INTUMESCENT COATINGS FOR PROTECTION OF COMPOSITES FOR AIRCRAFT APPLICATION

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Keywords: Composites, Intumescent Coating, Fire Testing, Nano-Fillers.

Abstract
Intumescent coatings are widely used for protection of steel structures. Despite this technology is well known, continuous performance improvement of such coatings is needed to meet demanding application requirements. Furthermore, the substitution of metal structures with fiber composite, especially in aircraft applications, delivers new challenges in terms of fire resistance of structures. Intumescent coatings (acrylic, epoxy and polyester-based) alone or modified by the inclusion of nano-fillers were applied on carbon fibre-reinforced polymer composites. The thermal protection provided by the different coatings on the substrate will be discussed in details in this paper.

1 Introduction
The use of composite structures in transportation and in particular for both commercial and general aviation aircraft has been increasing because of the advantages that it offers over metal; such as lower weight, better fatigue performance, no corrosion, better design flexibility [1,2].
Carbon fiber-reinforced polymer (CFRP) have become very suitable for the aeronautical applications which require high strength and low weight. However, because of their chemical structure, usually CFRP exhibit a low fire resistance.
A way to improve the flame resistance of a composite is related to the modification of the flame reactivity of the matrix [3]. The flame reaction of a material exposed to a fire consists in the evaluation of many parameters such as the time to ignition, heat release rate, mass loss etc. which can be studied by cone calorimeter [4]. Intumescent coating formulations can protect a composite matrix promoting the formation of a foamed cellular continuous char network over its surface during combustion. This physical and thermal barrier limits heat transfer and oxygen and pyrolysis products diffusion across the surface of the composite improving thus its thermal stability and fire resistance properties.
The intent of this work, inserted in the frame of the COCET project ("COmportamento di materiali compositi in Condizioni Estreme: alta Temperatura" - PON02_00029_3206086), is to clarify the effect of different intumescent coatings on fire behavior of CFRP in order to find a potentially solution to be applied in future aircrafts.

2 Materials and testing methods

2.1 Materials

Intumescent coatings (acrylic, epoxy and polyester-based, provided by IRIS Vernici) alone or modified by nano-filler octametyl-POSS (ome-POSS) or dodecaphenyl-POSS (dode-POSS) are applied on carbon fiber-reinforced polymer to realize a physical barrier that allows to improve the response to the fire of the CFRP. In Table 1 a description of samples analyzed is reported.

Substrate	Intumescent Coating type	Intumescent coating Thickness (mm)
CFRP	None (CFRP_ref)	–
	Char 27 (epoxy) as prepared	1 and 2
	Char 27 + 3% ome-POSS	1 and 2
	Char 27 + 3% dode-POSS	2
	Char 21 (acrylic) as prepared	1 and 2
	Char 21 + 3% ome-POSS	1 and 2
	Char 21 + 3% dode-POSS	2
	Char 33 (polyester) as prepared	1 and 2
	Char 33 + 3% ome-POSS	1 and 2
	Char 33 + 3% dode-POSS	2

Table1. Description of samples analyzed

2.2 Methods

Testing of heat shielding by the protective coating was carried out under a Fire Testing Technology (FTT) cone calorimeter apparatus. For fire performance evaluation, 100x100 mm^2 specimens with intumescent coating applied on (three replicates for each sample) were exposed to an external flux of 50 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. From this curve, important material fire behavior parameters, like peak of heat release rate (pkHRR) and time to ignition (t_{ig}) are obtained.

The temperature of the substrate was monitored during the test by a thermocouple embedded in the substrate (Figure 1), according to a method previously reported [5].

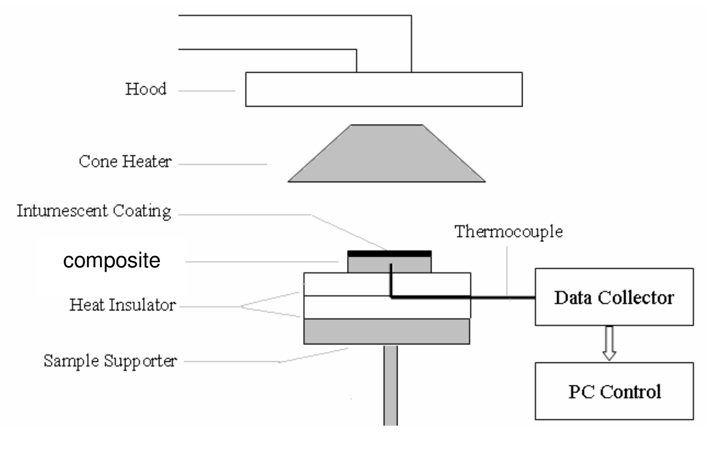

Figure 1. Experimental set-up

3 Results and discussions

3.1 Cone Calorimeter

Figure 2 shows the average plot of heat release rate as a function of time for specimens of CFRP reference (CFRP_ref) and CFRP covered by a 1mm of epoxy (Char 27), acrylic (Char 21) and polyester (Char 33) based intumescent coatings exposed to an irradiance of 50 kW/m^2. For Char 33 system, as for Char 27, intumescence begins in the first heating stages. After 20/25 seconds, combustion takes place with the consequent formation of a peak of HRR (≈50 kW/m^2 for Char 33 and ≈160 kW/m^2 for Char 27) to be attributed to the components of the intumescent coating. The formation of a carbonaceous layer protects the underlying composite material. The intumescence reaction for Char 33 is more effective than Char 27 (carbonaceous layer has an high expansion ratio), but however not so strong to ensure a total protection of the composite. In fact, the temperature of the composite reaches values at which the matrix decomposes and gases fuel the flame resulting in the formation of another peak of HRR.

The most promising system is the acrylic-based coating Char 21 which does not undergo combustion, and thus does not give any contribution in terms of heat evolved. In this case, during the intumescence reaction, a carbonaceous residue with a high expansion ratio (10 times the initial volume, Figure 3) is formed and more protection is ensured.

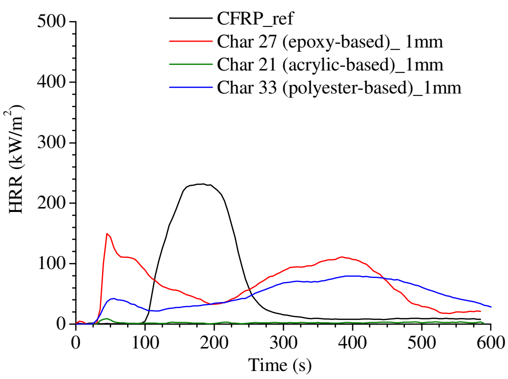

Figure 2. Mean value of HRR for specimens of carbon fibre-reinforced polymer (CFRP_Ref) and CFRP covered by a 1 mm of epoxy (Char 27), acrylic (Char 21) and polyester (Char 33) based intumescent coatings

(a) (b)

Figure 3. Images of a CFRP coated with intumescent Char 21 before (a) and after (b) a cone calorimeter test.

In Figure 4 it is shown the temperature profile recorded by thermocouples during the cone calorimeter tests for samples in Figure 2. It can be observed that all intumescent coatings act as a thermal barrier for the CFRP_ref. In fact, for any intumescent coatings, the temperature variation is always lower than CFRP_ref. It is clear that Char 21 ensures a temperature variation during the time lower than Char 27 and Char 33, and therefore provides greater protection to the virgin composite.

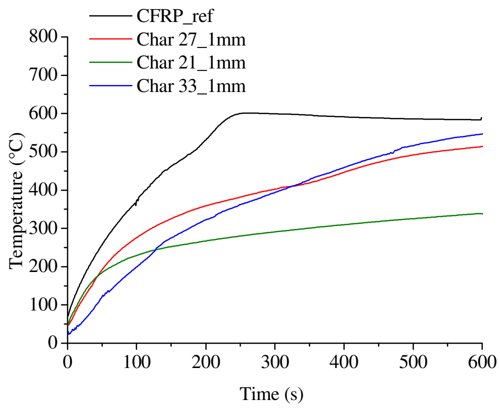

Figure 4. Temperature profile during the cone calorimeter test for sample free of intumescent coating CFRP_ref, and samples coated with an epoxy-based Char 27, acrylic-based Char 21 and polyester-based Char 33 intumescent coating.

Figure 5 shows the temperature profile recorded by thermocouples during cone calorimeter tests for specimens of CFRP reference (CFRP_ref), CFRP covered by a 1mm and 2mm of the most promising intumescent formulation Char 21, and CFRP covered by a 1 mm of Char 21 modified by 3 wt% ome-POSS. It may be noted that the thickness of the applied coating has influence on the thermal protection, and in particular, the higher is the thickness of intumescent formulation applied, the greater is the protection. The modification of the pre-formulated intumescent coating through the introduction of 3 wt% ome-POSS has a negligible effect on the thermal barrier ability of the Char 21 coating.

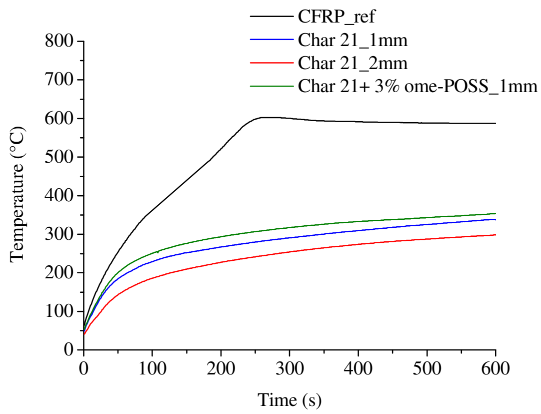

Figure 5. Temperature profile during cone calorimeter tests for specimens of CFRP reference (CFRP_ref), CFRP covered by a 1mm and 2mm of Char 21, and CFRP covered by a 1 mm of Char 21 modified by 3 wt% ome-POSS.

4 Conclusions

A series of cone calorimeter tests in order to clarify the effect of different intumescent coatings on fire behavior of carbon-fibre reinforced polymer (CFRP) have been performed. Some general trends are established. In particular, the intumescent coatings utilized (epoxy-based Char 27, acrylic-based Char 21 and polyester-based Char 33) provide thermal protection for CFRP.

Char 21 formulation ensures a thermal protection higher than Char 27 and Char 33. Indeed, the intumescence reaction causes the formation of a carbonaceous residue with a high expansion ratio and, therefore, more protective. Moreover, the paint CHAR 21 does not undergo combustion, and thus does not give any contribution in terms of heat in a possible fire scenario.

The thickness of the applied coating has an influence on thermal protection, and in particular, the higher is the thickness of intumescent formulation applied, the greater is the protection. The modification of the coating through the introduction of different types of POSS, instead, has a negligible effect on the thermal barrier ability of pre-formulated coatings.

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ACKNOWLEDGEMENTS

The authors wish to acknowledge all partners of the COCET project ("COmportamento di materiali compositi in Condizioni Estreme: alta Temperatura" - PON02_00029_3206086)