Effect of Hybridization on the Mechanical Properties of Chopped Strand Mat/Pineapple Leaf Fibre Reinforced Polyester Composites

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Abstract. Hybridization of synthetic and natural fibres as reinforcement makes the polymer composites environmental friendly and sustainable when compared to synthetic fibres based polymer composites. In this study chopped strand mat/pineapple leaf fibres were hybridized. Four laminates with six layers each, with different stack sequence (GGGGGG, GPPPPG, PGGGGP and PPPPPP) were fabricated using hand layup technique while maintaining a fibre to matrix ratio of 30:70 by weight with polyester resin as matrix. Mechanical properties such as tensile and flexural strength were determined and morphology of fractured specimens was studied. Maximum tensile strength of 180 MPa was obtained for the laminate with six layers of chopped strand mat followed by hybrid laminate with four layers of chopped strand mat at the centre (120 MPa). Tensile strength of hybrid laminate with four layers of pineapple leaf fibres at the centre was in third position at 86 MPa. Least tensile strength of 65 MPa was obtained for the laminate with six layers of pineapple leaf fibres. Similar trend was observed in case of flexural behaviour of the laminates with maximum flexural strength of 255 MPa and minimum flexural strength 107 MPa. Scanning electron microscopy of the fractured specimen reinforced with chopped strand mat only, indicated, fibre pull out, matrix cracking and lack of matrix adhesion to fibres. In case of hybrid composite (GPPPPG and PGGGGP) delamination was observed to be prominent due to improper wetting of the pineapple leaf fibres with the matrix. More significant delamination led to lesser strength in case of pineapple fibres reinforced composites even though the fibre pull out was relatively less.

1 Introduction

With the increased use of polymer composites in our day to day activities comes the need to reduce the cost of manufacturing the polymer composites, thus making it a safer and sustainable material. Polymer Matrix Composite (PMC) generally consist of a reinforcing fibre (natural or synthetic or hybrid) bound together by a polymer based matrix like epoxy, vinyl ester, polyester etc [1,2]. The fibres are the basic load bearing member whereas the matrices surrounding the fibres protect the reinforcement and also help in uniform transfer of the loads [3]. Glass fibre in the form of Chopped Strand Mat (CSM) is used as a reinforcing material in many PMCs as they form relatively strong and lightweight composites popularly known as Glass Fibre Reinforced Polymer (GFRP). Although GFRP offer high mechanical strength, they are expensive to fabricate and excess usage of these is not environmental friendly. On the other hand composites made of natural fibres have a much lower cost, they are more sustainable in comparison to synthetic fibres with lower density values (1.5 g/cm^3 vs 2.6 g/cm^3) for pineapple fibres and chopped strand mats respectively [4,5]. Two major drawbacks in the selection of natural fibre as reinforcement in composites is that, they offer lower strength in comparison to glass fibres and they are prone to moisture absorption either through direct contact or through the environment leading to swelling and the formation of voids in the polymer composite. Therefore by forming a hybrid composite reinforced by glass and natural fibres it is possible to obtain a product that is both cheaper and easy to use with moderate strength requirements [6]. Higher cellulose content of pineapple fibres make them a good choice for reinforcing material as it offers better mechanical properties [7]. George et al. observed that pineapple/polyethylene composites demonstrated stress relaxation behaviour due to better reinforcement caused by an increase in fibre weight fraction [8]. Chemical treatment of the natural fibres helps to reduce the problems associated with water absorption. Alkali treatment helps in cleaning the surface of the fibres and improves its surface properties for better adhesion with the matrix [9]. Pavithran et al. studied the Pineapple leaf fibre (PALF)/polyester composites with unidirectional orientation of the fibres. They observed that an increase in fibre angle resulted in increased composite toughness [10]. Uma Devi et al. characterized PALF/Polyester composite and studied the effects of coupling agents, fibre loading and fibre length. A linear increase in impact, flexural, tensile strengths and Young's modulus was noted when fibre weight fraction was increased. They concluded that the optimum length of fibres was 30mm [7]. Mishra et al. tested the mechanical properties of PALF/glass fibre hybrid polyester composites. They found that there was a noticeable improvement in impact, flexural, and tensile strengths of the composites which indicated a positive effect of hybridization through the addition of a small amount of glass fibres [11].

In the present study chopped strand mat and pineapple leaf fibres were hybridized with different stack sequence. Composites were fabricated using hand layup technique. Mechanical characteristics of the composites such as tensile and flexural strength were determined. Scanning electron microscopy was conducted on fractured specimens. This study intends to identify the possibility of using hybrid composites as alternative to synthetic fibre composites in automotive interiors, light loaded furniture and as temporary structural members.

2 Experimental Details

2.1 Materials

Pineapple fibres were obtained by serrating the pineapple leaves and extracting the fibres using a champ's agro unit. The leaves were procured from local plantations. Fibres were washed, dried and separated according to their diameter by inspecting them visually. They were chopped to 30mm in length and soaked in 5% NaOH solution for half an hour to remove impurities. This is followed by washing in 1% HCl solution and then rinsing with distilled water. Washing with an acid is essential to neutralize effect of any residual alkali [12]. The fibres were then dried for 24 hours at room temperature. Randomly oriented E-glass chopped strand mat (CSM) of 450 gsm was chosen as the synthetic reinforcing material. General purpose polyester resin of density 1.1g/cm^3 was chosen as the matrix material.

2.2 Fabrication of composites

Four laminates of 300mm x 300mm were fabricated using hand layup process with six layers of fabric each, among which two laminates were of hybrid composites. Designation of composites with stacking sequence of plies is presented in Table 1. Fibre weight fraction of 30% was maintained in all laminates. Composites were cured at room temperature for duration of 24h. Cured panels are shown in Figure 1.

Table 1: Designation and stacking sequence of composite laminates

Designation	No. of layers	Stacking sequence
GFRP	6	GGGGGG
HYB1	6	PGGGGP
HYB2	6	GPPPPG
NFRP	6	PPPPPP

P: Pineapple leaf fibres; G: E-glass CSM

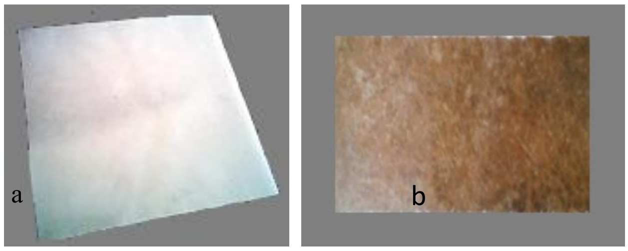

Figure 1. Cured composite panel – (a) GFRP Panel (b) Hybrid panel

2.3 Experimental Methods

Tensile and flexural strengths were determined on the Instron 3366 Universal testing machine having a maximum loading capacity of 10kN. Tensile test specimens of 250mm x 25mm were subjected to a constant cross head speed of 2mm/min as per ASTM D3039 [13].

Flexural testing (ASTM D7264) specimens of 116mm x 13mm for GFRP, 154mm x 13mm for HYB1/ HYB2 and 192mm x13mm for NFRP were subjected to three point bending at a constant cross head speed of 1mm/min [14].

All tests were conducted on conditioned samples at a temperature of 25^{0}C. Test specimens were cut from the panels using water jet cutting process. The results displayed are the averages of five individual tests. Specimens were visually checked for defects before testing.

Fractured surfaces of the laminates were analysed to understand the probable failure mechanism with the help of a Scanning Electron Microscope (SEM). A thin layer of silver coating was deposited on the specimen surface by ion sputtering and a 15kV accelerating voltage was used. The SEM was used in variable pressure mode.

3 Results and Discussions

3.1 Mechanical properties of composites

The comparison of tensile strength of the four laminates is presented in Figure 2. Tensile strength of hybrid laminate HYB1 is lower by 33.3% and that of HYB2 is lower by 52.2% while NFRP laminate is even lower at 63.8% when compared to the tensile strength of GFRP laminate, this can be attributed to fact that pineapple fibres have much lower tensile strength than glass fibres. The possibility of poor interfacial bonding between the layers of the hybrid laminate could be a potential cause as well.

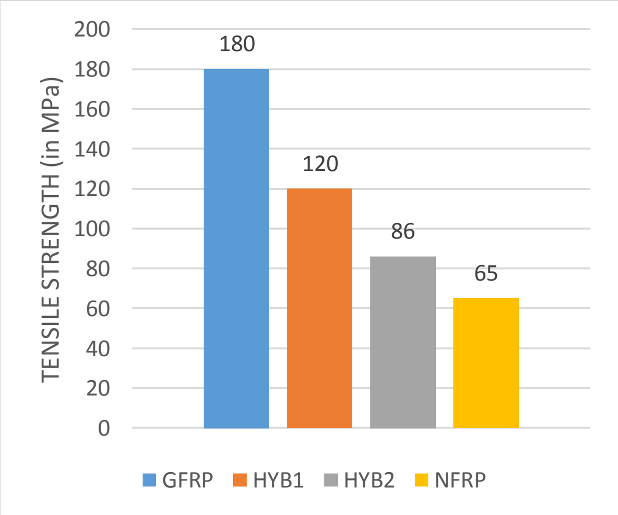

Figure 2. Variation in average tensile strength

From Figure 3 we can understand that the hybrid laminate HYB1 has a lower flexural strength by 24.3%, HYB2 is lower by 50.5% and NFRP laminate is even more weaker at 58.03% when compared to flexural strength of the GFRP laminate. Flexural loading subjects specimens to tension on the outermost layers, compression on the innermost layers and delamination in the intermediate layers. All samples in the above case failed due to tension primarily and the results match the values of the tensile test in which GFRP laminate was stronger. As seen in HYB1, higher number of layers of glass fibre led to a higher strength of the laminate whereas in case of laminate HYB2, after the outer layers of glass failed there is a possibility that delamination occurred in the layers of pineapple fibres leading to faster failure at a lower strength value. Since the pineapple fibres have lower tensile strength, the NFRP laminate displayed the weakest flexural strength among all laminates.

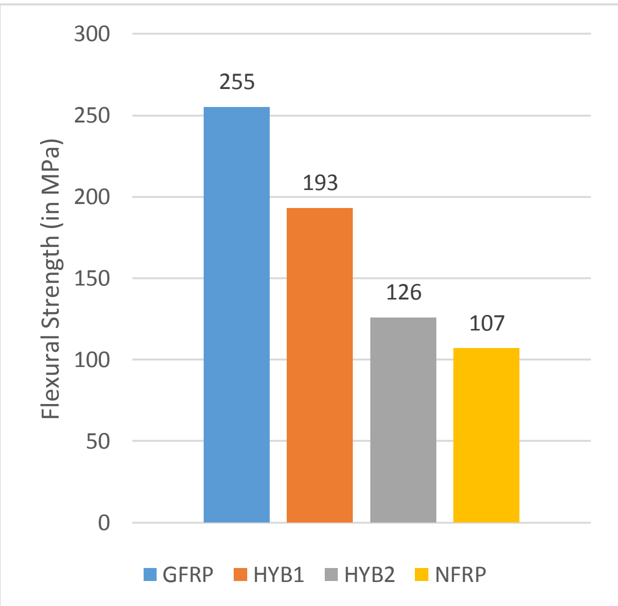

Figure 3. Variation in average flexural strength

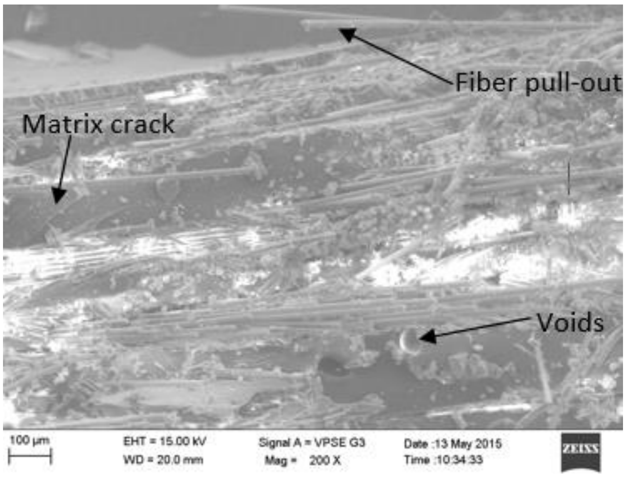

Figure 4. SEM image of GFRP tensile test specimen

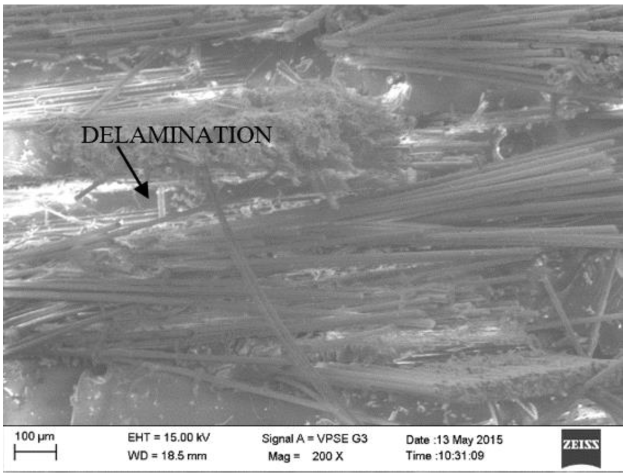

Figure 5. SEM image of GFRP flexural test specimen

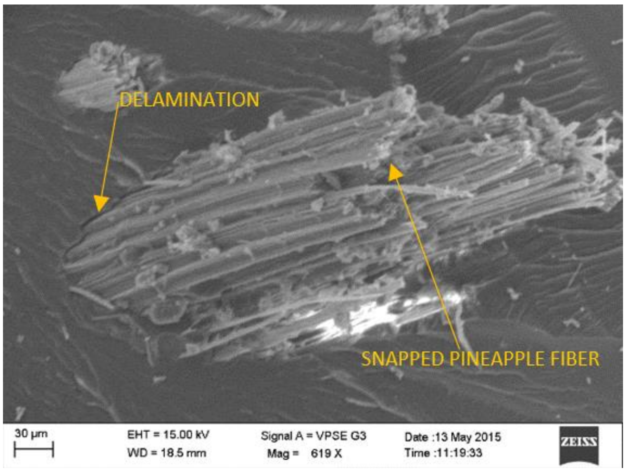

Figure 6. SEM image of NFRP tensile test specimen

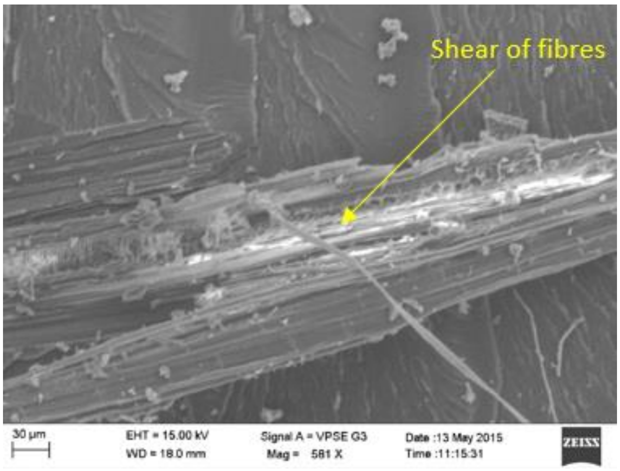

Figure 7. SEM image of NFRP flexural test specimen

3.2 Morphology of fractured surfaces

Micrographs of fractured specimens are presented in Figures 4 to 7. Figure 4 shows the micrograph of GFRP specimen failed through tensile loading. Fibre pull-out is seen at the extremities. Matrix cracking exists between layers of CSM fibres. The presence of voids further contributes to weakening of the laminates. A lack of matrix skin on the fibres displays poor interfacial bonding between fibres and matrix.

Figure 5 shows the micrograph of the GFRP flexural test specimen. A primary failure due to delamination can be observed which was caused by the bending load applied to the specimen. Figure 6 shows the micrograph of NFRP tensile specimen. Delamination can be seen which may be attributed to ineffective treatment of fibres which lead to poor wetting of natural fibres causing poor interfacial bonding with resin. Some fibre pull-out is also visible but it is comparatively lesser than GFRP specimen which is an evidence of lower tensile strength of pineapple leaf fibre. Fibre shearing is evident in the micrograph of NFRP flexural test specimen (Figure 7).

4 Conclusion

The GFRP laminate results obtained show an agreement to the generally accepted values of strength for this type of laminate. Hybrid laminates display lower tensile strength in comparison to GFRP but have a relatively decent flexural strength and hence can be used to reduce costs and increase recycling in objects that primarily undergo flexural loading like surfboards, automotive interiors, light loaded furniture and temporary structural members. Laminates having natural fibres closer to the centre of the laminate show lower strength in both loading conditions. The SEM images show delamination, fibre pull out and matrix cracking as modes of failure. Improving the treatment of natural fibres will help in proper wetting of fibres reducing the chances of delamination based failures, hence increasing the strength of hybrid laminates.

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