Transverse mechanical behavior of unidirectional composites under extreme low-temperature conditions

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EXTENDED ABSTRACT

Composite materials, particularly carbon fiber-reinforced polymers (CF/epoxy), have significantly increased their use in the aerospace industry due to their high mechanical performance to weight ratio, low density, and low thermal conductivity, making them especially attractive for structures subject to demanding efficiency and reliability requirements. In this context, their application in cryogenic structural supports has attracted growing interest. At very low temperatures (below −150 °C), these materials typically exhibit increased stiffness and strength, along with reduced thermal expansion, features that are relevant for applications in the aerospace industry, satellite design, and energy storage systems. However, the behavior at low temperatures also presents challenges, as the material may become more brittle, show an increased tendency for matrix cracking, and experience a reduction in fracture toughness. Despite their growing relevance, the available knowledge regarding their performance under these conditions remains limited, particularly for unidirectional (UD) laminates, where the lack of reliable constituent-level information on mechanical properties and failure mechanisms, as well as the role of the fiber–matrix interface, hinders an accurate assessment of material performance under cryogenic service conditions.

Quasi-static transverse tensile tests were performed on unidirectional AS4/8552 specimens, machined at 90° and ground from 3mm panels into a “dog-bone” geometry, Figure 1. (a), to evaluate their transverse response. The specimens were tested at room temperature, −70 °C, and −150 °C using a climatic chamber capable of combining dry ice and liquid hydrogen in a controlled manner to achieve stable thermal conditioning, Figure 1.(c). Strains were measured using HBK-C Series Strain Gauges bonded with M-BOND-610-1 adhesive, both designed for cryogenic environments, Figure 1. (c). Two thermocouples were connected to a portable datalogger (one attached to the specimen, and another placed inside the chamber) to continuously record the temperature and verify that the target conditions were maintained throughout testing. The experimental results show a dependence of transverse tensile strength on temperature, as well as noticeable changes in transverse stiffness across the different temperature levels tested.

In addition, scanning electron microscopy (SEM) observations were performed under high-vacuum conditions using a secondary electron detector on fracture surfaces of AS4/8552 composite specimens to examine the fiber–matrix interface under different temperature conditions (Figure 2). To prevent surface charging and improve image quality, a gold coating

was applied to the observation area. The resulting micrographs were used to compare the microstructural features observed after testing at the investigated low temperature levels..
The experimental results are complemented by finite element models based on computational micromechanics in ABAQUS/Standard, enabling the evaluation of constituent-level parameters and their impact on the macroscopic behavior. The proposed framework offers a systematic approach to connect the temperature-dependent micromechanical response with the overall performance of the material. Ongoing work focuses on refining the numerical models and validating them against the experimental data to establish a robust methodology for the low-temperature design of CFRP components.
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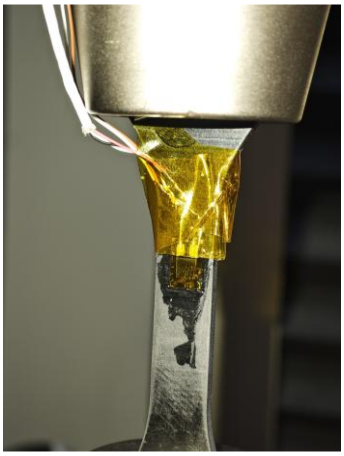
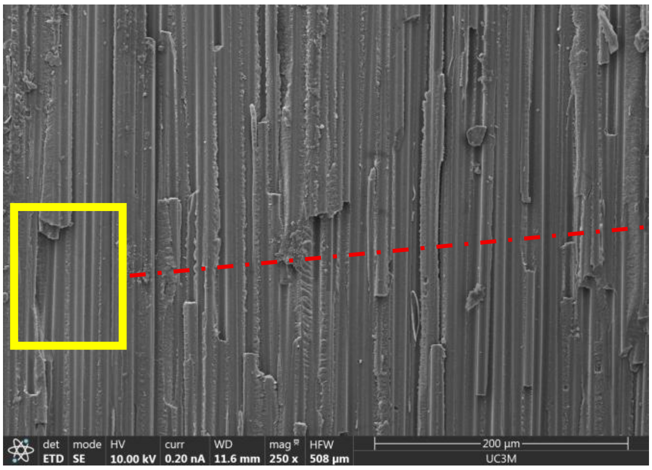
(a)
Specimen for QS tensile test UD 90º



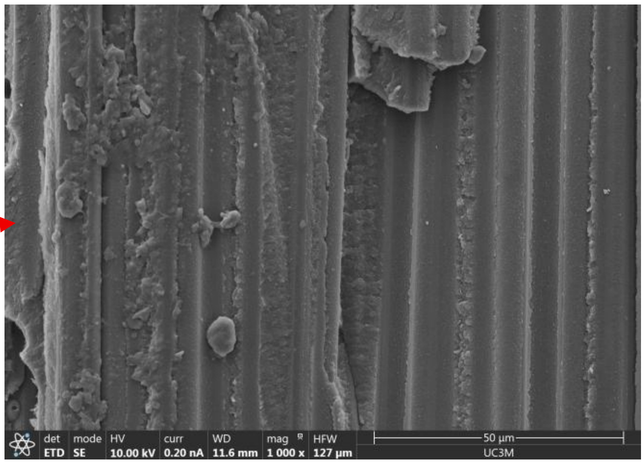
(b)
Strain gauge and thermocouple for low temperature

(c)
Setup tensile testing with thermal camera for low temperatures

Figure 1.



(a) Post-mortem SEM. AS4/8552, low temperatures 250x



(b) Post-mortem SEM. AS4/8552, low temperatures 1000x

Figure 2.