MECHANICAL PROPERTIES OF MULTIDIRECTIONAL CARBON-CARBON COMPOSITES

by

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Dedicated

To

My Father

CERTIFICATE

This is to certify that the thesis entitled **"MECHANICAL PROPERTIES OF MULTIDIRECTIONAL CARBON-CARBON COMPOSITES"** being submitted by **MALLIPUDI VENKATRAO** is the report of bonafide research work carried by him under our supervision. This thesis has been prepared in conformity with the rules and regulations of the Indian Institute of Technology Delhi, New Delhi. We further certify that the thesis has attained a standard required for a Ph.D degree of the institute. The research reported and the results presented in the thesis have not been submitted, in part or full to any other institute or university for the award of any other degree or diploma.

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ABSTRACT

Multidirectional carbon-carbon composites are specialized group of materials finding varied applications in components operating at high temperature. Commonly used architectures for these composites are 3-directional orthogonal, 3-directional plain-woven, 3-directional 8-harness satin weave and 4-directional in-plane. For these applications a clear understanding of the effect of the architecture on mechanical and thermal behavior of these composites is essential. The macro-mechanical properties of these composites can often be determined from mechanical behavior of the fiber and matrix provided interface behavior between fiber and matrix and the progress of cracking in matrix and fiber bundle is known. In this thesis, 3-dimensional unit cells are established for different architectures and asymptotic homogenization technique is used to determine the equivalent homogeneous material (EHM) properties corresponding to these unit cells. For implementing the homogenization technique periodic boundary conditions are imposed on the unit cells and finite element method (FEM) is used to compute the volume averaged stresses and strains and thereby the EHM properties.

The work has been done at two levels. First, the mechanical properties of a fiber bundle are predicted assuming the fiber bundle to be perfectly bonded uni-directional composite. Next, the predicted properties of fiber bundle are used to predict the mechanical properties of the multidirectional carbon-carbon composites. To understand the effects of fiber-matrix interface bonding, thermal residual stresses and matrix cracking on the mechanical properties four cases are studied: (1) perfect bonding between fiber-bundle and matrix, (2a) interfacial debonding due to mechanical loading i.e. no thermal residual stresses are included, (2b) interfacial debonding due to thermal residual stresses and (2c) interfacial debonding and matrix cracking due to thermal residual stresses. Cohesive zone model

(CZM) has been used to simulate the interfacial debonding. Octahedral shear stress failure criterion is used to predict matrix cracking.

To compute the various strength properties of unit cells of different architectures, the maximum stress failure criterion is used to predict fiber or fiber-bundle failure in addition to the interfacial debonding and matrix cracking. To predict the strength properties of the fiber bundle, the unit cell used to predict the stiffness properties of fiber bundle was modified and cohesive zone was incorporated at the fiber/matrix interfaces of the fiber bundle unit cell. For predicting the strength properties of multi-directional composites same unit cells used, that are used predicting the stiffness properties.

The interfacial debonding, matrix cracking and presence of residual stresses have significant effect on mechanical properties of the composite. When there are no residual stresses, debonding causes a significant reduction in properties of the composite. When residual stresses and debonding are already present, (before mechanical loads are applied) the resulting deterioration in the elastic moduli occurs at much lower strains. Debonding along with matrix cracking leads to further deterioration in the properties.

Tensile and shear experiments were carried out on specimens of 3-directional orthogonal, 3-directional 8-harness satin weave, 4-directional in-plane architecture. The experimental results obtained were compared with those predicted by numerical modeling. It was observed that the predicted properties match well with the experimental values, when the debonding and matrix cracking are included in the numerical modeling.

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