**Toughening polymer composites at cryogenic temperatures using nanoparticles**

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**Introduction**.

Lightweight fibre reinforced polymer (FRP) composite fuel tank development is crucial for affordable launch vehicles and transportation of liquid hydrogen fuel. Due to the high thermal stress induced by the large discrepancy between the coefficients of thermal expansion of the matrix polymer and carbon fibres [1], existing FRP composites suffer from premature matrix cracking that severely degrades the strength and gas permeability of composites, posing a significant challenge to the use of fibre composite in liquid hydrogen fuel tank.

The aim of this study is to develop multi-scale toughening systems to address the micro-cracking problem by incorporating nano-scale materials to simultaneously improve the fracture toughness of polymer matrix and reduce the coefficient of thermal expansion. This new technique will lower the thermal residual stress and increase resistance to matrix cracking.

**Experimental Methods**.

Nanoparticles were mixed with epoxy resin using various technique e.g. manual mixing and probe sonication. Carbon-epoxy and nanoparticle-carbon-epoxy laminated composite panels were produced using hand lay-up and resin infusion techniques. Laminated Composite panels were cut into double cantilever beam (DCB) testing specimens using multicam CNC router to carry out cryogenic testing of the composites at liquid nitrogen (LN2) temperature.

Results and discussion.

DCB testing was carried out to determine whether addition of nanoparticles has any effect on the interlaminar fracture energy. Fig. 1 shows the typical load displacement curve obtained from DCB testing at room temperature (RT) and cryogenic LN2 temperature. From the curves, it can be seen that LN2 temperature makes the composite less tough.



Figure. Typical load displacement curve obtained from DCB testing at (A) RT and (B) LN2 temperature.

Critical energy release rate *(GIc*) values (initiation and steady state propagation state) for all laminated composites modified with nanoparticles were seen to decrease at RT when compared to unmodified laminated composites. However, GIc values for modified laminated composites were generally seen to increase when compared with unmodified laminated composites at cryogenic LN2 temperature.

Conclusion.

Toughening effect was evident at LN2 temperature for nanoparticle modified laminated composites compared to unmodified laminated composites as obtained from DCB testing.

**References**

1. Agius, S.L., Joosten, M., Trippit, B., Wang, C.H. and Hilditch T. (2016). Rapidly cured epoxy/ anhydride composites: Effect of residual stress on laminate shear strength Compos Part A: Appl. Sci. Manuf., 90, 125-136.