FLAMMABILITY ASSESSMENT FOR NOVEL COMPOSITE MATERIALS FOR USE IN FUTURE AIRCRAFT

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Keywords: composites, fire testing, carbon nanotubes, fillers

Abstract

A comprehensive series of fire tests are performed to assess the performance of carbon fibre epoxy composites proposed for use in aircraft industry. Materials include different formulations that deem to exhibit good mechanical properties and durability (carbon fibre composites alone and modified by fillers). Oxygen index, heat release rate and ignition characteristics addressed using the cone calorimeter and flame spread by means of the IMO/LIFT test were evaluated. Some general trends are established regarding the impact of fillers on the different formulations.

1 Introduction

The use of fibre-reinforced polymer composite materials is accepted in the aerospace industry because of the advantages that offers over metals: substantial weight reduction, better creep and fatigue performances, better corrosion resistance [1].

Although mechanical performance of composites is of primary importance, other factors such as cost, environmental performance and fire safety are also relevant [2,3].

Organic matrix resins used in composites are susceptible to combustion, which affects structural integrity of composites laminates during and after exposure to fire [4-9]. One method of improving fire retardancy of these structures involves the use of flame retardant (FR) additives [10].

The intent of this work, inserted in the frame of the European Project "Green Regional Aircraft" (CSJU-GRA-2008-001), is to clarify the effect of different fillers on fire properties of carbon fibre polymer composites in order to potentially use them in conjunction with conventional flame retardants in future aircrafts.

2 Materials and testing methods

2.1 Materials

Carbon fibre-reinforced epoxy composites with different type of fillers have been provided by the GRA project. In table 1 a description of the samples analyzed is reported.

SAMPLES	MAIN FEATURES
A	(epoxy + carbon fibres + metallic wires interwoven)
B	(epoxy + carbon fibres + 1% w/w carbon nanotubes-CNT)
C	Ref (epoxy + carbon fibres) CNT1 (epoxy + carbon fibres + carbon nanotubes-CNT1) CNT2 (epoxy + carbon fibres + carbon nanotubes-CNT2)
D	ref (epoxy + carbon fibres) combi (epoxy + carbon fibres + silica particles)

Table1. Description of the samples analyzed

2.2 Methods

Combustion tests were carried out on a Fire Testing Technology (FTT) cone calorimeter apparatus. For fire performance evaluation, 100x100 mm^2 specimens (three replicates for each sample) were exposed to variable external fluxes in the range 15-90 kW/m^2 and tests were conducted according to ISO 5660 standard. The contribution of a material in terms of heat in a possible fire scenario is obtained as heat release rate (HRR) curve. From this curve, important material fire behaviour parameters, like peak of heat release rate (pkHRR) and time to ignition (t_{ig}) are obtained.

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 regards 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.

Flammability behavior of the materials has been evaluated at 23 and 60 °C by Oxygen Index (OI) test with an FTT instrument. The technique measures the minimum percentage of oxygen in the test atmosphere that is required for self-sustained combustion.

Normal atmospheric air contains about 21% volume of Oxygen, therefore a material with OI lower than 21% would easily burn in air. A material with OI greater than 21% but less than 28% would be considered “slow burning” and a material with an OI greater then 28% would be considered “self-extinguishing”. A self extinguishing material is one that would stop burning spontaneously after removal of the fire or ignition source.

3 Results and discussions

3.1 Cone Calorimeter

Figure 1 shows the average trend of heat release rate as a function of time for specimens of reference carbon fibre-epoxy composite (C_Ref) or carbon nanotubes (CNTs) loaded composite (C_CNTs1 and C_CNTs2) exposed to an irradiance of 30 kW/m^2.

The time to ignition (t_{ig}) of CNT nanofilled composites is larger than that of the reference composite, independently of the type of CNTs (CNT1 or CNT2), whereas the pkHRR is not influenced by CNTs.

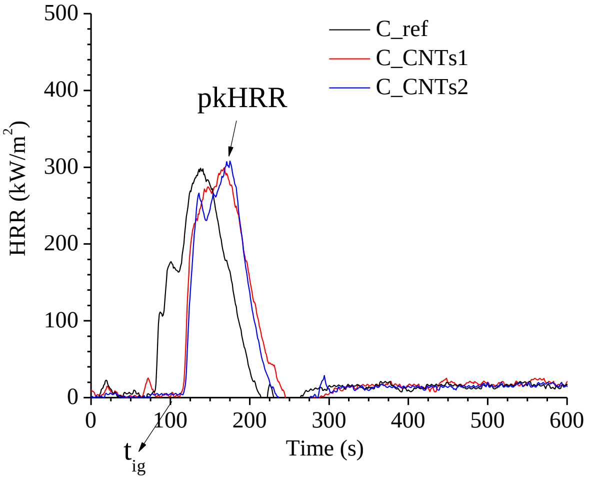

Figure 1. Mean value of HRR for specimens of carbon fibres-epoxy resin composite (– C_Ref) or CNTs loaded composite (– C_CNT1 and – C_CNT2).

Figure 2 shows the average trend of the heat release rate as a function of time for carbon fibres-epoxy resin composite specimens (D_Ref) or silica particles loaded composite (D_combi) exposed to an irradiance time of 50 kW/m^2.

Silica particles have no effect on ignition (t_{ig}) of the composite, whereas the pkHRR is higher than reference sample. The dispersion of silica particles into the epoxy matrix slightly worsens the properties of response to fire.

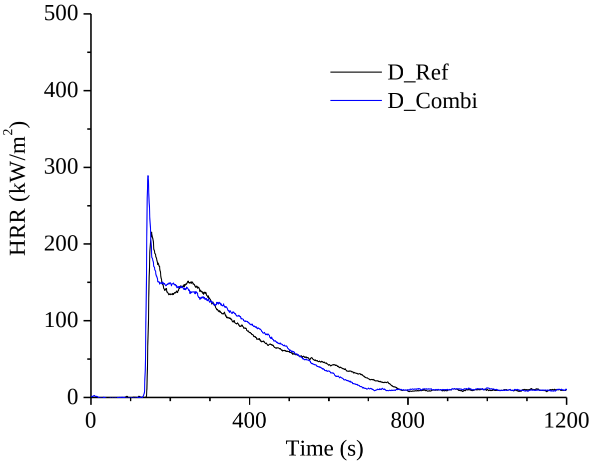

Figure 2. Mean value of HRR for specimens of carbon fibres-epoxy resin composite (– D_Ref) or silica particles loaded composite (– D_combi).

3.2 IMO/LIFT

Figure 3 shows, as an example, the time to ignition of sample A as a function of the external flux applied. From this curve, the minimum heat flux necessary for material ignition ($q_{0,ig}$) is determined. This value is important to calculate the material thermal inertia (kρc).

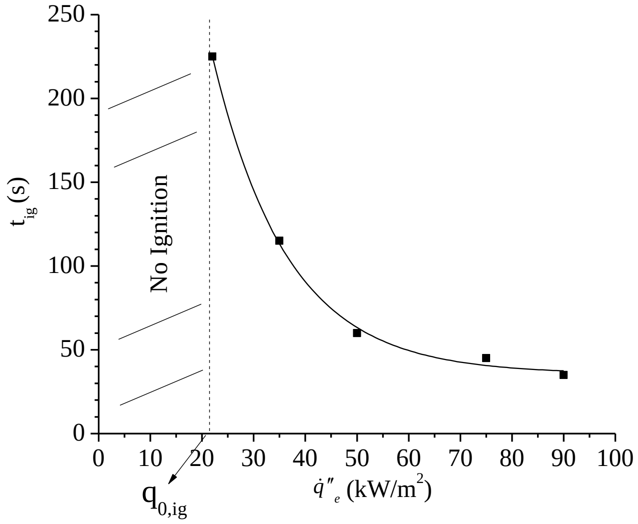

Figure 3. Ignition test on sample A, obtained according to ASTM E1321.

Figure 4 shows the flame spread rate test on sample A. The slope of the linear fit gives the flame heat transfer factor (C) necessary to calculate the flame heating parameter Φ.

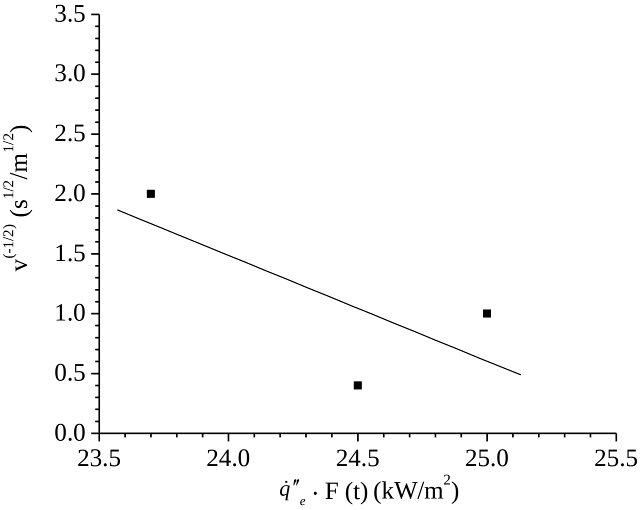

Figure 4. Flame spread test on sample A, obtained according to ASTM E1321.

In table 2 the ignition and flame spread parameters obtained for A and B samples are shown. Composite B with dispersed CNTs, shows lower flame propagation rate than composite A with interwoven metallic wires. In particular sample B thermal inertia (kρc) is lower than sample A, which means that sample A temperature increases more slowly under the influence of an external flux. Moreover, sample A flame heating parameter Φ is lower than B sample which implies a slower flame propagation.

Sample	$q_{o,ig}$ [(kW/m^2)]	kρc [(kW/m^2*K)^{2}s]	Φ [(kW^2/m^3)]
A	22	1.2	47
B	17.5	1.7	19

Table 2. Ignition and flame spread parameters for sample A and B.

3.3 Oxygen Index (OI)

The effect of silica particles on flammability of carbon fibre-epoxy resin composite, as measured by OI, is shown in Table 3 by comparison of samples D_Ref and D_combi. It is shown that addition of silica particles to the epoxy matrix does not cause, both at 23°C and at 60°C, a significant change in the composite OI value. The OI is very high which entails a relatively low material flammability.

Samples	Temperature (°C)	Oxygen Index (%vol)
D_ref	23	47
D_combi	23	48
D_ref	60	42
D_combi	60	42

Table 3. Oxygen Index of carbon fibre epoxy composite (D_Ref) and silica particles loaded composite (D_combi).

4 Conclusions

In the frame of the European Project “Green Regional Aircraft” (CSJU-GRA-2008-001), a series of fire tests on carbon fibre-epoxy resin composites modified by appropriate fillers have been performed.

Some general trends are established. In particular, as far as cone calorimeter tests are concerned, carbon nanotubes (CNTs) dispersed by sonication in the epoxy resin composites matrix induce a relevant increase of the time to ignition t_{ig}, whereas they have a negligible effect on the heat release rate (HRR).

Instead, silica particles have a negative impact on the burning behaviour of composites causing an increase of the peak of heat release rate (pkHRR).

Spread of flame tests by IMO/LIFT shows that CNTs reduce composites flame propagation much more than interwoven metallic wires.

Oxygen index (OI) tests highlight that nanofillers (CNTs and silica particles) have a negligible effect on the flammability characteristics of composites.

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ACKNOWLEDGEMENTS

The authors wish to acknowledge all partners of the European Project “Green Regional Aircraft” (CSJU-GRA-2008-001)