Iranian Polymer Journal (2018) 27:965–977
https://doi.org/10.1007/s13726-018-0668-8

ORIGINAL RESEARCH

Effect of carbon nanotube on cured shape of cross-ply polymer matrix nanocomposite laminates: analytical and experimental study

Ahmad Reza Ghasemi[1] · **Mohammad Mohammadi Fesharaki**[1]

Received: 27 April 2018 / Accepted: 13 October 2018 / Published online: 19 October 2018

Abstract

Cured shape of cross-ply $[0_2/90_2]_T$ fiber-reinforced composite laminates and the effect of multi-wall carbon nanotubes (MWCNTs) on the mechanical and thermal properties of laminates have been investigated. The nanocomposite laminate used in this study is composed of three phases: carbon fiber, polymer matrix and MWCNT. The volume fractions of 0%, 1%, 2% and 3% MWCNT were used to prepare nanocomposites. The mechanical and thermal properties of nanocomposites and fiber-reinforced nanocomposite laminates have been calculated by using analytical micromechanical models. Analytical micromechanical models were applied to determine the mechanical and thermal properties for two-phase nanocomposite composed of MWCNT and polymer matrix. The obtained mechanical and thermal data were considered as matrix properties and used in properties calculation of three-phase fiber-reinforced nanocomposite laminates. A developed model was used to determine curvature and the effect of MWCNT on the curvature in different specimens. Nonlinear relations have been considered for non-mid-plane strain equations. The addition of 1% volume fraction of MWCNT led to decreasing curvature and increasing critical size almost 14% and 9%, respectively, in different directions. The results were used to develop model and to compare with those calculated by Hyer model. Finally, unsymmetrical cross-ply $[0_2/90_2]_T$ laminates with different weight fractions of 0, 0.1%, 0.25% and 0.5% MWCNT were fabricated. The curvature of cured composite laminates, obtained by experimental study, was compared with that developed as Hyer models and good agreements were observed between the predicted model and experimental data. The experimentally predicted and developed model for the curvature of cross-ply $[0_2/90_2]_T$ fiber-reinforced nanocomposite laminates is better than the Hyer model.

Keywords Curvature · Polymer matrix nanocomposites · Multi-wall carbon nanotubes · Micromechanical models

Introduction

Because of the need for high strength and light materials in modern engineering, composite materials including fiber-reinforced polymer (FRP) laminates are fabricated and used in different industries. The advantage in using fibers, polymer matrix with different layups (layer orientation and stacking sequence) has made FRP laminates as preferable composite materials. Despite the advantages of FRP laminates, the remaining residual stresses in different laminates reduce the laminate strength after cooling from cure temperature to ambient temperature. According to their scale, residual stresses are included in two types of micro- and macro-residual stresses. Difference in coefficient of thermal expansion (CTE) of the fiber and the matrix generates micro-residual stresses after cooling. The difference in CTE in on-axis direction at various orientations results in macro-residual stresses, which lower the strength and deformation (warpage) of the laminates. The symmetrical layups of composite laminates are employed in different industries to overcome deformation and curvature in composite laminates after cooling. The application of cross-ply laminate of unsymmetrical layups in unsymmetrical cross-ply laminate is limited despite its special properties.

Hyer [1] developed a theory to determine the residual stresses, so that the restrictions of previous theories to be avoided. He presented numerical results for the in-plane residual strains over the temperature range from curing to room temperature in unsymmetrical laminates. He showed

✉ Ahmad Reza Ghasemi
Ghasemi@kashanu.ac.ir

[1] Composite and Nanocomposite Research Laboratory, Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan 87317-53153, Iran