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MECHANICAL PROPERTIES OF HYBRID CARBON FIBER REINFORCED POLYETHYLENE AND EPOXY COMPOSITES

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ABSTRACT

In this work, a hybrid polyethylene/epoxy combination matrix is reinforced with carbon fiber fabric. The objective is to develop a composite material with better tensile and impact properties. Three ratios of high molecular weight polyethylene powder were used as an additive to the epoxy matrix system. These composite materials were manufactured using hand-layup and vacuum bagging technique. The study carried out here is to find the effect of polyethylene weight fraction on tensile and impact properties of the carbon fabric reinforced epoxy composite material. The results show the tensile strength has been improved by the lowest used ratio of polyethylene additive while, all the hybrid composites exhibit higher tensile ductility. On the other hand, the Izod impact strength shows degradation in impact properties for the hybrid composites. Several suggestions are made about ways to improve the behavior of such materials.

Keywords: tensile, impact, hybrid, epoxy, polyethylene.

INTRODUCTION

Carbon fibers have been effectively used as reinforcements for polymers in many applications. Their use is spread out from making hand tools to building spaceships. Each material application usually has a polymer type that fulfills its characteristics needs. Epoxy matrix system is a type of polymers that has a very wide range of applications. Its characteristics, either neat or with additives, have been widely investigated over the years (Mohan 2013). Currently, the concept of hybrid composites materials started to draw a great attention from researchers. Hybrid composite materials can be divided into three categories; different types of fibers reinforcing the same polymer (Peijs and de Kok 1993; Dutra *et al.* 2000), different types of polymers reinforced by the same fibers (Guduri and Luyt 2006) or the same fibers reinforcing a polymer with small additives (Tehrani *et al.* 2013; Sprenger, Kothmann, and Altstaedt 2014; Sharma and Lakkad 2015; Rahman *et al.* 2015).

Carbon fibers reinforced epoxy (CFREP) composites materials have gone through many hybrid combinations in order to improve one of its properties without greatly affecting the others. Carbon nano additives were used to strengthen CFREP where it resulted in an improved ductility (Tehrani *et al.* 2013) and impact strength (Tehrani *et al.* 2013; Sharma and Lakkad 2015). Another study found that adding carbon nano tubes, indeed, improved the impact strength of CFREP composites material but made it stiffer (Rahman *et al.* 2015). Another approach is introducing layers of polystyrene in CFREP composites which give the possibility of controlling flexural stiffness of the composites by controlling its temperature (Maples *et al.* 2014).

Recently, interaction between thermoplastics and thermosets polymers have been sought to have great potential applications in the aircraft industry (Deng *et al.* 2015). For example, it provides better composites adhesion and bonging for cost-effective manufacturing of composites structures. Through the history of composite materials, several thermoplastic candidates have been found to have good compatibility with thermosets polymers in order to increase their toughness (Kinloch, Yuen, and Jenkins 1994). For example, adding high performance polyethylene fibers to CFREP composites materials have improved its impact strength (Peijs, Venderbosch, and Lemstra 1990). Likewise, adding polycarbonate and montmorillonite particles to epoxy matrix system has improved the impact strength of hybrid composites as well as the flexural strength and toughness (Bakar *et al.* 2011). An improvement in the epoxy matrix impact strength was found by adding oxidized polyethylene particles in one of the most recent studies (Chaudhary *et al.* 2015). Moreover, the use of a thermoplastic additive with high molecular weight has been sought to produce good compatibility with epoxy matrix (Hodgkin, Simon, and Varley 1998).

In this study, the interaction between ultra-high molecular weight polyethylene powder as an additive (thermoplastic) and epoxy matrix system (thermoset) have been sought by the authors as a new candidate for hybrid matrix that is reinforced by carbon fibers. Therefore, the performance of these hybrid composites is to be investigated under tensile and impact loadings.

To the best knowledge of the authors, using ultra-high molecular weight polyethylene powder as an additive to carbon fibers reinforced epoxy composites material is an innovation that may have never been attempted before.

MATERIAL PREPARATION AND TEST SETUP

The materials used in this study are carbon fibers plain weave fabrics, epoxy matrix system and ultra-high molecular weight polyethylene powder. The carbon fibers fabric has a density, tensile strength and an elastic modulus of 1.76 g/cm^3, 4200 MPa and 240 GPa, respectively. On the other hand, the epoxy matrix system that is used has a density, a tensile strength, an elastic modulus, and impact strength of 1.18 g/cm^3, 75 MPa, 3.3 GPa and 45 KJ/m^2 respectively. Finally, the ultra-high molecular weight polyethylene powder used here has a density of 0.95 g/cm^3 and particles' size of about 150 µm.

The composites plates were manufactured by hand-layup technique under vacuum pressure. Four plates were made; each with eight carbon fiber fabric plies that produced plates with around 60% fiber volume fraction. The hybrid composites plates were manufactured using a 2.5 wt.%, 5 wt.% and 7.5 wt.% weight ratios ultra-high molecular weight polyethylene powder as an additive to the epoxy system. The mixture of polyethylene and epoxy resin was mixed by hand for around 10 minutes before adding hardener and continuously during the fabrication process to achieve good homogeneity of the matrix system. Each of the produced plates has dimensions of 45 cm by 45 cm. The plates were then cut according to ASTM D3039/D3039-08 and ASTM D4812-10/D256-10 standards into 20 cm by 2 cm tensile specimens and into 6.4 by 1.3 cm Izod impact specimens respectively.

Static tensile tests were performed using an MTS 809 Axial/Torsional Servo-hydraulic test system rated at 100 kN tensile and 1100 Nm torque. Tests were carried out under constant extension rate of 2 mm/min and normal room conditions. The tests were repeated at least 5 times for each type of specimens.

Izod impact test was carried out on un-notched specimens using Zwick HIT 50P pendulum impact testers rated at 50J impact energy. The test was carried out under normal room conditions and was repeated at least 6 times for each type of specimens.

RESULTS AND DISCUSSION

Static Tensile Test

The static tensile test results are shown in figures 1-4 and Table-1. Figure-1 shows stress versus strain behavior, Figure-2 shows tensile strength, and Figure-3 shows tensile strain, while Figure-4 shows tensile elastic modulus. Adding 2.5% of polyethylene to the epoxy shows the highest tensile strength, while the samples with pure epoxy produced the stiffest material. Tensile modulus, on the other hand, shows an inverse relationship with the increase of the polyethylene additives. An interesting finding is that the 5% specimens failed at lower strain rates than the others while they kept approximately the same level of tensile elastic modulus as 2.5% specimens.

The tensile strength of the neat epoxy samples is considered acceptable for the used fabrication method (Rahmani, Najafi, and Ashori 2014). Ultra-high molecular weight polyethylene powder alters the homogeneity of the epoxy matrix; hence, the specimen exhibits higher ductility with the increase of additives. The increase in the polyethylene additives produced non-consisting change in the composite material behavior, which requires further in-depth investigation that has to incorporate even smaller percentage increase of the additives.

Tensile loading of the specimens have produced different failure types. Some specimens have failed with inclined crack lines to the loading axis, whereas others show a typical perpendicular cracking line. It can be considered as evidence to the inhomogeneity of the matrix. Figures-5 and 6 show the failure mechanism in a tensile specimen's side and front views, respectively.

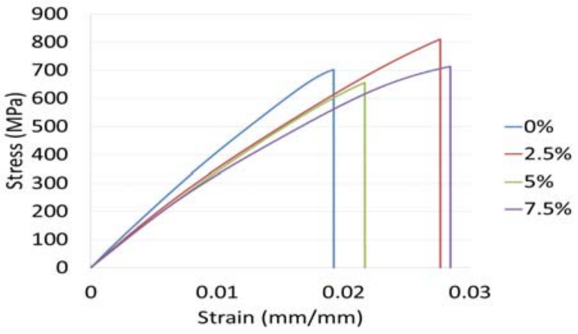

Figure-1. Stress versus strain of hybrid CFR tensile test.

Table-1. Hybrid CFR tensile results (Standard Deviation).

Additive %	0 wt.%	2.5 wt.%	5 wt.%	7.5 wt.%
Ultimate Tensile Strength (MPa)	702.6 (7.29)	811.1 (36.2)	656.7 (30.3)	714.3 (30.3)
Ultimate Strain (%)	1.921 (0.06)	2.764 (0.13)	2.167 (0.15)	2.844 (0.11)
Average Tensile Modulus (GPa)	40.53 (1.50)	34.33 (0.41)	33.90 (1.04)	31.15 (0.15)

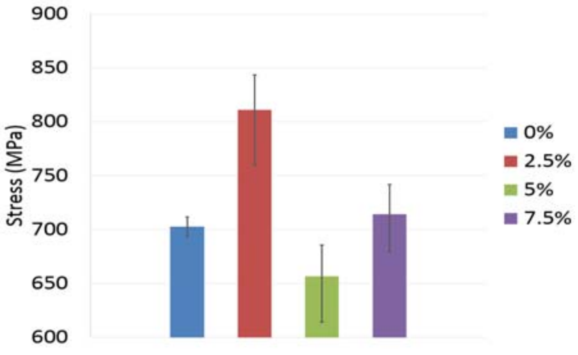

Figure-2. Stress of hybrid CFR tensile test.

The specimen exhibits three failure modes, fibers splitting, fiber pullout and delamination. Weak interaction between fibers and matrix is an evidence for the cause of fibers pullout and delamination. In addition, increasing polyethylene additives also increased these failure modes due to its concentration in areas around the fiber bundles seen in Figure-6. It has been reported that the matrix toughness is an important characteristic that affect the interlaminar fracture behavior of composite materials (Davallo 2010). This is indeed true for the observed fracture behavior of the specimens in this study.

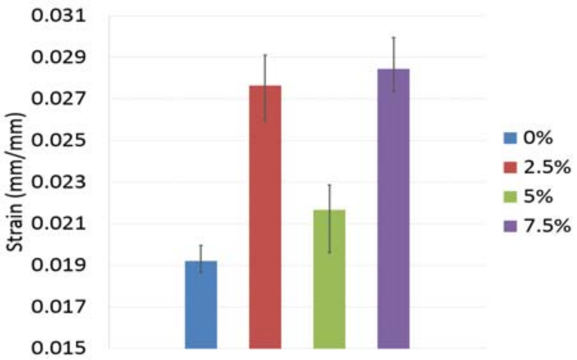

Figure-3. Strain of hybrid CFR tensile test.

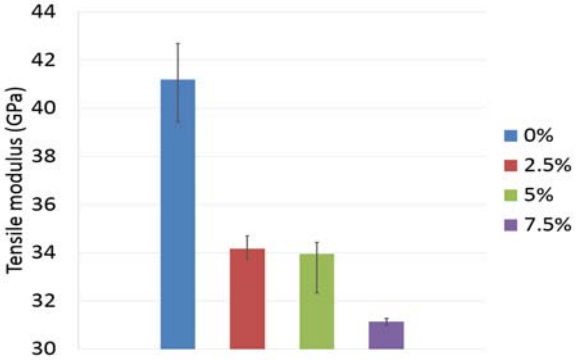

Figure-4. Tensile modulus of hybrid CFR tensile test.

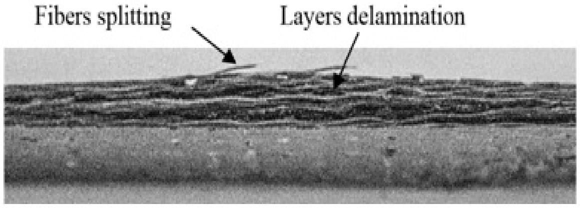

Figure-5. Hybrid CFR failed sample under tensile loading (side view).

Izod Impact Test

The Izod impact test results are presented in Figure-7 and Table-2. Note that the results of the Izod impact test is used only for comparison purposes rather than actual material property (Cantwell and Morton 1991). As seen in Figure-7, impact strength of the composite material is showing an inverse relation with the increase of the polyethylene additives. It should be noted here that the Izod impact test is employed on the side of the specimen, which cause shear and delamination of the composite layers. The inhomogeneity of the matrix is evident in the impact test results due to the worsen impact strength with the increase of the additives.

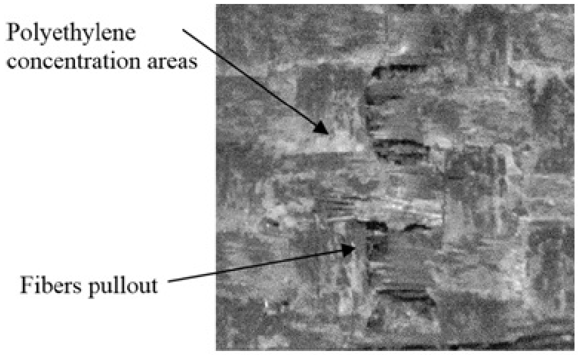

Figure-6. Hybrid CFR failed sample under tensile loading (front view).

Table-2. Hybrid CFR Izod impact results.

Additive %	0%	2.50%	5%	7.50%
Average impact energy (KJ/m)	3.35	2.68	2.46	2.45
Standard Deviation	0.14	0.25	0.21	0.16

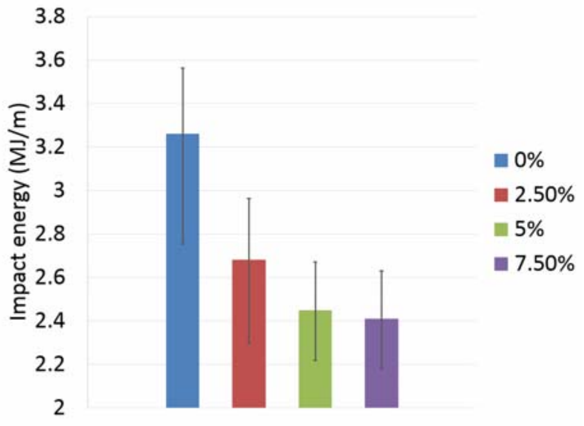

Figure-7. Impact Energy of Hybrid CFR Izod Impact Test.

In contrast with the results of the tensile tests, the increase in the ultra-high molecular weight polyethylene powder additive yielded consistent decrease in the impact strength. Unfortunately, the findings in this study are in contrast with other studies; the impact strength usually improve, in some cases by 20-40 % (Tehrani *et al.* 2013; Sharma and Lakkad 2015; Rahman *et al.* 2015), when an impact modifier is added to an epoxy matrix. Also, the findings are in contrast of what other studies found when adding polyethylene fibers or particles to the CFREP or the epoxy matrix, respectively (Peijs, Venderbosch, and Lemstra 1990; Chaudhary *et al.* 2015).

Figure-8 shows a typical failed sample under Izod impact test. It can be observed from the cracking line of the specimen that the fibers splitting and pullout are the dominant failing characteristics of the tested samples, yet layers delamination does occur.

Figure-8. Hybrid CFR failed sample under Izod Impact loading.

CONCLUSIONS

2.5 wt.% ratio of ultra-high molecular weight polyethylene powder is considered a good additive percentage to the epoxy in terms of tensile strength in this study. The composite material ductility was found to have a positive relationship with the increase of the additives except at 5 wt.% ratio where it exhibited a stiffer behavior. Further investigations of other polyethylene powder additive percentiles especially between 2 wt.% and 5 wt.% is recommended under the same conditions of manufacturing and testing the materials. On the other hand, the impact strength was found to have an inverse relationship with the increase of the additives. The impact loading exert stresses on the matrix higher than tensile loading due to the fact that it creates shear stress, which lead to delamination. This shows the importance of the matrix homogeneity and the effectiveness of the additives to transfer loads throughout the composite materials.

For future work, two factors should be considered, the homogeneity of the matrix and the interaction between matrix and additives. Homogeneity of the matrix can be improved by using ultrasonic mixer during manufacturing procedure. In addition, it can be improved by adding solvents to the epoxy resin to lower its viscosity, which needs to be evaporated before adding the hardener to the mixture. On the other hand, the interaction between matrix and additives can be changed by increasing the heat of the epoxy and polyethylene additives beyond the glass transition temperature (Tg) of the polyethylene additives.

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