PROCESSING AND CHARACTERIZATION OF MULTI-SCALE COMPOSITES MANUFACTURED BY OUT-OF-AUTCLAVE RESIN FILM INFUSION

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Introduction

The majority of polymer matrices currently used in the aerospace industry are thermosetting polymers. A main drawback of thermosets is their brittle fracture behaviour that may cause catastrophic failure in the composite materials. To overcome this critical drawback, one approach is to modify the properties of the polymers by adding small weight fractions of nanoscale filler particles, such as carbon nanotube (CNT). To harness the full potential of CNTs, they must be uniformly dispersed within the host polymer. Failure of achieving proper nanotubes dispersion may cause adverse effects, by which the overall performance of the polymer may even degrade below that of the neat polymer. The issue of dispersion is even more challenging when the nano-modified polymer is impregnating a dry fibre preform, in which case the infiltration of nanoparticles deteriorates the dispersion quality. The other difficulty associated with the integration of nanotubes into polymers is the net impact that they have on the resin physicochemical properties, such as viscosity and curing behaviour. This often results in poor processability and prevents from using these products at the industrial scale. As a result of these specific challenges, the processing conditions that are normally applied for manufacturing conventional composites might need to be modified to render multi-scale composites with the expected performance.

Composite materials are commonly manufactured under high pressure in an autoclave. The disadvantages associated with the use of an autoclave are limitations of the part size, as well as manufacturing and energy cost. An alternative approach is to perform the curing process out-of-autoclave at atmospheric pressure. The reduced pressure, however, might increase the void content, and therefore, decrease the mechanical properties.

In light of the above, the main objective of the present study is to investigate the processing and characterization of multi-scale composite laminates manufactured by the out-of-autoclave resin film infusion process (RFI).

Materials and methods

Composite laminates were manufacturing by stacking semi-solid epoxy resin films with carbon fibre (CF) reinforcement. The resin film contained 0.3 wt.% of multi-walled carbon nanotubes (MWNT). Two resin film stacking strategies were applied: grouped, in which resin film and fabric were stacked separately, and intercalated stacking strategy where the resin films were stacked between each dry fibre preform plies.

The laminate quality was determined by taking micrographs of sections and measuring fibre volume fraction, void content distribution and analysing the dispersion of the CNTs inside the manufactured laminates. The interlaminar properties were measured with double cantilever beam (DCB) tests using ASTM standard methods. A multimeter was used to

record specimen resistance in four-wire mode when three-point bending load was applied using an electromechanical testing system.

Results

The results of laminate quality measurements revealed a fibre volume fraction of 58.2% and 59.6% and void content of 0.16% and 0.017% for grouped and intercalated strategies, respectively. Fibre volume fraction could be increased by reducing the initial resin quantity or by placing a perforated Teflon film on top of the layup to enable the bleeding of dispensable resin. According to these results, a similar laminate quality was achieved for both stacking strategies. The observation of the cross-section of the composite laminates revealed that in both stacking strategies, CNTs agglomerated around the edge of the fibre tows, creating non-uniform CNT distribution inside the composite part (figure 1). This was caused by the filtration of CNTs with the fibres when the resin impregnated into the micro pores.

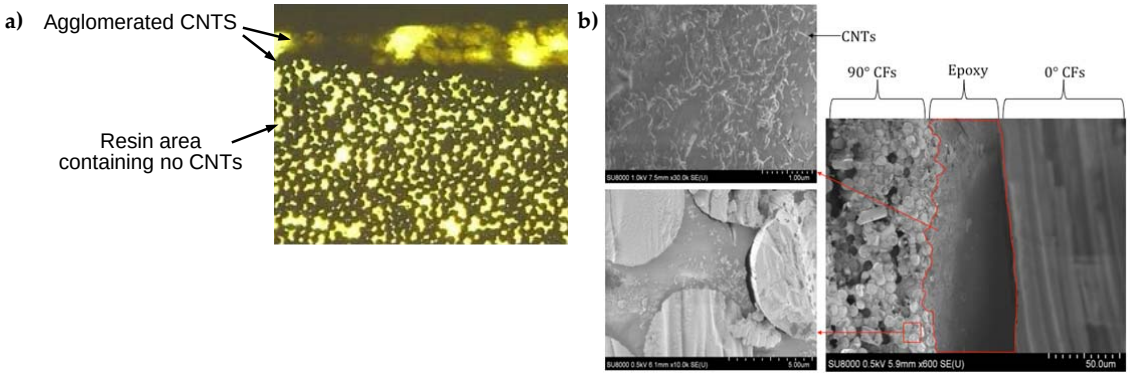

Figure 1: *CNTs distribution within the composite laminate using intercalated strategy: a) optical microscopy; b) scanning electron microscopy.*

Strain energy release rates for Mode 1 fracture toughness test on composite samples manufactured by intercalated strategy was measured as 367.1 J.m^{-2} and 417.7 J.m^{-2} for the sample containing neat resin and CNT-modified resin, respectively. This improvement in the energy release rate indicates the reinforcing effect of CNTs on the interlaminar properties of the composite laminate. Moreover, the addition of CNTs resulted in smoother electrical recording, better repeatability and larger electrical resistance change inside the composite laminate as shown in figure 2. This was attributed to the improved CF-CF contact quality in the presence of CNTs. This promising result showed the potential of these CNT-CF multiscale composites for self-sensing applications.

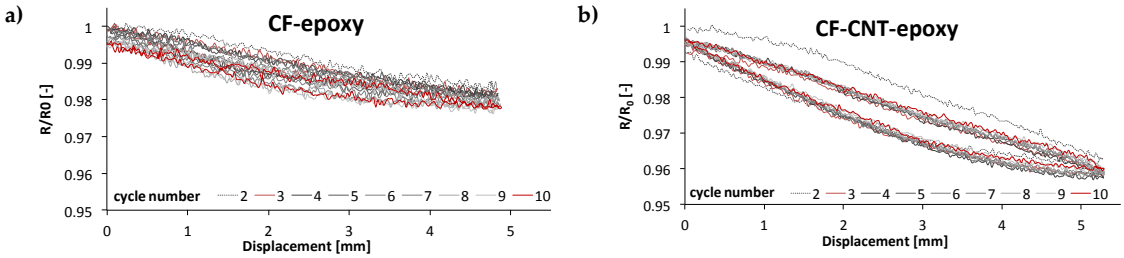

Figure 2: *Change in relative electrical resistances of a CF-epoxy specimen (a) and a CF-CNT-epoxy specimen (b) under elastic compression, for 10 consecutive load cycles.*