HOW NOT TO MEASURE THE TENSILE STRENGTH OF HIGH-MODULUS FIBERS

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Monofilament tensile strength and Young's Modulus measurements are standardized in ASTM C1557 - 14. The Standard prescribes the use of mounting tabs that are “appropriately designed to be self-aligning if possible, and as thin as practicable to minimize fiber misalignment.” We have now shown through analysis, and verified through experiments, that this method can be expected to have an increasingly negative impact on strength measurement as the Young's modulus and/or fiber diameter increases. We show that translational and angular misalignments are in fact neither measurable nor controllable in the Standard, and that even half the suggested misalignment tolerance can have an order of magnitude deleterious impact on the measured strength.

The Standard notes that there is no standard gage length but that current practice is to use 1”. We have found that, for the test procedure advocated by the Standard, the gage length cannot be considered independently of the fiber diameter, and that there is an optimal ratio that will minimize the influence of perturbations induced by the test apparatus.

The standard recommends recovering the fracture surfaces to measure the fiber diameter. However, it acknowledges that stiff fibers tend to shatter upon failure. This is in agreement with our experience with high-modulus Silicon Carbide ceramic fibers tensile tests, which shatter into small fragments, sometimes over the entire gage length. In an attempt to alleviate fiber fragmentation, the standard suggests vacuum grease to dampen fiber fracture. Experiments with fibers 15-50 µm in diameter and a Young’s modulus over 350 GPa resulted in complete fragmentation even when covered with vacuum grease. We found that using wax instead offered a better preservation of the fracture surface allowing for areal measurements.

The Standard considers a tensile test to be valid when fracture occurs within the gage length of the test fiber. Our experiments rigorously following the Standard with high modulus (>300 GPa) fibers (diameter 15-50 µm) covered with vacuum grease always resulted in a fractures occurring at the grip over 90% of the time. To prepare samples for the tensile strength measurement procedure, the Standard specifies: "Randomly choose, and carefully separate, a suitable single-fiber from the bundle or fiber spool." We observed that the process of teasing a monofilament out of a tow is not random. Indeed, the separation of a monofilament from a bundle is a self-selecting process that is biased towards minimally flawed single-fibers.

The Standard assumes a Weibull distribution of tensile strengths. This assumption is legitimate and in agreement with statistical failure analysis. A legitimate question is whether eliminating a source of perturbation has an effect on the Weibull statistics. Indeed the case can be made that the current standard, by restricting the measurable tensile strength would have the effect of artificially increasing the Weibull modulus, making the fiber quality appear to be more consistent that it actually is.

This article introduces a new testing procedure, which circumvents the limitations imposed by the Standard. Experiments consistently show that the Standard tensile strength measurement procedure systematically underreports, sometimes severely, the strength of high-modulus filaments and overreports the Weibull modulus.