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THE EFFECT OF STACKING SEQUENCE ON TENSILE PROPERTIES OF HYBRID COMPOSITE MATERIALS

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Abstract: Hybrid composite materials have found extensive applications in many areas such as in the medical field, aerospace, automobile and in the sport industry, between others. The effect of stacking sequence of glass/carbon fibers on the tensile behavior of the hybrid composites was investigated in this paper. Five groups of hybrid composite laminates were produced using various proportions of woven E-glass/carbon fibers reinforced epoxy matrix and subjected to tensile tests. The results showed that the hybrid laminations that consist of three layers of carbon and two layers of glass provided the best tensile properties. Group D showed the maximum force results (9255.7 N) and maximum tensile stress (382.7 Mpa). For three or less number of layers in the composites, when using carbon fiber layers more than glass fiber layers, the tensile strength was found similar. Otherwise, the tensile load increased with increasing number of layers. Moreover, for the tensile force and the stress of the hybrid composite samples that consisted of three or more layers, a significant effect of the stacking sequence was noticed.

Keywords: *Hybrid materials, E-glass fibers, carbon fibers, epoxy resin, tensile test.*

1.0 Introduction

During the last decades the use of hybrid material reinforced polymer composites has increased. The engineering designers are always searching for high specific stiffness, high specific strength, corrosive-resistant as well as low cost when choosing the material for structural applications (Fotsing *et al*., 2012). For the same reinforcing material regulations and standards may not properly apply if the composites undergoes various loading conditions during the serving life. Therefore, for such applications hybrid materials are the preferable solution. Hybrid materials are used as reinforcement in composites that demand high values of impact and compression strength and high stiffness in tension mode. As previous studies indicated, it is possible to get a composite with balanced properties if two or more types of fibers are used to reinforce a polymer matrix (Swanson, 1997).

Carbon and glass fibers with epoxy composites are increasingly in demand for structural applications in increasing number of industrial fields due to their excellent mechanical performance and design flexibility compared with traditional materials (Moutier *et al*., 2009). Normally, the stiffness and load bearing qualities are provided by the highest modulus fibers, while the low modulus fibers conserve its low cost. By varying the stacking sequences and volume fraction of reinforcing layers in the composites, high mechanical properties of hybrid materials can be achieved (Cheong and Lee, 1997).

A lot of studies on composite materials used unidirectional fibers such as the one by Seung *et al*. (2002), who studied the mechanical properties of hybrid with non-woven carbon fiber under static tensile mode. In this study was concluded that the tensile properties of hybrid composites, including the longitudinal Young's modulus and the strength of hybrid specimens were lower than those of the composite samples reinforced with only carbon fiber. While the effect of hybridization on the tensile properties of carbon/glass fibers epoxy composites has been studied by Fu *et al*. (2000). Miwa and Horiba investigated short fiber composites of carbon/glass fibers and found that the tensile strength of hybrid systems can be evaluated by the additive rule of hybrid mixtures (Miwa and Horiba, 1994). The fabrication, characterization, physical, thermal and mechanical behaviors of glass/carbon/epoxy hybrid laminated composites was discussed in terms of tensile strength and elastic modulus by Guermazi *et al*. (2014). Chiang *et al*. (2005) investigated the tensile characteristics of unidirectional hybrid composites of carbon/glass/epoxy resin using the Monte-Carlo simulation method elaborated with different angles.

Limited studies have been done with woven fabric composite materials, especially fabric carbon fiber with glass fibers. Woven fiber reinforced composite materials with single or different reinforcement fibers displayed preferable mechanical properties and crashworthiness (Mutsuyoshil and Aravinthan, 2010). Experimental investigations were conducted on in-plane mechanical properties of two types of hybridization materials by Pandya *et al*. (2011). Mechanical characteristics of hybridization material H1 (G3C2) and H2 (C3G2) were compared with each of carbon/epoxy and E-glass/epoxy composites. It was observed that there was a loss of 17.2% of tensile strength for the hybridization material H1 compared with that of carbon/epoxy composite while there was a gain of 90.4% of ultimate tensile strain in the hybridization material H2 compared with that of carbon/epoxy material. In this research, the tensile properties of multi layers of woven fabric carbon/glass reinforced epoxy hybrid composites were experimentally investigated. The hybrid composites consisted of five groups: A, B, C, D and E with various sequences of hybrid fiber layers

2.0 Materials and Methods

2.1 Materials

The materials used for the fabrication of the laminated composites were E-glass, carbon fibers and laminating epoxy resin (CIBA-GEIGYY, CY233), which is a viscous liquid at room temperature and it is turned into a solid state after adding the hardener. This epoxy resin is characterized by high toughness, low shrinking degree, good resistance to chemical attack and weather conditions, and strong adhesion with various synthetic fibers, in comparison with other types of thermosetting resins (Srivastava *et al*., 2011). The two kinds of fibers used to fabricate the hybrid laminates are glass mat with a 0 /90 angle and carbon mat at -45/45 angle.

2.2 Tensile Properties

Tensile test is an essential mechanical characterization test where specimens are loaded in a control procedure whilst measuring the applied load and the elongation of the samples. Table 1 shows the mechanical properties, such as Young's Modulus, tensile strength and volume density of carbon fiber, glass fibers and the epoxy resin (Velmurugan and Manikandan, 2007).

Table 1: Mechanical properties of the fibers and resin.

Material	**Modulus of elasticity (GPa)**	**Tensile strength (MPa)**	**Volume density (g/cm^3)**
E-glass mat	76	1956	2.57
Carbon	228	3950	1.8
Epoxy	1.9	68	1.2

2.3 Preparation of the Hybrid Specimens

A mold with inner dimensions (168mm, 60mm) was prepared to mold samples with a thickness of 4 to 5 mm. Five groups of hybrid composites were molded by using hand lay-up procedure in which layer of epoxy resin was coated on the sheet, reciprocally, layers of carbon fiber and glass fiber were laid upon another, with a layer of resin in between and on the last layer of the composites. Then a flat board with a static load was applied above these sheets and the whole set up was then allowed to cure for around 24 hours. Since the air bubbles result in void formations that will induce a concentration of stress and the initiation of cracks formation, particular care was taken to avoid air bubbles during the mixing of the epoxy and the hardener and during the application of the epoxy resin to the fibers.

Five groups consisted of carbon/glass fibers reinforced epoxy matrix with a different fiber layer arrangement were prepared. These aggregates are A, B, C, D and E contain several layers of fibers with various masses, as shown in Table 2.

Table 2: Shows the no. of layers and the weight of the glass, carbon fibers and epoxy resin that used on the specimens.

Type of hybrid	**No. of layers of the fibers plies**	**Glass fiber weight (g)**	**Carbon fiber weight (g)**	**Epoxy weight (g)**
Group A (carbon/glass/carbon/glass)	4	3.17	0.93	4.00
Group B (carbon/glass/carbon)	3	1.59	0.93	3.54
Group C (glass/carbon/glass)	3	3.17	0.47	3.54
Group D(carbon/glass/carbon/glass/carbon)	5	3.17	1.40	4.50
Group E (glass/carbon/glass/carbon/glass)	5	4.75	0.93	4.50

2.4 Experimental Procedure

The composite specimens were prepared using the procedure outlined above at laboratory temperature and produced in a dry state, forming a rectangular plate with different thickness. Specimens for tensile testing were cut first in equal rectangular forms with 165mm length and 19mm width +/- 0.5mm using iron scissors (cutter) then the specimens were cut to 13mm wide in the shape of a dog bone by using a milling machine to make the particular flanks of the specimens according to ASTM D 638 standard (ASTM, 2012). Figure 1 shows the tensile test specimens that had undergone the test with a crosshead speed of 2 mm/min. Standard tensile samples were carried out and the test was repeated three times for each composite group.

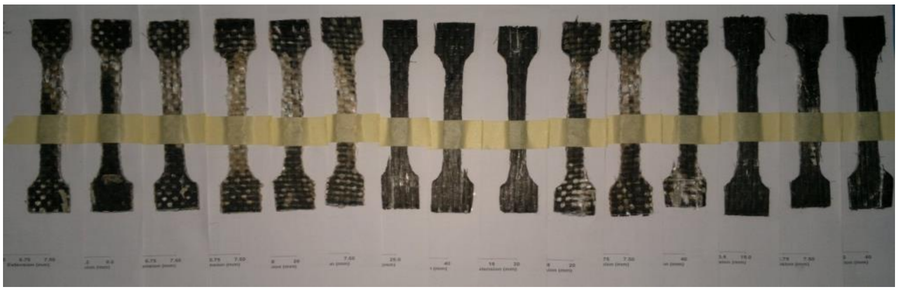

Figure 1: Shows all groups of specimens.

3.0 Results and Discussion

The average results of yield and maximum tensile force for all groups A, B, C, E and D are presented in Figure 2. In terms of the pattern of tensile results, these results are similar to other studies on examining the tensile properties of polymer matrix composites (Ying and Kin, 2002; Rong *et al*., 2001). In addition, the tensile response of all hybrid composites seems to be dominant essentially by the fiber behavior (Aucher *et al*., 2009). However, the interface quality seems to be no so efficient. Otherwise, plastic deformation must be observed under tensile since the epoxy matrix has plastic behavior and it presents large plastic deformations (Fiedler *et al*., 2001).

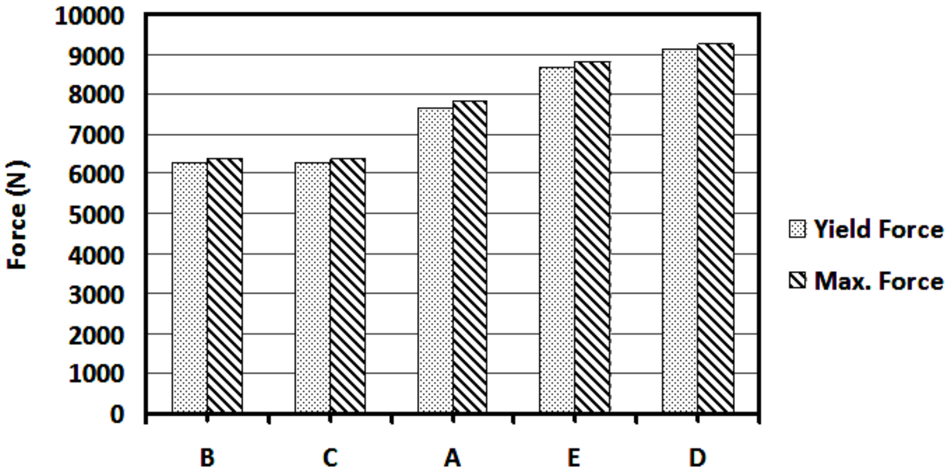

Figure 2: Shows the average results of yield and max. tensile force for all groups A, B, C, D and E.

From Figure 2, it can be observed that for the group which consists of two layers of carbon and a single layer of glass between them (group B), the average of maximum tensile stress is 327.5 Mpa. While the average of maximum tensile stress for group C is 330.3 Mpa. In addition, it appeared that there is no significant improvement in the tensile stress when using two layers of carbon instead of two layers of glass, as shown in figure 2. These are well defined properties and features of hybrid materials, i.e., to have high tensile stress when adding another fibers with low cost. While the most significant change in tensile properties was noticed after adding one layer of glass at the surface in the group that consist of two layers of carbon/glass (group A). This result differs to that observed in (Hatta *et al*., 2005; Yasmin and Danie, 2004), which is improved due to the existence of a hybrid effect in the material properties. Furthermore, the values of hybrid effects are also in good agreement with values quoted in Reference (Cao *et al*., 2009) despite the fact that different materials were used.

It is also noticed that tensile properties increased with the number of layers, this behavior appeared more obvious for the other two hybrid groups (B and C), with this trend being accompanied by a significant increase in tensile strength. It could be observed when using three layers of carbon mats and two layers of glass mats (group D) that the tensile properties of the hybrid material were improved largely in comparison when using three layers of glass mats and two layers of carbon mats (group E). This means that with increasing the number of layers the effect of the hybridization of carbon fiber also increased. Therefore, for the same structural application it can be replaced in the composites some of the single-type of reinforcing fiber layers with hybrid combinations that reduces the cost and improves the tensile performance of the materials.

Figure 3 presents the average values of the yield stress and max tensile stress of the tested samples. The stress values increased with increasing the number of layers, similarly as in the previously presented forces chart (see Figure 2). The fiber content of the reinforcement affect the stiffness properties by a large amount because of the fact that stiffness being a volume averaged quantity, which is proven analytical in References (Banerjee and Sankar, 2014; Yun *et al*., 2001). Such a trend in relation to the tensile properties is expected with light weight composite panels, which allow using them in applications that require high tensile strength and light weight, as well.

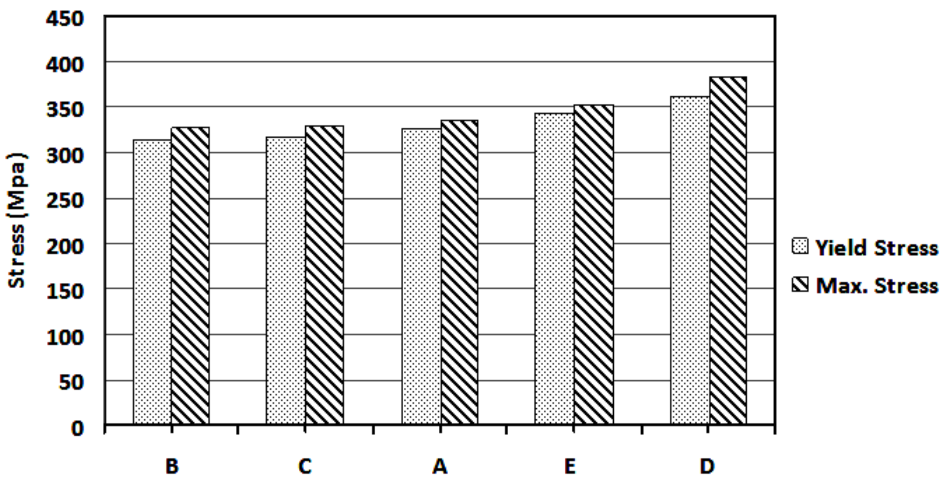

Figure 3: The average results of yield and maximum tensile stress for all groups A, B, C, D and E.

4.0 Conclusions

Tensile properties of laminated carbon and glass fiber hybridization composites with different number of layers and stacking sequence were investigated and compared. Group D showed the maximum force results (9255.7 N) and maximum tensile stress

(382.7 Mpa). The general conclusion that could be drawn from this study was that although the tensile strength appeared to obey the rule of number of layers and type of hybridization of the fiber reinforced polymer matrix composites, there was no significant change in the tensile properties when using three or less number of layers. The results also confirmed that when using more than three layers, the tensile strength increased proportionally. Furthermore, when glass fiber was replaced at the surface side of the laminates, the composite reported lower tensile strength than when carbon fiber was at outer surface of the tested composite material.

5.0 Acknowledgements

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