EFFECT OF FIBER DISTRIBUTIONS ON THE MECHANICAL PERFORMANCE OF CMC MATERIALS: VIRTUAL MANUFACTURING AND TESTING APPROACH

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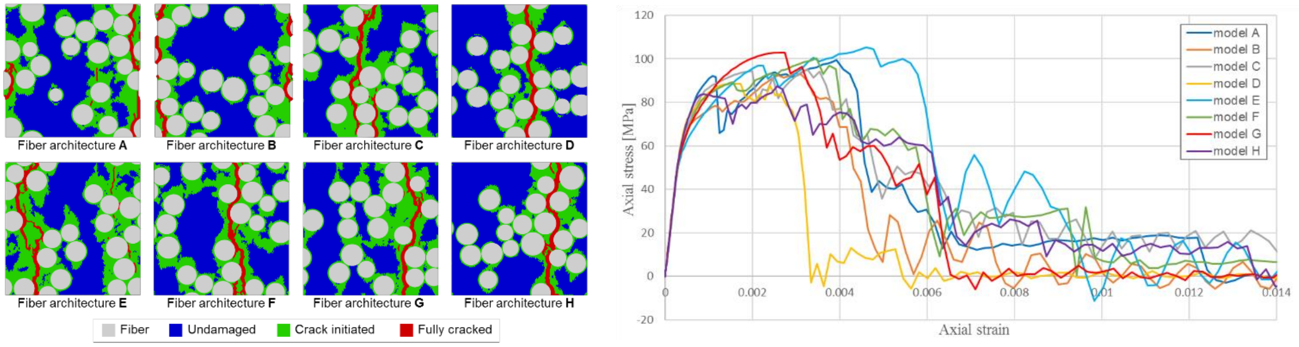
Ceramic matrix composites (CMCs) exhibit superior thermal stability in an elevated temperature environment and thus are considered as a promising candidate material for gas turbine applications in the field of power generation industry. CMCs also have a higher fracture resistance than conventional technical ceramics owing to the coated ceramic fibers embedded in the matrix. However, the complex heterogeneous microstructure results in complicated damage and failure behavior at the fiber length scale, which appears non-linear stress-strain response at the macro length scale. When a crack is initiated in the matrix phase, the crack grows very rapidly since the ceramic matrix is a brittle material. However, the rapid crack propagation is restrained when the crack tip reaches the ductile coating interface. This fracture process occurring inside the CMC material results in a highly complicated post-peak response and makes its fracture toughness comparable to that of metals.

The post-peak response is greatly influenced by local topology of fibers situated inside the composite material and thus the fracture toughness of a CMC may vary locally due to the irregular distribution of fibers. In the present study, the effect of fiber distributions on the post-peak response and the corresponding mechanical performance of a CMC material is closely investigated by utilizing representative volume elements (RVEs) with various fiber distributions. Two-dimensional square RVE enclosing randomly distributed circular fibers with coating layers is considered to represent the microstructure of a long-fiber-reinforced CMC material. Random, yet realistic distribution of fibers is achieved through the virtual force dispersion (VFD) algorithm. The present VFD algorithm arranges fibers with coating layers after the fibers are randomly seeded into a square RVE. Fibers should be rearranged after the random seed, since overlapped regions between fibers are unavoidable during the initial distribution process. The VFD algorithm assumes that fibers are connected through virtual springs, which provide repulsive forces between them. The VFD algorithm finds an equilibrium state in which the springs are completely relaxed and there exists no repulsive force in the system. In this manner, various RVEs with different fiber distributions are easily created for the next step of analysis.

Finite element analysis (FEA) is performed on the RVE models with different fiber patterns to examine the effect of different fiber patterns on the response of CMCs. In order to apply the periodicity to loading and boundary conditions, each node at the edges of the RVE is related to the corresponding node at the opposite edge. Degrees of freedom (DOF) of the two nodes are constrained to satisfy the periodic boundary conditions. Fibers, coating interphases, and the matrix are modeled as a linear isotropic homogeneous material. Fracture behavior of the matrix and coating materials is also accounted for through the smeared crack approach (SCA) with the maximum strength criterion. SCA is a mesh-objective fracture model, of which solutions are not affected by element sizes. Figure 1(a) shows the RVE models created by using the VFD algorithm. Figure 1(a) also shows the fracture patterns obtained through the SCA when the RVEs are subjected to tensile loading. Figure 1(b) shows the corresponding stress-strain responses of the RVEs in Figure 1(a). It is obvious that the responses of CMCs are greatly affected by the fiber distributions.



(a) *(b)*

Figure 1 (a) Cracking patterns in RVEs of various fiber distribution (b) Stress-strain response of the RVEs