Effect of short fibre orientation on the mechanical characterization of a composite material-hybrid fibre reinforced polymer matrix

D BINO PRINCE RAJA^{1,*} and B STANLY JONES RETNAM²

¹Department of Aeronautical Engineering, Noorul Islam Centre for Higher Education, Kanyakumari 629180, India

²Department of Automobile Engineering, Noorul Islam Centre for Higher Education, Kanyakumari 629180, India

*Author for correspondence (binoaero87@gmail.com)

MS received 17 February 2018; accepted 21 November 2018; published online 11 April 2019

Abstract. Polymer matrix composites (PMCs) are widely used materials in aerospace structures, boat hulls, automotive parts, etc. Since the progression of PMCs, a single fibre composite lags the addition of one or more fibres prepared as a hybrid composite which can be used to enhance their mechanical properties. Hybrid bamboo/glass fibres as the alternative replacement for polyester composites have been fabricated with $\pm 60^\circ$ orientation, and coconut shell powder in micro and nanosized particles was added as the filler materials. Mechanical properties such as tensile, flexural, and impact strength, hardness number, and fatigue behaviour were investigated. The fractured surfaces of the composites were observed by scanning electron microscopy analysis. The test results reveal that the bamboo fibres in combination with glass fibres show an enhancement in their mechanical properties like strength and stiffness, and are suitable for aerospace applications.

Keywords. Hybrid fibre; polyester; tensile strength; flexural; fatigue; SEM.

1. Introduction

Hybrid composites have become key important materials nowadays from an economic and ecological compatibility point of view. These are materials that are made up of two or more different natural and synthetic fibres, reinforced with suitable polymer matrices to form a composite material with properties comparable to those of manmade materials. Also, in order to keep up with modern technological trends, it has become mandatory to develop materials which are less hazardous to nature in order to preserve our environment for many more years. This concept has encouraged humans to use hybrid composite materials in applications for daily life [1]. Natural polymers are abundant in nature and cheap compared to synthetic fibres. Among these, bamboo fibres are one of the sustainable sources which have been recycled for millions of years by the environment and further by human smartness. These fibres are wholly recyclable, eco-friendly, has good specific strength, less abrasive, of low cost and rapidly bio-degradable [2,3]. Bamboo fibre is one of the dominant species in Orissa, Andhra Pradesh, Madhya Pradesh and Western Ghats of India. The properties of bamboo include lesser density and higher mechanical strength. The specific gravity and high tensile strength of bamboo are lower than those of the typical glass fibres. A fundamental way of improving the mechanical properties of the composite can be accomplished by reinforcing two or more types of

fibres in a single matrix, which leads to hybrid composites distinctively [2]. When compared with glass fibers, bamboo fibres are of low cost, low density, have no health risk when inhaled, show no abrasion to machining, consume low energy, neutral to CO₂ and are biodegradable [4]. The disadvantage of using natural fibres is their high level of moisture absorption and inadequate adhesion between untreated fibres [5]. Among the well-known natural fibres (banana, jute, kemp, coir, straw, etc.) bamboo has low density and high mechanical strength. The specific tensile strength and specific gravity of bamboo are considerably less than those of glass fibres. However, cost considerations make bamboo an attractive material for reinforcement [3]. Hybridization of natural fibres is stronger and their high corrosion resistance compared to synthetic fibres like glass can improve the various mechanical and chemical properties of polymer matrix composites (PMCs), and due to their improved properties, they are mostly used in different areas such as defence, aerospace, engineering applications, marine, automotive sectors, etc. [5]. The advantages of bamboo materials compared to conventional materials are largely from higher strength to weight ratio, high stiffness and fatigue characteristics. In recent years, due to the demand of overhauling and retrofitting swiftly impairing the infrastructure, nowadays, there are greater possibilities of utilizing the fibre matrix composites for various purposes [6,7]. These composites propose superior detention to circumstantial matters and debility

in addition to the dominance of high strength-to-weight and stiffness-to-weight ratios among all other conventional construction materials. Even though there are various research studies on fatigue and environmental fatigue of the composite materials for over thousands of years [8], much of them are restricted to the application of structural composites in the aerospace industry [9,10]. Based on the fibre orientation, specific strength, stress-strain behaviour, failure mode and ductility, the FRP composites change with their corresponding properties. Woven composites possess high flexural strength due to their dissimilarity of the cross-section. Composites with woven fabric reinforcement possess better stiffness, strength and toughness and easier handling in production compared to unidirectional composites [11,12].

In the present investigation, an attempt has been made to develop hybrid composites in which the percentage of glass and bamboo fibres in the composites has been varied to evaluate the effect of hybridization on the properties of the composites. The enhancement in the mechanical properties of PP reinforced with glass and lignocellulose bamboo fibre has been investigated. The damping characteristics in the bamboo/glass fibre PP hybrid composites have been studied using dynamic mechanical analysis. The fibre matrix morphology of the interface region has been investigated by employing scanning electron microscopy (SEM) analysis [13,14]. The use of inorganic fillers has been a common practice in the plastic industry to improve the mechanical properties of thermoplastics and thermosets, such as heat distortion temperature, hardness, toughness, stiffness and mold shrinkage. The effects of fillers on the mechanical and other properties of the composites depend strongly on the filler shape, size, aggregate size, surface characteristics and degree of dispersion [8]. The main objective of this research was to investigate the mechanical properties of hybrid FRP composites added with filler materials, with respect to the fibre orientation [15,16]. The results were compared with each other to find the best among them.

2. Experimental

2.1 Preparation of materials

Material processing is carried out by using bamboo with a diameter of 10 μm and glass fibre with a diameter of 5 μm . To enhance the properties of bamboo fibre, it was chemically treated with silane. According to the size of the moulding box 200 $\times$ 150 mm, the bamboo fibres were woven by using a weaving machine after they are dried off. The woven glass fibres were used for composite fabrication. Polyester resin is treated as the matrix source; methyl ethyl ketone peroxide and cobalt naphthenate were employed as the catalyst and oxidizer, respectively.

2.2 Manufacturing and testing

2.2a Composite preparation. The moulding box of the recommended size 200 $\times$ 150 $\times$ 10 mm was prepared in wood and wax polish was used to avoid the stickiness between the mould and composites. Seven distinctive kinds of plates were constructed with a pure bamboo reinforced polyester matrix and the other with bamboo/E-glass hybrid fibre with micro- and nano-coconut shell powder reinforced polyester combinations. The method implemented for developing composite samples was the compression moulding process. Polyester resin was expanded with necessary quantities of cobalt naphthenate as the oxidizer and the latter with the catalyst, methyl ethyl ketone peroxide. The bamboo fibre woven was positioned and then the essential quantity of polyester resin was drizzled over it.

The process continued until the prerequisite thickness and volume percentage of fibre were attained. Fibre was compressed so as to remove the air bubbles from it initially. Hybrid PMC plates' preparation was carried out by means of a hydraulic hot press machine. The polymer was made to preheat at a certain temperature for a specified time period in order to soften them. Then to acquire the desired mould shape, they were compressed at the same temperature. After the requisite thickness and volume fraction were obtained, the composite plates were allowed to cool under pressure for particular intervals. Finally, after fabricating all the PMCs, the plates were removed from the mould.

2.2b Mechanical testing. According to ASTM standards, the specimens were cut into PMC plates made of bamboo and hybrid PMC composites and various experiments were conducted. For attaining the prerequisite orientation, in an appropriate angle, the specimens were prepared as templates from the GI sheets and are extracted as plates. Subsequently, by employing a milling cutter, preceding the 60° fibre orientation, the plates made were cut into a definite angle.

The specimens were cut as per the ASTM D 638 standard, whereas a computerized servo-controlled UTM machine was used to test the tensile strength of the hybrid FRP composites and bamboo. Samples which were secured in the UTM with the specifications of 5 mm gauge length and 2 mm min^{-1} cross head speeds were tested and the tested specimens are shown in figure 1.

With the specimen standardized as ASTM D 790, flexural examination was conducted on a computerized UTM machine with distinctive accessories. Specimens which bent after the analysis are shown in figure 2. The speed of the test was regulated as 2 mm min^{-1} and the span-to-depth ratio was aligned as 16:1.

A Charpy impact testing machine was utilized to do the impact test accompanying the specimen standards ASTM D 6110. The energy obtained from the results is divided by the area of cross-section of the specimen in order to estimate the values of the fracture occurred. The cracked samples are shown in figure 3.

Figure 1. Tensile specimens.

Figure 4. Hardness specimens.

Figure 2. Flexural specimens.

Figure 5. Fatigue specimens.

Figure 3. Impact specimens.

As per the required specimen standard ASTM D 785 shown in figure 4, the hardness test was performed on them by means of a Rockwell hardness tester. Regardless of the laminate dimensions, a standard sample of thickness 6.4 mm was carved. The hardness value was evaluated by imparting the load for a period of 15 s. The average of 3 samples of each type is taken into account for obtaining all the numbers.

Fatigue samples were prepared as per ASTM E 399 as shown in figure 5. In the fatigue test, the specimens were cycled to tension–tension fatigue loading at a stress ratio of 10 Hz in order to determine the fatigue life and its life characteristics at given 6 stress levels. Fibre content ratios were found to affect the fatigue life strongly in the low cycle fatigue regime.

SEM analysis is usually carried out to detect the fibre matrix morphology. Determining the implication of the bonding between the matrix and reinforcement is one of the main purposes of this test. Figure 6 shows the test specimen that has been used for this test.

Figure 6. SEM specimens.

3. Results

3.1 Effects of fibre orientation on hybrid PMCs

3.1a Tensile strength. Figure 7a shows the tensile stress–strain curve of the above-mentioned combinations of polyester resin, bamboo fibre and glass fibre/coconut shell powder micro/nano with respect to fibre orientation $\pm 60^\circ$. On comparing all other combinations in the stress–strain curve, the hybrid FRP composite named C (hybrid bamboo/glass fibre) demonstrated a high breakage point in the curve among all. The above-mentioned graph was drawn using MATLAB. Also, figure 8 shows that the combinations F and G exhibited a prominent significant increase in tensile strength, in comparison with the non-woven bamboo strip mat and glass hybrid fibre [7].

The surface morphology of the fibres with respect to bonding on the tensile specimens after breakage was scrutinized by the execution of SEM analysis. The cross-section of the composites of specified combination with respect to orientation is shown in figures 9(A–G) of 200 μm magnification and 9(A–G) of 200 μm magnification. It was perceived that hybrid fibre exposed high degree of intensity and compactness than the single fibre arrangement. Hence, it is proved that the tensile, flexural, impact and hardness properties of hybrid composites are higher, when compared with those of pure bamboo fibre composites. The manufacturing of polymer composites with rough surface fibre would exhibit good bonding properties.

3.1b Flexural strength. The stress–strain curve shown in figure 7b is the combination of polyester resin, bamboo fibre and glass fibre/coconut shell with respect to fibre orientation $\pm 60^\circ$ and figure 10 shows the flexural strength of pure bamboo and hybrid FRP composites with respect to the specimen of $\pm 60^\circ$ orientation. The flexural strength of the intertwined hybrid FRP composites with the micro coconut shell powder (specimen F) is higher when compared with others.

Figure 7. (a) Tensile stress–strain curve and (b) flexural stress–strain curve.

Figure 8. Samples of different combinations vs. tensile strength.

Figure 9. SEM image of all seven combinations (A–G) with $\pm 60^\circ$ orientation.

3.1c Impact strength. Figure 11 shows the Charpy impact strength of bamboo and hybrid FRP composites with respect to the orientations defined. Despite the fact that the stuffing between the fibres is adjacent, all of the combinations displayed a better impact strength. Yet, while associating the specimen B, the hybrid composites expressed a certain low impact strength. It is agreed that the impact feedback of fibre composites is mostly dominated by the collaborated bond strength, fibre and the matrix resources. Impact energy is consumed by debonding, fibre and/or matrix rupture and fibre evacuation. The fibre dissipates low energy when compared with fibre pull out [2]. Hence, it is again confirmed that the hybrid with a strong binding force will withstand the excessive impact.

Figure 10. Samples of different combinations vs. flexural strength.

Figure 11. Samples of different combinations vs. impact strength.

Frictional loss: an instrument error caused by friction in the instrument mechanism is said to be 'Frictional loss'. The error is observed by reading the instrument and measuring the vibration in it; the difference between the two is the instrument friction.

For example, for reading 12,
 $(12/11) \times (100/300) = 0.36\%$
 Frictional loss = 0.36%

3.1d Hardness number. Figure 12 shows the Rockwell hardness number for pure bamboo and hybrid FRP composites with respect to fibre orientation of different combinations. The hybrid fibres of combination E stated a good hardness value when compared to other specimens. It was the glass

Figure 12. Samples of different combinations vs. hardness number.

Table 1. Combination of polyester resin, bamboo fibre and E-glass fibre.

Specimens	Combinations	Volume (%)	Weight (g)
A	Polyester resin	70	1080
	Bamboo fibre	30	450
B	Polyester resin	75	1150
	E-glass fibre	25	425
C	Polyester resin	70	1100
	Bamboo fibre	15	200
	E-glass fibre	15	200
D	Polyester resin	70	1125
	Bamboo fibre	10	150
	E-glass fibre	20	300
E	Polyester resin	70	1125
	Bamboo fibre	20	300
	E-glass fibre	10	150
F	Polyester resin	70	1125
	Bamboo fibre	15	225
	E-glass fibre	12	180
	Coconut shell powder in micro size	3	12
G	Polyester resin	70	1125
	Bamboo fibre	15	225
	E-glass fibre	12	180
	Coconut shell powder in nano size	3	10

fibre which was slightly merged that caused the non-uniform values which were considered by averaging them to have the required hardness value. In this, the orientation played a non-critical role while taking other analysis into account (table 1).

Figure 13. Samples of different combinations vs. number of cycles (in lakhs).

3.1e Fatigue behaviour. Figure 12 shows that there is a significant dispersion in the fatigue lifetime results of hybrid bamboo/glass added coconut shell powder in micro and nano-sized composites i.e. specimen G exhibits a higher fatigue lifetime than other combinations for a given stress level as shown in figure 13.

4. Conclusions

The mechanical characteristics of the bamboo reinforced polyester matrix and bamboo/E-glass hybrid fibre with micro and nanococonut shell powder reinforced polyester composites, which were prepared using compression moulding technique and tested using ASTM standards, were determined. The following conclusions are drawn:

- The tensile stress–strain curve of polyester resin, bamboo fibre and glass fibre/coconut shell powder micro/nano with respect to fibre orientation $\pm 60^\circ$, and the hybrid FRP composite (hybrid bamboo/glass fibre) showed a high breaking point.
- Hybrid specimens with $\pm 60^\circ$ orientation exhibit an 18% improvement in the tensile strength at 3 wt% addition of nanopowder which is higher than several other orientations of $\pm 30^\circ$ and $\pm 45^\circ$.
- The fatigue test reveals that 3 wt% of nanopowder and 27 wt% of hybrid fibre will greatly increase the fatigue life. This is mainly due to the addition of the filler material.
- The SEM test reveals that the hybrid specimens with filler materials possess densified bonding because of the low porosity when compared to pure fibre materials.

References

- [1] Madhu P, Sanjay M R, Mohammad J, Pradeep S, Yogesha B and Naheed S 2018 *Sustain. Compos. Aerosp. Appl.* **315**
- [2] Stanly Jones Retnam B, Sivapragash M and Pradeep P 2014 *Bull. Mater. Sci.* **37** 1059
- [3] Ashik K and Sharma R 2015 *JMMCE* **3** 420
- [4] Paul W, Jan I and Ignaas V 2003 *Compos. Sci. Technol.* **63** 1259
- [5] Gassan J 2002 *Compos. Part—A Appl. Sci. Manuf.* **33** 369
- [6] Rajendran B, Muthusamy S and Chinnaswamy T V 2011 *J. Reinf. Plast. Compos.* **30** 1
- [7] Sanjay M R, Arpitha G R and Yogesha B 2014 *IOSR-JMCE* **11** V
- [8] Nagalingam R, Sundaram S and Stanly Jones Retnam B 2010 *Bull. Mater. Sci.* **33** 525
- [9] Mariatti M, Jannah M, Abu Bakar A and Abdul Khalil H P S 2008 *J. Compos. Mater.* **42** 931
- [10] Barbero E and Ganga Rao H V S 1991 *SAMPE* **27** 9
- [11] Konur O and Matthews F L 1989 *Composites* **20** 317
- [12] Pradeep K, Kushwaha P K and Rakesh K 2010 *J. Reinf. Plast. Compos.* **29** 1952
- [13] Sushanta K S, Smita M and Sanjay K N 2008 *J. Reinf. Plast. Compos.* **10** 2729
- [14] Edwards K L 1998 *Mater. Des.* **19** 1
- [15] Wonga K J, Zahi S, Low K O and Lim C C 2010 *Malays. Mater. Des.* **31** 4147
- [16] Zhu Y T, Valdez J A, Beyerlein I J, Zhou S J, Liu C, Stout M G *et al* 1999 *Acta Materialia* **47** 1767