Simulations of Yarn Micro-Mechanics of Woven Heat Shield Materials (3MDCP)

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Abstract

Carbon and phenolic fibers are commonly used in ablative thermal protection materials, such as 3-dimensional Mid-Density Carbon Phenolic (3MDCP), a 3D-woven composite comprised of mixed-fiber yarn bundles. Predicting the micro-mechanical response and fracture of twisted yarns composed of brittle and ductile fibers requires a modeling approach that captures per-fiber yielding, fiber fracture, and inter-fiber friction and contact. This work presents an extended bonded particle model (BPM) for discrete element method (DEM) simulation of fiber and yarn mechanics, implemented in LAMMPS. The model builds on the incremental bond formulation of Guo et al. and introduces a piecewise elasto-plastic constitutive law for axial extension, enabling representation of fibers that yield before failure. 3MDCP yarns were constructed using measured fiber radius distributions and helical twist geometry. Tensile simulations of single-ply 3MDCP yarns show good agreement with vender stress–strain results. Fiber breakage models also show details on yarn breakage propagration, centered radially in the yarn. Yarn breakage of multi-ply 3MDCP also matched experimental observations in per-ply breakage; however, predicted yarn breakage strength were found higher than experimental observations.

Keywords: discrete element method, bonded particle model, yarn mechanics, thermal protection systems, 3MDCP

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