glass/Epoxy/Intumescent integrated fabric	A	1110	3558	214	1656	<10	<5	20	<20
		B	1125	3698	218	1527	<10	<5	17	<20
		mv	1118	3628	216	1592	<10	<5	19	<20

Graphs







12.3.15 Sample 17 – PVC/Glass/Polyester/Intumescent gelcoat

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of PVC, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with a gelcoat. Nominal thickness of panel was 45.3 mm.

Test results

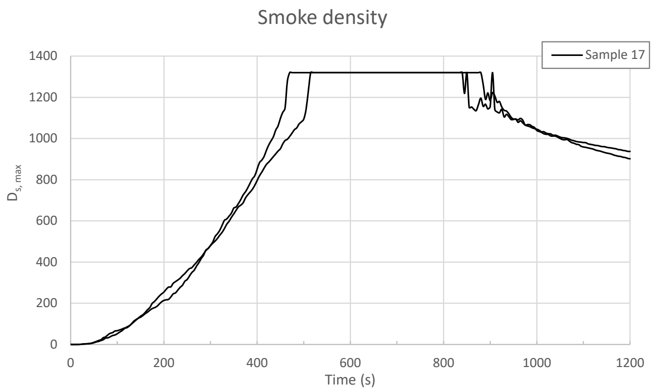
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

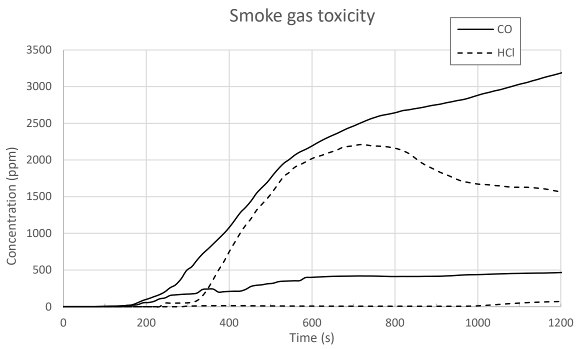
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
17	PVC/Glass/Polyester/	A	120	868	1320	515
	Intumescent gelcoat	B	125	1160	1320	470
		mv	123	1014	1320	493

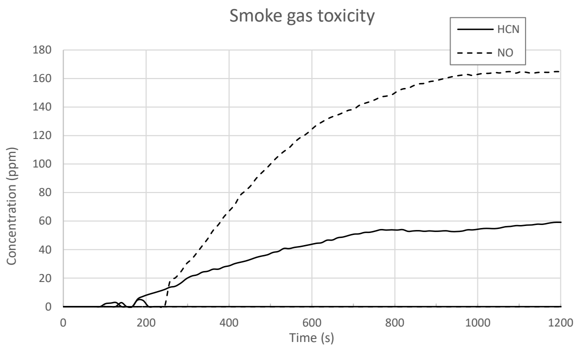
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
17	PVC/Glass/Polyester/	A	515	350	<3	9	<10	<5	<10	<20
	Intumescent gelcoat	B	470	1794	38	1574	<10	<5	<10	102
		mv	493	1072	38	792	<10	<5	<10	102

Graphs







12.3.16 Sample 18 – Balsa/Glass/Polyester

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of balsa, and lower laminate of polyester reinforced with glass fibres. Nominal thickness of panel was 42.8 mm.

Test results

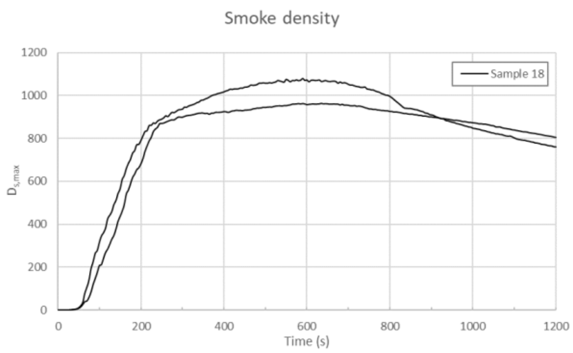
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

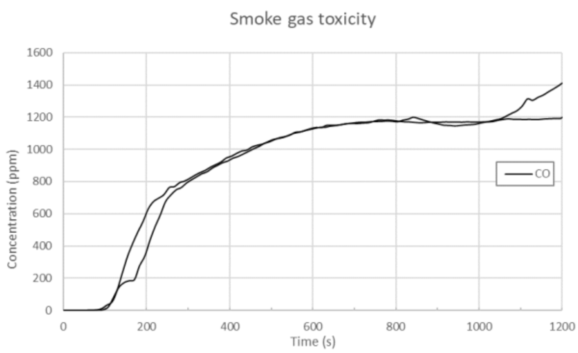
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
18	Balsa/Glass/Polyester	A	58	1115	1079	590
		B	73	1200	963	635
		mv	66	1158	1021	613

The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
18	Balsa/Glass/Polyester	A	590	1137	<3	<5	<10	<5	<10	<20
		B	635	1157	<3	<5	<10	<5	<10	<20
		mv	613	1147	<3	<5	<10	<5	<10	<20

Graphs





12.3.17 Sample 19 – Balsa/Glass/Polyester/Intumescent coating

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of balsa, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 43.1 mm.

Test results

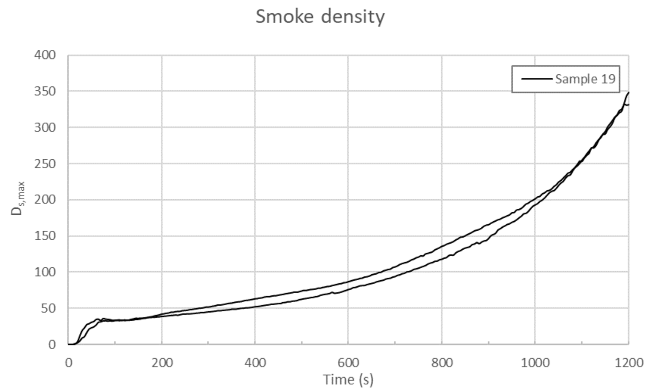
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

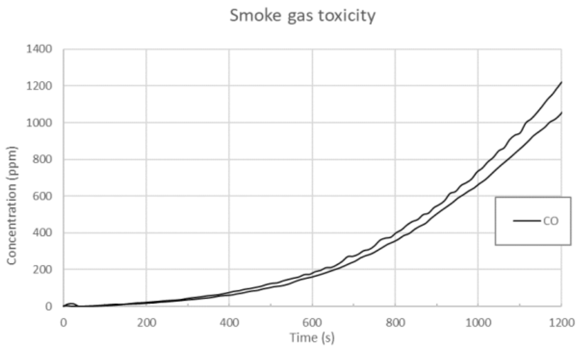
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
19	Balsa/Glass/Polyester/Intumescent coating	A	NI	-	349	1200
		B	1160	1200	332	1190
		mv	-	-	340	1195

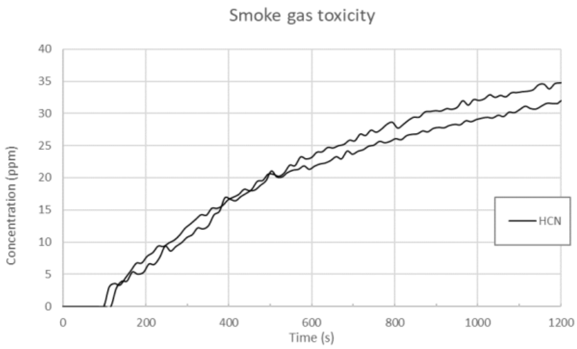
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
19	Balsa/Glass/Polyester/Intumescent coating	A	1200	1220	32	<5	<10	<5	<10	<20
		B	1190	1087	35	<5	<10	<5	<10	<20
		mv	1195	1154	34	<5	<10	<5	<10	<20

Graphs







12.3.18 Sample 20 – Balsa/Glass/Epoxy/Intumescent integrated fabric

Sample description

Sandwich panel with upper laminate of epoxy reinforced with glass fibres, core of balsa, and lower laminate of epoxy reinforced with glass fibres. An intumescent fabric was integrated in the lower laminate. Nominal thickness of panel was 42.7 mm.

Test results

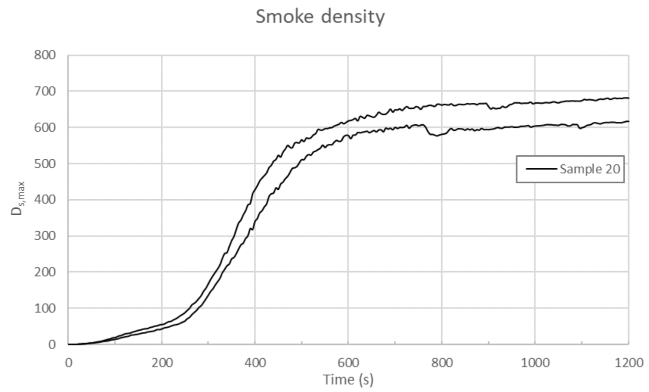
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

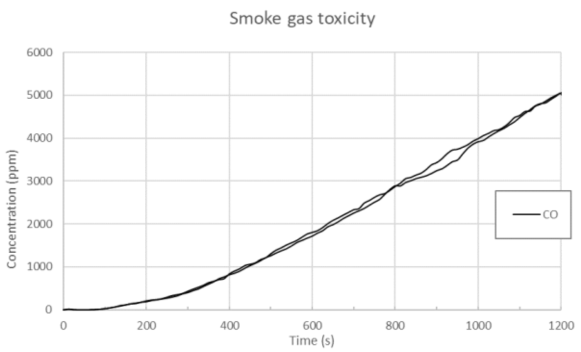
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
20	Balsa/Glass/Epoxy/ Intumescent integrated fabric	A	NI	-	681	1190
		B	NI	-	616	1200
		mv	-	-	649	1195

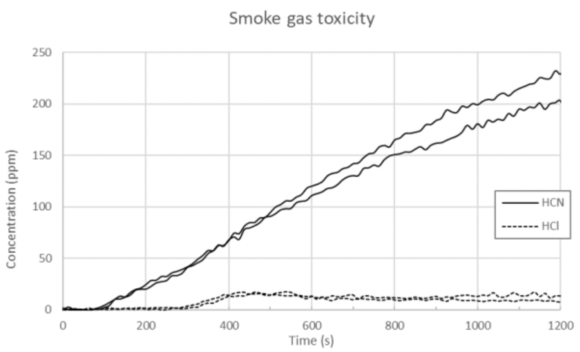
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
20	Balsa/Glass/Epoxy/ Intumescent integrated fabric	A	1190	5124	238	14	<10	<5	<10	<20
		B	1200	4704	189	9	<10	<5	<10	<20
		mv	1195	4914	214	12	<10	<5	<10	<20

Graphs







12.3.19 Sample 21 – Balsa/Glass/Polyester/Intumescent gelcoat

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of balsa, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with a gelcoat. Nominal thickness of panel was 42.9 mm.

Test results

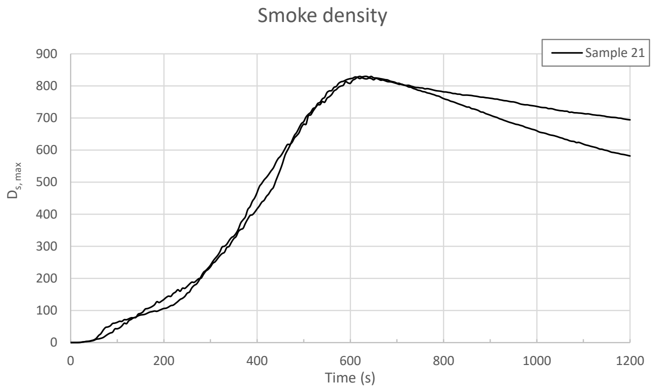
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

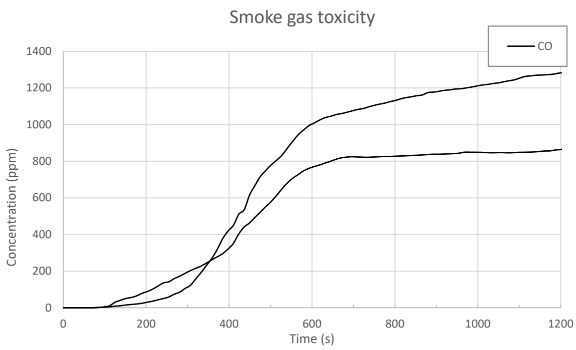
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
21	(Glass/Polyester)/Balsa/	A	229	1200	830	635
	(Glass/Polyester)/Intumescent	B	72	1200	827	615
	gelcoat	mv	151	1200	828	625

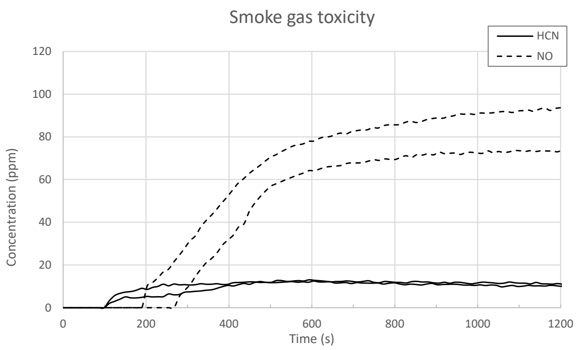
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
21	(Glass/Polyester)/Balsa/	A	635	1060	12	<5	<10	<5	<10	67
	(Glass/Polyester)/Intumescent	B	615	798	12	<5	<10	<5	<10	80
	gelcoat	mv	625	929	12	<5	<10	<5	<10	74

Graphs







12.3.20 Sample 22 – PET/Glass/Polyester/Intumescent coating

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of PET, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 45.0 mm.

Test results

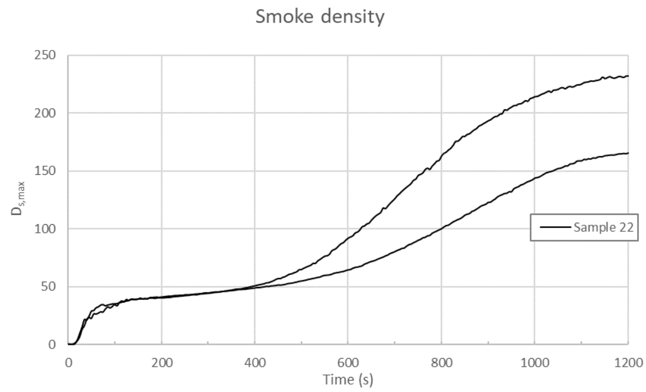
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

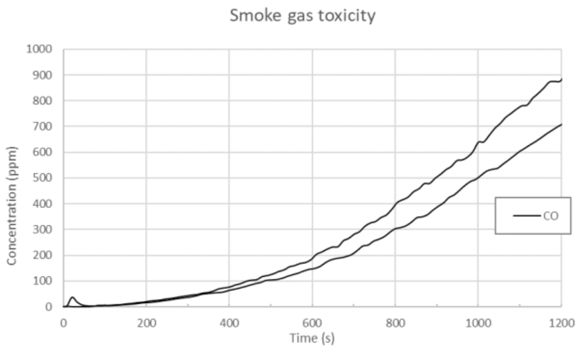
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
22	PET/Glass/Polyester/Intumescent coating	A	NI	-	166	1200
		B	NI	-	232	1200
		mv	-	-	199	1200

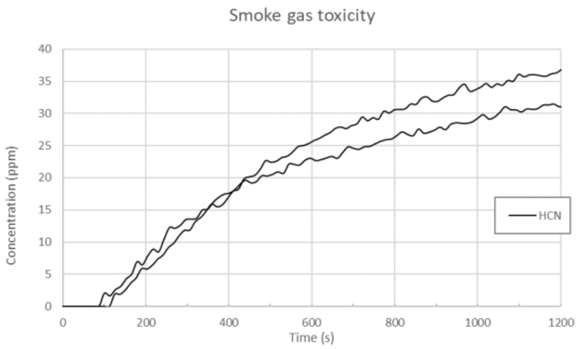
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
22	PET/Glass/Polyester/Intumescent coating	A	1200	710	37	<5	<10	<5	<10	<20
		B	1200	905	31	<5	<10	<5	<10	<20
		mv	1200	808	34	<5	<10	<5	<10	<20

Graphs







12.3.21 Sample 24 – PIR/Glass/Polyester/Intumescent coating

Sample description

Sandwich panel with upper laminate of polyester reinforced with glass fibres, core of PIR, and lower laminate of polyester reinforced with glass fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 45.4 mm.

Test results

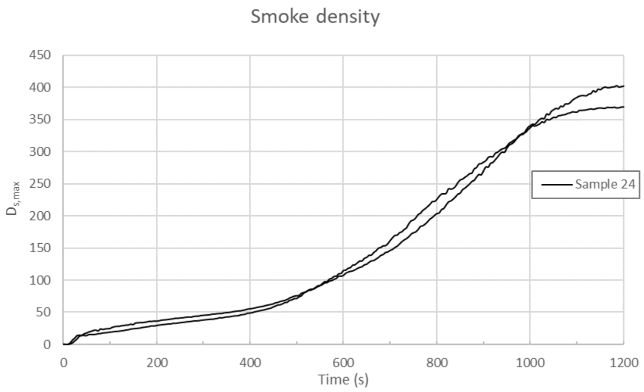
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

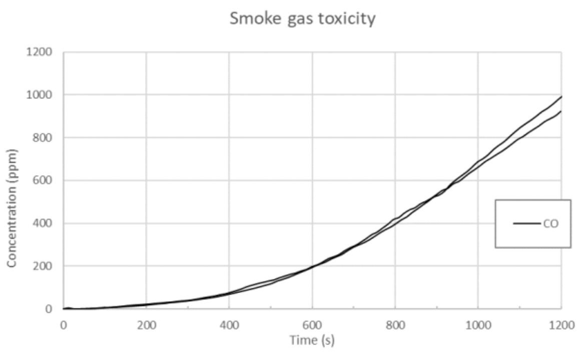
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
24	PIR/Glass/Polyester/Intumescent coating	A	NI	-	402	1185
		B	860	1200	369	1200
		mv	-	-	386	1193

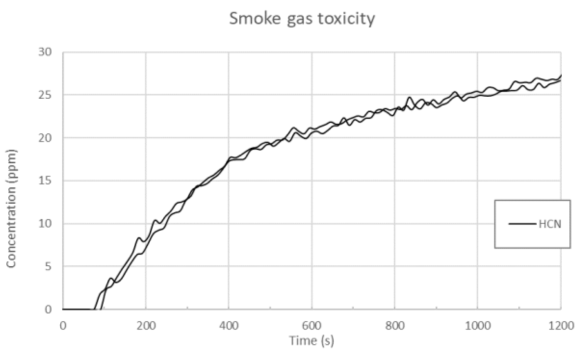
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
24	PIR/Glass/Polyester/Intumescent coating	A	1185	999	28	<5	<10	<5	<10	<20
		B	1200	925	27	<5	<10	<5	<10	<20
		mv	1193	962	28	<5	<10	<5	<10	<20

Graphs







12.3.22 Sample 25 – Balsa/Glass/PFA

Sample description

Sandwich panel with upper laminate of PFA reinforced with glass fibres, core of balsa, and lower laminate of PFA reinforced with glass fibres. Nominal thickness of panel was 42.5 mm.

Test results

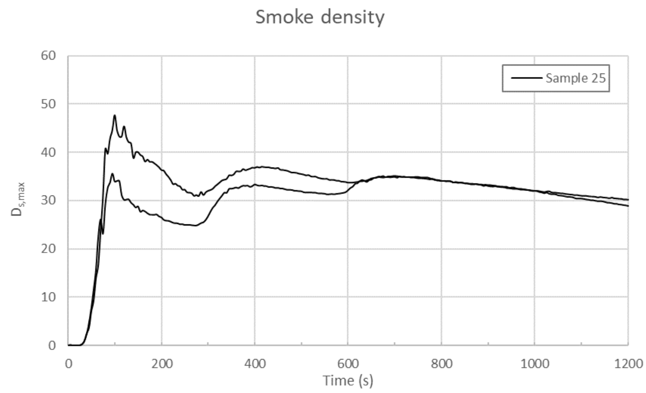
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

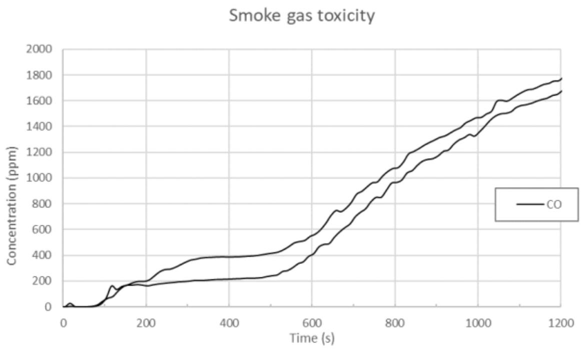
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
25	Balsa/Glass/PFA	A	65	597	36	95
		B	77	628	48	100
		mv	71	513	42	98

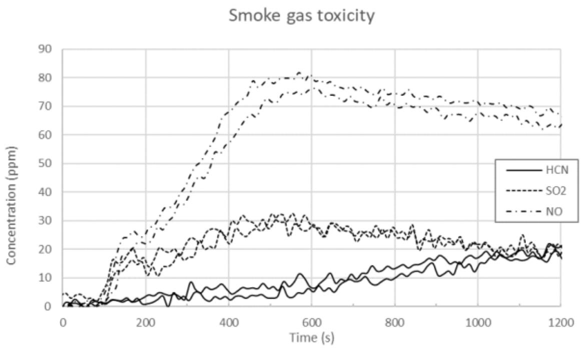
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
25	Balsa/Glass/PFA	A	95	121	<3	<5	<10	<5	<10	<20
		B	100	158	<3	<5	<10	<5	<10	<20
		mv	98	140	<3	<5	<10	<5	<10	<20

Graphs







12.3.23 Sample 26 – Balsa/Glass/PFA/Intumescent coating

Sample description

Sandwich panel with upper laminate of PFA reinforced with glass fibres, core of balsa, and lower laminate of PFA reinforced with glass fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 42.7 mm.

Test results

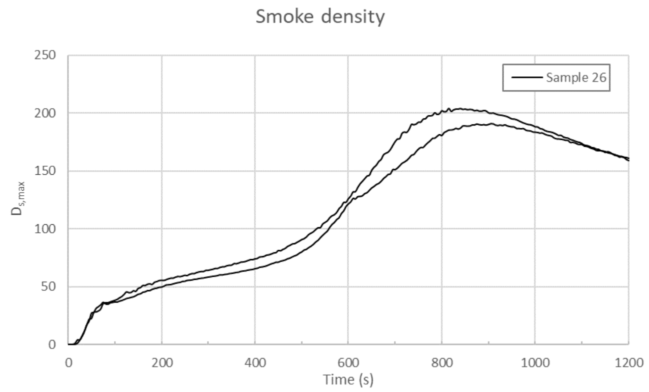
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

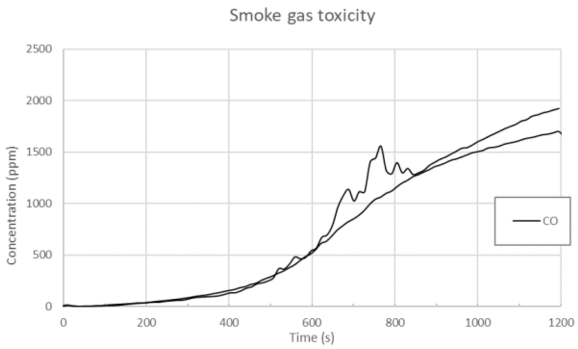
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
26	Balsa/Glass/PFA/Intumescent coating	A	NI	-	204	815
		B	NI	-	191	905
		mv	-	-	197	860

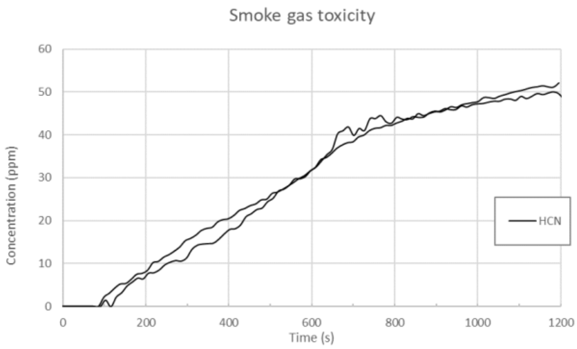
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
26	Balsa/Glass/PFA/Intumescent coating	A	815	1199	43	<5	<10	<5	<10	<20
		B	905	1480	47	<5	<10	<5	<10	<20
		mv	860	1340	45	<5	<10	<5	<10	<20

Graphs







12.3.24 Sample 27 – PVC/Basalt/Polyester/Intumescent coating

Sample description

Sandwich panel with upper laminate of polyester reinforced with basalt fibres, core of PVC, and lower laminate of polyester reinforced with basalt fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 44.4 mm.

Test results

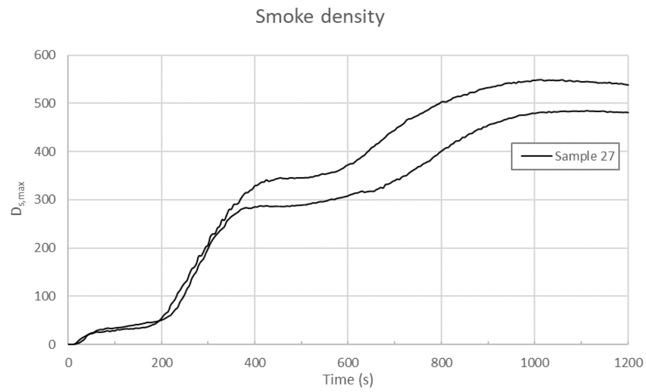
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

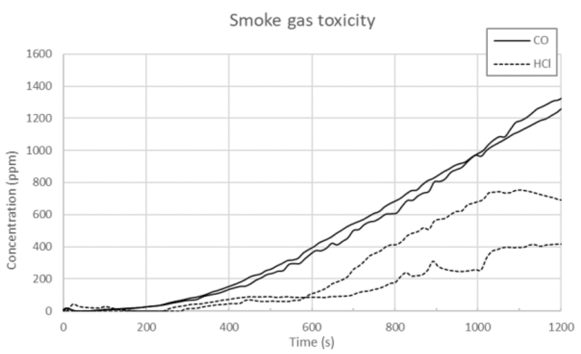
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
27	PVC/Basalt/Polyester/Intumescent coating	A	NI	-	548	1010
		B	810	1200	485	1110
		mv	-	-	517	1060

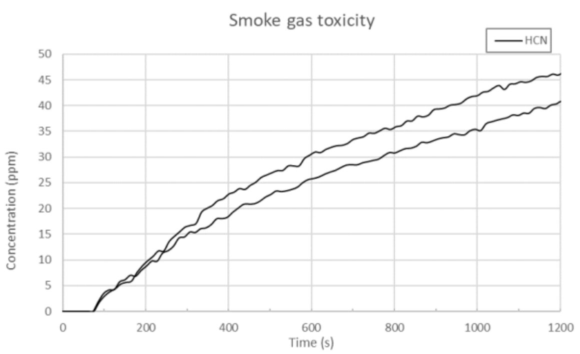
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
27	PVC/Basalt/Polyester/Intumescent coating	A	1010	1043	37	382	<10	<5	<10	<20
		B	1110	1259	45	732	<10	<5	<10	<20
		mv	1060	1151	41	557	<10	<5	<10	<20

Graphs







12.3.25 Sample 28 – Balsa/Basalt/Polyester/Intumescent coating

Sample description

Sandwich panel with upper laminate of polyester reinforced with basalt fibres, core of balsa, and lower laminate of polyester reinforced with basalt fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 42.4 mm.

Test results

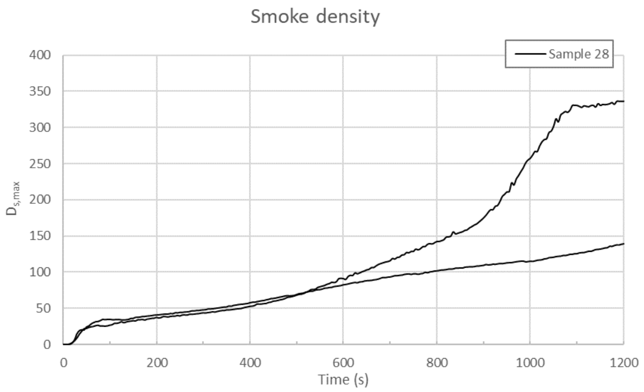
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

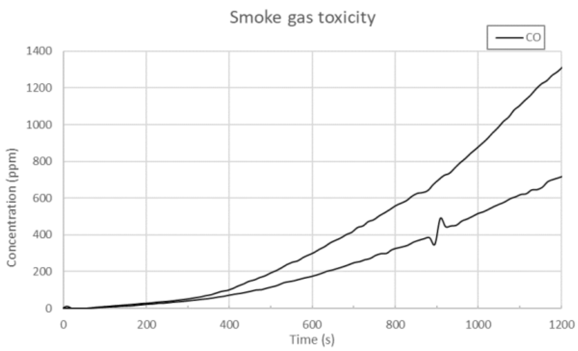
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
28	Balsa/Basalt/Polyester/Intumescent coating	A	850	1200	337	1200
		B	NI	-	139	1200
		mv	-	-	238	1200

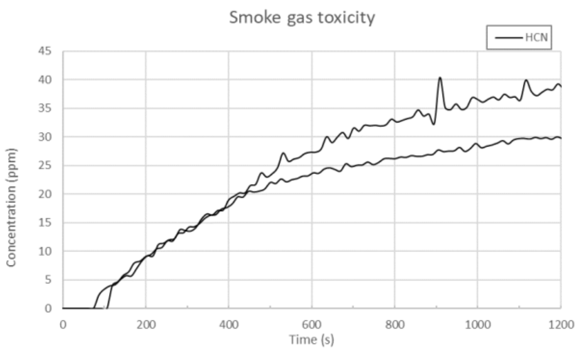
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
28	Balsa/Basalt/Polyester/ Intumescent coating	A	1200	1316	30	<10	<10	<5	<10	<20
		B	1200	724	39	<10	<10	<5	<10	<20
		mv	1200	1020	35	<10	<10	<5	<10	<20

Graphs







12.3.26 Sample 29 – PET/Basalt/Polyester/Intumescent coating

Sample description

Sandwich panel with upper laminate of polyester reinforced with basalt fibres, core of PET, and lower laminate of polyester reinforced with basalt fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 44.7 mm.

Test results

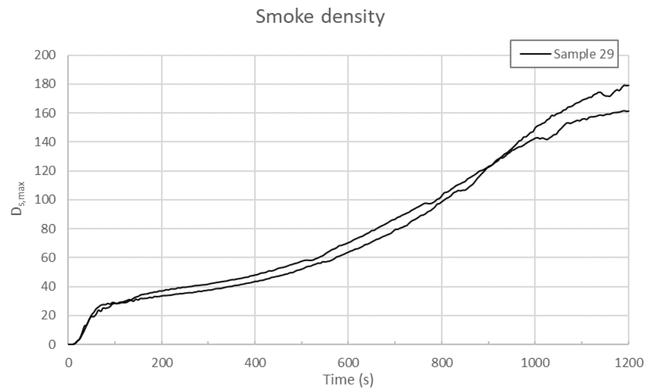
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

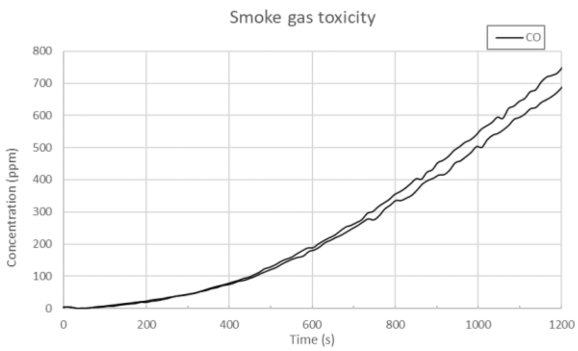
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
29	PET/Basalt/Polyester/Intumescent coating	A	NI	-	162	1190
		B	NI	-	179	1200
		mv	-	-	170	1195

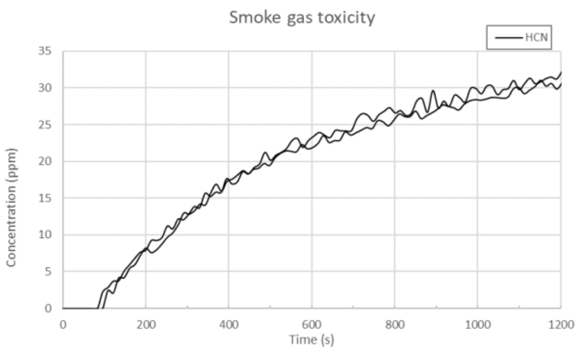
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
29	PET/Basalt/Polyester/Intumescent coating	A	1190	691	32	<10	<10	<5	<10	<20
		B	1200	751	31	<10	<10	<5	<10	<20
		mv	1195	721	32	<10	<10	<5	<10	<20

Graphs







12.3.27 Sample 32 – PVC/Basalt/PFA/Intumescent coating

Sample description

Sandwich panel with upper laminate of PFA reinforced with basalt fibres, core of PVC, and lower laminate of PFA reinforced with basalt fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 45.3 mm.

Test results

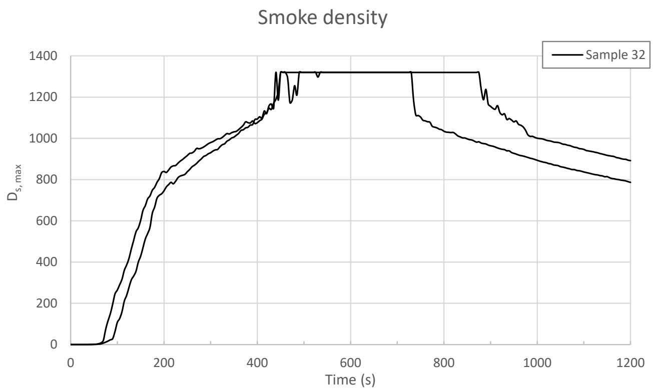
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

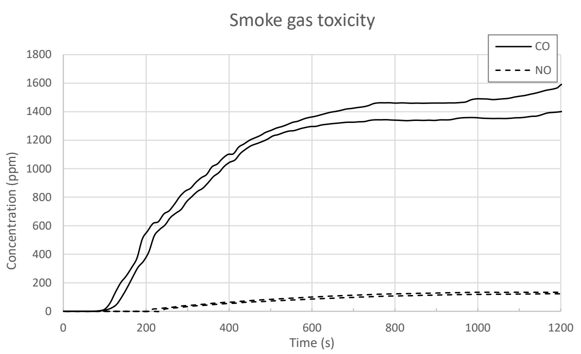
Material	Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
	A	67	1200	1320	450
	B	90	1200	1320	440
	mv	79	1200	1320	445

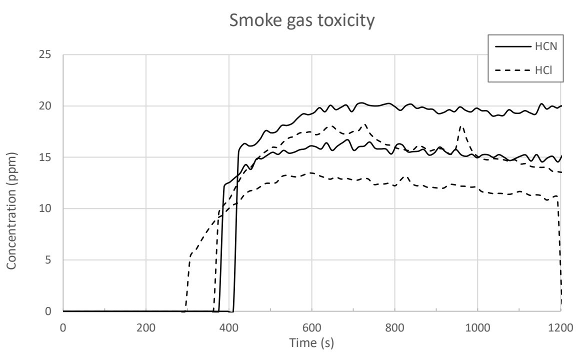
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material	Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
	A	450	1255	18	12	<10	<5	<10	82
	B	440	1175	15	15	<10	<5	<10	67
	mv	445	1215	17	14	<10	<5	<10	75

Graphs







12.3.28 Sample 34 – Balsa/Basalt/PFA

Sample description

Sandwich panel with upper laminate of PFA reinforced with basalt fibres, core of balsa, and lower laminate of PFA reinforced with basalt fibres. Nominal thickness of panel was 55.2 mm.

Test results

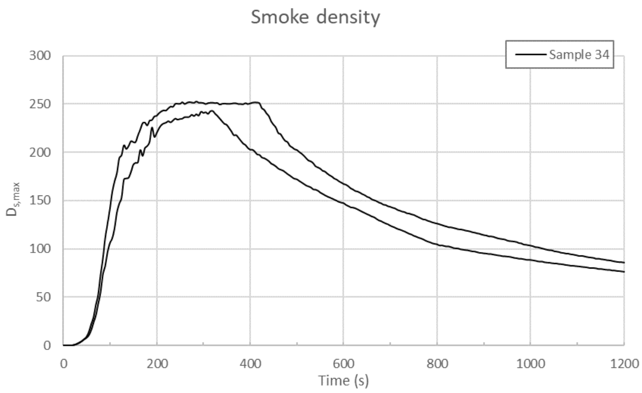
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

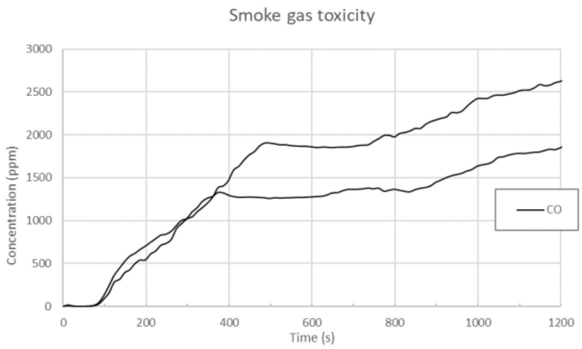
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
34	Balsa/Basalt/PFA	A	322	800	243	320
		B	416	822	253	285
		mv	369	811	248	303

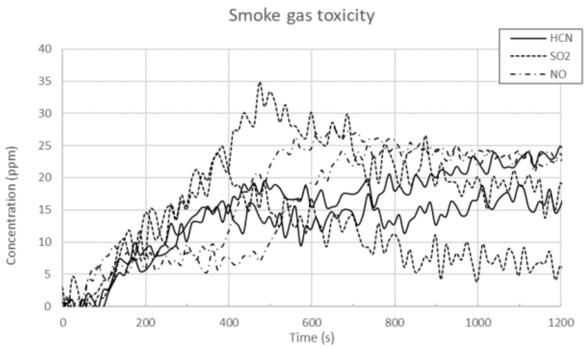
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
34	Balsa/Basalt/PFA	A	320	1280	15	<10	<10	<5	23	<20
		B	285	1106	13	<10	<10	<5	21	<20
		mv	303	1193	14	<10	<10	<5	22	<20

Graphs







12.3.29 Sample 35 – Balsa/Basalt/PFA/Intumescent coating

Sample description

Sandwich panel with upper laminate of PFA reinforced with basalt fibres, core of balsa, and lower laminate of PFA reinforced with basalt fibres. The lower laminate was coated with intumescent coating. Nominal thickness of panel was 56.1 mm.

Test results

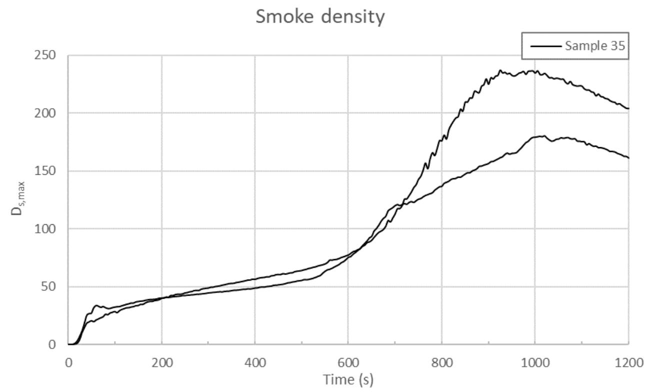
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

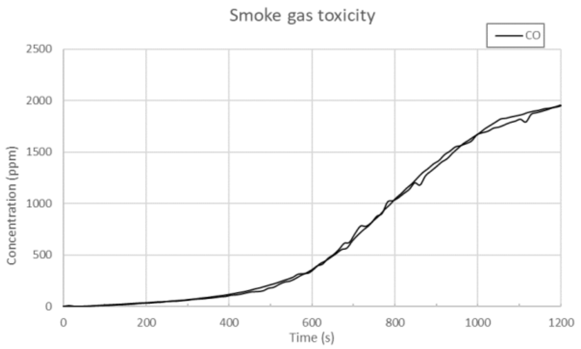
Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
35	Balsa/Basalt/PFA/Intumescent coating	A	700	1080	180	1020
		B	NI	-	237	925
		mv	-	-	208	973

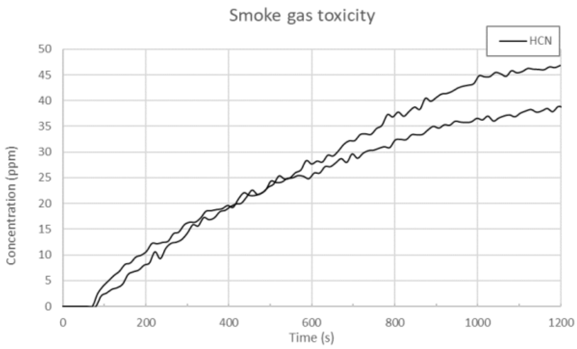
The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
35	Balsa/Basalt/PFA/ Intumescent coating	A	1020	1820	45	<5	<10	<5	<10	36
		B	925	1561	36	<5	<10	<5	<10	<20
		mv	973	1691	41	<5	<10	<5	<10	36

Graphs







12.3.30 Sample 36 –Balsa/Basalt/PFA/Intumescent integrated fabric

Sample description

Sandwich panel with upper laminate of PFA reinforced with basalt fibres, core of balsa, and lower laminate of PFA reinforced with basalt fibres. An intumescent fabric was integrated in the lower laminate. Nominal thickness of panel was 56.9 mm.

Test results

The table show the test results from duplicate tests tested according to IMO FTP Code Part 2, smoke density.

Material		Test	$t_{ignition}$ (s)	$t_{extinguishment}$ (s)	$D_{s,max}$	Time for $D_{s,max}$ (s)
36	(Basalt/PFA)/Balsa/	A	NI	-	232	900
	(Basalt/PFA)/Intumescent	B	NI	-	274	705
	coating	mv	NI	-	253	803

The table show the test results from duplicate tests tested according to IMO FTP Code Part 2 with the smoke gas toxicity analysis. The gas specie concentrations are given at time of $D_{s,max}$, as stipulated by the standard.

Material		Test	Time for $D_{s,max}$ (s)	CO (ppm)	HCN (ppm)	HCl (ppm)	HBr (ppm)	HF (ppm)	SO_2 (ppm)	NO_x (ppm)
36	(Basalt/PFA)/Balsa/	A	900	2472	55	<5	<10	<5	<10	<20
	(Basalt/PFA)/Intumescent	B	705	1868	66	<5	<10	<5	<10	<20
	coating	mv	803	2170	61	<5	<10	<5	<10	<20

Graphs