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EVALUATION OF FRACTURE TOUGHNESS BEHAVIOUR OF GLASS-BANANA FIBER REINFORCED EPOXY HYBRID COMPOSITES

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ABSTRACT

The present work deal with fabrication and investigation of fracture toughness of banana reinforced with glass fiber as natural hybrid composite. Composites of different combinations with varied fiber content were prepared using hand lay-up technique using L-12 epoxyresin and K-6 hardener as reinforcing materials. Banana fiber with 15, 20, 25 and 30% were hybridized with 20, 15, 10 and 5% of glass fiber to form composites and compared with non-hybrid 35% glass and banana fiber composites. The fracture toughness (K_{IC}) was investigated according to ASTM D5045 by single edge notch bending (SENB) technique, with SEM image confirmation. The non-hybridized 35% banana fiber showed highest K_{IC} value and 35% glass fiber showed the least. Whereas, the hybrid composite with fiber volume of 20% banana and 15% glass showed higher K_{IC} value when compared with other hybrid fractions. The results thus obtained signified the fracture toughness got improved in banana-glass hybrid composite with increased glass fiber content from 5%-15%, thus acting as a positive reinforcement in providing extra strength and smooth surface finish to the composite and at the same time the banana fiber imparted elasticity to the composite.

KEYWORDS: Glass fiber, Banana fiber, Epoxy resin, Reinforcement, Hybrid composites

INTRODUCTION

Composites are materials made up of two or more component parts differing in physical and chemical properties, bonded together to form an amalgamated material. Composites are made of matrix and fiber, where, matrix surrounds fibers to form a compact material. Since last thirty years composite materials has established numerous applications by dominating new markets persistently [1].
The current challenge in composites is to make them cost effective by adopting several innovative manufacturing techniques. The best choice is by selecting suitable combination of matrix and reinforcement material, forming a new material which exactly meets the necessities of a particular application. Currently, many composites are available with broad applications. The modern composites made up of glass, carbon, kevlar, boron, metal, silicon carbide, aramide, quartz and silica fibers are most widely used in industries for making boat hulls, aerospace materials, sports equipment, building panels and many car bodies. There are many other fibers available with varied applications but all of them are synthetic and are non bio-degradable. Natural fibers are bio-sustainable, environmentally friendly, fully biodegradable and renewable fibers, contributing to a healthy ecosystem with fundamental research and

industrial applications. Fibers obtained from the various parts of the plants are known as vegetable fibers, such as flax, hemp, jute straw, rice husk, wheat, barley, jowar, oats, rye, bamboo, sisal, banana, etc. are utilized to obtain new high performance composite materials [1].

The use of banana (Manila Hemp), a natural fiber as reinforcement for composite formation is a sustainable option which is used in the present study. These fibers get easily decomposed and releases less amount of CO_2 during putrefaction [2]. They are abundantly available (India occupy first position under banana cultivation) [3-4] and cheaper, fulfilling the economic interest of the material industry [5-6]. They are less dense and are lighter having high mechanical strength [7-8] when compared to glass, carbon and aramid fibers [9]. The lingo-cellulosic nature gives high mechanical strength and low microfibril angle imparts dynamic mechanical properties of high tensile and flexural strength [10]. The geometric alignment of fibers induces maximum stress value and young's modulus with maximum deflection under the maximum load conditions [7], a much needed factor for composite formation. They show visco-elastic behavior with relevant stiffness and damping characteristics making them most suitable reinforcement material [11]. They are less abrasive, hence in regard to technical and recycling process they are easy go composite materials. But at the same time, these fibers also have some disadvantages like, low modulus elasticity, high moisture absorption, decomposition in alkaline environments or on biological attack, prone to infections and variability in mechanical and physical properties.

The mechanical properties of a natural-reinforced composite depend on many parameters, such as fiber strength, modulus, fiber length and orientation, in addition to the fiber-matrix interfacial bond strength. A strong fiber-matrix interface bond is critical for high mechanical properties of composites [12]. Mechanical properties of banana-fiber-cement composites were investigated physically and mechanically by Corbiere-Nicollier et al., [13]. Several papers have already been published on the study of banana fiber reinforced composites using thermosetting plastics with epoxy and polyester resins [14-16]. Rao and Mohana [17] and Zhu et al., [1] studied the use of banana fibers with thermosetting polymers as a reinforcement material with cement. Joseph et al., [18] established the mechanical properties of banana/phenol formaldehyde composites and compared with glass fiber/phenol formaldehyde composites. Venkateshwaran et al., [19] studied on tensile strength, flexural strength, impact strength and water absorption rate of sisal and banana fibers reinforced epoxy composite materials. Ashwani Kumar and Deepak Choudhary [20] evaluated tensile, flexural and impact strength of banana fiber reinforced composites. They also characterized the diameter variability and mechanical properties, with stress on fracture morphology in case of both glass fibers as well as banana fiber reinforcement. Joseph et al., [18] investigated the effects of chemical modification on the physical properties of banana fibers. Mukhopadhyay et al., [21] examined the behavior of fresh and aged fibers and their reaction to different concentrations of alkali. Paul et al., [22] determined the effect of fiber loading and chemical treatments (10% NaOH, $KMnO_4$ and benzoyl) on the thermophysical properties of banana fiber/polypropylene composite materials. The hybridization of banana fiber and glass fiber not only improve the mechanical properties of composite but also reduce its cost and make it eco friendly composite [23]. Thus, banana fiber in combination with glass has proved to be excellent for making cost effective composite materials.

Similar studies were carried out by many researchers on different natural fiber composites. Finegan and Gibson [24] and Gassan and Bledzki [25] investigated different fiber matrix combinations for enhancement of damping in polymer composites and dynamic mechanical analysis on jute/epoxy composites. They observed an improvement in dynamic modulus by the incorporation of treated jute fiber in epoxy resin. Saha et al., [26] made comparative studies on the damping of unmodified and chemically modified jute-polyester composite samples. In a different study done by Parween Ali khudhur et al., [27] the fracture toughness and energy release rates of sugar palm fiber reinforced epoxy composite was determined.

Venkatasubramanian et al., [28] dealt with fabrication and investigated the mechanical properties of abaca and banana fiber reinforced with Bisphenol-A. Wong et al., [29], envisaged short bamboo fiber reinforced polyester matrix composites for their fracture behavior. Rathna Prasad and Mohana Rao [30] conducted experiments on determining the tensile and flexural strengths on reinforced composites made up of jowar with polyester resin matrix. Okubo et al., [31], presented a paper on the development of eco-composites using bamboo fibers and investigated on their basic mechanical properties. Yuanjian and Isaac [32] investigated the impact and fatigue behavior of non-woven hemp fiber composites reinforced with polyester resin. Li [33] have evaluated and correlated the compressive strength, flexural strength, toughness, specific gravity and water absorption rate of hemp fiber reinforced composites (HFRC) with different compositions.

In the present experimental study, the banana-glass fiber reinforced composite materials are fabricated by hand lay-up process. The mechanical property fracture toughness is studied and presented in detail. The results indicated that the combination with increase in banana fibers and glass fiber improve the mechanical properties of the composite.

METHODOLOGY

2.1 Materials

In this investigational study the hybrid composites are prepared by using banana and glass fiber. The raw banana fiber is supplied by Coir goods fiber Ltd., Kerala, India. The raw banana fiber is subsequently sun dried for eight hours then dried in oven for 24 hours at 105°C to remove water present in the fiber. Then the fiber is kneaded to thread of proper diameter (finely twined to thickness of 1 mm) for mat formation (compact mat of 20x20 mm^2 dimension). The readily available glass fibers with mat finish is obtained from Suntex fibers Pvt. Ltd. Bangalore and lapox (L-12), hardener (K-6) are purchased from Yuge enterprises, Bangalore., India. The L-12 resin with higher thickness and viscosity is mixed with hardener K-6 (a low viscosity curing liquid hardener) in the ratio of 10:1 to make clear slurry.

2.2 Preparation of hybrid composites (Hand lay-up technique)

2.2.1 Preparation of 35% banana fiber

The releasing film was cut into a dimension of 20x20 mm^2 and attached firmly on to a table. The epoxy resin matrix (L12 and K-6 mixed in the ratio of 10:1 and continuously stirred for 10-15 mins without air bubble to form a matrix preparation of 65%) was coated as a thin film on top of the releasing film and a layer of banana mat (20x20 mm^2, 1mm) was placed and further coated with matrix mixture to fill the gaps in the banana mat.

Fig.1 Banana fiber

Fig.2 Banana fiber in mat form

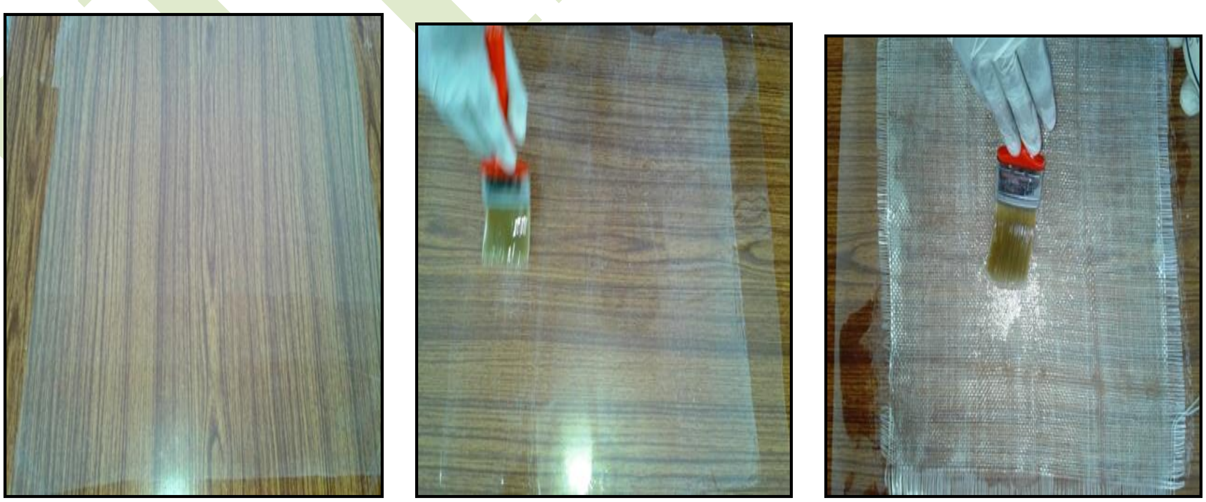
Again another layer of banana mat was placed and simultaneously coated with the matrix mixture. Finally an overlay of releasing film was added to enclose the matrix-fiber combination and was cured under the loaded condition for 24 hours with the help of the weight press. The raw banana fibers with mat formation used in for fabrication of composite laminates are presented in Fig.1 and Fig.2. The step wise fabrication procedure of composite laminates formation is given in Fig.3.

2.2.2 Preparation of 35% Glass Fiber

The same procedure as explained in section 2.2.1 was followed for preparing 35% glass fiber also. Here 10-15 times the glass fiber mat was overlaid between epoxy matrixes to get a thickness as same as that of banana fiber.

2.2.3 Preparation of Hybrid Composites

Different percentages of banana and glass fiber are prepared as given in the table below (Table.1). The coarsely and sparsely arranged banana fiber mats were prepared so as to suit the different combinations for hybrid formation. The so formed composite of different combinations was tested for their fracture toughness through SENB technique.



(a) **(b)** **(c)**

(d) (e) (f)

Fig. 3(a-f) Stepwise fabrication procedure

Table. 1 Different combination of BF and GF for formation of composites

Sl no.	**Different combination of BF and GF**	**Number of BF**	**Number of GF**
1	BF 15% + GF 20%	1 (CA)	8
2	BF 20% + GF 15%	2(SA+SA)	6
3	BF 25% + GF 10%	2(50%CA+SA)	4
4	BF 30% + GF 05%	2(CA+SA)	2

BF=Banana fiber and GF=Glass fiber; SA=Sparsely arranged banana fibers and CA= Coarsely arranged banana fibers

2.3 Mechanical Properties of Composites-SENB (single-edge-notch bending) testing

The SENB test specimens are prepared and testing of the composite laminates is carried out as per ASTM D5045 standards and procedures. The six specimens are used from each laminates for testing fracture toughness behavior of both hybrid and unhybrid laminates. The test has been carried out on the universal testing machine, by means of applying load on the specimen until it breaks. An ideal linear graph/diagram is obtained and K_Q is determined for maximum load. The methodologies are followed for the entire specimen to get the mean fracture toughness for comparison of results.

2.4 Scanning electron microscopy

The fractured surfaces of the composite specimens are inspected by using a scanning electron microscope JEOL JSM-6480LV. The fractured specimen surfaces are first cleaned carefully, air dried and then coated with 100Å thick gold film with vacuum evaporation to enhance the conductivity of specimen sample. The samples are then placed in JEOL sputtering unit and SEM is observed at 20 kV.

RESULT AND DISCUSSION

The formation of reinforced 35% banana, glass and different combinations of banana, glass hybrid composites were obtained through hand lay-up technique. The fabrication of banana-glass fiber based epoxy composites with different fiber fractions of different lengths was possible, thereby proving the easiness and superiority of the simple lay-up technique. The composites were tested for their fracture toughness by SENB testing method. The fracture toughness of the composites depend on many factors like fiber content, fiber strength, fiber length, modulus, orientation and fiber-matrix interfacial bond strength. In the present work, the length of banana fibers was determined by its weight in woven mat condition. The fibers having more weight were of thickly woven mat with minute pores between. Hence, a continuous fiber formation was observed, which proves to be the best in forming a good composite (Fig. 2) [34].

In the current study, to determine the fracture toughness, specimen composites were cut to a standard (ASTM) shape and size by using water jet machining technique, Fig.4 shows the specimen preparation for SENB testing method. By using UTM with applying different loads of mechanical stress the composites were made to undergo cracking (Fig.5 shows the UTM with crack in the sample with application of stress). The application of load with displacement of the composite (mm) is recorded graphically and is represented as a curve. The deviation in the curve determines the breakdown of composite, due to their brittleness for notwithstanding the load pressure. By using the graphical curves (Graph 1), the fracture toughness K_Q is calculated and the tabulated values are as shown in the Table 2.

Fig. 4 SENB test specimen before fracture

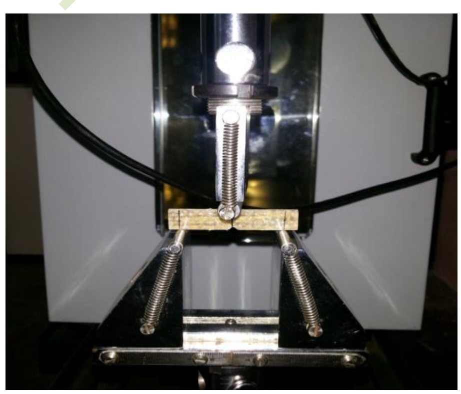
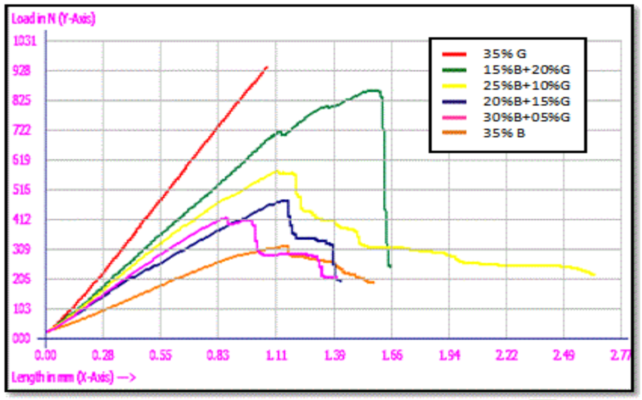


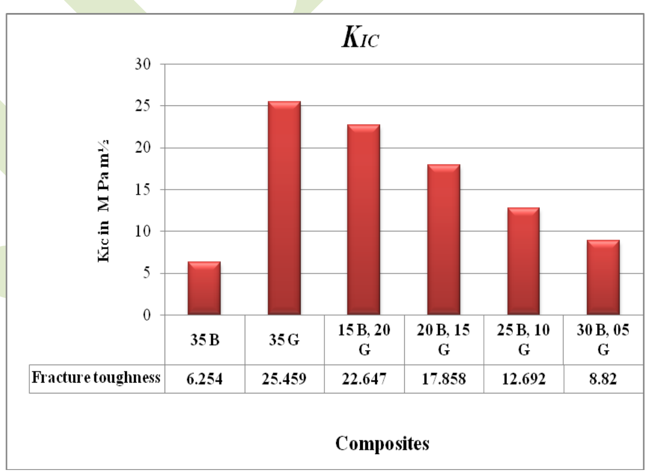
Fig. 5 SENB with three point bending for crack formation using UTM



Graph.1 Typical load vs length (mm) of displacement curve generated from SENB

Table. 2 K_Q values of SENB

Specimen Designation	**Peak Load P_Q (N)**	**Maximum Peak Load P_{MAX} (N)**	**Fracture Toughness K_Q ($MPa m^{½}$)**
35% B	291.66	317.77	6.254
35% G	933.83	936.92	25.459
15%B+20%G	762.74	856.63	22.647
20%B+15%G	476.83	475.04	17.858
25%B+10%G	468.36	578.28	12.692
30%B+05%G	417.83	416.00	8.820



Graph. 2 Fracture toughness comparisons of different hybrid composite samples

The K_Q value of non-hybridized glass fiber showed the highest value of 429.28 $MP_am^{1/2}$ and banana fiber showed the least value of 42.82 $MP_am^{1/2}$. Further the highest fracture toughness among hybrid composites was observed in the composites made up of 15% banana fiber reinforced with 20% glass fiber showing K_Q value of 226.47 $MP_am^{1/2}$. The 20% banana fiber reinforced with 15% glass fiber composites showed second highest K_Q value with 178.53 $MP_am^{1/2}$, whereas, the third highest K_Q value was shown by 25% banana fiber reinforced with 10% glass fiber having 88.94 $MP_am^{1/2}$ and next highest K_Q value was shown by 25% banana fiber reinforced with 10% glass fiber with 88.28 $MP_am^{1/2}$. The variations all the six samples are depicted in the form of bar graph with load vs displacement of samples in mm (Graph 2).

The SENB testing results in the present study indicated the significance of hybrid composite formation. With the hybridization of glass and banana fiber at varied weight percentage within 65% epoxy matrix showed superior fracture toughness than individual banana fiber reinforced epoxy composite and inferior to glass fiber reinforced epoxy composite. It has been noticed that by adding a small weight percentage of glass fiber in banana fiber reinforced epoxy composite, an enhanced surface toughness was induced that too in a very greater extent. Hitherto, agreeing to similar type of results obtained by Santhana et al., [23] and Rathna Prasad and Mohana Rao [30] in bamboo, sisal and jowar natural fibers. Although many results revealed, that the higher the fiber length, higher will be the fracture toughness [29], the present study results did not completely accept this concept. The banana fiber alone, without hybridization failed to show high fracture toughness, even though having continuous long fiber arrangement in their matrix [35].

The present study also showed another significant result, where the 35% glass fiber gave a very high K_Q value referring to high fracture toughness with higher brittleness. The glass fiber matrix showed highest resistance in with standing load pressure, but a sudden breakage was observed with a huge crack showing its brittle nature. This again is not a very good result, where the crack cuts the composite into pieces which is not suitable for its application as a good composite material. But, the same glass fiber when mixed with banana fiber at 15 to 20% showed good fracture toughness with greater K_Q value by not getting fragmented into pieces. Thus signifying the glass fiber induced toughness to the composite, although being brittle natured the glass fibers readily gets mixed with the banana fibers and adopts the flexibility of natural fibers by imparting mechanical toughness to the composite. Hence, this result of the present study totally signifies the hybrid composites can with stand the load pressure by showing good fracture toughness without much fragmentation.

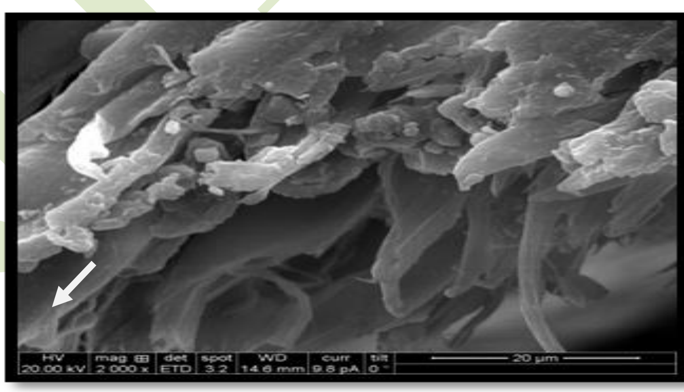


Fig. 6 SEM pictures of banana composite with broken fibre with tapered ends

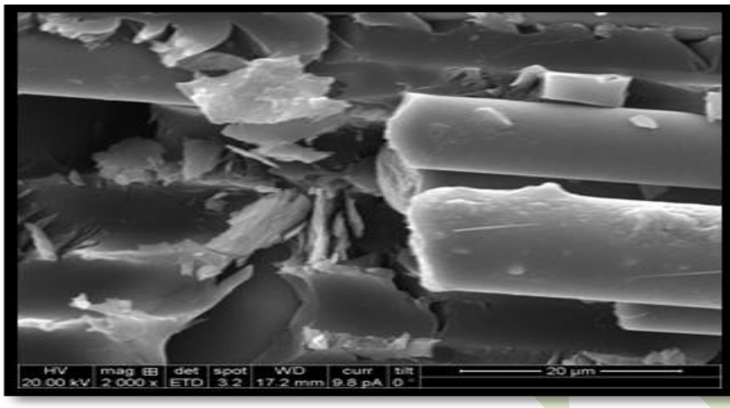


Fig. 7 SEM pictures of glass composite with broken fibre with blunt ends

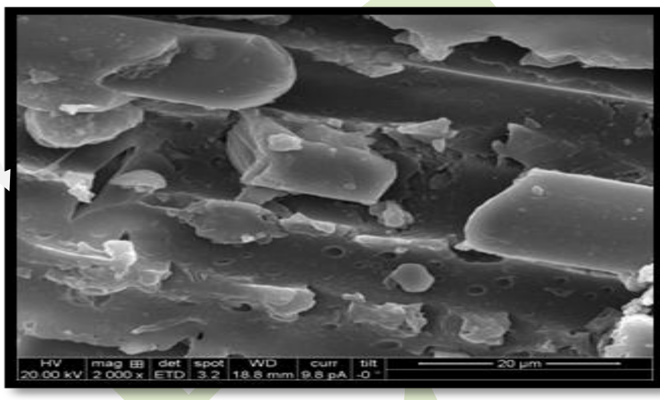


Fig. 8 SEM pictures of banana-glass hybrid composite with broken fibre with non tapered ends

The view in SEM pictures clearly shows the fiber extension and breakage of fibers with extension due to stress. In all composites, a change in the microstructure was observed with fiber shrinkage, breakage, indicating the loss in fracture toughness when stress was applied (Fig.6-8) [36]. The non hybridized glass-epoxy composite upon induction of load stress showed higher tendency fiber shrinkage, fiber breakage and spontaneous formation of micro-cracks. The fiber breakage was rapid with blunt ends (Fig.7). The delaminating with crack propagation due to the micro-crack formation and interfacial bonding failure between the adjacent fibers was also observed in banana-epoxy non-hybridized composites and the rate of crack propagation increased frequently by decreasing the integrity of the structure. But the break formation was gradual and not sudden, which can be observed in the SEM pictures, where the breakage was non rapid with tapering ends (Fig.6). In banana and glass hybrid composites, micro-cracks were formed, but the breakage was non rapid. The ends were non tapering, non pointed and non blunted (Fig.8). Formation of micro-cracks due to the interlaminar failure revealed higher misalignment of glass-epoxy composites when compared to that of glass-banana hybrid composites. This surely specifies the superiority of hybrid composites.

CONCLUSION

In the study, synthesis of banana fiber based bio-composite materials was done and correlated to fracture toughness of varying banana and glass fiber concentration with fixed epoxy resin concentration. Banana fiber has already proven to be an excellent alternative natural fiber in composite formation, as it is a resource with vast availability and fast growth with biodegradation. The hybridization of banana fiber and glass fiber not only improve the mechanical properties of composite but also reduce its cost and make it eco friendly composite. Thus, banana fiber in combination with glass has proved to be excellent for making cost effective composite materials. From the fracture toughness test carried out on composite materials by SENB testing method and by thoroughly evaluating the results obtained, it concludes that the glass fiber provides toughness and banana fiber provides elasticity by making the composite cheaper, bio-degradable composites.

REFERENCES

[1] W.H. Zhu, B.C. Tobias, R.S.P. Coutts, G. Langfors, *Air-cured banana-fiber-reinforced cement composites, Cement and Concrete Composites, Vol 16 (1), 1994, pp 3-8.*

[2] K.M.M. Rao and K.M. Rao, *Extraction and tensile properties of natural fibers: vakka, date and bamboo, Composite Structures, Vol 77, 2007, pp 288-295.*

[3] B. Kumar, Eds. N.C. Mistry, B. Singh, C.P. Gandhi, *Indian Horticulture Database-2011, National Agricultural Board, Ministry of Agriculture, Gurgoan, India, 2011.*

[4] S.M. Sapuan, A. Leenie, M. Harimi and Y.K. Beng, *Mechanical properties of woven banana fibre reinforced epoxy composites, Materials and Design, Vol 27, 2006 pp 689-693.*

[5] Mukhopadhyay S. S., Fangueiro R. R, Yusuf A, *Banana fibers – variability and fracture behaviour, Journal of Engineered Fiber and Fabrics, Vol 3, 2008, pp 1-7.*

[6] Benitez AN, Monzon MD, Angulo I, Ortega Z, Hernandez PM, Marrero MD, *Treatment of banana fiber for use in the reinforcement of polymeric matrices, Measurement, Vol 46, 2013, pp 1065-1073.*

[7] M. Ramesh, K. Palanikumar, K and Hemachandra Reddy, *Comparative evaluation on properties of hybrid glass fiber- sisal/jute reinforced epoxy composites, Procedia Engineering, Vol 51, 2013, pp 745-750.*

[8] N. Venkateshwaran, A. Elayaperumal, A. Alavudeen and M. Thiruchitrambalam, *Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites, Materials and Design, Vol 32, 2011, pp 4017-4021.*

[9] M. Boopalan, M. Niranjana and M.J. Umapathy, *Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites, Composites: Part B, Vol 54, 2013, pp 54-57.*

[10] K. Bilba, M.A. Arsene and A. Ouensanga, *Study of banana and coconut fibers: Botanical composition, thermal degradation and textural observations, Bioresource Technology, Vol 98, 2007, pp 58-68.*

[11] A. Laly, Pothana, Zachariah Oommenb, and S. Thomas*, "Dynamic mechanical analysis of banana fiber reinforced polyester composites", Composites Science* and *Technology, 63(2), 2003, pp 283-293.*

[12] R. Karnani, M. Krishnan and R. Narayan, "*Biofiber-reinforced polypropylene composites", Polymer Engineering and science, 37(2), 1997, pp 476-48.*

[13] T. Corbiere-Nicollier, B.G. Laban, L. Lundquist, Y. Leterrier, J.A.E. Manson and O. Jolliet, *"Life cycle assessment of bio-fibers replacing glass fibers as reinforcement in plastics", Resources conversion and recycling, 33(4), pp 267-287.*

[14] M. Idicula, N.R. Neelakantan, Z. Oommen, K. Joseph and S. Thomas, *A study of the mechanical properties of randomly oriented short banana and sisal hybrid fiber reinforced polyester composites, Journal of Applied Polymer Science, Vol 96(5), pp 1699-1709.*

[15] L.A. Pothan, S.T homas, and N.R. Neelakantan, "*Short banana fiber reinforced polyester composites: mechanical, failure and aging characteristics," Journal of Reinforced Plastics and Composites, vol 16(8), 1997, pp 744-765.*

[16] L.A. Pothan, Z. Oommen and S. Thomas, *Dynamic mechanical properties of banana reinforced polyester composites, Composite Science Technology, 63(2), 2003, pp 283-293.*

[17] M.M. Rao, R.K. Mohana, *Extraction and tensile properties of natural fibers: Vakka, date and bamboo, Composite Structures, Vol 77, 2007, pp 288-295.*

[18] S. Joseph, M.S. Sreekala, P. Koshy, Z. Oommen and S.Thomas, *A comparision of mechanical properties of phenol formaldehyde composites reinforce with banana fibers and glass fibers, Composite Science Technology, 62(14), 2002, pp1857-1868.*

[19] N. Venkateshwaran, A. Elayaperumal, A. Alavudeen, M. Thiruchitrambalam, *Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites, Materials and Design, Vol 32, 2011, pp 4017-4021.*

[20] A. Kumar and D. Choudhary, *Development of glass/banana fibers reinforced epoxy composite, Int. Journal of Engineering Research and Applications, Vol 3(6), 2013, pp. 1230-1235.*

[21] S. Mukhopadhyay, G. Vijay, R. Talwade, J.D. Dhake and A. Pegoretti, *Some studies on banana fibers, international conference on advances in fibrous materials, Nonwoven and Technical Textiles, 2006, pp 7-9.*

[22] S.A. Paul, A. Boudenne, L. Ibos, Y. Candau, K. Joseph and S. Thomas, *Effect of fiber loading and chemical treatments on thermophysical properties of banana fiber/polypropylene commingled composite materials, Composites: Part A, Vol 39, 2008, pp 1582-1588.*

[23] V. Santhanam, Dr.M. Chandrasekaran, N. Venkateshwaran and A. Elayaperumal, *Mode I Fracture toughness of banana fiber and glass fiber reinforced composites, Advanced Materials Research, Vol 622-623, 2013, pp 1320-1324.*

[24] I.C. Finegan and R.F Gibson, *Recent research on enhancement of damping in polymer composites. Comp Strs, Vol 44, 1999, pp 89-98.*

[25] J. Gassan and A.K. Bledzki, *Possibilities of improving the mechanical properties of jute/epoxy composites by alkali treatment of fibers, Compos Sci Technol, Vol 59, 1999, pp 1303-1309.*

[26] A.K. Saha, S. Das, D. Bhatta and B.C. Mitra, *Study of jute fiber reinforced polyester composites by dynamic mechanical analysis, Journal of Applied Polymer Science, Vol 71, 1999, pp 1505-13.*

[27] P. A. Khudhur, S.Z. Omer, A.K. Basim and Z.S. Radif, *Fracture toughness of sugar palm fiber reinforced epoxy composites, International Journal of Science and Research, Vol 2(12), 2013, pp 273-279.*

[28] H. Venkatasubramanian, C. Chaithanyan, S. Raghuraman and T. Panneerselvam, *Evaluation of mechanical properties of abaca-glass-banana fiber reinforced hybrid composites, International Journal of Innovative Research in Science, Engineering and Technology, Vol 3(1), 2014, pp 8171.*

[29] K.J. Wong, S. Zahi, K.O. Low and C.C. Lim, *Fracture characterization of short bamboo fiber reinforced polyester composites, Materials and Design, Vol 31, 2010, pp 4147-4154.*

[30] A.V. Ratna Prasad and K. Mohana Rao, *Mechanical properties of natural fiber reinforced polyester composites: Jowar, sisal and bamboo, Materials and Design, Vol 32, 2011, pp 4658-4663.*

[31] K. Okubo, T. Fujii and Y. Yamamoto, *Development of bamboo-based polymer composites and their mechanical properties, Composites: Part A, Vol 35, 2004, pp 377-383.*

[32] T.Yuanjian, D.H. Isaac, *Impact and fatigue behavior of hemp fibre composites, Composites Science and Technology, Vol 67, 2007, pp 3300-3307.*

[33] Z. Li, X. Wang, L. Wang, *Properties of hemp fibre reinforced concrete composites. Composites: Part A, Vol 37, 2006, pp 497-505.*

[34] P. Shashi Shankar, Dr.K. Thirupathi Reddy and V. Chandra Shekar, *Mechanical performance and analysis of banana fiber reinforced epoxy composites, International Journal of Recent Trends in Mechanical Engineering, Vol 1(4), 2013, pp 1-10.*

[35] S.K. De and J.R. White, *Short fiber polymer composites, Woodhead Publishing Series in Composites Science and Engineering Series, 1st Edition, 1996.*

[36] M. Lewin and E.M. Pearce, *Handbook of fiber chemistry, Dekkar, New York, 2nd Edition, 1998.*