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M3Or2D-04: In situ observation of microcrack formation in carbon fibre reinforced composites under mechanical load at cryogenic temperatures.

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There is rapidly growing interest in the aviation sector for the use of liquid hydrogen (LH2) as a zero emissions fuel for commercial aircraft, with major OEMs committing to hydrogen aircraft by 2035. Currently metallic tanks are used to store the LH2, which are much heavier than those used for conventional fuels resulting in significantly reduced operational range and/or payloads. Hence, carbon fibre reinforced polymer (CFRP) composite tanks are being considered as an alternative to conventional metallic tanks due to predicted potential 40% weight savings. However, when CFRPs are cooled to cryogenic temperatures, internal stresses are developed as a result of the mismatch in coefficient of thermal expansion between the constituent materials. The internal stresses can lead to microcracking of the CFRP that reduce the mechanical performance of the tank and cause hydrogen permeation leading to tank failure.

Despite the importance of assessing the resistance of CFRPs to microcracking at cryogenic temperature, standardised tests procedures do not exist. The most common test involves thermally cycling CFRP coupons by repeated immersion in liquid nitrogen and inspection of the coupon edges using optical microscopy at ambient temperature between thermal cycles [1]. As the coupons are not subjected to mechanical loading, either during immersion or the inspection, the procedure is limited. Firstly, in-service the material will be subjected to additional loading, and more importantly when the inspection takes place at ambient temperature the microcracks can close and not be visible. A further challenge is that some highly toughened polymers do not crack until several hundred cycles or not crack at all without the introduction of additional load.

Microcrack Fracture Toughness (MFT) [2] provides an alternative to the repeated immersion procedure. The MFT test in [2] involved loading various cross-ply CFRP coupons in tension and observing the evolution of the microcracks in the 90o plies using optical microscopy. Images of the microcrack evolution were recorded alongside load and displacement from the test machine allowing a quantitative evaluation of microcrack density against applied load, from which the applied stress was calculated. In [2] an attempt was made to characterise the microcrack fracture toughness at cryogenic temperatures. During the tests the coupons were unloaded and imaged at ambient temperature, resulting in similar challenges to those associated with the closure of the microcracks as the immersion test procedure. Furthermore, the removal of the coupon from the test machine at predefined intervals and warming for inspection means the test is time consuming and costly.

In the present work, a novel in-situ microcrack measurement technique is developed to obtain the microcrack fracture toughness at cryogenic temperatures. In the new experimental set up, a bespoke cryostat is designed and manufactured using 3D printing. The cryostat enables observation of the transverse microcracking within the CFRP coupon during mechanical testing. A mixture of nitrogen gas and liquid is injected into the cryostat, facilitating local cooling of the coupon, which enables a more efficient and comprehensive testing campaign.

A range of CFRPs are evaluated for their microcracking resistance at both ambient and cryogenic temperature. This enables a comparison of the impact of temperature and thermal stress state on the materials microcracking behaviour. The same materials are also evaluated using the repeated immersion method. The results from MFT are then compared to the resistance to microcracking in the immersion tests.

1. Bechel, V.T. and R.Y. Kim, Damage trends in cryogenically cycled carbon/polymer composites. Composites Science and Technology, 2004. 64(12): p. 1773-1784.
2. Ryan, K., et al., Evaluating the Resistance to Microcrack Formation of Composites at Cryogenic Temperatures. AIP Conference Proceedings, 2006. 824(1): p. 257-263.

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