Indian Journal of Fibre & Textile Research
Vol. 42, June 2017, pp. 230-234

Short Communications

Effect of stacking sequence on mechanical strength of bamboo/Kevlar K29 inter-ply laminated hybrid composite

Thingujam Jackson Singh & Sutanu Samanta[a]

Department of Mechanical Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli 791 109, India

Received 31 August 2015; revised received and accepted 5 November 2015

In this study, a hybrid composite of bamboo/Kevlar K29 with epoxy matrix has been developed with different staking sequences. The variation in mechanical properties, such as tensile, compressive and flexural of composite due to variation in staking sequence is analysed and presented. From the analysis, it is observed that the sandwich composite with Kevlar laminates at both the ends exhibits better tensile and compressive properties and on the other hand, the composite with both the bamboo layers on the upper side displays better flexural properties.

Keywords: Bamboo fibre, Hybrid laminate, Kevlar K29 fibre, Staking sequence

Owing to the high price, depletion of natural reservoir and threat to the environment, the researchers, in the past few years, are forced to develop environment friendly, bio-degradable and recyclable material for using as reinforcement in polymer composite materials[1-5]. Natural fibres like bamboo, jute, sisal, coir, etc. possess unique properties, which make them feasible for application in polymer composites. Nowadays these are considered as one of the new classes of engineering materials due to its wide range of application domains. The interest in this type of composite materials is rapidly growing both in terms of their industrial applications and fundamental research[6]. Among natural fibres, bamboo fibre, which is extracted from bamboo plant, is one of the most favourite constituents for using as reinforcement in FRP composites. In Asia and South America, it is found in large quantities. Chemically, it consists of cellulose (73.83%), hemi-cellulose (12.49%), lignin (10.15%), aqueous extract (3.16%) and pectin (0.37%)[7,8]. Due to its high cellulose content and lower micro-fibrillar angle, it possesses very good mechanical properties[9]. It is quite flexible in its applications in composite industries due to its structural variation, better mechanical and thermal properties, and highly versatile nature of its extraction processes[10-12]. Compared to other synthetic fibre composites, the natural composites acquire lower modulus, lower strength and relatively poor moisture resistance properties. Therefore, in a view to improve its properties and develop superior but economical composites, these are hybridized with synthetic fibres to achieve the best properties of both [13-15]. The additions of glass fibre to pineapple leaf fibre and sisal fibre reinforced polyester have improved the mechanical properties of the composite[16]. The hybridization of bamboo fibre reinforced composites with glass fibre brought changes to their thermal as well as mechanical properties and also improves its resistance to the chemicals[17-20].

Further, the interplay hybridization of two different fibre laminates helps in preventing the catastrophic failure of composite material due to failure of fibre with lower elongation properties. Mismatch of Poisson’s ratio and coefficient of mutual influence between adjacent layers, cause high inter-laminar normal and shear stresses at the free edges of the laminates. This inter-laminar normal stress can be changed from tensile to compressive by changing the ply staking sequence, so that opening mode delamination can be suppressed [21], thereby improving its mechanical properties. In a study, the effect of stacking sequence on tensile, flexural and interlaminar shear properties of untreated woven jute and glass fabric reinforced polyester hybrid composites has been presented[22]. It was found that the composite with glass plies at extreme ends exhibited superior properties. In another work, the effect of staking sequence on woven coir/glass hybrid laminated composite was investigated experimentally[23].

Of all the synthetic fibres, the aramid fibre known as Kevlar fibre acquire very unique properties. It exhibits higher stiffness, lower fibre elongation, superior tensile strength and modulus in comparison to other synthetic fibres[24-31]. Different varieties of Kevlar with different grades are available. Of these, K29 and K49 are most commonly used. For this work, K29 is selected because of its cost effectiveness, enhanced properties [32] and wide range of industrial

[a]Corresponding author.
E-mail: jackson_thingujam@yahoo.com

and ballistic applications[33-35]. It also exhibits very good high temperature properties for a polymeric material. There has been very little work reported in the characterization of bamboo and Kevlar hybrid polymer composite material. Among the polymeric material, epoxy (thermoset) possesses very good mechanical properties with low cure shrinkage. It consists of an epoxide group (one oxygen and two carbon atoms). It is cured by introducing cross linkage between the epoxide and hydroxyl groups of adjacent chains. This crosslink is achieved by reacting with an organic amino or acid compound [36]. Since, triethylenetetramine (TETA) consists of considerably high amount of amine groups, it is selected as a curing agent for epoxy in this work. About 10-15% by weight of amines or acid anhydrides is mainly used for proper curing of epoxy resin[36]. In this work, an attempt has been made to hybridize bamboo fibre with Kevlar K29 woven fibre in epoxy matrix composite and the effect of stacking sequence of composite laminates on mechanical properties like tensile, compressive and flexural strength of the composite is analyzed and presented.

Experimental

Fabrication of Composite Specimen

Plain woven bamboo fibre mat and Kevlar K29 fabric of GSM 280±20 with bi-directional fibre orientation $0^o/90^o$, were used as fibre reinforcement for fabricating the composite. Epoxy resin (LAPOX B-11) and triethylenetetramine (TETA) were used as matrix and hardener respectively. Prior to fabrication, bamboo fibre mat was dried in vacuum oven to remove the absorbed moisture from it, so that proper wetting of the fibre with resin can be achieved. Hand layup method[37] was employed for composite fabrication. The composite laminates of the size 400 mm × 400 mm were prepared. The epoxy resin and hardener, at a proportion of 10:1 by weight respectively, was mixed thoroughly till it gets suitably warm. Before moulding, the mould release sheet was thoroughly polished to obtain a smooth glossy finish and ensure the absence of moisture or any other foreign particles. Thereafter, waxpol was used as mould release agent for easy removal of composite from the mould after curing. When the release agent got completely dried, epoxy resin in the form of paste was spread on the mould sheet with a brush. Bamboo and Kevlar fibres were then laid on the resin. Subsequently, the entrapped air was forced out by rolling with a roller over the layer of fibre in order to prevent the formation of voids inside the composite. In the same manner, layers of fibre reinforcement and resin were added until the desired number of layers was obtained. Fabrication and curing of composite sample were done at room temperature for 24 h curing time. The composite consists of 4 layers, 2 each of bamboo and Kevlar layers. The concept behind this design is to determine the variation in the mechanical properties of the fabricated composite samples with the variation in staking sequences of the different laminas. The composite samples, fabricated with different staking sequences, are listed in Table 1. In all the cases, the fibre volume fraction was maintained as 0.4, i.e. V_f= 40%.

Testing

ASTM D3039/D3039M–00$^{\epsilon 1}$, D3410/D3410M–03 and D 790–03 were used for testing the tensile, compressive and flexural properties of the fabricated composite samples respectively. The tests were performed on Instron 8801 machine, at a strain rate of 1.5mm/min for tensile and compressive test and 2.5mm/min for flexural test. Three point bending method was used for the flexural test.

Results and Discussion

Tensile Properties

The tensile properties of composite samples, with different staking sequence, are listed in Table 1. The sandwich composite, with Kevlar layer at the ends,

Table 1 — List of different types of composite samples and their properties

Matrix	Staking sequence (composite code name)	Composite thickness mm	Tensile strength, MPa	Compressive strength, MPa	Flexural strength, MPa	Loading face (flexural test)	
						Top	Bottom
Epoxy	BBKK	4	105.16	46.09	150.15	B	K
Epoxy	BKBK	4	97.76	47.36	134.68	B	K
Epoxy	BKKB	4	104.98	43.52	130.48	B	B
Epoxy	KBBK	4	120.81	51.81	128.23	K	K
Epoxy	BBBB	6	78.62	64.04	87.07	B	B
Epoxy	KKKK	2	182.29	41.67	292.50	K	K

B–Bamboo, and K- Kevlar.

exhibits maximum strength. Similar trend is observed with woven jute/glass hybrid laminated composite, where the composite with glass fibre layer at the end surfaces gives superior properties[22].

Figure 1 illustrates the stress-strain curves of composites with different staking sequences. The curve shows similar pattern, i.e. it is linear up to some load and after that, with further increase in load the non-linearity of the curve begins. The initial deviation from linearity may be due to the beginning of matrix cracking and the major change in the nature of curve signifies the major cracking of matrix and initiation of fibre failure with the increase in applied load. At this point, the load carrying capacity of the composite decreases and exhibits brittle failure. The tensile strength of composite generally depends on the strength of fibre, chemical stability of matrix and effective matrix-fibre interfacial load transfer[38]. The higher tensile strength of composite with stacking sequence KBBK is attributed to better load transferring capacity of bamboo fibres with the epoxy resin in comparison to that of Kevlar.

Compressive Properties

Compressive test results for composite samples are listed in Table 1. It shows that the composite with Kevlar layer at both the ends possesses highest compressive strength. This is credited to higher inter laminar strength of bamboo fibres. Moreover, due to smooth surface debonding of Kevlar fibre[39], the compressive load transfer capacity decreases when both Kevlar laminates are stacked together.

The compressive stress-strain curve of different composite sample is presented in Fig. 2. The curves are almost linear upto some point. With the further increase in load, the curve starts exhibiting non-linear nature. The failure of matrix or fibre may occur after this point and the non-linear portion of the curve indicates the progressive failure of fibres. Since the failure mechanism of all the composite samples are same, the curves display almost similar trend. Under compressive load, the composite material is generally failed with shear crippling and kinking failure modes[40]. In the present experiment, composite is failed mainly due to a combination of shear crippling, kinking and compressive mode.

Flexural Properties

The flexural strength of the composite laminate measure its resistance to the bending force before reaching the breaking point. Table 1 listed the flexural test results of composite samples and its change owing to variation in staking sequence.

The composite with stacking sequences BKBK, BKKB and KBBK shows almost similar strength. But, the composite with BBKK and KKKK sequence gives higher strength. The flexural strength of the composite laminates under bending load is controlled by the strength of the fibre at extreme layers [40]. For the BBKK composite, under flexural load, the bamboo laminate is exposed to compression load and Kevlar to tension. Also, from the experimental results, it is observed that bamboo possesses higher compressive strength and Kevlar gives higher tansile strength. As a result, BBKK exhibits higher flexural strength in comparison to BKBK, BKKB and KBBK composites. On the other hand, in the case of KKKK composite, the flexural strength is large due to its lower thickness, which is shown in Table 1. The

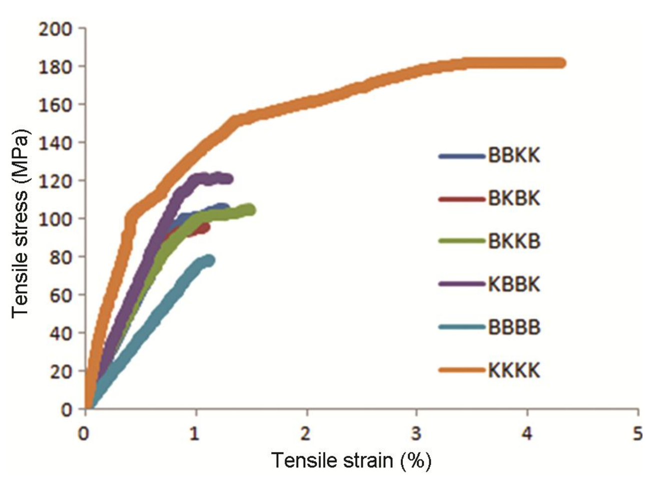

Fig. 1 — Tensile stress-strain curves of different composite samples

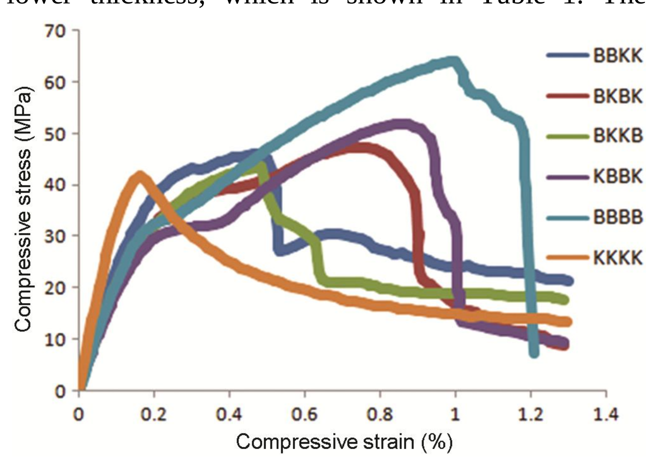

Fig. 2 — Compressive stress-strain curves of different composite samples

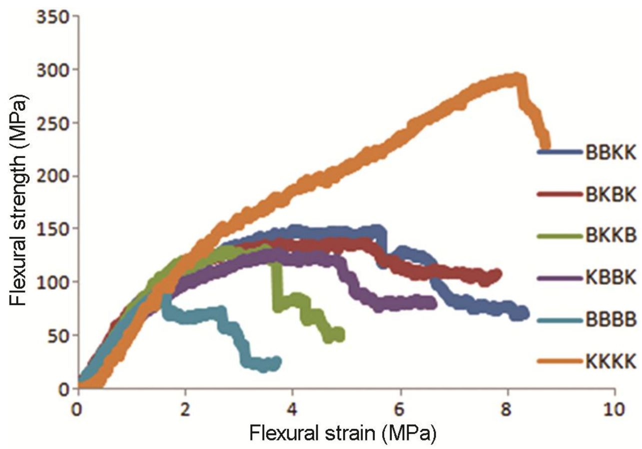

Fig. 3 — Flexural stress-strain curves of different composite samples

flexural strength of the composite is inversely proportional to the square of its thickness, as shown in the following equation:

$$\sigma_f = \frac{3PL}{2wt^2} \quad ...(1)$$

where P, L, w and t are the maximum bending load, span length of the specimen, width and thickness of the specimen respectively.

The flexural stress-strain curve of composite samples, with different staking sequences, is shown in Fig. 3. All the curves show similar nature i.e. non-linear in nature. From the curve, it can be observed that initially the behaviour of all composite samples is close to linear segment, and after the ultimate load, it displays an irregular staggered decrease in stress due to development of crack on the tension side. Bending fractures are mainly found to be concentrated near the middle of the specimen, where the load is applied.

Conclusion

In this study, an attempt has been made to experimentally investigate the effect of staking sequence on tensile, compressive and flexural properties of bamboo/Kevlar K29 inter-ply hybrid laminated composite material. The following conclusions are drawn from the test results:

- Under tensile and compressive load, the sandwich composite with Kevlar layer at both the ends exhibits superior properties. This is attributed to higher inter laminar strength and load transfer capacity of bamboo fibre.
- On the other hand, the composite with both the bamboo layers on the upper side displays better flexural strength.

Acknowledgement

The authors are sincerely thankful to the Department of Mechanical Engineering, Indian Institute of Technology Guwahati, for granting permission to conduct experimental work at their laboratories.

References

1 Jawaid M & Abdul K H P S, *Carbohyd Polym*, 86 (2011) 1.
2 Puglia D, Biagiotti J & Kenny J M, *J Nat Fibres*, 1 (2005) 23.
3 Khalil H P S A, Tehrani M A, Davoudpour Y, Bhat A H, Jawaid M & Hassan A, *J Reinf Plastics Compos*, 32 (2013) 330.
4 Shalwan A & Yousif B F, *Materials Design*, 48 (2013) 14.
5 Kumar K P & Sekaran A S J, *J Reinf Plastics Compos*, 33 (2014) 1879.
6 Singh T J & Samanta S, *Int J Res Eng Tech*, 3 (2014) 187.
7 Wang Y P, Wang G & Cheng H T, *Text Res J*, 84 (2010) 334.
8 Li L J, Wang Y P, Wang G, Cheng H T & Han X J, *J Fibre Bio Eng Inform*, 3 (2010) 94.
9 Khalil H P S A, Bhat I U H, Jawaid M, Zaidon A, Hermawan D & Hadi Y S, *Materials Design*, 42 (2012) 353.
10 Amar K M, Manjusri M & Lawrence T D, *Natural Fibres, Biopolymers, and Biocomposites* (CRC Press, Taylor & Francis Group), 2005, Chap 11.
11 Amada S, Ichikawa Y, Munekata T, Nagase Y & Shimuzu H, *Composit Part B – Eng*, 28 (1997)13.
12 Idowu D I, Tamba J, Rotimi E S, Williams K K, Stephen C A & Gbenga E, *J Reinf Plastics Compos*, 34 (2015) 1347.
13 Mehmet K & Nevin K, *J Reinf Plastics Compos*, 34 (2015) 795.
14 Venkateswaran N, Elayaperumal A & Sathiya G K, *Compos* B, 43 (2012) 793.
15 Samanta S, Muralidhar M, Singh T J & Sarkar S, *Proceedings Materials Today*, 2 (2015) 1398.
16 Mishra S, Mohanty A K, Drzal L T, Misra M, Parija S, Nayak S K & Tripathy S S, *Compos Sci Technol*, 63 (2003)1377.
17 Thwe M M & Liao K, *Composit Part A*, 33 (2002) 43.
18 Nayak S K, Mohanty S & Samal S K, *Mater Sci Eng A*, 523 (2009) 32.
19 Rao H R, Rajulu A V, Reddy G R & Reddy K H, *J Reinf Plastics Compos*, 29 (2010) 1446.
20 Reddy E V S, Rajulu A V, Reddy K H & Reddy G R, *J Reinf Plastics Compos*, 29 (2010) 2119.
21 Mallick P K, *Fibres Reinforced Composites–Materials, Manufacturing and Design*, 3rd edn (Marcel Dekker, Inc; New York) 2003.
22 Ahmed K S & Vijayarangan S, *J Materials Processing Technol*, 207 (2008) 330.
23 Jayabal S, Natarajan U & Sathiyamurthy S, *Bull Mater Sci*, 34 (2011) 293.
24 Agarwal B D, Broutman L J & Chandrashekhara K, *Analysis and Performance of Fiber Composites*, 3rd edn (Wiley Publication), 2006.
25 Mathews F L & Rawlings R D, *Composite Materials: Engineering and Science* (Woodhead Publication, Cambridge), 1994.

26 Yang H H & Bunsell A R, *Fiber Reinforcement of Composite Materials* (Elsevier, Amsterdam), 1988, 246.

27 Young R J, Lu D, Day R J, Knoff W F & Davis H A, *J Materials Sci*, 27 (1992) 5431.

28 Singh T J & Samanta S, *Proceedings Materials Today*, 2 (2015) 1381.

29 Abu Talib A R, Abbud L H, Ali A & Mustapha F, *Material Design*, 35 (2012) 12.

30 Ferreira J A M, Reis P N B, Costa J D M & Richardson M O W, *J Compos Materials*, 47 (2012) 1885.

31 Reis P N B, Ferreira J A M, Santos P, Richardson M O W & Santos J B, *Compos Str*, 94 (2012) 3520.

32 Kadir B, *J Industrial Text*, 41(2011) 201.

33 Kulkarni S G, Gao X L, Horner S E, Zheng J Q & David N V, *STR Composite*, 101 (2013) 313.

34 Wong W C, Ruan D & Sesso M L, *Materials Design*, 64 (2014) 360.

35 Albert M, Jason G, Gregory F, Jihua G & Seetha R, *Compos Sci Technol*, 116 (2015) 41.

36 Krishnan K C, *Composite Materials Science and Engineering*, *2nd* edn (Springer Publication), 1998.

37 Agarwal B D & Broutman L J, *Analysis of Fiber Composites* (John Wiley and Sons Publication USA) 1990.

38 Gao Z & Reinfshinder K L, *J Compos Technol Res*, 14 (1992) 201.

39 Kulkarni S V, Rice J S & Rosen B W, *Composite*, 6 (1975) 217.

40 Gowda T M, Naidu A C B & Rajput C, *Composites: Part A*, 30 (1999) 27.