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Adhesive layer analysis for scarf bonded joint in CFRE composites modified with MWCNTs under tensile and fatigue loads

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ABSTRACT

The effects of bondline thicknesses (0.17&0.25-mm) and scarf angles (5°&10°) on the tensile and fatigue properties are investigated, for the first time, for carbon-fiber/epoxy composites scarf adhesive joints (SAJs) modified with optimum weight percentages of multi-walled carbon nanotubes (CNTs). New experimental/analytical model was developed to measure the adhesive displacement parallel to the adherend surface (Δu_x) using instrumented specimens with extensometer and strain-gauge. The measured values of Δu_x were used to determine the deformations, normal stresses, in-plane shear stresses and Young's moduli of the adhesive layers in the SAJs under tensile loads. Results from tensile tests showed remarkable increase in apparent and local stiffnesses for the SAJs with CNT-adhesive, 0.17-mm bondline thickness and 10°-scarf angle. The Young's moduli of the adhesive layers of the 5°-SAJs is about 2-3.2 times higher than that of bulk adhesives. The tensile strength of CNT-SAJs is 15.9-33% higher than that of the neat-SAJs with different bondline thicknesses and scarf angles. On the other hand, CNTs have marginal effect on the fatigue strength at lower lives and insignificant effect at fatigue limits (10^7-cycles). The fatigue strength/life of the SAJs was improved with decreasing scarf angle from 10° to 5° and bondline thickness from 0.25-mm to 0.17-mm.

Keywords: Woven carbon fiber-reinforced epoxy; multi-walled carbon nanotubes; scarf adhesive joints; Tensile and fatigue; Bondline thickness; Scarf angle

1. Introduction

Fiber reinforced polymer (FRP) composites are increasingly being used in modern aviation-structures where strength and weight is of paramount importance. Carbon fiber reinforced polymer (CFRP) composites have been utilized to manufacture aircraft fuselage, outer flaps, wing structures, main deck floor panels, landing gear components and other primary and secondary structures. Furthermore, FRP composites exhibit progressive failure mechanisms prior to fracture, which provide early signs of incipient failure and thus reduce the probability of catastrophic failure. Recently, some researchers [1,2] have focused on the improving of the mechanical properties of FRE composites via introducing carbon nanotubes (CNTs) into epoxy materials. Although nano-hybridization of structural composites is a new approach that has not been yet fully addressed, the so far reported studies have revealed promising results as regards improvement of the mechanical as well as vibration properties.

The effect of CNTs on the tensile strength of the scarf adhesive joints (SAJs) with different bondline thickness and scarf angles has not yet been fully explored and there are a few available data for single lap-joints (SLJs) [3-6]. Mactabi [3] modified the SLJs with different weight percentages (0.5, 1.0 and 2.0wt%) of CNTs. They found that the mechanical properties of the SLJs that were modified with 0.5wt% and 2.0wt% CNTs are almost equal, and achieved improvements of 12% and 3% compared to those of adhesive joints with neat epoxy and 1.0wt% MECNTs adhesives respectively. Contradictory results were obtained by Kang et al. [4] for the modified SLJs with 2.0wt% CNTs. They reported that the strengths of adhesive joints with 2 wt% CNTs were about 36.6% lower than those of neat epoxy adhesive joints.

Adhesively bonded joints are increasingly used nowadays in aeronautical structural composites for their convenience and high efficiency. Compared with the mechanical fastening methods, there are some advantages of adhesively bonded joints, such as uniform stress distribution along the overlap, its high specific stiffness and strength, smooth configuration, ease of practical operation, low cost and suitability for bonding composite adherends with complex shapes and geometries [6,7]. There is, therefore, no wonder that adhesive bonding is the primary joining technique for CFRP used in the aerospace industry [8]. On the other hand, drilling holes for mechanical fastening joints in composites is not straightforward. The economic impact of the damage induced in drilling FRP composites is significant, especially when considering the added value associated with the component when it reaches the assembly stage [9,10]. Therefore, the demand for improving the mechanical properties of the adhesive bonded joints is required forever and is the main objective of this study.

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