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Quasi-Static Micro-Mechanical Representative Volume Element Modeling of Dry Fiber Bundles

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With the increase of computational capabilities, the number of physical phenomenon captured with computational models is increasing and the scale of the modeled mechanisms is decreasing. This is also true in the field of fibers and textiles. Where once only macroscopic models of textiles characterized through extensive experimental programs existed, there is now the possibility of capturing more detailed behaviors at the fiber bundle (tow / roving / yarn) scale [1–3]. These textile-scale models either create a material model from a Representative Volume Element (RVE), communicate between the textile and macro scales one way or both using homogenization and localization, or only model the textile-scale. These models typically consider a tow as a homogenized continuum, and set the transverse properties of the tow to be a value much smaller than the axial properties. The transverse properties are not explicitly determined, but are estimated.

More recently, models are emerging which consider even smaller scales such as the fiber (filament) scale [4–6]. Since carbon fiber tows typically contain 3-50 thousand fibers, modeling each individual fiber would be extremely costly in time and computational resources. These models do not consider each fiber individually, but break up the tow into 1-100 fiber groups with each group representing hundreds or thousands of fibers. These fiber groups are explicitly modeled with bar or beam elements, and contact between elements is enforced. The search of contact pairs is one of the computations requiring the most resources, and consequently much effort has been expended to create more efficient contact algorithms [7]. Additionally, tribological attributes are determined experimentally, as shown in [8]. These methods are some of the only models which can predict the effects of fiber entanglement and fiber twisting within a tow. Results show that these models can predict many micro-geometric cross-sections of different manufacturing processes and there is an excellent future for such models, but they are currently not very practical for part-scale models. The number of elements and degrees of freedom required for a converged solution is so large that the textile size is severely limited or the computational time can be astronomical. Furthermore, tows with thousands of fibers cannot be properly modeled with an element for each fiber without considerable pre- and post-processing effort, not to mention actual processing time.

The present research introduces a fiber-scale model, where the homogenized fiber bundle properties are obtained by a RVE for cases where the fiber radius is magnitudes smaller than the cross-sectional dimensions of the fiber bundle. This RVE is generated using the discrete element method, which is a particle-based method extremely popular for the modeling of granular materials, especially soils and geo-type materials [9] and more recently adapted to molecular dynamics simulations. The method considers each fiber as a point mass, and elasticity of the fiber is only imitated through the appropriate contact law. One of the main advantages of an RVE model for dry textiles is that fiber-scale mechanisms such as sizing, fiber radius distribution, and non-cylindrical fiber shape can be integrated with less computational resources than fiber beam models. Mechanisms which may be missing in such a model include individual fiber bending, fiber entanglement, and individual fiber buckling. Early model development and issues will be illustrated, such as RVE size determination, significance of micro-scale properties, application of periodic boundary conditions, relaxation methods for equilibrium and limits of such a model.

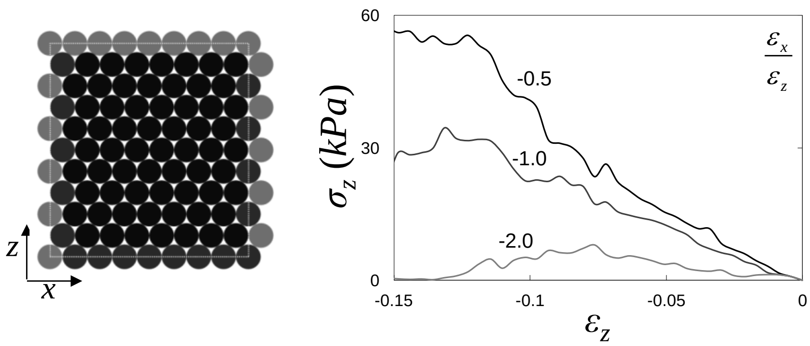

Figure 1. Stress-strain relationship of a compressed representative volume element (RVE) at different ratios of x to z strain.

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