UNDERSTANDING AND WORKING WITH MAJOR INTERNATIONAL FIRE STANDARD FOR ARCHITECTURAL BUILDINGS AND MASS TRANSIT SYSTEMS.

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ABSTRACT

The applications of Fiber Reinforced Composite materials in critical primary structures has increased over the last 2 decades. The regulators around the world are employing national standards for specifying use of composites in Fire sensitive applications like public usage building and mass transit systems. The paper discusses practical understanding, interpretation and specifying of modern composite materials to comply with major British, European and American Fire standards. The paper describes relevance of these standards for end users, consultants, designers manufacturers, and installers of composites. The paper also discusses how to interpret the test results in context of the intended applications in Architectural Building construction and mass transit applications.

INTRODUCTION

FRP Composite Materials for Primary Structure applications on exteriors and interiors have been finding a place since last 25-30 years. As the Composites in these application are getting wider acceptance, the regulatory bodies are rapidly reviewing the compliance of the Composites for several fire related codes. This paper discusses Composite applications in the Architectural Building and Mass Transit Applications in the context of some British, European and US fire codes.

FRP Composites Applications in Architectural Buildings:

Hotel Exterior

Lobby Interior

Composites are finding applications in architectural building as exteriors as well interiors as structural components. Major applications include primary structural roofing, Curtain Wall cladding, Doors, Partitions, Furniture etc.

FRP Composites in Mass Transit applications:

FRP Composites are a major part of Mass Transit Systems. The applications include Rolling Stock Exteriors, interiors and Claddings for Over ground and underground stations.

Seats

Metro interiors

The development of modern composites into light weight, primary and secondary structures has made a major headway in applications on composites in Mass Transit applications.

Understanding Fire:

Fire is a complex phenomenon, which can create serious dangers to life and property if it is uncontrolled. These hazards may be critically assessed in relation to the different phases of fires. These phases will include the initiation and growth stages (where properties such as ignitability, heat release, flame spread and smoke generation are the most important) and the fully developed stage where product properties such as insulation and integrity are vital to contain the fire. Fire test methods have evolved to allow materials, semi-finished and finished products to be evaluated according to the physical conditions found in these distinct phases of a fire.

The earlier day regulations were limited to measurement of spread of flame under fire. This can be called Fire related specifications. This is most relevant aspect related to applications in exterior exposure only and for areas with limited mass human access. However with the advent of composites into interior confined spaces, two major aspects needed to be accounted for. As the fire develops, there is a possibility of generation of smoke. The smoke density in confined spaces can increase to such levels that the evacuation of personnel from the closed spaces could be hampered due to visibility reduction and suffocation. Hence Smoke is the next important parameter that is now accounted for in the regulations. Fire also results in the emission of Toxic gases that are a major health hazard for the occupants as well as rescue workers. Hence measurement of toxic gasses generated as a result of burning of each element that could potential contribute to fire forms the 3rd major parameter to be measured for the regulatory compliances. Hence the modern specifications would need measurement and assessment of the material is these 3 major aspects, popularly called FST compliance.

Fire

Smoke

Toxicity

Codes and Standards for testing:

Over the years different countries have developed national codes and standards for the measurement of the FST for material. We will discuss some of the major test standards here. There are extremely diverse test methods and standards specific to applications like IMO standards for marine applications, Boeing and Airbus standards for Aircraft applications, SBI and MAHRE based inductive tests etc. As the scope of this paper limits to Mass Transit and Architectural Building applications, some of the most practiced standards for these applications are discussed below:

BS: 6853 -Code of practice for fire precautions in the design and construction of passenger carrying trains

The main aim of this standard is to ensure the safety of passengers in the event of fire on or around a vehicle comprising passenger carrying trains.

The standard has been extensively revised to assist vehicle builders in interpreting guidance from safety Regulatory Authority by upgrading the responsibilities of railway vehicle designers and manufacturers , Encouraging them to produce safer materials which release less toxic effluent in fire.

Classification of Vehicle categories :

There are two main classes of operating environment which are designated as follows.

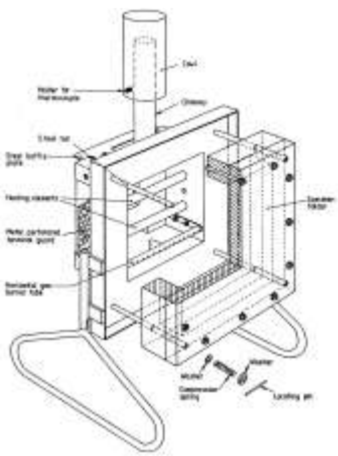
Category –I : Ia and Ib – (Underground.)
Category – II – Surface.
Category –Ia : substantial operating periods in single track tunnel with no side exits to railway and escape shafts, which operate underground for significant periods.
Category- Ib : Substantial operating periods in a multi-track tunnel with side exits to walkway and escape shafts which do not operate underground for significant periods.
Category – II : Surface stock with no substantial operating period in tunnels.

BS : 476-6 Fire tests on building materials and structures.
Part -6 Method of test for fire propagation for products.

The test provides information on the influence that materials have on propagation of flame. Although often termed a "heat release" test, the result represents a much more complicated product of several factors including ignition, heat release and thermal properties. Comparisons are made between the effluent gas temperature/time relationships within the chimney of the apparatus for a reference material and for the product under evaluation.

In this method of test, the result being expressed as a fire propagation index, provides a comparative measures of the contribution to the growth of fire made by an essentially flat material , composite or assembly.

It is used for assessment of the performance of wall and ceiling linings. Fire propagation is determined by exposing the specimen to the fourteen jets of gas pipe burner at a distance of 3mm. heat evolved is 530J/s. The two electric elements with a total output of 1800W are switched on after 2min 45 sec. test duration. There output is reduced to 1500W 5 min test duration and then maintained constant until the end of the test. (25 Min.)



Test Specimen sizes :

225 x 225 mm – 5 Nos.

(Thickness =50mm max.)

Two curves are evaluated by establishing the temperature from the calibration curve and test curve at

30 sec. interval from start to 3 min test duration. (i1)

1 min interval from 4 min to 10 min. test duration.(i2)

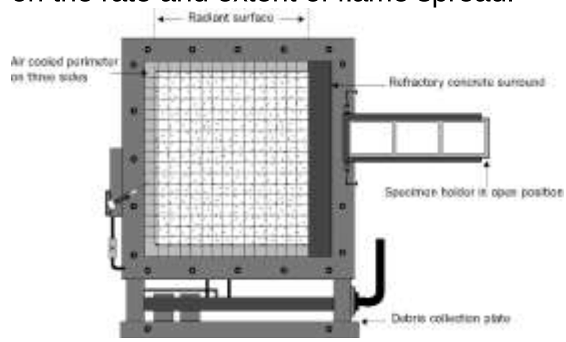
2 min interval from 12 min to 20 min. duration. (i3)

Total index I = i1 + i2 + i3.

BS 476 : Part 7 Fire tests on building materials and structures.

Part -7. Method for classification of the surface spread of flame of products.

This standard assesses the flammability performance of flat materials, composites or assemblies, which are used as the exposed surfaces of walls or ceilings.. The spread of flame along the surface of a specimen held in a vertical position is determined and the subsequent classification system is based on the rate and extent of flame spread.



The test equipment consists of a vertically mounted radiation panel,. The specimen holder swivels so that it is located at 90^{o} to the face of the radiation panel during the test.

The specimen is mounted in a water-cooled holder and is exposed to radiant panel over a 10 min. test duration. In addition a pilot flame is applied to the bottom corner of the specimen during first minute of test.

Time required for the flame front to reach reference marks on the specimen is noted, together with the extent of flame spread at 1 min 30 sec. test duration and the end of the test.

Materials are classified according to the test performance as shown in table below.

The sample is exposed to the radiation panel for 10 minutes (or until the flame has reached a reference line drawn at 825mm - whichever occurs first) and for the first minute a pilot flame is applied to the bottom corner of the sample. During the test, the time taken for the flame to reach various reference marks is noted, along with the extent of flame spread at 1.5 minutes and at the end of the test. A minimum of six and a maximum of nine samples are tested and are classified according to the performance results.

Test Specimens required

9 Specimens of -- 885mm x 267 mm

Classification of spread of flame				
Classification	**Spread of flame at 1.5 min.**		**Final spread of flame**	
	Limit (mm)	Limit for one specimen in sample (mm)	Limit (mm)	Limit for one specimen in sample (mm)
Class 1	165	165+25	165	165+25
Class 2	215	215+25	455	455+45
Class 3	265	265+25	710	710+75
Class 4	Exceeding the limits for class 3			

BS:6853 Annex –D Method of Measuring Smoke density.

The smoke density measurement taken from a material under fire conditions gives an indication of the visibility through the smoke, this is important as reduced visibility in a real fire situation makes it more difficult to escape from a fire hence increasing the threat to human life from the toxic gases, flames and heat.

Test Specimens required 4 Specimens of -- 1000mm x 500 mm

Test Chamber.

The test is performed inside a chamber measuring 3 m x 3 m x 3 m.
The test duration is 40 minutes.

The test is performed by monitoring the transmittance reduction of a white light beam running from one side of the chamber to the other at a set height. Thus monitoring the buildup of smoke inside the chamber. A small fan is utilized inside the chamber to prevent the smoke building up in layered effect and a draft screen is utilized to protect the specimen and the flame source from any wind turbulence.

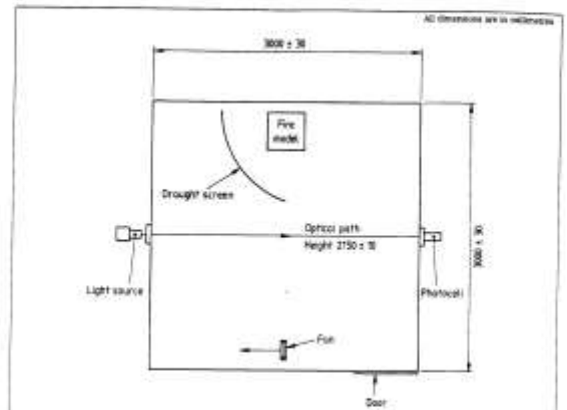


Figure D.1 — Plan view of test chamber

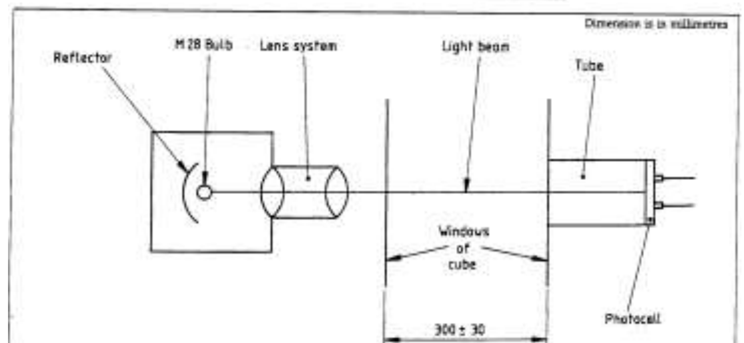


Figure D.2 — Photometric system

Test Results :

A_0 values are used to determine if the product has passed or failed the test requirements.

The results are calculated using following equation converting transmittance of light received by the detector into the measured optical density of the smoke (A_m)
$A_m = \log (I_0 / It)$ where
I_0 = is the initial luminous intensity.
It. = is the transmitted luminous intensity.
A_0 is calculated by the following equation.

$A_0 = (A_m \times V) / (K \times I)$ where

A_m is the optical density measured in the cube.

V is the volume of the cube in meters.

I is the length of the optical path between windows in meter.

K is no of units of material constituting a test specimen.

Note : (k =1 for panel & seat test., 0.04 for floor test.

Ex. Requirement of Interior Vertical surfaces

Test method	parameter	Vehicle category.		
		Ia	Ib	II
Annex - D Panel test.	A_0 (ON) A_0 (OFF)	2.6 3.9	4.2 6.3	9.4 14.0

BS:6853 Annex –B.2 Method of Measuring Toxicity.

Measuring fumes produced from a material exposed to controlled fire conditions gives an indication of the fumes which may be produced in real fire situation. This enables us to choose materials with lower level of risk to human life.

For composite panels area based test method is utilized to determine the toxic fumes produced from materials.

The test is generally performed in the smoke chamber at an irradiance of 25kW/m2 in presence of a pilot flame. Test is carried out at the time when 85% of the peak smoke emission is reached. Toxic fume emission testing is then carried out in triplicate.

The toxic fume emission is expresses in gm/m2 of the material, on the assumption that the area of the test piece is 0.0058m2. The average concentration for each gas is used to calculate the "R" value.

The gases which are analyzed are as follows.

Gas	Reference value , f(mg/g.)
Carbon Di-oxide (CO_2)	14000
Carbon Monoxide (CO.)	280
Hydrogen fluoride (HF)	4.9
Hydrogen Chloride (HCl)	15
Hydrogen Bromide. (HBr.)	20
Hydrogen Cyanide (HCN.)	11
Nitrogen Dioxide (NO_x)	7.6
Sulphur Dioxide (SO_2)	53

Test results :

The "R" value is calculated by taking into account of the gases evolved and their IDLH values. The IDLH values are concentration of the gas in the atmosphere, which for an exposure time of 30 min. is Immediately Dangerous to Life or Health, The gases measured and their ref. values from IDLH are given in chart.

Calculating "R"- value :

Divide the value for each specified gas by its reference value to obtain its individual index, r, and then sum the individual indices to give the weighted summation index, "R", in accordance with the following equations.

$r_x = C_x / f_x$

$R = \sum r.$

Where

C_x is the emission of the x th species in the appropriate units.

F_x is the ref value for the x th species as given in table.

r_x is the individual index for the x th species.

Test Specimens required: 9 Specimens of - - 75 mm x 75 mm

ASTM E-84 Standard Test Method for Surface Burning Characteristics of Building Materials (Tunnel test.)

This test is best used to assess the flammability characteristics of composite panels It is a ceiling fire simulation carried out in a 25 feet long and 2 feet wide enclosure - the "tunnel". Test materials are suspended on the tunnel ceiling and subjected to a 4.5 ft long flame for 10 minutes. The rate at which the flame advances is measured and used to produce a calculated value known as the "Flame Spread Index". At the same time, the opacity of the smoke exiting the chamber is monitored to calculate the "Smoke Developed Index".

The method of determining the comparative surface burning behavior of building materials. Test is applicable to exposed surfaces, such as ceiling / Walls etc.

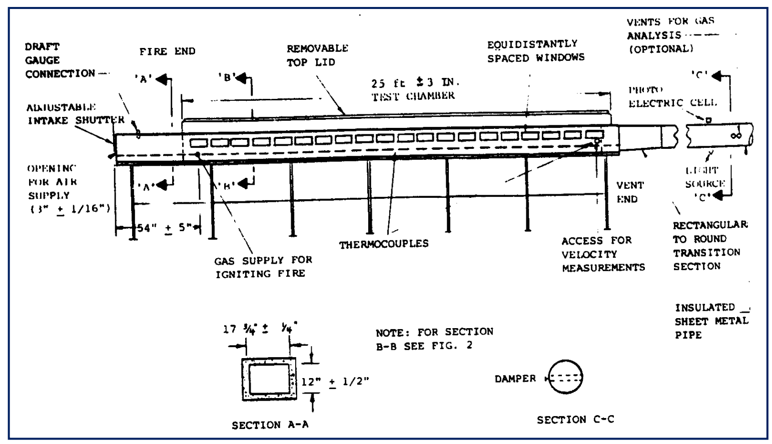
The purpose of the method is to determine the relative burning behavior of the materials by observing the flame spread along the specimen.

Test specimen surface is exposed to a flaming fire exposure during 10 min. test duration. While flame spread over surface and density of the smoke are measured.

Test	**Life Safety Code**		
	Class I **or A**	Class II or **B**	Class III or **C**
Flame Spread	25 max	75 max	200 max
Smoke Developed	450 max		

Test Specimen Sizes. 514 x 7320 mm.

Testing arrangements.



ASTM E-662.

Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials

This fire-test standard covers determination of the specific optical density of smoke generated by solid materials and in thicknesses up to and including 1 in. (25.4 mm).

Measurement is made of the attenuation of a light beam by smoke (suspended solid or liquid particles) accumulating within a closed chamber due to non flaming pyrolytic decomposition and flaming combustion.

Smoke Density Chamber

This measures the specific optical density of smoke generated by materials when an essentially flat specimen, up to 25 mm thick, is exposed vertically to a radiant heat source of 25 kW/m2, in a closed chamber, with or without the use of a pilot flame.
Test Specimens ---- 6 Nos.
Size— 3" x 3," (76.2 x 76.2 mm)
thickness up to 1 in. (25.4 mm).

Smoke density (D_s.) testing conducted in sealed furnace, Radiation heat is 2.5 w/cm^2 of flaming, combustion and non-flaming test modes. The test duration is 20 min. recording the 4 Min, 8 min, 20 min, of maximum smoke density.
The data requirements : D_s (1.5) ,/= 100 and D_s. (4.0) </=200.

ASTM E 162 : Standard test method for surface Flammability of materials using a radiant heat energy source.

This test method of measuring surface flammability of materials employs a radiant heat source consisting of a 12 by 18-in. (305 by 457-mm) panel, in front of which an inclined 6 by 18-in. (152 by 457 mm) specimen of the material is placed.

The orientation of the specimen is such that ignition is forced near its upper edge and the flame front progresses downward.
A factor derived from the rate of progress of the flame front and another derived from the rate of heat liberated by the material under test are combined to provide a radiant panel Index.
Radiant Panel Index: "I_s", is the product of flame spread factor "F_s" and the heat Evolution Factor factor "Q" as follows..
$I_s = F_s \times Q$.
Test Specimen : 4 Nos. 6" x 18"

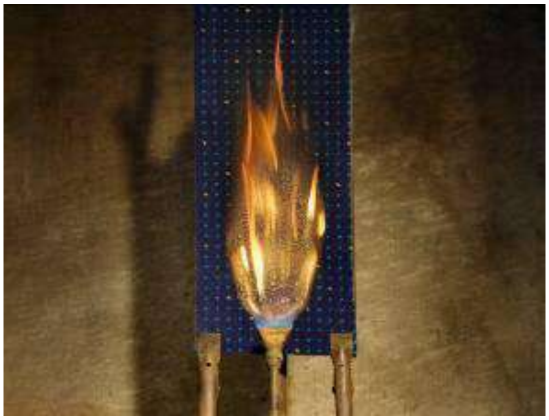
DIN 5510-2:

Preventive fire protect in railway vehicle parts 2: \ DIN 5510-2 is sued for the determination of the fire classification of railway vehicle material and structure by burning behavior, smoke density, dropping behavior and toxic.

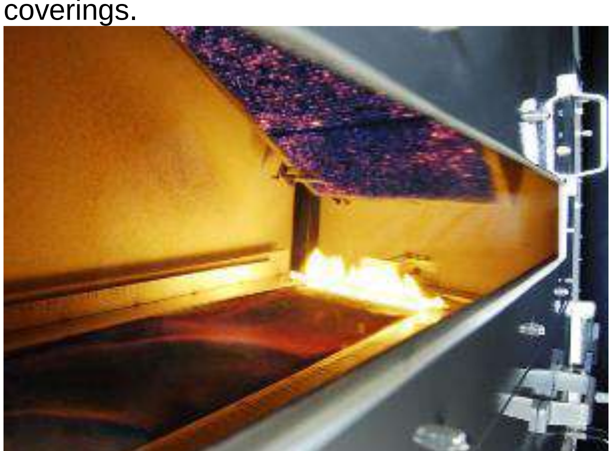
Materials and components of the combustion characteristics and combustion complication phenomenon are the primary considerations of this standard.
The following parameters are used to describe materials and components (including the body's internal and external materials) of the act of combustion:
Flammability classification is defined from S1 to S5
Length of destroyed area: (includes dripping):
Number and size of specimens
The test requires 5 specimens measuring 500 x 190 mm in end-use thickness

After flame time:

1. S1</=15 cm. 2. S2 </= 30 cm 3. S3:</= 25 cm 4. S4: </= 20 cm 5. S5: 0 cm	• S2: After flaming of the specimen until extinguished at test end is permissible • S3:< 100 s (no single time > 120 s) • S4:< 10 s • S5: 0 s



For floor it is divided into three levels SF1 to SF3.
The flooring radiant panel test determines the flammability classes SF1 – SF3 of floor coverings.



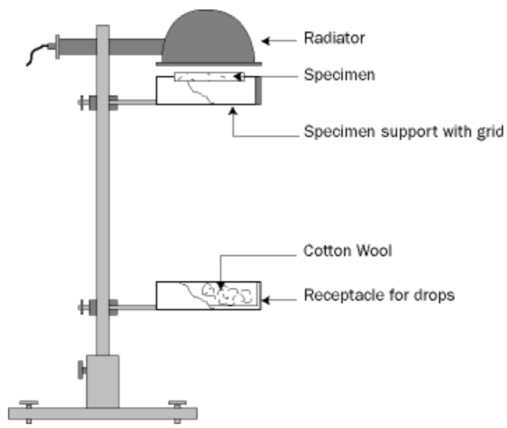
Requirements of DIN 5510-2 Critical radiation intensity (kW/m2):	Integral of light attenuation (%min)	Requirements of CEN/TS 45545-2
• SF1: >/= 2.5 • SF2: >/= 2.5 • SF3: >/= 4.5	• SF1: no requirement • SF2: </= 2500 • SF3: </= 750	• HL1 4.5 kW/m2 • HL2 6.0 kW/m2 • HL3 8.0 kW/m2

According to the "smoke" two categories: classified as a grade two SR1 and SR2.
the specimens are exposed to radiant heat of 25 kW/m2 and an ignition flame. After 4 and 8 minutes, gas samples are taken from the chamber and quantified with FTIR.
The test requires 3 specimens measuring 75 x 75 mm in end-use thickness (max. specimen thickness 25 mm).

Smoke development class	Integral of low light intensity % * min.
Not reached SR1	> 100
SR1	≤ 100
SR2	≤ 50

Requirements : FED (Fractional effective dose) < /=1 Smoke density is measured pursuant to DIN 54837

Droplet classification :



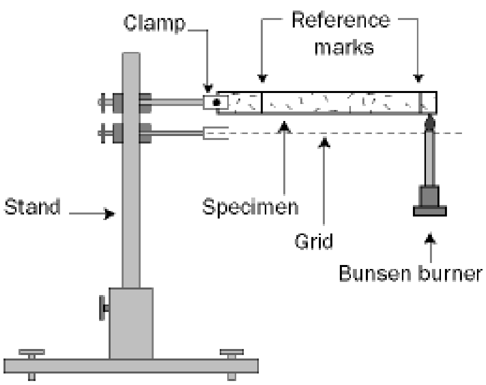
According to the droplet is divided into two grades: ST1 and ST2
When the parts burnt on the floor faller/dropped, the average of further burning not exceeding 20sec is to be taken those products are also considered in ST2.

Liquid formation class	Observations
ST1	Dropped/liquidated burnt
ST2	Liquidate, not dropped not burnt

FIRE CLASSIFICATION AS PER FRENCH NORMS. NFF 16-101

The values adopted for these coefficients, designated " risk" factors and noted "M" for fire and "F" for smoke respectively.

Rate of flame spread test
This complimentary test to the Electric Burner helps establish a classification on samples which behave unusually during the primary test - for example, melting rapidly or shrinking away to form a hole so that the pilot flame cannot come into contact with the sample at 20 seconds, or if samples were unable to achieve even M3 rating.



For materials which melt or shrink away from the heat source, after flame, non-propagation of flame and burning/non burning droplets are observed. Rate of flame spread is also measured if the material does not achieve M3.

The non-propagation of flame test involves a flame being held against the free end of a horizontal sample, 10 times for 5 seconds; the time of after flame is measured. In the flame spread test, the time taken for flame to spread between two reference marks at 50mm and 300mm is established. The production of burning droplets is also noted.

Classification criteria are given below:-

Classification	M1	M2	M3 a	M3 b	M4
Duration of Combustion	none	<5s	<5s	>5s	>5s
Droplets	None or non burning	None or non burning	Burning	None or non burning	Burning

Smoke & Toxicity :

The smoke index noted "S.I." is calculated from the values of the maximum specified from the values of the specific optical density. (Dm), the value of obscuration (VOS4) and the value of the conventional index of toxicity (C.I.T.) which are values obtained from the examination of smoke in accordance with the requirements according to the formula.

$$S.I. = \frac{Dm}{100} + \frac{VOS4}{30} + \frac{C.I.T.}{2}$$

Toxicity of emitted gases.
The test method is described in NFF X70 - 100. The test is carried out at 600^{0}C.
The content found in analysis are compared to reference values called "Critical Concentrations" which are expressed in mg./m3 and noted as "CC" (maximum Critical concentration of gas.)

Gas	**C.C. (mg./m^3.)**
CO	1750
CO2	90,000
HCl.	150
HBr.	170
HCN.	55
HF.	17
SO2	260

According to the values obtained for S.I. materials are classified in six classes from F_0 to F_5. Defined as below.

Class	**Value of S.I.**
F_0	</= 5
F_1	</= 20
F_2	</= 40
F_3	</= 80
F_4	</= 120
F_5	>120

Number and size of specimens

Test & Standard Number	*Number and size of the specimens*	Classification
NF P 92-501	9 samples 300 mm x 400 mm x thickness (5 < thickness < 121 mm)	**Classification --- M** **(M_0 hig. to M_5 Low)**
NF X 10-702	9 samples of 76 mm x 76 mm x thickness thickness < 20 mm)	**Classification --- F** **(F_0 hig. to F_5 Low)**
NF X 70-100	30 g.	

The French NF F 16-101 and U.K. BS 6853 specifications are identical because both require the same test method for elastomers (NF X 70-100). The only difference is that the U.K.'s specification requires an addendum for nitrous oxides.

Values are calculated based on levels of gas in a particular atmosphere for 30 min that would pose an immediate risk. Converting the mg/m 3 values of the U.K. standard to ppm.

BS 6853 specification is the most stringent, closely followed by the French,

Toxicity component maximums by specification			
Specification	**French (mg/m^3) NF X 70-100**	**U.K.(mg/m^3) NF X 70-100**	**U.K (ppm) NF X 70-100**
CO	1,750	1,750	1,200
CO_2	90,000	90,000	40,000
HCl	150	150	50
HBr	170	170	30
HCN	55	55	50
HF	17	17	30
NO/NO_2		38	20
SO_2	260	260	100

Standards for U.S., U.K., France, Germany			
	FLAME PROPAGATION	TOXICITY	SMOKE GENERATION
American	ASTM E 162	SMP 800C	ASTM E 662
U.K.	BS 6853 Appendix A9 & BS 2782 (material dependent)	BS 6853 Appendix B.5 & NF X 70-100	BS 6853 Appendix D.8.3
France	NF T 51-071 & NF C 20-455	NF X 70-100	NF X 10-702
Germany	DIN 53438 Parts 1 to 3 & E DIN 54 837		

Interpretation of Test results

From the parameters as discussed in various test methods, the test reports give actual values achieved and a reference to the designated values of the standard to achieve a particular classification. This gives a good indication as to whether the material or product has comfortably achieved the required classification or has just crossed the required parameters. Due to the complex nature of manufacturing of composites, mix ratio dependent chemical nature of Matrix materials and the fact that major manufacturing processes have human and atmospheric conditions as major unpredictable variables, it recommended that required classification is achieved with a margin for error. For example, for BS 476 Part 7, to achieve Class 1 limit of flame spread is 165 mm and for 1 specimen 190 mm. If a material or product test report shows the value as 155-165 mm for 4 specimen and 185 for 1 specimen, the material will still qualify as Class 1. However chances of actual serial production of parts failing the test are high. Hence it is suggested that the products are developed to achieve a comfortable margin on qualification. Hence on this particular test a material achieving 130-140 mm for all test specimen is much reliable material.

Methods to achieve the required fire qualification is outside the scope of this paper. However specifiers and end users as well as fabricators can work with the Matrix Manufacturers and independent consultants to design the material systems and manufacturing processes as well as process and quality control systems to achieve the required fire classifications.

Recommended Specifications;

The Fire specifications for mass transit and transport applications are fully covered in major Fire standards. The recommended reference for specifiers is BS 6853. The classes based on service applications are well defined. French Standard NFF 16-101 also is a well established reference for specification of FRP composites in mass transit applications.

For the Architectural and building applications the predominantly specified standards are BS 476 Parts 6 & 7 and ASTM E 84. On the BS 476 Parts 6 & 7, there is a common practice to specify Class 'O' as alphabet O not Zero. This needs a clarification. As per BS 476 Parts 6 & 7, there is no classification called Class O. Class O is specified in the UK building regulations part B page 112 section 13 as a material that achieves Class 1 as per BS 476 Part 7 and values of i1<6, I<12 as per BS 476 Part 6. Hence is class O specification is to be specified, it is suggested that reference is given to UK Building regulations. Besides the flame spread and flammability, it is recommended that due consideration is given in specifying the composites as to whether toxicity and Smoke density have a role to play. For exterior applications where public access close to the installation is possible, it is recommended that Toxicity test as per BS 6853 Annex B.2 is specified. Similarly if the application is for the interiors with public access, additional Smoke Density specifications is added. One of the common specifications for the interiors is ASTM E 84 with flame spread index < 25 and Smoke Developed Index < 450.

For the material developers and composite manufacturers it is very handy to have an access to a simple Oxygen Index testing facility. Oxygen Index testing gives a useful indication as to where the material would stand in full scale testing. It needs to be stressed that Oxygen Index is only a very initial judgment tool and in no way should be used as a replacement for complete testing.

Future Work

The new European unified Fire standard for rail applications is EN 45545 (1 - 7) which is due for release, will be the best standard that covers design, testing, control and management aspects of fire particularly for Railway Vehicles. This standard will also help remove ambiguity on trying to find equivalent for one standard into another standard due to several European fire standards. Although this standard is developed for Rail applications, it provides a very detailed methodology of testing of materials and systems for several aspects of fire and hence can be a good reference for setting up tests for other applications.

Conclusion

In the world where growing use of composites in sensitive mass utilization areas necessitates critical assessment of risks mitigation due to fire situation, it is important for the designers and specifiers as well as manufacturers and end users to assume responsibility to understand composites and their fire hazard. It is important the materials are tested and manufactured in compliance to codes without using any means to undercut the regulatory requirement in interest of public safety and to ensure that composites do not become a material to be avoided due to incorrect applications.

Indian Standards for fire classifications for Architectural Buildings as well as Mass Transit applications need to be developed as the use of Composites in these applications is rapidly increasing.

References:

Standards:
BS 476 Parts 6,7
BS 6853 Annex D8.4, B.2
ASTM E84
DIN 5510-2
NF F 16-101

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