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# DEVELOPMENT OF CARBON-GLASS FIBER REINFORCED HYBRID COMPOSITES BY VACUUM INFUSION TECHNIQUE

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**Abstract:** Fiber-reinforced composite materials are used in various applications in aviation, maritime, sport, automotive, and defense industry due to their several advantages. Beside this, they have some disadvantages. The behavior of hybrid composites is a weighed sum of the individual components in which there is a more favorable balance between the inherent advantages and disadvantages. The aim of this study is to develop of the carbon-glass fabric reinforced polyester hybrid composites. PA66 nonwoven fabrics were also incorporated within the composite laminates to modify interlaminar region. The results show the addition of the PA66 nonwoven fabrics affects the mechanical properties in hybrid composite.

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## INTRODUCTION

Composites containing two or more different reinforcing materials bound in the same matrix are commonly known as hybrid composites (Pegoretti *et al*., 2003). The development of composite materials improves their performance based on the reinforcement of two or more fibers in a single polymeric matrix, which leads to the advanced material system called hybrid composites with a great diversity of material properties (Prabhakaran *et al*., 2012). Hybrid composite materials have a great potential for engineering in many applications. Hybrid polymer composite material offers the designer to obtain the required properties in a controlled considerable extent by the choice of fibers and matrix. The properties are tailored in the material by selecting different kind of fibers incorporated in the same resin matrix (Jagannatha and Harish, 2015). In most cases, the purpose of hybridization is to obtain a new material retaining the advantages of its constituents, and hopefully overcoming some of their disadvantages. Another desired achievement is related to the cost, with one of the two components being generally cheaper than the other one (Pegoretti *et al*., 2003). Carbon fiber reinforced polymer composites exhibit superior specific strength and modulus but have a lower failure strain and high cost. Hence, the combination of both glass and carbon fiber in polymer composite may yield optimized mechanical properties (Shukla *et al*., 2015). Hybrid composites can be classified into two main categories: interlamingled or intraply and interlaminated or interply (Naik *et al*., 2001).

More widespread applications have been limited by the propensity for interlaminar failure of the composite under mode-I loading. Insufficient resistance to interlaminar stresses through fiber-polymer interactions results in the generation of cracks above some critical stress characterized by the critical interlaminar fracture toughness. These cracks propagate as delamination. Accordingly, interlaminar fracture toughness is a key parameter to assess the performance of composites under conditions such as fatigue, compression, impact or compression after impact. Strategies to improve the interlaminar fracture toughness in composites include modifying fabric architectures by manufacturing, *e.g.* 2D patterns, weft-knitted fabrics or 3D textiles. In each case, the volume fraction of fibers in the composite and its homogenity is the key; the absorption of stresses induced during loading being improved for a greater and more homogeneous fibre fraction (Ramirez *et al*, 2015).

In this study, interply carbon-glass fiber reinforced hybrid composites were developed with/without PA66 nonwoven fabrics. Composite laminates were manufactured by vacuum infusion technique.

## EXPERIMENTAL

### Materials

Unidirectional carbon (500 gsm) and E-glass (675 gsm) fabrics were used as reinforcement materials. Polyester resin (Polipol-335, Poliya) was used in this study. Cobalt octoate and methyl ethyl ketone peroxide were used as resin accelerator and hardener, with a weight ratio of 0.5% and 1.5%, respectively. The PA66 nonwoven fabrics (17 gsm, N-fusion) were incorporated into the laminates between reinforcement fabric at interlaminar region.

### Design

The test samples were designed as Carbon/E-Glass(0/90) and Carbon/E-Glass(0/90)+PA66 where 0/90 denote the fiber orientations of 0° and 90° respectively. The Carbon/E-Glass(0/90)+PA66 specimens consist of PA66 nonwoven fabrics which added into the laminates between the reinforcement fabric. The represantative carbon-E-Glass hybrid composite is shown in Figure 1.

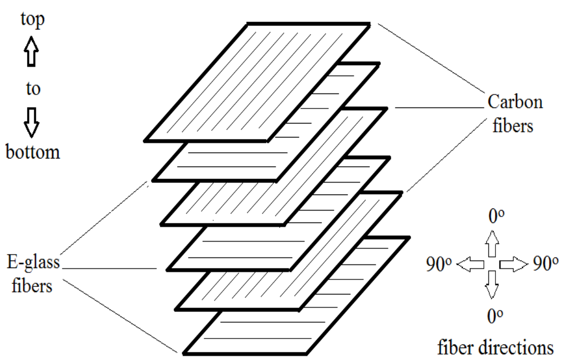


**Figure 1:** Design of hybrid composite without PA66**.**

### Method

The vacuum infusion technique was used to manufacture the composite laminates. This process is a type of closed mold process. The vacuum infusion process utilizes vacuum to infuse resin into the laminates. The first step is to load the fabric and other processing aid materials into the mold. Then the dry material is sealed using a vacuum bag. A high vacuum pump is used to remove all of air in the cavity. Under vacuum, the resin is infused into the mold cavity to wet out the fabric fibers. In this study, the composites were cured in mold for 24 hours at room temperature. The post-curing was completed at 100 °C for 2 hours. The advantages of vacuum infusion include high quality, high fiber-to-resin ratio, high strength and stiffness, good consistency, minimal shrinkage, good outside and inside surfaces, great process control, fast cycle time and low cost.

## TESTS AND RESULTS

Mechanical properties of the composites were evaluated by tensile, charpy impact, flexural and Mode I interlaminar fracture toughness (DCB) experiments.

### Tensile Test

Experiments were carried out according to ASTM D3039 standards by SHIMADZU AG-IC equipment. Tensile test results showed that Carbon/E-Glass(0/90) specimens exhibit a relatively higher tensile strength as compared to those with PA66 addition, as seen in Figure 2. In both hybrid configurations, the stiffer carbon fibers were parallel to the loading direction. When the PA66 nonwoven fabrics were added between hybrid layers, composites with the Carbon/E-Glass(0/90)+PA66 configuration exhibited a lower tensile modulus as compared to those without PA66.

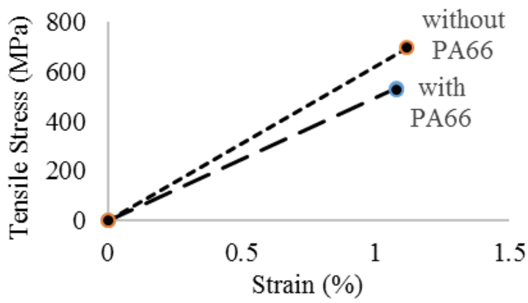


**Figure 2:** Stress-strain graph of hybrid composites

According to the tensile test in Fig. 2, elastic moduli of the composites were calculated as 58.4 GPa for Carbon/E-Glass(0/90) and 47.2 GPa for Glass(0/90)+PA66.

### Charpy Impact Test

The experiments were carried out according to ASTM D6110 standards by CEAST Resil Impactor. Charpy impact test results showed that Carbon/E-Glass(0/90)+PA66 specimens has a higher impact strength as can be seen Figure 3.

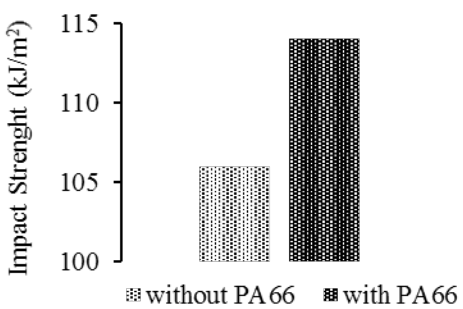


**Figure 3:** Impact strength of composites

When the PA66 nonwoven fabrics were added between hybrid layers, the Carbon/E-Glass(0/90)+PA66 impact strength increased about 8% as compared to the Carbon/E-

Glass(0/90). In both hybrid configurations, the E-glass fibers were parallel to the loading direction. If the ductile E-glass fibers were perpendicular to the loading direction, the impact strength is observed to increase.

## Flexural Test

Experiments were carried out according to ASTM D790-03 standards by MTS - 100 kN load cell equipment. Flexural test results showed that the Carbon/E-Glass(0/90) specimens have a higher flexural strength as seen in Figure 4.

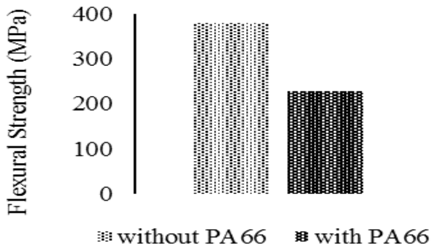


**Figure 4:** Flexural strength of composites.

When the PA66 nonwoven fabrics were added between hybrid layers, the Carbon/E-Glass(0/90)+PA66 flexural strength decreased about 40% as compared to the Carbon/E-Glass(0/90). In order to determine the effects of fiber orientation on the flexural properties of the composites, the Carbon/E-Glass(0/90)+PA66 were prepared in both 0° and 90° directions. For 0° direction the carbon fibers were perpendicular to the loading direction while for 90° direction, the E-glass fibers were perpendicular to the loading direction. The load carrying capacity of the carbon fibers are lower than E-glass fibers in compression. Therefore, the specimens which were prepared in 0° direction exhibited lower flexural properties.

## Mode-I Interlaminar Fracture Toughness Test (DCB)

The experiments were carried out according to ASTM D5528 standards by SHIMADZU-AGS-J equipment. The Mode-I interlaminar fracture toughness values of Carbon/E-Glass(0/90) and Carbon/E-Glass(0/90)+PA66 were determined as 0.45 and 0.60 kJ/$m^2$ respectively, as can be seen Figure 5.

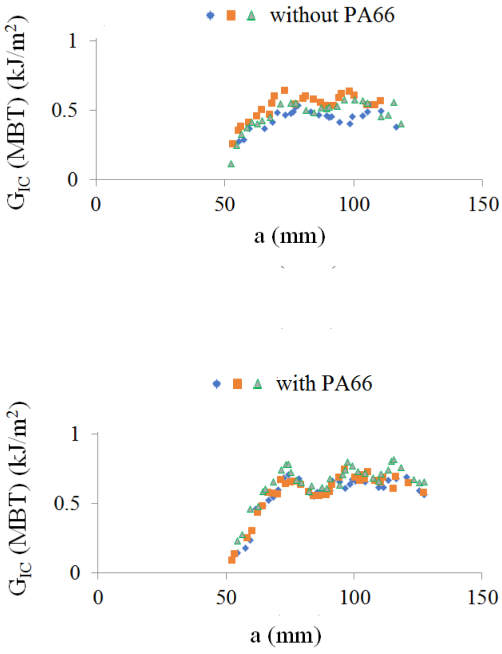


**Figure 5:** Mode-I interlaminar fracture toughness of composites.

The improvement for the specimens containing PA66 layers associates with fiber briding observed during the crack propagation. The fibers were also examined by Scanning Electron Microscopy (SEM).

## Scanning Electron Microscopy (SEM)

The PA66 fibers were observed on the test sample by JEOL JSM-5600LV scanning electron microscope. The fibers are seen in Fig. 6.

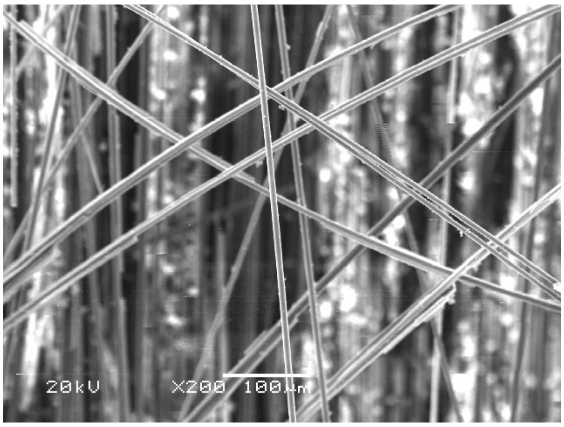


**Figure 6:** SEM image of the fibers.

## CONCLUSION

Hybrid composites were manufactured by vacuum infusion technique. Experimental evaluation of the mechanical properties of these composites as per ASTM standards were performed. In conclusion, when the PA66 fabrics are added into the interlaminar region of the composites, the

Mode-I fracture toughness and impact strength values were observed to increase, however tensile strength and flexural strength values were found to be decreased. The results show the addition of the PA66 nonwoven fabrics exhibit some effects on the mechanical properties of hybrid composite.

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