Effect of Ceramic Fillers on Mechanical Properties of Bamboo Fiber Reinforced Epoxy Composites: A Comparative Study

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Abstract: In order to obtain the favoured material properties for a particular application, it is important to know how the material performance changes with the filler content under given loading conditions. In this study, a series of bamboo fiber reinforced epoxy composites are fabricated using conventional filler (aluminium oxide (Al_2O_3) and silicon carbide (SiC) and industrial wastes (red mud and copper slag) particles as filler materials. By incorporating the chosen particulate fillers into the bamboo-fiber reinforced epoxy, synergistic effects, as expected are achieved in the form of modified mechanical properties. Inclusion of fiber in neat epoxy improved the load bearing capacity (tensile strength) and the ability to withstand bending (flexural strength) of the composites. But with the incorporation of particulate fillers, the tensile strengths of the composites are found to be decreasing in most of the cases. Among the particulate filled bamboo-epoxy composites, least value of void content are recorded for composites with silicon carbide filling and for the composites with glass fiber reinforcement minimum void fraction is noted for red mud filling. The effects of these four different ceramics on the mechanical properties of bamboo- epoxy composites are investigated and the conclusions drawn from the above investigation are discussed.

Keywords: Ceramic filler, Epoxy resin, Bamboo fiber, Glass fiber, Mechanical properties

Introduction

The properties of natural-fiber reinforced composites depend on a number of parameters such as volume fraction of the fibers, fiber aspect ratio, fiber-matrix adhesion, stress transfer at the interface, and orientation. Most of the studies on natural fiber composites involve study of mechanical properties as a function of fiber content, effect of various treatments of fibers, and the use of external coupling agents [1]. Despite the fact that glass fiber-reinforced plastics have excellent thermal and mechanical properties, it is difficult to devise suitable disposal methods for them. Due to many environmental problems, the disposal methods for GFRP and their recycling have been seriously acknowledged [2]. Natural fibers may play an important role in developing naturally degradable composites to resolve the current ecological and environmental problems. In the case of the 'green' composites, natural fibers derived from bamboo [3], hemp [4], or flax [5] are added to natural degradable resins to reinforce polymer matrix materials and improve the mechanical properties of the resultant composites. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractories, ceramics, and numerous high-performance applications. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. Moreover, silicon carbide has low density, low thermal expansion, high elastic modulus, high strength, high hardness, and superior chemical inertness.

Composite fabrication

Cross plied bamboo and E-glass fibers (50 wt%) are reinforced separately in epoxy resin to prepare the fiber reinforced composites B_1 and Z_1 in which no particulate filler is used. The other composite samples B_2 – B_9 and Z_2 – Z_9 with different particulate fillers of varied amount but with fixed fiber loading (50 wt %) are fabricated. The composition, designation and mechanical properties of the composites thus prepared for this study are listed in Table 1.

Part-1: This part of the paper presents the mechanical characteristics of bamboo-epoxy and glass-epoxy composites filled with red mud. As is seen in Table1, the density increased with the red mud filling for both bamboo and glass fiber reinforced composites. The neat epoxy taken for this study possess a density of 1.1 g/cc which increases to 1.53 g/cc (with a void fraction of 0.9%) with the reinforcement of 50 wt% of glass fiber in it and to 1.243 g/cc (with a void fraction of 0.956 %) with the reinforcement of 50 wt% of bamboo fiber without any particulate filler in it.

Table 1. Designation, detailed composition and Mechanical properties of the composites

Designation	Composition	Volume fraction of voids (%)	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Impact energy (J)
B_1 (Z_1)	Epoxy +50wt%BF Epoxy +50wt%GF	0.956 (0.906)	130.8 (516)	3.62 (8.77)	134.87 (393.1)	0.232 (0.976)
B_2 (Z_2)	Epoxy +50wt%BF + 10wt% RM Epoxy +50wt%GF + 10wt% RM	4.565 (3.225)	134.51 (494)	4.87 (8.24)	160.00 (275.9)	0.321 (1.301)
B_3 (Z_3)	Epoxy +50wt%BF +20wt% RM Epoxy +50wt%GF +20wt% RM	7.422 (7.894)	125.12 (468)	2.62 (8.32)	163.9 (401.81)	0.415 (0.958)
B_4 (Z_4)	Epoxy +50wt%BF +10wt% CS Epoxy +50wt%GF +10wt% CS	6.893 (6.893)	153.29 (447)	8.15 (9.64)	133.20 (429.23)	0.243 (1.361)
B_5 (Z_5)	Epoxy +50wt%BF +20wt% CS Epoxy +50wt%GF +20wt% CS	7.305 (7.305)	122.18 (397)	4.26 (7.11)	138.17 (286.29)	0.394 (1.652)
B_6 (Z_6)	Epoxy +50wt%BF +10wt% Al_2O_3 Epoxy +50wt%GF+10wt% Al_2O_3	5.137 (5.241)	159.73 (427)	5.49 (7.57)	151.10 (378.02)	0.331 (1.198)
B_7 (Z_7)	Epoxy +50wt%BF+20wt% Al_2O_3 Epoxy +50wt%GF+20wt% Al_2O_3	1.317 (6.880)	129.11 (385)	3.76 (6.95)	126.70 (258.19)	0.462 (1.311)
B_8 (Z_8)	Epoxy +50wt%BF+10wt%SiC Epoxy +50wt%GF+10wt%SiC	4.281 (4.817)	146.31 (412)	6.47 (8.91)	148.47 (433.76)	0.267 (1.398)
B_9 (Z_9)	Epoxy +50wt%BF+20wt%SiC Epoxy +50wt%GF+20wt%SiC	8.627 (8.025)	112.60 (353)	3.89 (5.42)	136.11 (241.33)	0.174 (1.075)

BF: Bamboo-fiber , GF: glass fiber, RM: Red mud, CS: Copper slag, Al_2O_3:Alumina,

But when these fiber reinforced epoxy composites are filled with micro-sized red mud particles, the density of the resulting hybrid composites assume higher values irrespective of the type of fiber. The tensile properties of the bamboo/glass-epoxy composites are presented in Table 1. On comparing with the available tensile test results for glass-epoxy composites, it becomes clear that as far as the tensile strength is concerned bamboo based epoxy composites are far inferior to the glass fiber based epoxy composites both with and without red mud filling. The modulus is increased from 3.62 GPa of unfilled composite to 4.87 GPa for composites with 10wt% red mud filled bamboo fiber reinforced epoxy composites. The highest increase of tensile modulus for filled composite is unexpected because the fiber stiffness of bamboo is lower compared to for example flax. The addition of filler did not affect the strength, which is an indication of poor adhesion between the fibers, filler and the matrix and that the stress cannot be transferred from the matrix to the stronger fibers. Similarly, the flexural properties of the bamboo-epoxy composites are studied (Table 1) and it is found that the flexural strength keeps increasing with the addition of red mud and the maximum value of 164MPa is obtained with a filler content of 20 wt%. This improvement in the flexural strength may be related to the presence of red mud particulate located at the interface of the fiber and the matrix. Table 1 also presents a comparison of flexural properties between composites with bamboo and glass fiber. It is clearly seen that the flexural strength of glass fiber reinforced epoxy composites is far superior to that of bamboo-epoxy composites. The impact failure of a composite occurs by factors like matrix fracture, fiber/matrix debonding and fiber pull out. Table 1 presents the impact energy of the red mud filled composites under investigation. It is seen that the impact energy increases linearly with increasing filler content between 0% and 20%. At higher filler content, the impact strength seems to increase slightly faster.

Part-2: Mechanical properties of copper slag filled polymer composites

This part of the paper presents the mechanical characteristics of bamboo-epoxy and glass-epoxy composites filled with another industrial waste i.e. copper slag. As is seen in Table 4.2, the density increased with the copper slag filling for both bamboo and glass fiber reinforced composites. But when this glass reinforced epoxy is filled with micro sized copper slag particles, the density of the resulting hybrid composites assume higher values i.e. 1.693 g/cc and 1.701 g/cc for composites containing copper slag of 10 and 20 wt% respectively. Similar trend is observed in case of bamboo fiber reinforced composites. The tensile strength of glass-epoxy composites are found to be much superior than the bamboo based composites in all the cases. A gradual decrease in the strength is recorded for bamboo composites with the increase in the copper slag content. Similar trend in variation of tensile strength is also exhibited by the glass-epoxy composites. But the results obtained for the tensile modulus present an entirely different trend (Table 1). For glass-epoxy composites the tensile modulus is seen to be very marginally decreasing with the addition of copper slag while in case of bamboo-epoxy composites, the pattern of variation is just opposite. A steady rise in the value of tensile modulus is noticed as the weight fraction of copper slag increases from 0 wt% to 10 wt% and then to 20 wt%. It can be concluded that although the tensile properties become distinctly poorer with the incorporation of copper slag particles in the glass-epoxy composites, tensile modulus improves for bamboo reinforced epoxy resin. The flexural strengths decrease with increase in the copper slag content for bamboo-epoxy composite (Table 1). Impact strength of the composites is measured as well and the results are reported in Table 1. In this case, the impact strength increases linearly with copper slag content increasing from 0 wt% to 20 wt%. This pattern of variation is noticed for both glass as well as bamboo reinforced epoxy resin.

Part-3: Mechanical properties of alumina filled polymer composites

This part of the paper presents the mechanical characteristics of bamboo-epoxy and glass-epoxy composites filled with a conventional filler alumina (Al_2O_3). The present investigation reveals that the presence of alumina has substantial effect on the physical and mechanical properties of the epoxy composites both with glass and bamboo fiber reinforcement. As is seen in Table 1, both the measured and theoretically calculated density values have increased with alumina content in the composites. The neat epoxy taken for this study possess a density of 1.1 g/cc which increases to 1.53 g/cc (with a void fraction of 0.906 %) with the reinforcement of 50 wt% of glass fiber and similarly, increases to 1.296 g/cc (with a void fraction of 4.565 %) with the reinforcement of 50 wt% of bamboo fiber without incorporating any particulate filler into them. The tensile properties of the bamboo/glass-epoxy composites are presented in Table 1. While a gradual drop in tensile strength of glass-epoxy composites with alumina content is noticed, there is no significant change of tensile strength due to the presence of alumina in the composites with bamboo fiber. Similarly, the variation of tensile modulus of the composites with the weight fraction of filler for both bamboo as well as glass fiber reinforced composites is shown in Table1. On the other hand, the flexural strength of the glass-epoxy composites drops by about 34% while the alumina content increases from 0 to 20 wt%. The reduction in the flexural strengths of the composites with filler content is probably caused by an incompatibility of the alumina particles and the epoxy matrix, leading to poor interfacial bonding. As can be seen from the Table 1, the impact strength of the composites is significantly improved by the addition of filler contents irrespective of the fiber type. The increased filler content (up to approximately 20 wt%) leads to a higher impact strength due to the interfacial reaction and provides an effective barrier for pinning and bifurcation of the advancing cracks.

Part-4: Mechanical properties of SiC filled polymer composites

This part of the paper presents the mechanical characteristics of bamboo-epoxy and glass-epoxy composites filled with another conventional filler silicon carbide (SiC). It is clear from Table 1 that in the unfilled composites, in case of both with the bamboo as well as glass reinforcements, the volume fractions of voids are negligible and this is due to the absence of particulate fillers. With the addition of filler materials more voids are found in the composites. As the filler content increases from 10 wt% to 20 wt% the volume fraction of voids is also found to be increasing. Table 1 shows the variation of tensile strength of bamboo fiber reinforced epoxy composites filled with SiC. An increase in tensile strength is observed for the composite with 10wt% of filler content as compared to composites without filler. This may be due to good particle dispersion and strong polymer/filler interface adhesion for effective stress transfer. Therefore, the composite strength is increased. But further increase in filler content (up to 20wt%) the tensile strength is found to be decreasing. Tensile modulus of bamboo based composites shows significant improvement with filler content up to 10wt%. But further increase in filler content up to 20wt%, the tensile modulus of the composite is decreasing. A comparison with respect to flexural strength shows that glass fiber reinforced composites are far superior to the bamboo fiber reinforced composites irrespective of filler content (Table 1). However, impact strength may largely influenced by the type and content of filler. Table 1 shows the variation of impact energy of bamboo fiber reinforced epoxy composites with the SiC content. It can be seen from the Table that the impact strength of the composites is increasing with the addition of filler content up to 10 wt%. However further increase in filler content up to 20wt% the impact strength is decreasing. As far as comparison between glass fiber and bamboo fiber reinforced epoxy composites with respect to impact strength is concerned glass fiber based composites are far superior as compared to bamboo fiber based composites irrespective of filler content.

Conclusions

Industrial wastes like copper slag and red mud can also be gainfully utilized for the composite making purpose. Incorporation of these fillers modifies the tensile, flexural, impact and inter-laminar shear strengths of the glass epoxy composites and density of the composites are also greatly influenced by the type and content of fillers.

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