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14. ABSTRACT

The work performed in the reporting period has been focused on completion of Tasks 1.2 on ply lavel cracking and 1.3 related to Synergistic Damage Mechanics and Tasks 2.2 and 2.4 related to Peridynamics, as described in the project proposal. The activities related to Task 1.2 concern growth and instability of initiated cracks in the environment of the disordered fiber distribution, and Task 1.3 evaluates the effect of these cracks on the response of the composite to imposed impulses. The specific focus in the reporting period was to study the effect of voids on crack initiation. The activities related to Task 2 cover the new peridynamic model for elasticity and fracture at an interface in a multi-phase composites.

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A Hybrid Approach to Composite Damage and Failure Analysis Combining Synergistic Damage Mechanics and Peridynamics

Award Number N00014-16-1-2173

DOD – NAVY – Office of Naval Research

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Executive Summary

The work performed in the reporting period has been focused on completion of Tasks 1.2 on ply lavel cracking and 1.3 related to Synergistic Damage Mechanics and Tasks 2.2 and 2.4 related to Peridynamics, as described in the project proposal. The activities related to Task 1.2 concern growth and instability of initiated cracks in the environment of the disordered fiber distribution, and Task 1.3 evaluates the effect of these cracks on the response of the composite to imposed impulses. The specific focus in the reporting period was to study the effect of voids on crack initiation. The activities related to Task 2 cover the new peridynamic model for elasticity and fracture at an interface in a multi-phase composites.

Tasks 1.2 and 1.3 Modeling of RVE based initiation of matrix ply cracks in the presence of matrix voids

The physically observed effect of matrix voids on crack initiation within plies is illustrated in Figure 1.

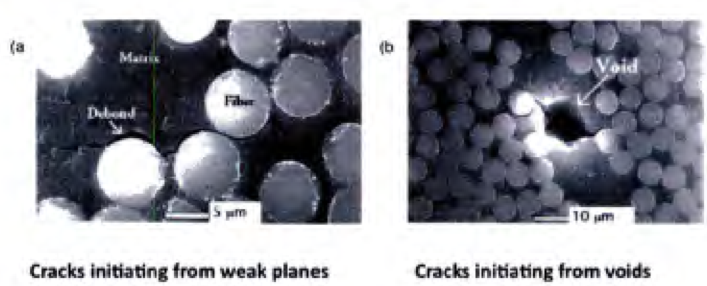

Figure 1. Cracks initiation without matrix voids (a) and with matrix voids (b).

The observed behavior is simulated by constructing a representative volume element (RVE), as described in previous reports. Voids are then embedded in the matrix region between fibers in each RVE realization and it is subjected to tension loading normal to fibers. The specific study in the reporting period looked at the effect of brittle cavitation as a precursor to crack initiation under these conditions. Figure 2 shows the two cases studied: 1) circular voids and 2) elliptical voids placed with the major axis normal to the loading direction.

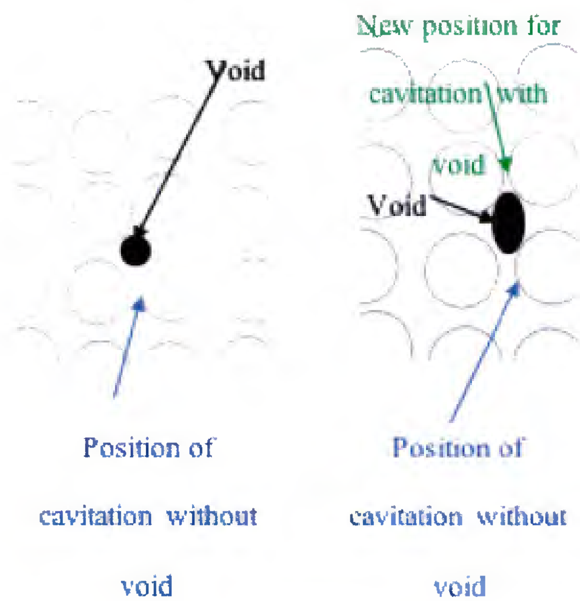

Figure 2. Figure shows regions of RVE realizations analyzed with matrix voids inserted. Left: a circular void and Right: an elliptical void placed with its major axis normal to the load direction (horizontal). The position of points where brittle cavitation occurs is indicated. As shown, this position shifts to another location when an elliptical crack is present.

Using the critical energy density criterion, the initiation of fiber/matrix debonding was predicted in each realization for each case of selected fiber mobility during composite processing. The variations of the maximum values of dilatation and distortion energy densities in the realization with a circular void subjected to transverse tension are displayed in Figure 3. It was found that for this case of a circular void, no change occurred in the position of the point where the dilatation energy density reached its maximum value, which increased with the applied tensile strain without being affected by the presence of the void. Similarly, no effect was seen on the distortion energy density change.

The results for the case of an elliptical void are shown in Figure 4. It was found that the position of the point where brittle cavitation occurred without void was shifted to another point, as shown in Fig. 2 (right). However, as for the case of no void, brittle cavitation was found to occur before yielding, as indicated by the two energy densities plotted in Figure 4.

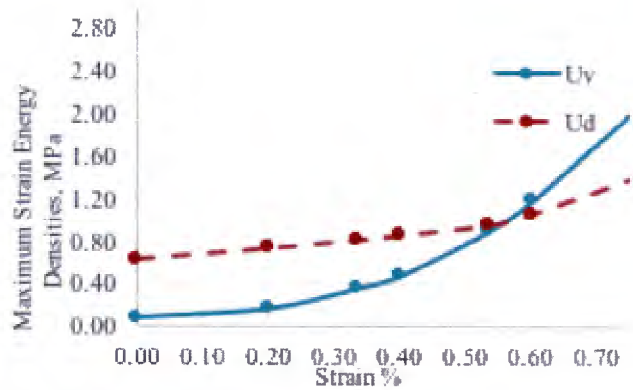

Figure 3: Variations of maximum dilatation energy density (U_v) and distortion energy density (U_d) in the RVE realization shown in Figure 2 (circular void) with the applied transverse strain.

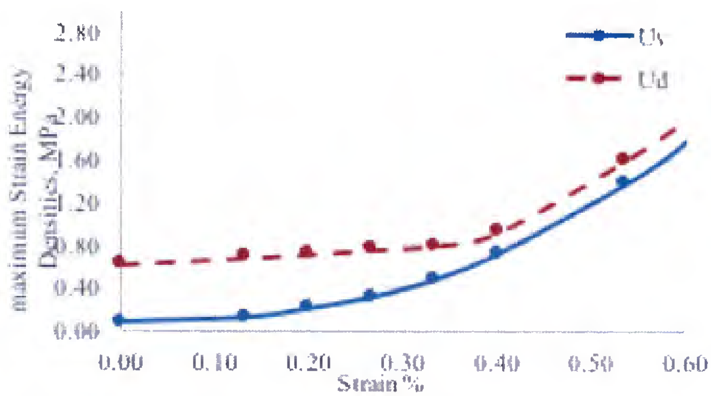

Figure 4: Variations of maximum dilatation energy density (U_v) and distortion energy density (U_d) in the RVE realization shown in Figure 2 (elliptical void) with the applied transverse strain.

The ongoing research will study more cases of voids along with irregular fiber distributions. Also, the boundary loading on the RVE will be changed to axial shear.

Tasks 2.2 and 2.4 Peridynamic Modeling of fiber-reinforced composite based on the SDM model for an RVE.

The goal of this work is to couple the two models: SDM and Peridynamics, in modeling the evolution of failure in FRCs with manufacturing defects. For this purpose, we start with a RVE (provided by Prof. Talreja group) that has cross-section of a fiber bundle embedded in the matrix, and surrounded by the effective (homogenized) composite material (see Figure 5). We intend to model the initiation, growth, and coalescence of cracks at the microstructure level. For this, we discretize the explicit microstructure geometry of the RVE using a FE grid. We then import the grid and transform it into a non-uniform peridynamic grid by assigning nodal areas to the peridynamic nodes (nodes in the Fem mesh) using the algorithm published in [1].

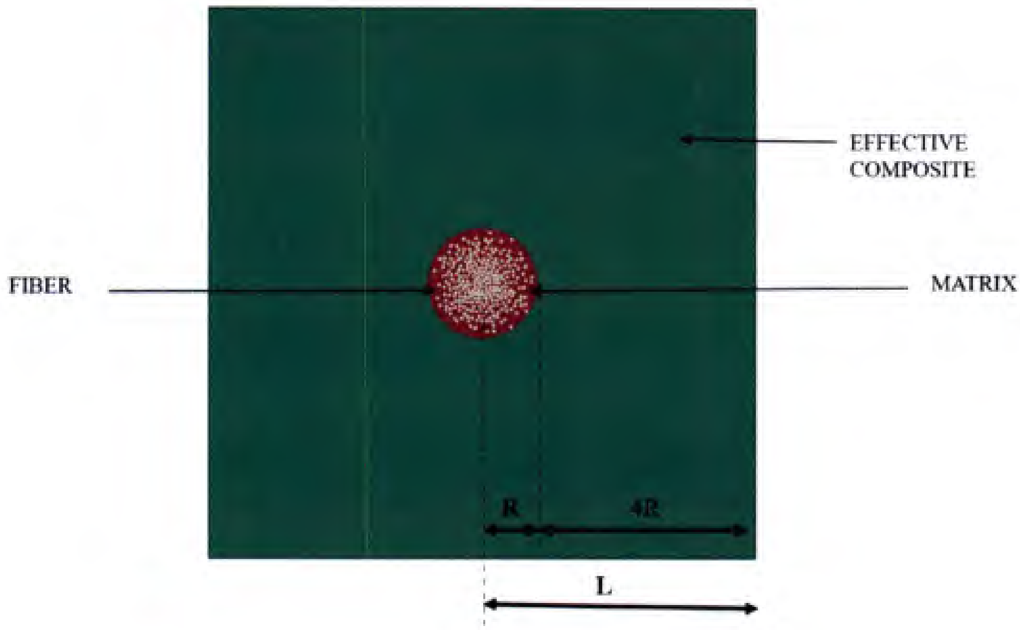

Figure 5: The RVE from the SDM model (provided by Prof. Talreja's group) used in the peridynamic model. To reduce computational costs, a smaller amount of effective composite material is used by transferring the appropriate boundary conditions to near the fiber bundle region. The new sample is re-meshed to ensure a more uniform size of elements (which will result in a more uniform size of nodal areas for peridynamic nodes. This is shown in Fig. 6.

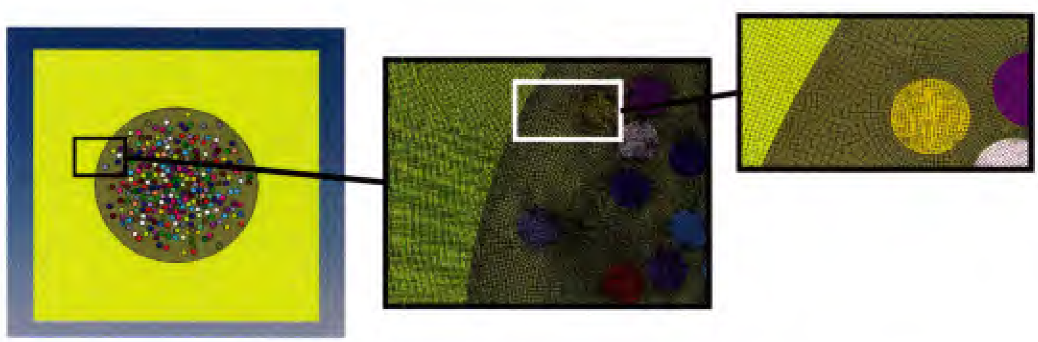

Figure 6: The re-meshed sample showing the different fibers, the surrounding matrix, and the effective composite around the RVE.

To ensure that the nonlocal region does not create fiber bonds between different fibers, we need to make sure that such bonds are first "erased" from the model. Since each fiber cross-section has a unique material index, we cut the bonds between any two different fibers. The result of this process can be seen from Fig. 7.

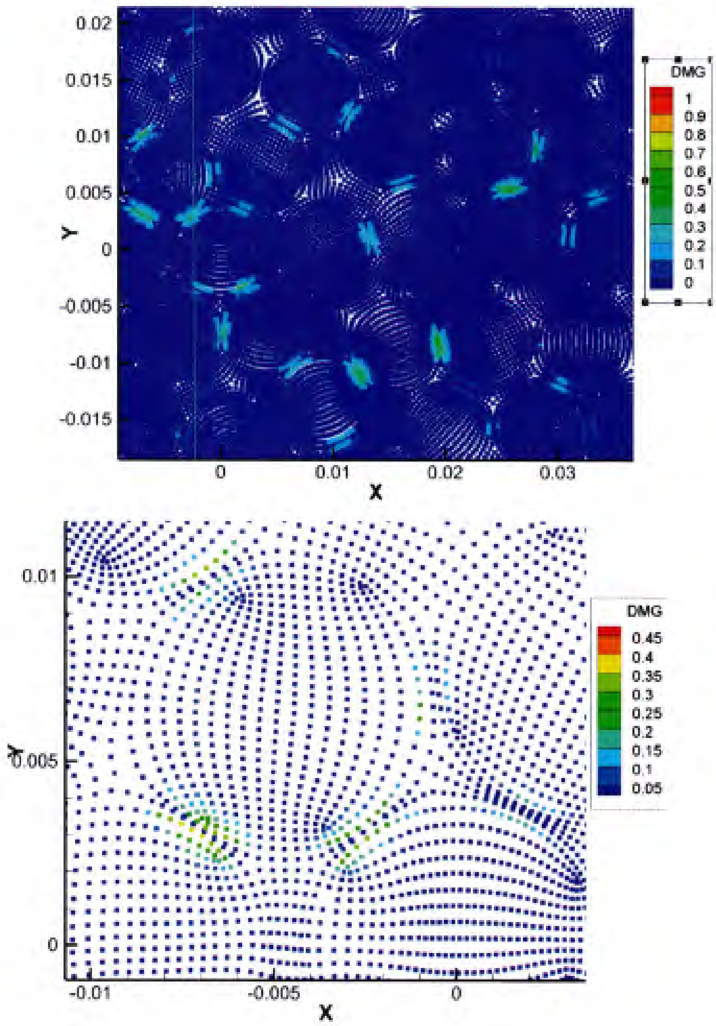

Figure 7: Top: the damage index over a set of fibers showing that fiber-bonds that cross between two fibers have been eliminated. Bottom: a zoomed-in figure around one fiber.

This initial damage is then reset to zero. A convergence study was performed to ensure that this needed "separation" of different fibers (which would otherwise be all bonded with fiber-bonds between them if the peridynamic horizon size is large enough that it covers two nearby fibers) performs as intended. Note that matrix bonds are not eliminated through this process and they still link fibers, indirectly between them (via fiber-matrix bonds).

Initial damage can be introduced by breaking bonds in the matrix material (to represent pores in the matrix) or between the fibers and the matrix (to mimic the presence of fiber-matrix disbonds). The case when the fibers are touching each-other and there is no matrix between them can also be simulated by removing the matrix material between them. This would simulate the case when not all fibers were wetted by the polymer matrix.

The next step is to implement the effective composite for the surrounding material, and run simulations with and without defects. We will monitor the stochastic failure behavior to the presence of defects.

References:

[1] F. Bobaru and YD. Ha, "Adaptive refinement and multiscale modeling in 2D Peridynamics", *International Journal for Multiscale Computational Engineering*, **9**(6): 635-659 (2011).