Plasticity and damage in 3D non-woven carbon fibre reinforced composites

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The ability to independently control fiber alignments and structural geometry is critical for design of optimal three-dimensional (3D) fibrous structures. We present a novel method to 3D-assemble carbon fiber structures, containing no seams or adhesive joints, using a confluence of several textile methodologies. A variety of complex structural shapes with tailored fiber topologies are demonstrated to be achievable. These optimized structures are shown to have unprecedented static and dynamic strength as well as damage tolerance and ductility. We also discuss constitutive modelling challenges for such fibrous composites that showing exceptional ductility. In particular, we demonstrate that a model wherein the tows are modelled using a pressure-dependent crystal plasticity approach, to capture texture evolution under large deformations, replicates many of the experimental observations with a high degree of fidelity. On the other hand, a model wherein the tows are modelled using an anisotropic Hill plasticity framework (absent plastic spin) gives poor agreement with measurements. This highlights the importance of accounting for the evolution of the material substructure within the tows of these high ductility 3D composites. The results of this work illustrate the unique mechanical behaviour of 3D non-woven fibre composites and also provide insight into how 3D fibre architecture can be used to enhance the mechanical performance of fibre composites.