Modeling unidirectional composites by bundling fibers into strips with experimental determination of shear and compression properties at high pressures

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2014, in Composites Science and Technology, vol. 101, pp. 32-40. ISSN: 02663538. DOI: 10.1016/j.compscitech.2014.06.016.

Abstract

Numerical models of unidirectional panels of ultra-high-molecular weight polyethylene (UHMWPE), like Dyneema® HB80 or Spectra®, have been a difficult challenge. The problem arises from the intimate structure of the material. It is a huge collection of fibers loosely held together by a matrix. For example, for HB80 the fibers are very small in diameter (~17 µm) but extremely strong (~3.5 GPa). The amount of matrix is small (~20% in volume) and very weak.

The ''natural'' scale to use in the numerical model for this material is the fiber scale (~17 µm). This scale would provide the right sound speed, transverse wave speed, failure strain, strength of the laminate, deflection, slippage between the fibers/layers, etc. which are all essential details if we want to have predictive capability. But even with the very powerful computers available nowadays we are still very far from being able to simulate a real-size laminated target (for example 30 cm wide and 1 or 2 cm thick) at the fiber scale.

This paper proposes an ''intermediate'' scale that bundles or consolidates many fibers together so that the numerical problem is solvable in a few hours (or maximum one or two days for thick targets) of computation in a single board (24 processors). The scale is chosen precisely so that the essential physics of the ballistics problem is kept and the material properties used are the ones measured in the lab for the fiber and matrix. A similar approach was presented in a previous paper for fabrics (Kevlar, Dyneema, and PBO) where a yarn-level model was able to reproduce both the wave propagation patterns and the ballistic limits.

This paper first describes new material test results (shear and compression at low and high confinement pressures). These were essential in properly capturing the delamination of the material. Then, for completeness, transverse wave propagation and ballistics results in Dyneema published elsewhere are briefly presented. Finally the numerical model in LS-DYNA is developed and comparison with deflection history and ballistic limits is conferred.

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