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FINITE ELEMENT MODELLING OF THE SHEAR STRESS DISTRIBUTION OF EMBEDDED POLYVINYL ALCOHOL - CARBON NANOTUBE FIBERS IN GLASS FIBER REINFORCED COMPOSITES

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ABSTRACT

Polyvinyl alcohol carbon nanotube (PVA-CNT) fibers were embedded in glass fiber reinforced plastic (GFRP) composites in order to be used as strain sensors of the composite. Strain sensing of the composite was made by the in-situ measurement of the embedded fiber's electrical resistance change during the mechanical tests. A finite element (FE) model of non conductive GFRP with embedded PVA-CNT fibers as mechanical sensors will be developed to investigate shear stress distribution at the interface between GFRP and the PVA-CNT fiber. The values of maximum shear stress will be calculated and correlated to fiber Young's modulus, while the effect of fiber pre-stretching will be also examined.

Keywords: PVA-CNT, GFRP, electrical resistance change, finite elements, axial strain, shear stress, interface, composites.

INTRODUCTION

The electrical resistance change (ERC) method was successfully applied in conductive carbon-fiber reinforced polymers (CFRPs) before three decades ago, that used the electrical conductivity of the carbon fibers to monitor damage, such as fiber breakage, delamination, matrix cracking (Schulte, 1989). ERC monitoring concept could also work in non-conductive composites such as glass fiber reinforced polymers (GFRPs); Muto (2001) inserted a carbon fiber into GFRP during manufacturing and monitored the carbon fiber's electrical response versus the externally applied mechanical loading of the composite.

To this end, the authors have recently presented a methodology according to which innovative polyvinyl alcohol-carbon nanotube (PVA-CNT) fibers can be embedded into GFRP during manufacturing (Alexopoulos et al., 2010a). The fibers were produced according to the standard process with injection of a carbon nanotubes (CNTs) suspension into a spinning coagulation agent, explicitly described in Vigolo et al. (2000). It was demonstrated that the electrical resistance of the embedded fibers changed with the applied tensile loading of the composites, and thus, this new sensor can be used for strain sensing purposes of composites. Increase in ERC is attributed to loss and modifications of contacts of CNTs inside the PVA matrix; the key parameter in this sensor is translating this effect and transforms it into axial mechanical strain. The advantages of this sensor are remarkable; it is very thin (approximately 40 μm in diameter), its modulus of elasticity is very close to that of GFRPs and its elongation to fracture exceeds 100 %.

However, the effect of PVA-CNT fiber pre-stretching to shear stress distribution at the interface between the PVA-CNT fiber and the matrix of a non conductive composite - due to stiffness variation - has not yet been investigated for the case of mechanical loading. It was shown that pre-stretching of the fiber normalizes the resistance change values of PVA-CNT fiber and doesn't lead to residual electrical resistance during mechanical testing of the composite (Alexopoulos et al., 2010b). Shear stress will lead to possible debonding between the fiber and the composite, which will result to erroneous strain (and electrical resistance) readings of the fiber.

RESULTS AND CONCLUSIONS

A 3D finite element model of the composite with an embedded PVA-CNT fiber was developed. The model takes into account the stiffness of the fiber and the non-linear behaviour of the composite until failure. A progressive damage scheme was adopted in order to investigate the initiation and progression of debonding based on the interfacial maximum shear stresses (τ_{max}). The results indicate that the higher the pre-stretched ratio of the fibers, the greater the interfacial shear stresses between the fiber and the woven composite (up to a factor of 6), which may lead to possible debonding between the fiber and the composite. Based on the interfacial strength, the applied nominal stress on the composite that initiates debonding was also evaluated.

In order to establish the PNA-CNT fiber as a sensor, the relationship between the normal strain of the fiber and the resistance reading was then evaluated. Since the fiber experiences a distribution of strain, which is highly non-uniform in the case of partial debonding, the resistance was related to both the maximum strain and the mean strain on the fiber. It was found that the measured resistance is related better with the maximum strain, which means that it also takes into account the possible debonded area.

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