NANO-ENGINEERED HIERARCHICAL COMPOSITES WITH MULTI-FUNCTIONALITIES: FROM NANOFILLER NETWORK FORMATION TO SELF-SENSING AND DE-ICING

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Abstract

Hierarchical composites based on continuous micro-level carbon or glass fibre together with various forms nano-level materials such as carbon nanotubes (CNTs) and graphene have been explored extensively in last decade for next generation advanced composite materials, not only due to their improved mechanical performance, but also the embedded new functionalities such as electrical and thermal properties, strain and damage sensing, de-icing functions, as well as self-healing or easy repairing [1-4]. However, the methodology to integrate nanofillers into traditional fibre reinforced composites has to be carefully designed, in order to avoid agglomeration of nanofillers and subsequently filtration effect during the resin infusion processes [5-6].

In this study, the network formation of reduced graphene oxide (rGO) within the epoxy resin during the curing process has been *in-situ* visualised, with their effects on the electrical, mechanical, and multifunctional properties of fabricated composites explored. Different initial dispersion status with various filler loadings were employed to examine the nanofiller network formation process. When transferring those nanoreinforcements to continuous fibre reinforced composite, both top-down method – direct dispersing graphene nanoplatelets (GNPs) within the epoxy using three roll mills, as well as bottom-up method - localised deposition of CNTs and GNPs via spray coating are explored for the manufacturing of hierarchical composites with nanofillers. Multifunctionalities including strain and damage sensing have been explored for those nano-enigneered composite laminates.

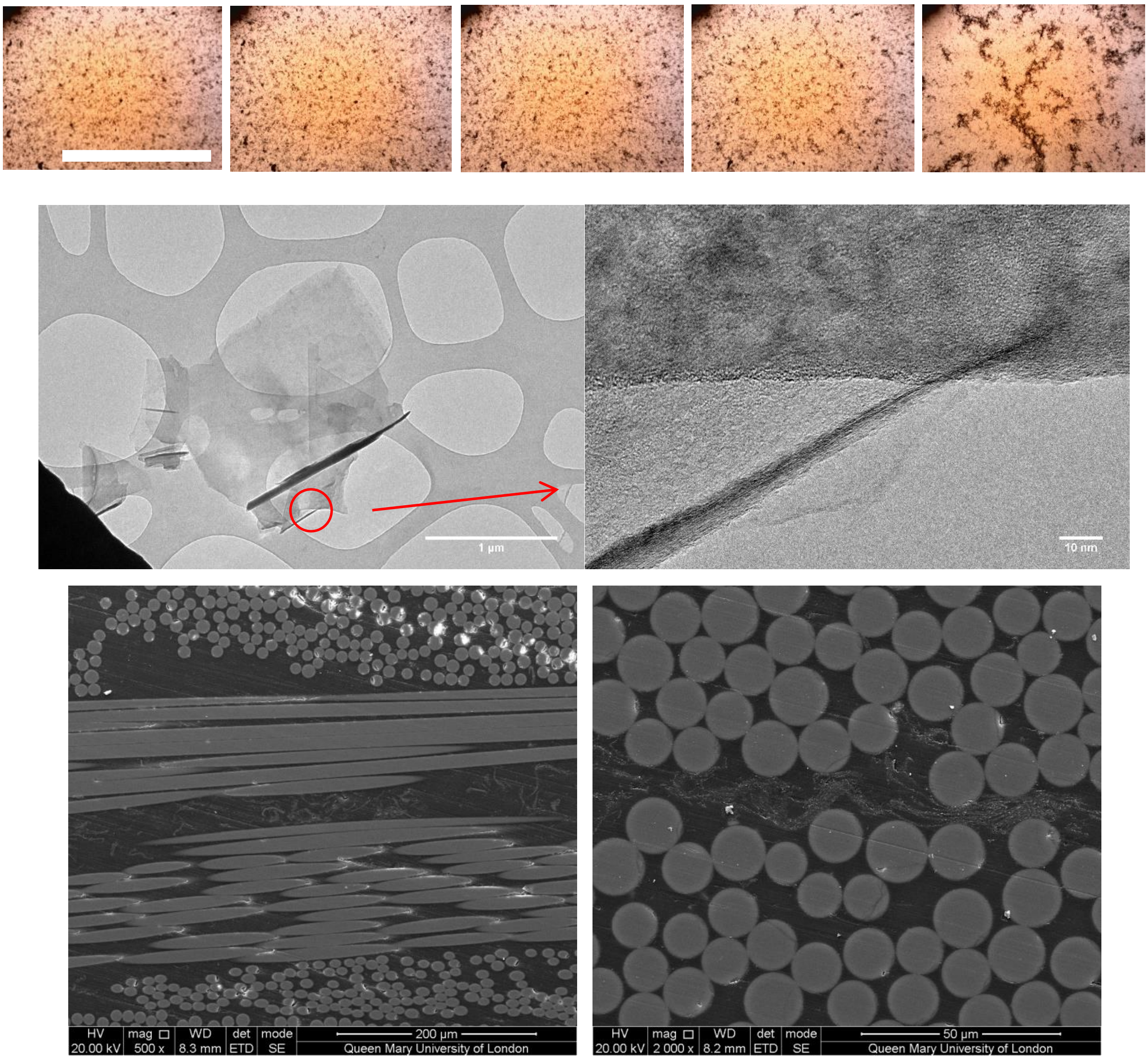

Figure 1. Top line: the GNP network formation within the epoxy resins during curing (from left to right), showing a clear process from dispersed particles to the re-establishment of the percolated network (scale bar = 1mm); middle and bottom: TEM images of the graphene nanoplatelets, and SEM image of the cross-sectional views of GNPs localised at the interfacial regions of fibre reinforced composites.

The graphene reinforced epoxy nanocomposites with different network have been characterised for electrical, mechanical, as well as multifunctional properties. Fig. 2 shows the electrical sensing signals under flexural loading conditions. Clear correlation can be found between electrical resistance change and applied strain, while a high sensitivity of gauge factor of 40 was achieved.

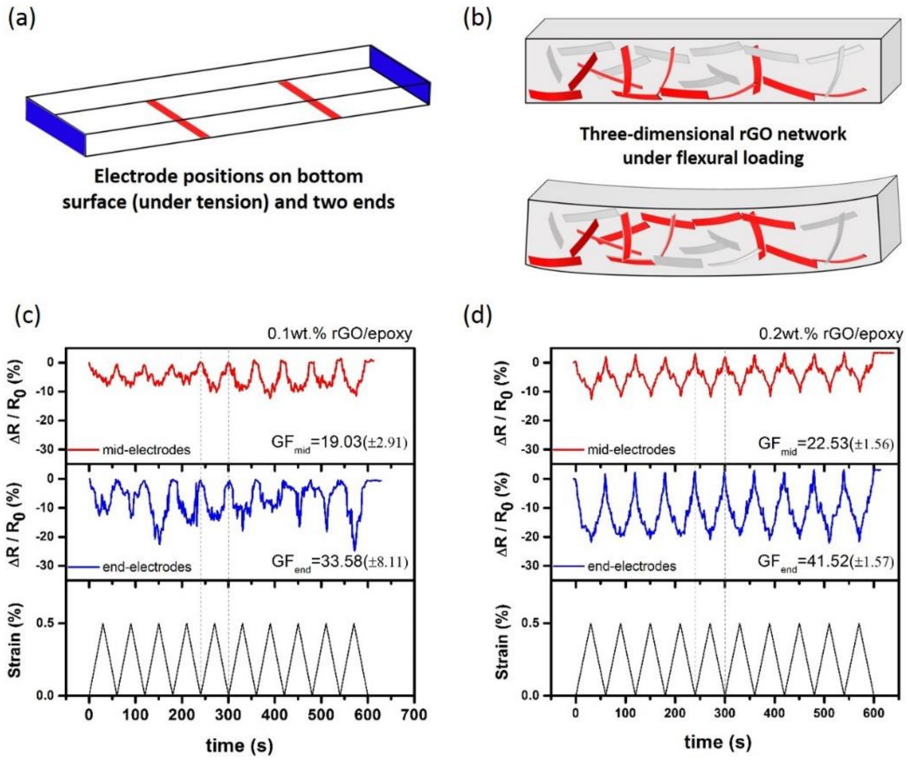

Fig. 2 Strain sensing results of rGO/epoxy nanocomposites based on electrical methods, showing clear correlation between electrical resistance and applied strain.

The de-icing functionality has also been explored based on Joule heating effects of percolated nanofiller network. Fig. 3 shows the temperature profile of fabricated panel, showing efficient heating capability which raise the temperature from -20 ℃ to 20 ℃ in 2 min.

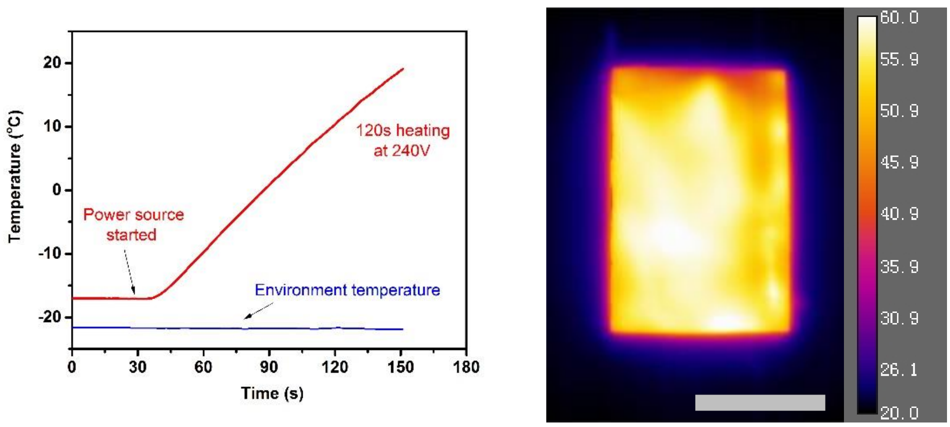

Fig. 3 De-icing performance of rGO/epoxy nanocomposites based on Joule heating effects.

To avoid the filtration effect of graphene nanoplatelets during resin infusion process, spray coating has been employed to localise the nanofillers into damage prone areas for in-situ damage detection. The manufactured hierarchical composites with percolated network have been used as smart materials to detect various external stimuli such as strain/damage sensing for mechanical deformation, and de-icing by applying electrical current. Due to the localised deposition at interlaminar regions (Fig. 1), the electrical conductivity has been enabled for insulating system such as glass fibre composites at very low filler loadings (less than 1 wt.% GNPs to reach electrical conductivity of 10-3 S/m level). The mechanical performance, including Mode-I interlaminar fracture toughness has been characterised, while the feasibility of utilising those interleaves as a quick repairing phase to provide a self-healing functionality has also been explored.

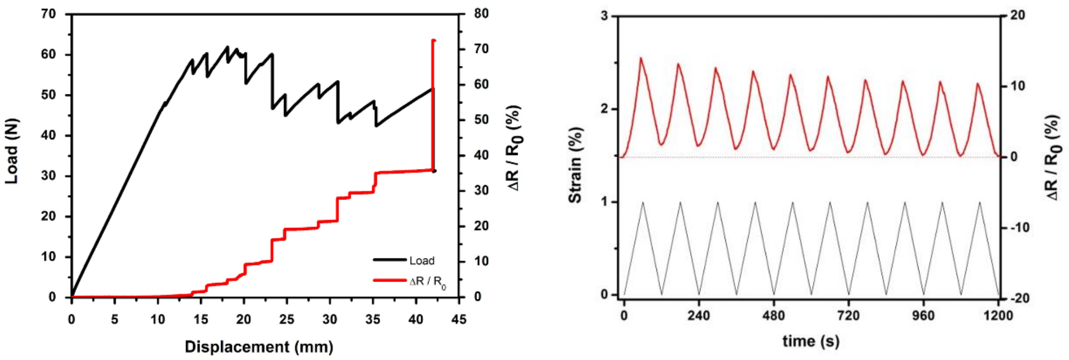

Figure 4. The in-situ sensing results of hierarchical composites for: Mode-I interlaminar fracture toughness (left); and cyclic strain sensing under flexural loading (right).

Acknowledgments

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