Abstract

Woven fabric composite (WFC) materials are popularly used in various fields of application including structures related to aerospace, civil, military, automotive, defense and space shuttle. Higher inter-laminar strength, impact resistance, fracture toughness, and delamination resistance are its advantages over unidirectional composites. Present research work utilizes the combined experimental and numerical frameworks to characterize WFC with respect to various aspects such as void defects, resin infiltration, weave pattern, stacking effects, etc.

Any void present in composites significantly affects the mechanical and thermomechanical properties. Consequently, these unwanted void defects significantly reduce the stiffness and strength of the composites. This leads to the failure of structures during their service period. Voids are inevitable in textile composites because of the complex nature of resin infiltration process and its controlling parameters, i.e., vacuum pressure, temperature, resin flow velocity, etc. Therefore, study of presence of voids is essential for accurately achieving the effective properties of textile composites. Experimental characterization studies are carried out for E-glass/epoxy composites containing void defects. Composite laminates containing void defects are fabricated using the resin film infusion molding process. The mechanical and physical properties of the WFC are characterized. In addition, non-destructive tests such as X-ray Microtomography (XMT) and scanning electron microscopic (SEM) analyses are also carried out to characterize the post-cured composites and fractographic study of the plain WFC, respectively.

Further, the experimental characterization studies are carried out for carbon/epoxy 5-harness satin weave composites (SWC) containing void defects. This laminate was fabricated from bidirectional carbon prepreg (Hexply 914/40%/285H%/ AS4C-3K/1170 mm) using an autoclave curing process to accomplish optimum laminate properties. Diverse cure system (DCS) has been used to introduce void defects in the laminate during the curing process. The tensile and in-plane shear tests are conducted to investigate the in-plane mechanical properties of the SWC. The fractographic and post-cured microstructural studies were carried out for

SWC using SEM and XMT analyses, respectively. In addition, the short beam shear tests are conducted with pristine laminates for both normal (room) and (150°C) elevated temperature environments to determine the inter-laminar shear strength (ILSS) of the SWC. The influence of temperature effects on the ILSS has been discussed. The compression tests are conducted to investigate the compressive strengths of 5-harness SWC. Fractographic study has been performed for specimens failed during compression tests and corresponding compressive failure modes are discussed.

In this work, the in-plane mechanical properties of both E-glass and carbon composites are determined experimentally to verify the efficacy of the present numerical approach. Multiscale finite element (FE) based representative volume element (RVE) models have been developed, and periodic boundary conditions (PBCs) are applied to the RVE models to evaluate the homogenized thermo-mechanical properties of WFC containing void defects. Present numerical model incorporates the geometrical microstructures of post-cured woven composites and void contents obtained from XMT analysis. Void defects are incorporated and assumed to be identical for both fiber yarn and WFC in micro and mesoscale RVE analysis, respectively. The influence of void defects and resin infiltration effects are incorporated to evaluate the thermo-mechanical properties of the WFC. Parametric studies have been carried out with variation of void defects in the yarn and WFC models. Monte-Carlo simulations (MCS) are carried out to study the influence of void contents on the thermo-mechanical constants of both fiber yarn and WFC. Results obtained from the present numerical approach show a good agreement with experimental results. Further, the two-step homogenization approach has been extended to predict thermo-mechanical properties of 5-harness SWC considering void contents using an artificial neural network (ANN) and MCS. Results obtained from ANN and FEM approaches agree well, and both results show a good agreement with experimental results. Presence of voids are observed to have significant influences on the thermo-mechanical properties of both yarn and WFC.

Further, this approach is extended to the study of mechanical and thermo-mechanical properties of 3D textile composites. Various parameters such as 3D woven architecture, temperature variations and stacking effects on thermomechanical constants are discussed. Present FE results are in well agreement with the available literatures. Multiscale FE models are also developed for steady-state thermal analysis to investigate the thermal conductivities of 2D and 3D woven fabric composites using two-step homogenization approach.

Keywords: Multiscale modeling, Two-step homogenization, Textile composites, X-ray microtomography, Thermo-mechanical modeling, Void modeling, Monte-Carlo simulations, ANN, RVE, Local fields, Periodic boundary conditions.