Numerical Simulation of Progressive Damage in Hybrid Composites

Abstract for the Mechanics of Composites (MECHCOMP2014), USA, 8-12 June, 2014

Sayan Banerjee[1] and Bhavani V. Sankar[2]
Department of Mechanical & Aerospace Engineering
University of Florida, Gainesville, FL 32611-6250

Multiphase composites, also known as hybrids, are increasingly finding use in many industrial applications. Hybrid composite materials have major engineering applications where strength to weight ratio, low cost and ease of fabrication are required. By mixing two or more types of fiber in a resin to form a hybrid composite it may be possible to create a material which has the combined advantage of individual fibers and simultaneously mitigating the less desirable qualities. There are situations where a high modulus material is required but the catastrophic brittle failure associated with it will be a major challenge. For example, Kevlar-graphite hybrid composites overcome the key drawbacks of graphite/epoxy composites which are high costs and brittle failure due to low toughness. The potential aspects of Kevlar 49-graphite/epoxy system were initially studied. It has also been found that considerable reduction in costs without loss of mechanical properties can be achieved by using Kevlar-graphite hybrid. In another study, tensile and flexural properties of cementious composites reinforced with whiskers of alumina and carbon was studied and significant strength increase was reported. Laminated hybrid ceramic composites find applications in cutting tools, ballistic armor and structural components subjected to high temperatures.

Experimental techniques can be employed to understand the effects of various fibers, their volume fractions and matrix properties in hybrid composites. However, these experiments require fabrication of various composites which are time consuming and cost prohibitive. Advances in computational micromechanics allow us to study the various hybrid systems by using finite element simulations and it is the goal of this research. The mechanical properties of hybrid short fiber composites can be evaluated using the rule of hybrid mixtures (RoHM) equation, which is widely used to predict the strength and modulus of hybrid composites. It is shown however, that RoHM works best for longitudinal modulus of the hybrid composites. Since, elastic constants of a composite are volume averaged over the constituent microphases, the overall stiffness for a given fiber volume fraction is not affected much by the variability in fiber location. The strength values on the other hand are not only functions of strength of the constituents; they are also very much dependent on the fiber/matrix interaction and interface quality. The computational model presented in this research takes into account, random fiber location inside a representative volume element for a given volume fraction ratio of fibers, in this case, carbon and glass. The variability in fiber location seems to have considerable effect on the transverse strength of the hybrid composites. For the transverse stiffness and shear moduli, a semi-empirical relation similar to Halpin-Tsai equations has been derived. Direct

1 Graduate Student, Corresponding Author (sbanerjee@ufl.edu)
2 Ebaugh Professor (sankar@ufl.edu)

Micromechanics Method (DMM) is used for predicting strength, which is based on first element failure method; although conservative, it provides a good estimate for failure initiation.

The fiber packing arrangement, for most composites, is random in nature, so that the properties are approximately same in any direction perpendicular to the fiber (i.e., properties along the 2-direction and 3-direction are same, and does not vary with rotations about the 1-axis), resulting in transverse isotropy. For our model, it is assumed that the fibers are arranged in a hexagonal pattern and the epoxy matrix fills up the remaining space in the representative volume element (RVE). Hexagonal pattern was selected because it can more accurately represent transverse isotropy as compared to a square arrangement. The RVE consists of 50 fibers. Multiple fibers were selected to allow randomization of fiber location. Hybrid composites are created by varying the number of fibers of carbon and glass to obtain hybrid composites of different volume fractions. It has been shown that RoHM predicts the longitudinal modulus, longitudinal Poisson's ratios and longitudinal shear modulus, with very good accuracy. For predicting the transverse moduli, transverse Poisson's ratio and the transverse shear Moduli, modified Halpin-Tsai equation has been proposed, that matches the finite element results with reasonable accuracy. Longitudinal tensile and compressive strengths vary linearly with the volume fraction of the reinforcement, and are dependent on the longitudinal modulus and the least strain to failure of the constituent. All other strengths show variability with the fiber location inside the RVE. This is attributed to the transverse modulus of the introduced fibers to form the hybrid composite, which causes a local stress concentration, resulting in the failure of the neighboring matrix elements.

The mechanical behavior of fiber reinforced composite materials is significantly affected by the nature of the bond between the fibers and matrix material. Interfacial zones between the fiber and matrix control the overall mechanical properties and strength of fiber reinforced composites. The interfacial bond can influence various aspects of the composite behavior such as modes of failure, interlaminar shear strength, bending stiffness, and compressive strength. Several damage models for fiber reinforced composites have been established by defining the damage tensors and their damage evolution laws. Another area of computational engineering, cohesive zone modeling, have been widely used in the last decade in many areas of computational mechanics which deal with delamination, debonding or more generally with crack propagation and/or initiation. A cohesive zone model normally assumes a relation between the normal and shear tractions and the opening and sliding displacements, and is capable of capturing the debonding process in fiber matrix interfaces. In the present work two major categories of damage has been studied. Firstly, a ductile damage model for the matrix is considered without interface failure. In this model, linear elastic behavior for the matrix is assumed up to the yield stress, after which elastic-perfectly plastic behavior prevails as shown in various experimental stress-strain behavior for epoxy matrices. The matrix is then assumed to soften linearly until failure and the final failure strain is governed by predefined damage energy. Secondly, cohesive zone modeling is used to model the fiber-matrix interface along with the matrix failure model described as before. The traction-displacement relation is similar to as mentioned before with known normal and shear strength of the carbon-epoxy and glass-epoxy interface. The effect of random location and diameter of the multiple inclusions having different mechanical properties on the progressive damage behavior of hybrid composites is also studied.