ENHANCEMENT OF ELECTRICAL CONDUCTIVITY OF AEROSPACE STRUCTURES BY INCORPORATION OF CNT DOPED CARRIER MATERIALS INTO DRY PREFORMS

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ABSTRACT

The paper looks into a specific route of incorporating nanodoped materials in dry preforms to enhance the electrical conductivity of the final infused carbon fibre reinforced epoxy laminate, without affecting mechanical room temperature (RT) and hot/wet (H/W) performances. The aim is to select suitable nanodoped polymeric carriers followed by an assessment of the manufacturing, electrical and mechanical properties of nanodoped carbon-fibre reinforced composite.

1. INTRODUCTION

In recent years we have seen a gradual migration from metallic aeronautical structures to composite structures, particularly CFRP (Carbon Fibre Reinforced Plastics). Among the many advantages of this evolution, there are also some disadvantages; one of them is the loss of intrinsic electrical conductivity of the material. This has a direct effect on the electrical functions of structures, like ESD (Electro-Static Discharge), electrical bonding, EMI (Electro-Magnetic Interference) shielding and the LSP (Lightning Strike Protection) effectiveness. This is due to the fact that the single carbon fibre/yarns (conductive by themselves) are actually surrounded by the resin matrix (typically epoxy resin) that works as an electrical isolation layer and affects the electrical conductivity in plane and particularly through thickness.

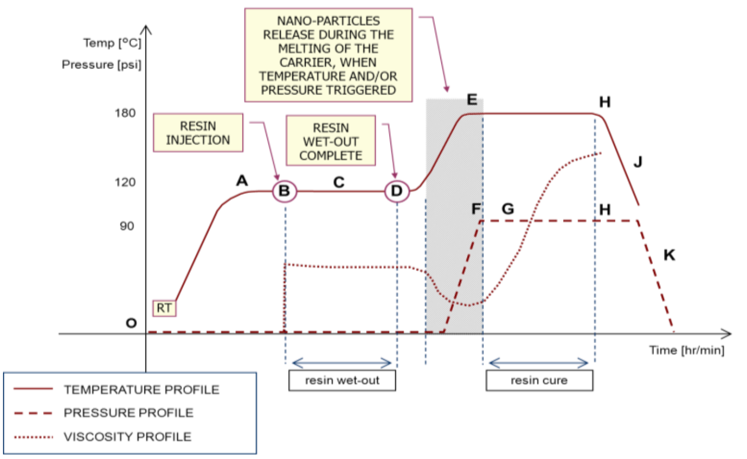
Aim of this research is to find alternative non-metallic materials/solutions to achieve LSP (and in general electrical conductivity) aiming at a lower weight and lower overall cost for production of aircraft structural components (typically wing covers or fuselage skin panels). One option to improve the electrical conductivity is to incorporate carbon nanotubes in the polymer matrix. Researchers have shown at lab scale that CNT doping can increase the transverse electrical conductivity of CFRP[1,2]. Moreover, the inclusion of CNT and related materials into the matrix has the potential of creating materials with multi- functional properties, e.g. a combination of electrical, thermal conductivity and improved mechanical performance in addition to self-sensing capabilities[3].

For Bombardier Aerospace Belfast, EADS Innovation Works Germany and other industrial partners in the project ELECTRICAL, the LRI (Liquid Resin Infusion) composite manufacturing process has been selected. This choice is in line with the targets that the commercial aerospace industry has set on R&D groups of “lighter AND cheaper” structures.

However, mixing CNTs in the resin bulk before infusion leads to (a) an undesired increase in viscosity and (b) a significant filtering effect; these can lead to (a) issues during wet-out of large size aero-structures (where resin viscosity needs to be lower than 100cPoise) and (b) to an inhomogeneous dispersion of CNTs in the final composite structure. The solution to overcome these issues was sought to incorporate the CNTs in the preform using a carrier material, such as a binder or, more in general, a thermoplastic or thermoset interlayer, preferably in the shape of a veil, grid or film[6]. To this end, several carrier materials were tested and one was selected based on manufacturing criteria. This carrier material was subsequently used to manufacture coupons for electrical and mechanical property measurements.

2. CARRIER MATERIAL SELECTION

The criteria for selection of the most suitable carrier material were manufacturing based. For example, one key effort in the ELECTRICAL project was to find a CNT carrier material that would not be activated until the wet-out process of the fibres with the epoxy matrix is complete, that means at a temperature well above the 120°C (and ideally below the 180°C). This concept is explained in the graph below.



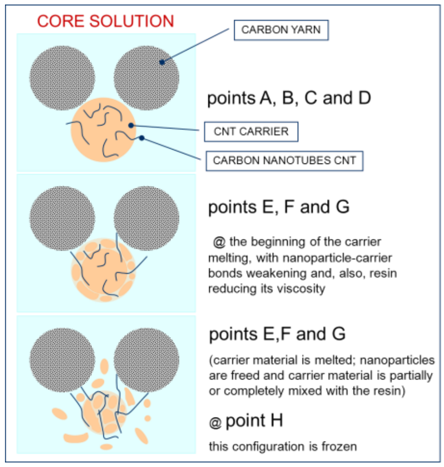
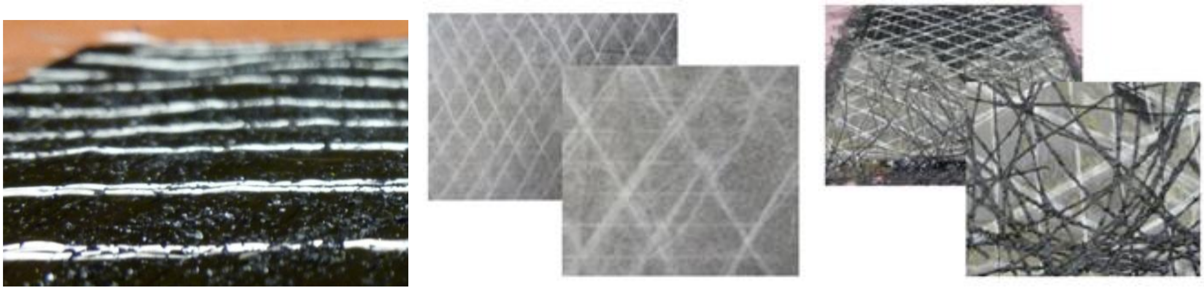


Figure 1: Typical temperature, pressure and viscosity profile of one LRI process. Figure 2: a graphical representation of expected carrier behaviour during the resin infusion cycle.

A series of preliminary screening tests were focused on the manufacturing compatibility of the available materials, see Table 1. The objective of the tests was to choose the most appropriate methods for the incorporation of CNTs in a dry fibre preform by assessing;

- the handling and application
- the dispersion/homogeneity of CNTs across the surface area
- the carrier materials suitability as a preforming aid (binding action)
- if the melt temperature is in line with the processing parameters that have been defined above
- if any adverse effects on the wet-out/permeability were noted.
- Also, the addition of novel materials such as thermoplastic veils has been observed to increase the moisture absorption of laminates, which may lead to a large knock-down in properties in hot/wet conditions. Hence, the manufactured laminates were subjected to an accelerated conditioning test.

The CNTs were either incorporated in thermoplastic materials that were subsequently formed into an extruded or melt-blown veil, or in thermoset masterbatches (based on MVR444 epoxy system, Cytec) doped with 20-25% of CNTs and mechanically cryo-ground into fine granules, see Figure 3. Each binder form was interleaved in a multi-ply, unbindered carbon non-crimp fabric (Saertex) stack. It proved difficult to evenly spread the supplied granules (a), which varied in size, over the carbon fabric. The veils however, took much less effort to apply though the visible difference in the dispersion of the extruded fibre and melt blown veils showed a bigger and more open system in the latter.



(a) **(b)** **(c)**

Figure 3: Forms of material screened; (a) granular masterbatch, (b) melt-blow veil and (c) extruded fibre veil

The stacks were then preformed at a range of temperatures so as to discover the optimum preforming temperature, if any, with the doped HTM PA (high temperature melting polyamide) displaying no binding action within the 160°C range of our equipment.

The subsequent preforms were then infused with MVR444 resin and cured, with any negative infusion/permeability signs noted. The doped LoTM PA (low temperature melting polyamide) + HTM PA blend laminate displayed dry spots when infused indicating that it may pose a risk when manufacturing is scaled up. The B-stage doped epoxy masterbatch laminate caused unacceptable undulations due to the granules being left unreacted with the bulk resin.

Specimens were extracted from the laminates and subjected to the accelerated conditioning test. All screened solutions had a negative effect though the least effected material was the doped epoxy granule (184% increase in moisture absorption on baseline), see Table 1.

Table 1: Selection of Carrier materials (reported moisture absorption is related to epoxy-only matrix CFRP)

Material	Form	Preforming Temp (°C)	Suitable as a binder?	Infusibility	Moisture absorption
LoTM PA	Pure Thermo-plastic (TP) Veil	110-120	Yes	Good	264%
LoTM PA + 7wt.% CNT	TP Doped Veil (Extruded Fibre)	120-130	Yes	Good	352%
LoTM + HTM PA +20%CNT	Granules	120-140	Yes	Unsuccessful	208%
ITM PA	Pure TP Veil	130-140	Yes	Good	220%
ITM PA + 7wt.% CNT	Doped TP Veil (extruded fibre)	140-150	Yes	Good	220%
MVR 444 Masterbatch+ 25wt.% CNT	Cryo-ground doped thermoset Granules	>150	Partial	Good	184%
HTM PA + 10% CNT	doped TP Veil	-	No	Good	204%

Based on the lower moisture absorption and preforming feasibility, Arkema’s PA (hereafter named ITM – for intermediate temperature melting) veil with and without 7wt% CNTs was selected.

3. LAMINATE PROPERTIES

After selecting the most promising solution with the help of the pre-screening testing phase, electrical and mechanical characterization is being performed to obtain an assessment of the newly manufactured CNT modified CFRP. CNT-doped thermoplastic non-wovens veils were specially designed and manufactured for the purpose of the project by Technology Partners, Warsaw, Poland[5] by melt-mixing an intermediate temperature melting (ITM) copolyamide polymer with 5wt% CNTs into pellets, which were subsequently melt-blow into non-wovens with areal weights ranging from 6 to 12 g/m^2. For comparison an unfilled ITM veil and a commercially available veil with 12 g/m^2 LoTM PA (low temperature melting polyamide) was used.

The three (LoTM, ITM without CNTs, ITM with CNTs) non-woven binders were incorporated in the preforms to reach an amount of 12g/m^2 of thermoplastic material inserted in-between each carbon fibre ply. All composites were manufactured using vacuum-assisted liquid resin transfer moulding. The quality of the manufactured CFRP laminates was assessed using ultrasonic inspection to look for potential inhomogeneity’s, delamination and porosity. In addition, light microscopy observation was performed on polished cross-sections of the material.

Electrical conductivity measurements in the through-thickness direction were carried out according to Airbus Test Method AITM2-0065, using composite specimens with a quasi-isotropic lay-up. Square specimens with a thickness of about 4.40 mm, and lengths ranging from 40 mm to 15 mm were tested using a Keithley Series 2400 four-probes ohmmeter.

The interlaminar fracture toughness energy in mode I (GIc, DIN 65-563) was measured using composite specimens with a $[0]_{12}$ lay-up. For each material and each mechanical test at least five specimens were tested at room temperature.

3.1 Results and Discussion

Quality inspection with US-scanning and microscopy confirmed the high quality of the manufactured laminates.

Figure 4 shows an outline of transverse electrical conductivity values of CFRP modified with LoTM non-wovens (baseline), ITM non-wovens without CNTs and ITM non-wovens with CNTs. ITM with and without CNTs offer a value of 0.9 S.m^{-1}, while the baseline material exhibits a value of ~1.3 S.m^{-1}.

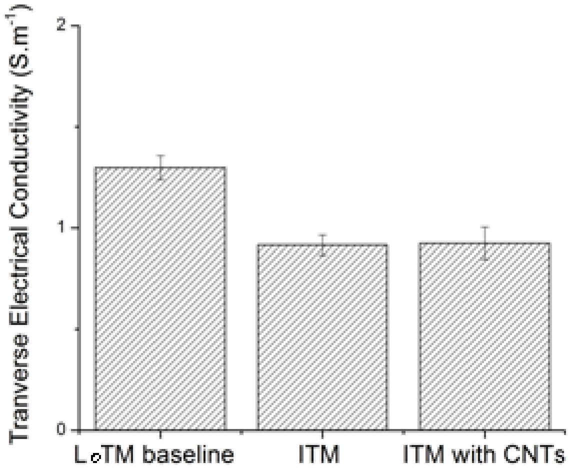


Figure 4: Transverse Electrical Conductivity of various CFRP materials

Unfortunately, no increase in conductivity could be observed due to the addition of CNTs, remaining far from the targeted 5 S.m^{-1} for edge glow. One explanation could be the insufficient conductivity provided by the doped non-wovens. Thus far, it was not yet possible to determine the electrical conductivity of the non-wovens themselves with the available equipment, though further trials are planned to determine the electrical conductivity of such non-woven material and explain these results. Moreover the ITM material exhibits a slightly lower conductivity compared to the baseline LoTM material, which may be explained by varying thicknesses of the veil, causing a thicker insulation layer between the carbon layers, though this remains to be verified.

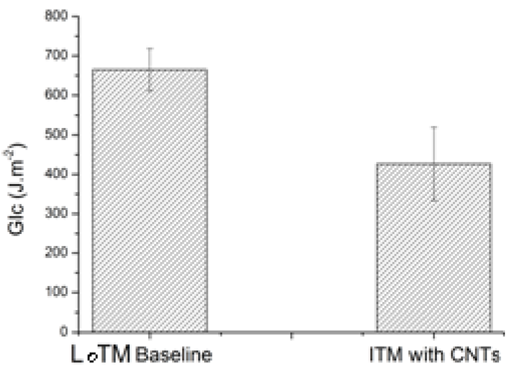


Figure 5 shows the GIc results, and again the non-woven ITM veil performs worse than the LoTM baseline material. This may be attributed to a lower interaction

between the polyamide and epoxy resin due to the higher melting temperature. Further investigations are planned to verify this hypothesis, as well as further mechanical testing including interlaminar shear (room temperature and hot/wet environment) and GIIc testing.

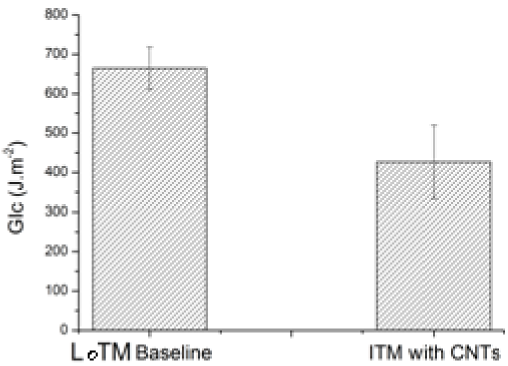


Figure 5: Interlaminar fracture toughness results

4. CONCLUSIONS

A non-woven consisting of an intermediate melting temperature polyamide was selected as carrier material for CNTs to improve the through-thickness electrical conductivity of CFRPs. First results did not show the expected improvement, which may be related to a poor conductivity of the veils themselves, though this remains to be evaluated. More experiments are required to investigate the effects of the non-woven on the mechanical properties.

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