

NOTCHED TENSILE TESTS AND ANALYSIS OF UNIDIRECTIONAL FIBER COMPOSITES ENCOMPASSING SELF-HEALING OF INTERFACIAL DEBONDING

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ABSTRACT

Interfacial debonding can cause a reduction in strength and stiffness of fiber-reinforced polymers (FRPs) and is extremely difficult to detect and repair by conventional methods. Thus, self-healing has the potential to mitigate the interfacial debonding. Recently, Sanada et al. [1] proposed a methodology for self-healing of interfacial debonding in unidirectional FRPs by using fiber strands coated with the self-healing polymer developed by White et al. and conducted transverse tensile tests to assess the self-healing efficiency. Sanada et al. [2] also investigated the effect of microstructure on the efficiency of transverse tensile strength recovery of self-healing FRPs. The objective of this study is to investigate the interfacial debonding behavior of single edge notched tensile (SENT) specimens of unidirectional FRPs encompassing self-healing and to assess the performance of self-healing system for interfacial debonding as shown Figure 1.

Self-healing FRP and reference FRP plates made of unidirectional carbon fiber-reinforced polymer were prepared. For self-healing FRP plates, Torayca T300B (Toray Industries, Inc.) carbon fiber strands were coated by manually dipping them into the Epikote 828 (Japan Epoxy Resins Co. Ltd)/Ancamine K54 (Air Products and chemicals, Inc.) epoxy mixture containing 30wt% microcapsules and 2.5wt% Grubbs catalyst (Sigma-Aldrich Co.). The healing agent used in this study was dicyclopentadiene (DCPD) monomer. DCPD was microencapsulated and the microcapsules with mean diameter of 300nm were used. To aid inspection for the release of healing agent from broken microcapsules, the microcapsules were also made from DCPD mixed with UV fluorescent dye (Blenny Giken Ltd.). For reference FRP plates, coated carbon fiber strands without Grubbs catalyst were prepared using similar procedures.

After coating, the semi-cured fiber strands were placed in mould and impregnated with the Epikote 828/diethylenetriamine. The mould was then closed and the samples were moulded into the plate for 24h at room temperature, followed by 24h at 40 °C. Once the plates were cured, they were machined using a water cooled diamond saw to produce SENT specimens with thickness $t=2$ and 3mm as

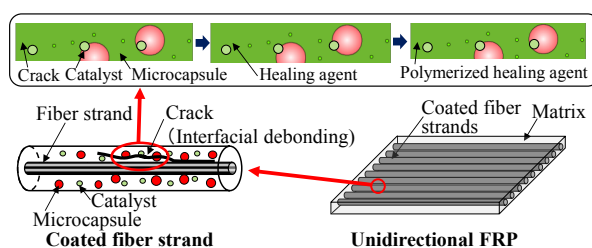


Figure 1: Self-healing system of interfacial debonding.

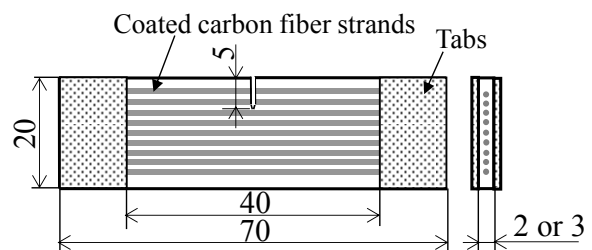


Figure 2: Specimen geometry (dimensions in mm).

shown in Figure 2. A notch was cut using a diamond wafering saw and a sharp pre-crack was created by gently tapping a razor blade into the notch in the specimens.

The SENT specimens were tested using a tensile test machine in the displacement control at rate of 0.5mm/min. The self-healing FRP specimens were loaded until large load drops occurred, indicating damage progression. Before the specimen fractured completely, the specimens were unloaded, clamped closed, and allowed to heal for 10 days at room temperature. After healing, the specimens were tested again. For the reference FRP specimens, the specimens were immediately unloaded and reloaded to fracture after virgin test. The healing efficiency was evaluated by the critical fracture loads of healed and virgin specimens.

In addition to conducting experiments, finite element analyses were performed using a three-dimensional model to predict the damage evolution of SENT specimens. Microcracking of the matrix and the coating layer was detected by the von Mises criterion. Maximum stress criterion was also used to evaluate breaking of the fiber strand.

Measured load-displacement curves for a self-healing FRP specimen with $t=2\text{mm}$ are shown in Figure 3. After two large load drops, the specimen was unloaded and allowed to heal. The healing efficiency for the specimen shown in Figure 3 is 57%. Figure 4 presents the predicted damage progression in the SENT specimen of self-healing FRP with $t=2\text{mm}$ at the applied displacement value of 0.86mm. The microcracking of the matrix initiated from the initial notch tip and propagated along the coated fiber strands. Moreover, the microcracking of coating layer was followed by the microcracking of the matrix. This leads to the release of healing agent from the microcapsules.

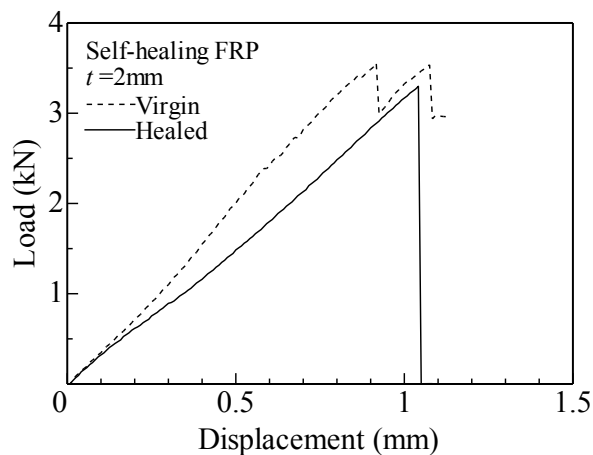


Figure 3: Measured load-displacement curves for a self-healing FRP specimen with $t=2\text{mm}$.

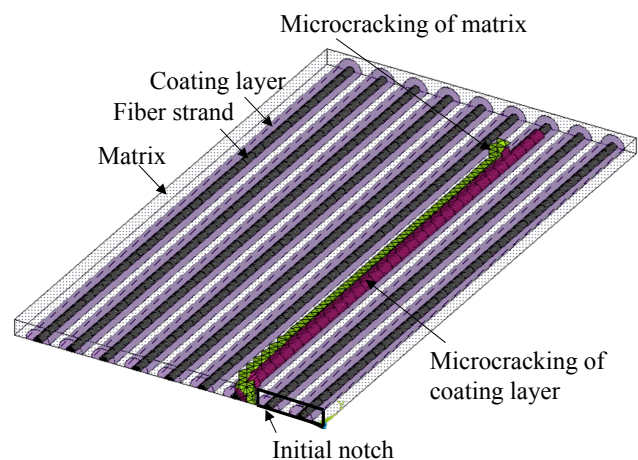


Figure 4: Predicted damage growth pattern in a SENT specimen with $t=2\text{mm}$ at the applied displacement value of 0.86mm.

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