Mechanical properties at cryogenic temperature of multi-scale nano-carbon/micro-fiber reinforced epoxy composites

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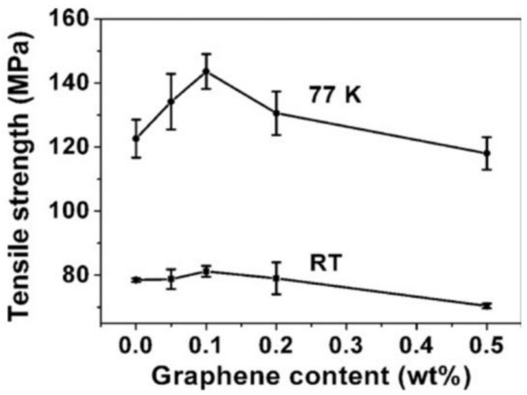
Epoxy resins are a kind of thermosetting polymers that have been widely applied in various industries and technologies due to their low cost, easy processability, good thermal, mechanical and electrical properties, etc. In addition, epoxy resins have been increasingly employed in extremely low temperature environments as impregnating materials, adhesives and matrices for advanced composites with the rapid development of aerospace engineering, superconducting cable technology and other large cryogenic engineering industry [1, 2]. However, pure epoxy resins are usually brittle at room temperature and may generate roughness degradation which leads to structural damages in form of microcracks or delamination at very low temperatures such as liquid nitrogen (77K) or liquid helium temperature (4K), which makes them unsuitable for cryogenic engineering applications [3, 4]. Therefore, it is of great significance to enhance the cryogenic mechanical properties of epoxy resins by reinforcements such as carbon fibers, glass fibers, carbon nanotubes and graphene etc. so that epoxy resins can be successfully applied in cryogenic engineering technologies.

Carbon nanotubes (CNTs) and graphene, as the representatives of nano-carbon materials, have attracted much attention over decades due to their unique mechanical, electrical and thermal properties. They have been incorporated into epoxy resin to enhance the mechanical properties of composites due to their high mechanical strength and excellent Young's modulus. This paper gives a brief review about recent advances on enhanced mechanical properties at cryogenic temperatures such as 77 K etc. of epoxy composites by CNTs, graphene, carbon and glass fibers.



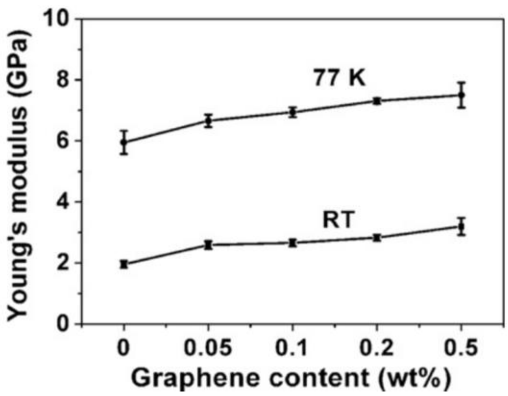


Figure 1: Effect of the graphene content on the tensile strength and Young's modulus of the graphene/epoxy composites at RT and 77 K. Cited from [6].

Kim et al. [5] fabricated 3-phase carbon fiber/CNT/epoxy unidirectional prepregs via a hot-melting process with the addition of CNTs into the epoxy resin formulation. It was found that the tensile strength and modulus were both increased with the addition of moderate CNTs compared with traditional carbon fiber/epoxy composite, attributed to the good interfacial bonding quality. Shen et al. [6] investigated the reinforcing effect of graphene in enhancing the cryogenic tensile properties of epoxy composites at a weight fraction of 0.05–0.50%. As shown in Figure 1, the tensile strength was enhanced at the low graphene content of 0.1 wt% because of the uniform dispersion of graphene nanosheets. However, the composite strength at both room temperature (RT) and 77K was decreased by the introduction of graphene nanosheets when the graphene content was increased over 0.1 wt% due to the aggregation of graphene. When it came to Young's modulus, graphene contributed to an almost linearly increase due to the high modulus of graphene.

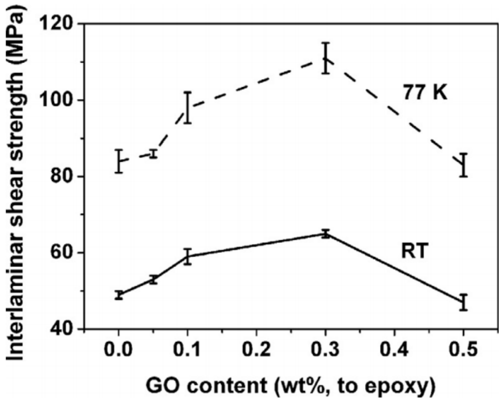


Figure 2: Effect of the GO content on the interlaminar shear strength of GF/epoxy composites at RT and 77 K. Cited from [7].

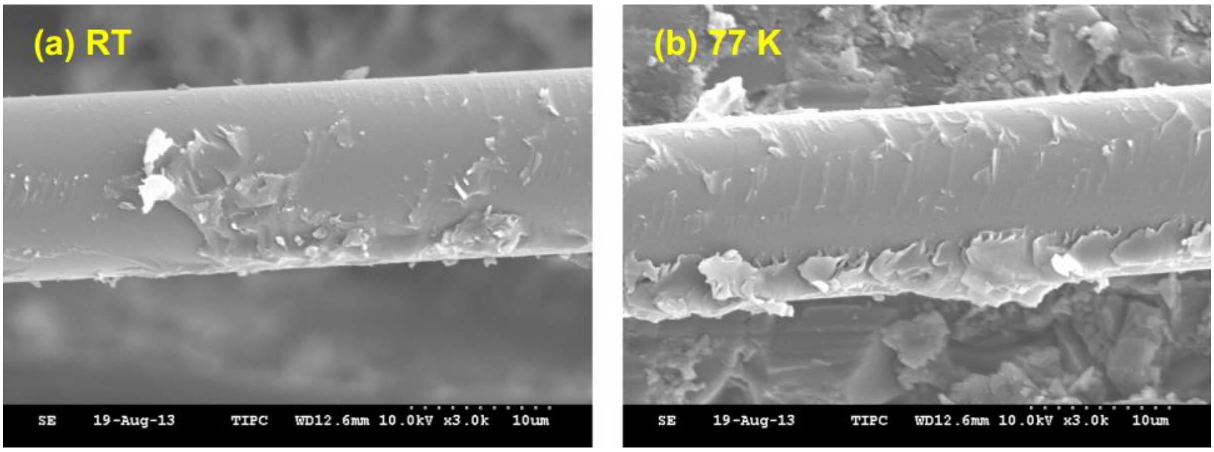


Figure 3: SEM images of the interlaminar shear fracture surfaces of the GF/epoxy composites with 0.3 wt% GO relative to epoxy after testing at (a) RT and (b) 77 K. Cited from [7].

The cryogenic ILSS at 77K of glass fabric/epoxy composite was investigated in [7]. In Figure 2, the ILSS increased initially with the increase of the GO content and reached the maximum at the GO content of 0.3 wt%. In addition, the ILSS of the composite at 77K was much higher than that at RT due to the relatively strong interfacial GF/epoxy adhesion at 77K compared to the RT case. As shown in Figure 3, the bonding between fiber and GO-modified epoxy at a higher GO content became better shown by more amount of the attached matrix when more GO was introduced, leading to higher ILSS.

Yang et al. [8] investigated the effect of CNTs on the cryogenic fracture toughness of poly(ethersulfone) (PES) modified epoxy. The fracture toughness (K_{IC}) at 77K was improved by about 13.5% compared to that of the PES modified epoxy matrix when the 0.5 wt% CNTs content was introduced. In addition, Liu et al. [9] studied the effect of CNTs on the mode II interlaminar fracture toughness (G_{IIc}) at cryogenic temperature of glass fiber/epoxy composites. It was demonstrated that the epoxy modification by multiwalled CNTs can lead to great improvements G_{IIc} in both RT and 77K.

In conclusion, it is shown that the introduction of carbon nanotubes and graphene at proper contents into epoxy resins can effectively enhance the cryogenic mechanical properties of the composites. Furthermore, the epoxy nanocomposites as matrices are beneficial for further improving the mechanical properties of multi-scale fiber reinforced composites.

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