Predicting the Finite Strain Behavior of 3D Non-Woven Orthogonally Oriented Composites Using Crystal Plasticity Modeling

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Fiber composites have become prominently used in industrial applications in recent years due to their excellent strengths and strength to weight ratios. However, they are susceptible to interlaminar fracture, compressive microbuckling and a low ductility that often leads to catastrophic failure. Modern fabrication techniques have enabled the creation of complex 3D fiber architectures that can overcome some of these limitations and greatly enhance the toughness and energy absorption properties [1]. While these properties of 3D fiber composites are attractive for mechanical design purposes, understanding the micromechanical origins of their behavior and developing numerical models that capture their finite strain response has proved difficult.

Here we investigate the mechanical performance of a 3D non-woven orthogonally oriented and bound (NOOB) carbon fiber reinforced polymer composite. We performed shear and compression experiments on representative sized specimens and analyzed the micromechanical deformation mechanisms using both X-Ray computed tomography (CT) scanning and optical microscopy. Both shear and compression showed pronounced ductility during testing. Shear specimens deformed in excess of 50% strain while exhibiting a strong strain hardening response before failing via tensile rupture of the axial tows. X-Ray CT revealed minimal internal damage developed in the specimens tested in shear. Compression specimens notably had a stable compressive microbuckling response and accumulated significant internal microbuckling damage prior to their failure at over 8% strain. Compression specimens also showed a strong strain hardening response after the onset of buckling failure.

We developed a tow-level crystal plasticity-based model to capture the finite strain behavior of the composites. The model inherently captured plastic spin within the tows, and was thereby able to accurately predict texture evolution in the material substructure during the deformation. In shear, we find that incompatible plastic deformation leads to the development of large elastic stresses in the tows. The 3D architecture then produces a confinement effect that allows large hydrostatic pressures to develop in the sample and directly produces the large strain hardening response. In compression, the model reproduces the confined microbuckling response observed experimentally. The microbuckling events are inhibited due to incompatible plasticity mechanisms in the 3D architecture, and the hardening response is cause by indirect tension of the tows orthogonal to the compression direction. This talk will investigate the implications of these finding for the design of advanced 3D composite architectures.