COMPREHENSIVE METHODOLOGY TO ASSESS THE FLAMMABILITY OF COMPOSITES TO BE USED FOR RAILCAR APPLICATIONS

E. Milella [1], G.Ortale[1],A.Gallone[2,] J.L.Torero[3], G.Camino[4]

[1]*Technological District on Engineering of polymeric and composite Materials and Structures (IMAST), Portici, Naples, Italy)*
[2] *AnsaldoBreda S.p.a. , Italy)*
[3] *BRE Centre for Fire Safety Engineering, University of Edinburgh, UK*
4 Polytechnic of Turin, Alessandria Campus, Italy)
*giovanni.camino@polito.i*t,*

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Abstract
This paper concerns a methodology for evaluating materials flammability related to fire evolution within a rail car compartment, to assess the capability of furnishings and interior linings to bring the compartment to untenable conditions. The methodology is based on Heat Release Rate measured with the Oxygen Consumption Calorimeter, flame spread rate obtained using ASTM-E-1321, Oxygen Index and Temperature Oxygen index. Complementary toxicity and smoke density analysis was also conducted. This paper presents as an example, the application of the methodology to a composite material formed by a core of balsa wood to which two epoxy resin layers are attached with a structural adhesive.

1 Introduction
The everyday more generalized use of composite materials in the rail industry requires a comprehensive analysis of material flammability that goes beyond the simple criteria proposed by individual standardized test. Material flammability needs to be intimately linked to the evolution of a fire within the rail car compartment and outside. Two scenarios appear as critical, depending on whether the fire is external or internal to the compartment. In the former case the capability of the fire to breach the compartment and eliminate protection to the occupants represents the relevant criterion. In the latter case the capability of furnishings and interior linings to bring the compartment to untenable conditions represents the main parameter to be assessed. A third scenario could also be contemplated, which is the potential of the flammable materials present to create an untenable environment within a tunnel.
This paper addresses the second scenario. When a fire starts in the interior of a compartment, heat and smoke are produced and accumulate within the compartment. At some point the smoke layer will start to interact with the occupants leading to untenable conditions. It has been demonstrated that the Heat Release Rate (HRR) will control the mass of smoke produced and the air entrained towards the fire. Thus this single parameter controls not only the temperature and volume of the smoke layer but also the concentration of toxic species.
Furthermore, the flame spread rate which is obtained using ASTM-E-1321 is the single variable controlling the growth of the burning area and is controlled by the thermal inertia of the material (kρC), the flame spread parameter (ϕ) and the ignition temperature (or critical heat flux for ignition). Three qualitative complementary variables are the Oxygen Index,

Temperature Oxygen index and critical heat flux for propagation. Complementary toxicity and smoke density analysis serve to establish the nature of the smoke layer. This paper presents as an example, the application of this methodology to a composite material formed by a core of balsa wood to which two epoxy resin layers are attached with a structural adhesive.

2 Materials and testing methods

2.1 Materials

The sandwich composite materials are reported in Table 1

Core	Pro balsa PB Standard produced by DIAB
Adhesive	Structural Adhesive AS 60/AW 60 produced by Elantas
Skin	Prepreg with resin type Cycom 977-20 RTM with PRIFORM technology
Resin	Cycom 977-2 produced by Cytec

Table 1. Details of the sandwich material

2.1 Tests

Cone Calorimeter

A Fire Testing Technology (FTT) cone calorimeter apparatus was used to evaluate, according to ISO 5660 standard, 100x100 mm^2 specimens. Reported results are average of three replicates for each sample, exposed to variable external fluxes in the range 15-90 kW/m^2. The contribution of a material in terms of heat in a possible fire scenario is obtained as heat release rate (HRR) curve.

Flame spread

Flame spread tests (IMO/LIFT) have been performed according to ASTM 1321. This standard includes two kinds of experiments (ignition test and flame spread test) for determining material ignition and flame spread properties.

With the ignition test, the time necessary for the ignition of a sample exposed at several heat fluxes is determined. This test gives the minimum heat flux for the ignition ($q_{0,ig}$) and the thermal inertia ($k\rho c$). The former is the lowest flux level at which the material will ignite within preset time limit, while the latter is a measure of how easily the material absorbs energy and hence how quickly the temperature will rise to ignition value. The spread of flame test concerns the propagating front velocity measurement. This test gives the critical flux at extinguishment of flame (CFE or CFH) and the flame heating parameter Φ which is related to flame propagation, the higher its value the faster the flame propagation.

Oxygen Index

Oxygen Index (OI) i.e. the minimum percentage of oxygen in the test atmosphere that is required for self-sustained combustion was measured with an FTT instrument, at different temperatures.

Smoke chamber test

Smoke optical density during combustion was measured using the NBS smoke density chamber test following the ISO 5659 standard. The sample has been meticulously protected and sealed at the edges using a sheet of aluminum since it is noted that the sample, exposed to the action of the radiator, left flammable gas to escape due to degradation of the adhesive, which would give misleading results in terms of composite ignition time.

Toxic gases produced by the combustion were collected through colorimetric Draeger tubes to detect and evaluate concentration of NO_2, HF, HCN, HCl , HBr , CO_2 , CO, SO_2.

3 Results and Discussion

The sandwich composite combustion produces a carbonized residue mainly due to the cellulosic material which constitutes the balsa wood, that can act as insulation barrier for the transmission of heat within the panel (Figure 1).

Figure 1. Sandwich composite, original (a), after cone calorimeter testing (b)

The HRR curve of the sandwich composite exposed to 50kW/m^2 is shown in Figure 2. Two peaks are seen in the curve of heat released rate, the first of which more pronounced. The first peak is due to combustion of the resin on the surface of the composite . The resin is then gradually replaced by the fabric of carbon fibers underlying combined, where appropriate, with the phase produced by the combustion of the carbonized resin surface. A layer which protects the remaining resin by the effect of the flame and consequently, reduces the rate of heat release. Continuing the exposure to the radiator there is the collapse of the thermal protection and the complete combustion of the resin with a new growth of the HRR and formation of the second peak.

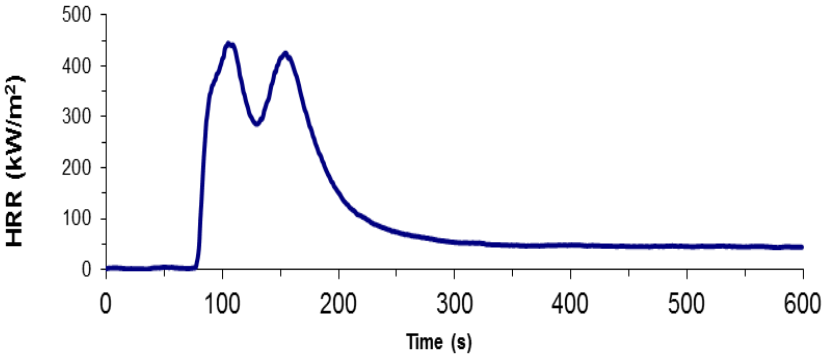

Figure 2. Heat Release Rate at 50 kW/m^2

Specific optical density as a function of sandwich composite burning time is shown in Fig 3 . Comparison with data of figure 2 shows that the most relevant smoke production, occurs when flaming combustion is strongly reduced (>200s) which indicates that it is due to smouldering of the carbonized residue produced by the sandwich combustion. The reduction in optical density (Ds) after 200 seconds could be attributed to the deposition of solid heavier particles after flame extinction.

A complementary study of toxicity using a simple colorimetric Draeger pipes gives information about qualitative toxic gases that combustion of the material examined produced. In this case relevant quantities, compared to the SEL (Significant Effect Level) of NO_2, HF,HCN, HCl , HBr , CO_2 , CO; SO_2 were found as shown in Table 5.

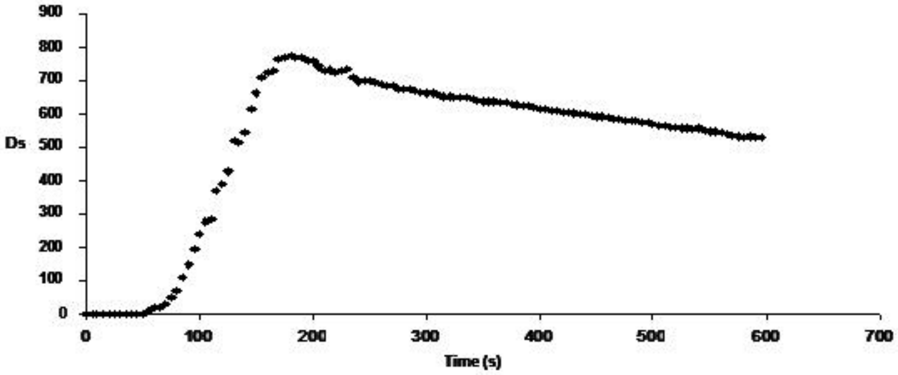

Figure 3. Mean specific optical density D_s at 50 kW/m^2

SEL, ppm	Measured, ppm
CO_2 36.675	n.n.
SO_2 100	25
CO 1.205	1.411
HF 30	15
HCN 50	30
HBr 29	> 1
NO_2 20	16
HCl 50	50

Table 2. SEL and toxic fumes concentration measured at Smoking Chamber

Comparison of measured concentration of toxicants NO_2, HF, HCN, HCl, HBr, CO_2, CO, SO_2 from sandwich composite combustion and literature Significant Effect Level is reported in Table 2

The sandwich composite does not burn in air at room temperature since its oxygen index is 32%, but it will burn if it is hit by a sufficient amount of heat produced by an external source such as an incident fire.. The trend reported in Figure 4 for burning time as function of temperature, shows that ignition and combustion occurs above 150°C .

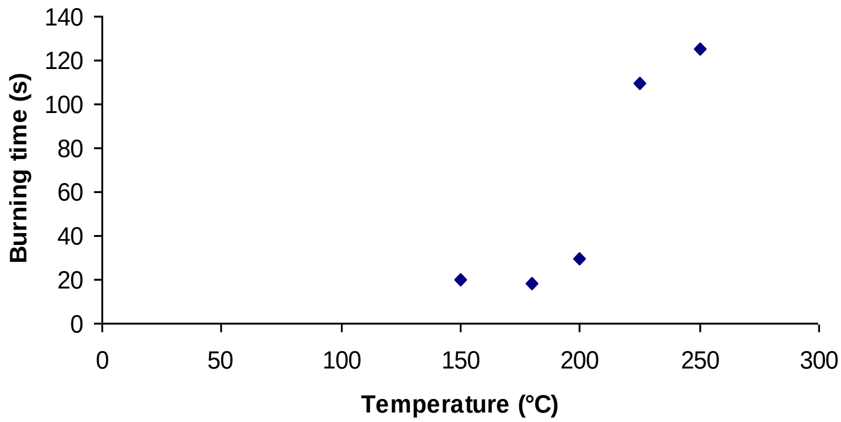

Figure 4. Burning time as a function of temperature

The ignition time decreases to the increasing of the heat flux applied as shown in Figure 5. Measured ignition flux and thermal inertia are reported in table 3.

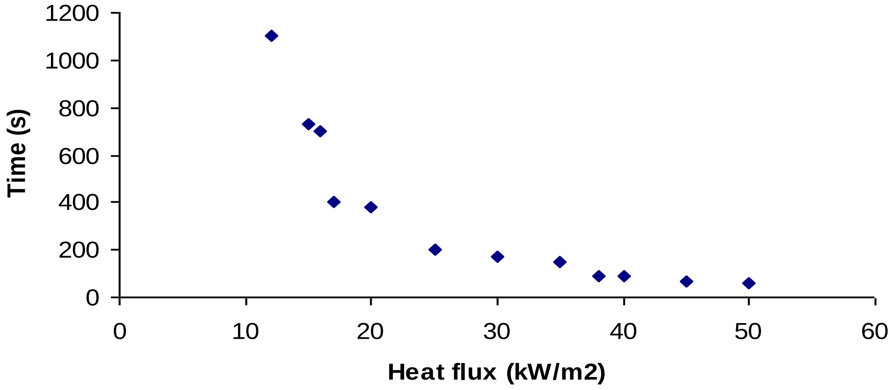

Figure 5. Ignition trend at LIFT

$\dot{q}''$ ig	12 kW/m^2
Kρc	2.03 (kW/m^{2}K)^2/s

Table 3. Ignition flux($\dot{q}''$ ig) and thermal inertia (*Kρc)*

4 Conclusions

In a fire scenario where the fire could start form a radiation source or from a small fire that starts on the floor and then propagates to all the railway wagon, the sandwich composite characterized here with this new integrated methodology, using small and medium scale tests, Gives access to useful flammability parameters which could be used in the design or installation stage of this innovative material with considerably reduced weigh.

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