ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

AN EXPERIMENTAL STUDY ON PROCESSING, CHARACTERIZATION AND MODEL ANALYSIS OF RANDOMLY ORIENTED SHORT BANANA & GLASS FIBER REINFORCED HYBRID POLYMER COMPOSITES

Mr. Nuresh Kumar Khunte
Asst. Professor, Mechanical Engineering Department, Kalinga University, Naya Raipur

Abstract- Fiber reinforced polymer composites has been used in a variety of application because of their many advantages such as relatively low cost of production, easy to fabricate and superior strength compare to neat polymer resins. Reinforcement in polymer is either synthetic or natural. Synthetic fiber such as glass, carbon etc. has high specific strength but their fields of application are limited due to higher cost of production. Recently there is an increase interest in natural fiber based composites due to their many advantages. In this connection an investigation has been carried out to make better utilization of banana fiber for making value added products. The objective of the present research work is to study the mechanical behavior of banana/glass fiber reinforced epoxy based hybrid composites. The effect of fiber loading on mechanical properties like tensile strength, flexural strength, hardness of composites is studied. Its validation has been done by FEM using ANSYS software. Crystallography /amorphous nature of composites is determined by XRD analysis. Also, the surface morphology of fractured surfaces after tensile testing is examined using scanning electron microscopy (SEM).

Keyword- Banana , Glass Fiber Reinforced Hybrid Polymer, ANSYS software.

Introduction - In fiber reinforcement polymer composites, the reinforcements are either synthetic or natural fibers. Now-a-days, the natural fibers have a great attention as they are a substitute to the exhausting petroleum sources. Among all reinforcing fibers, natural fibers have increased substantial importance as reinforcements in polymer matrix composites. The benefits accompanying with the usage of natural fibers as reinforcement in polymers are their availability, biodegradability, low energy consumption, non-abrasive nature and low cost. In addition, natural fibers have low density and high specific properties. The specific mechanical properties of natural fibers are equivalent to those of synthetic reinforcements. A great deal of work has been carried out to measure the prospective of natural fibers as reinforcement in polymers. Studies on cements and plastics reinforced with natural fibers such as coir, sisal, bamboo, jute, banana and wood fibers have been reported. Among various natural fibers, banana finds a wide variety of applications around the world.

Literature Review

Sabu Thomas et al. was investigated the mechanical performance of short randomly oriented banana and sisal hybrid fiber reinforced polyester composites with reference to the relative volume fraction of the two fibers at a constant total fiber loading of 0.40 volume fraction (V_f), keeping banana as the skin material and sisal as the core material. It was found that the tensile strength is found to be increased in banana/sisal hybrid fiber reinforced polyester composites when the volume fraction of banana is increased and The impact strength of the composites is increased when the V_f of sisal is increased.

Kerim et al. studied the bending strength of single and double layer specimen of banana/glass hybrid composite. The test results showed that the highest and lowest bending strengths for a single layer specimen were found to be 13.085 N/mm² and 8.957 N/mm², respectively. While, the highest and lowest bending strengths for the double layer specimens were found to be 18.196 N/mm² and 16.834 N/mm².According to these results, it can be said that these produced banana / glass fiber bio composites can be used for indoors and outdoors applications where very high strength is not required. Thus, economic benefits of the waste can be realized.

S.Raghuramn et al.deals with fabrication and investigation of mechanical properties of natural fibers such as abaca and banana fiber and compares with the hybrid natural fiber composite. It is found that Abaca-Glass composite is found to have better tensile strength than the other two combinations and Abaca-Glass-Banana Hybrid Composite is found to have better Flexural strength and Impact value.

M. Niranjanaa et al. investigate and compare the mechanical and thermal properties of raw jute and banana fiber reinforced epoxy hybrid composites. To improve the mechanical properties, jute fiber was hybridized with banana fiber in this study. Experimental results showed that addition of banana fiber in jute/epoxy composites of up to 50% by weight results in increasing the mechanical and thermal properties and decreasing the moisture absorption property.

G. Dharmalingam et al. The purpose of this work is to establish the tensile, flexural, and impact properties of banana-coir reinforced composite materials with a thermo set for treated and untreated fibers .it was concluded that The tensile and impact tests of treated banana-coir epoxy hybrid composites have higher tensile strength and impact strength than untreated composites. However, untreated fiber composites have greater flexural strength than the treated fiber composites.

Sanjay K. Nayak et al. studied Fabrication and Performance Evaluation on Banana/Glass Fiber-Reinforced Polypropylene Hybrid Composites. This study included Hybrid composites of Polypropylene (PP) reinforced with intimately mixed short banana and glass fibers were fabricated by compression molding with and without the presence maleic anhydride grafted polypropylene (MAPP) as a coupling agent. The result was reported that the BSGRP composites at banana to glass ratio of 15:15 shows improved performance. The maximum improvement in the properties is observed at 30 wt% of fiber loading, which is chosen as the critical fiber loading. Furthermore, the composites and hybrid composites with MAPP exhibited higher mechanical strength as compared with the composites without MAPP.

Material and Methodology

The mechanical tests have been conducted only in one direction because of random orientation of reinforcement (short glass and banana fiber) composites are considered as nearly isotropic. It may be mentioned here that tensile strength, flexural strengths and hardness are important for recommending any composite as a material for structural applications. The effect of fiber parameters such as fiber loading on the performance of composites is also discussed.

1.Mechanical tests

Table 4.1: Tensile strength and tensile modulus of samples

Designation	Composition	Tensile strength (MPa)	Young's modulus (MPa)
C_1	90wt% Epoxy + 10wt% Fiber	2.807	650.581
C_2	85wt% Epoxy + 15wt% Fiber	11.550	2385.414
C_3	80wt% Epoxy + 20wt% Fiber	18.991	2425.076
C_4	75wt% Epoxy + 25wt% Fiber	25.111	2144.789

Table 4.2: Flexural strength of various samples

Designation	Composition	Flexural strength (Mpa)
C_1	90wt% Epoxy +10wt% Fiber	25.11
C_2	85wt% Epoxy +15wt% Fiber	29.899
C_3	80wt% Epoxy +20wt% Fiber	44.393
C_4	75wt% Epoxy +25wt% Fiber	61.962

Table 4.3: Measured hardness of various samples

Designation	Composition	Hardness (Shore D)
C_1	90wt% Epoxy +10wt% Fiber	81.621
C_2	85wt% Epoxy +15wt% Fiber	83.455
C_3	80wt% Epoxy +20wt% Fiber	84.229
C_4	75wt% Epoxy + 25wt% Fiber	85.783

Structure analysis by XRD

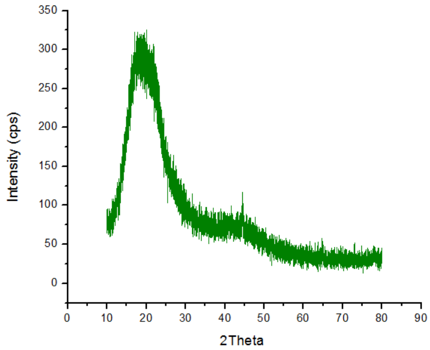


Figure 4.9: XRD results of samples C_1

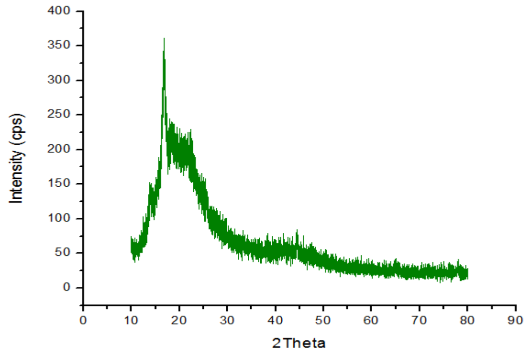


Figure 4.10: XRD results of samples C_2

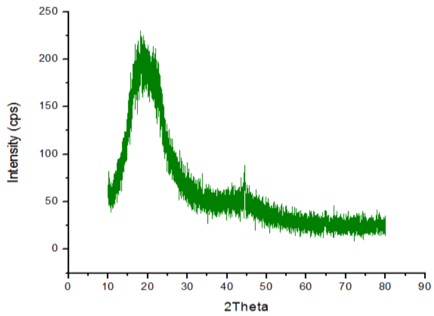


Figure 4.11 : XRD results of samples

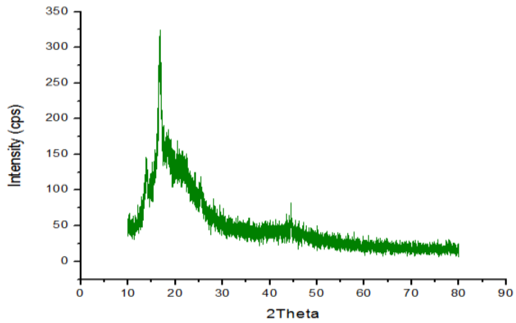


Figure4.12 : XRD results of samples C_4 C_3

Figure 4.13, 4.14, 4.15, 4.16 shows most nearly matches profile of samples C_1, C_2, C_3 and C_4 respectively.

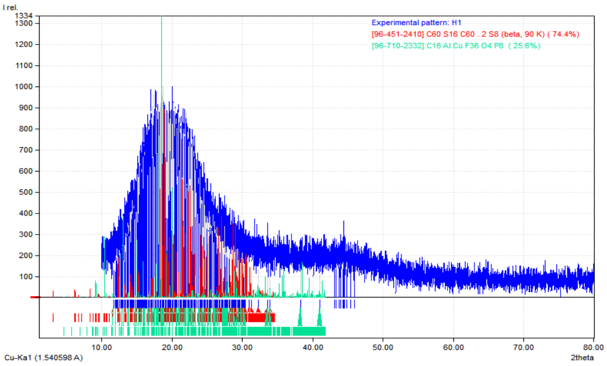


Figure 4.13:XRD images of 10% weight of fiber

Table 4.4: Matched Phases of sample C_1

S. NO	Entry No.	Element	Crystal System	Calculated Density (gm/cc)	Amount **(%)**
1	96-451-2410	C60 S16	Triclinic (anorthic)	1.929	74.44
2	96-710-2332	C16 Al Cu F36 O4 P8	Orthorhombic	2.225	25.6

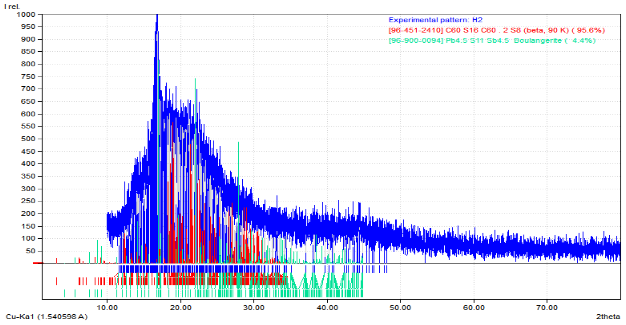


Figure 4.14: XRD images of 15% weight of fiber

Table 4.5: Matched Phases of sample C_2

S.NO	Entry No.	Element	Crystal System	Calculated Density(gm/cc)	Amount (%)
1	96-451-2410	C60 S16	Triclinic(anorthic)	1.929	95.6
2	96-900-0094	Pb4.5 S11 Sb4.5	Orthorhombic	3.040	4.4

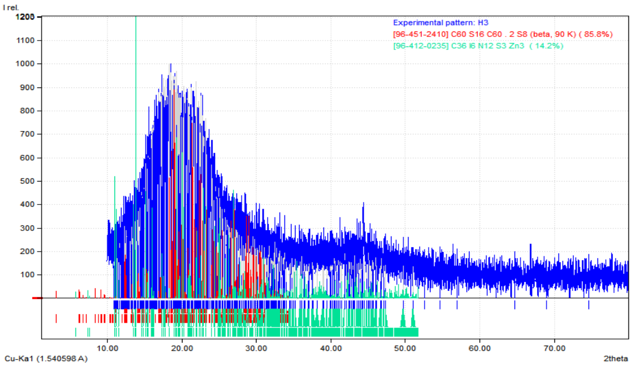


Figure 4.15: XRD images of 20% weight of fiber

Table 4.6:Matched Phases of sample C_3

S.NO	Entry No.	Element	Crystal System	Calculated Density (gm/cc)	Amount (%)
1	96-451-2410	C60 S16	Triclinic(anorthic)	1.929	85.8
2	96-412-0235	C36 I6 N12 S3 Zn3	Monoclinic	2.116	14.4

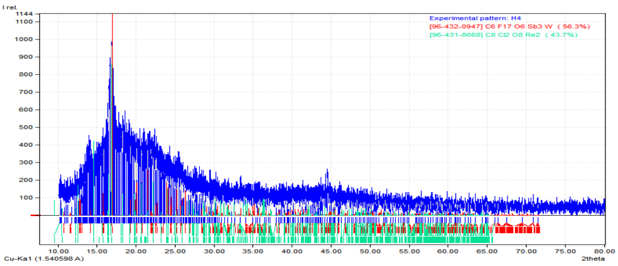


Figure 4.16: XRD images of 25% weight of fiber

Table 4.7:Matched Phases of sample C_4

S.NO	Entry No.	Element	Crystal System	Calculated Density(gm/cc)	Amount (%)
1	96-432-0947	C6 F17 O6 Sb3 W	Monoclinic	3.366	56.3
2	96-431-8668	C8 Cl2 O8 Re2	Monoclinic	3.220	43.7

Surface Morphology by Scanning electron microscope (SEM)

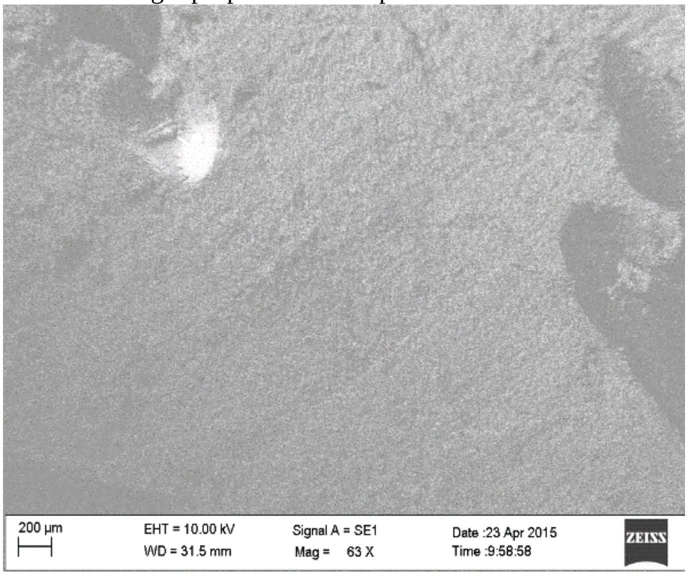
Figure 4.17a, 4.17b, 4.17c and 4.17d shows the SEM images of fractured surfaces of banana/glass fiber reinforced epoxy based hybrid composite after the tensile test with different fiberloading.

Figure4.17a shows the tensile fracture surface of composite with 10wt% fiberloading. It can be clearly observed from the figure that the fibers wt% is very less and 90wt% of composite is contribute by epoxy due to absence of excess fiber with high amount of resin, less void is to be develop in composite sample C_1. Less wt% of fibers results least value of tensile strength in sample C_1.

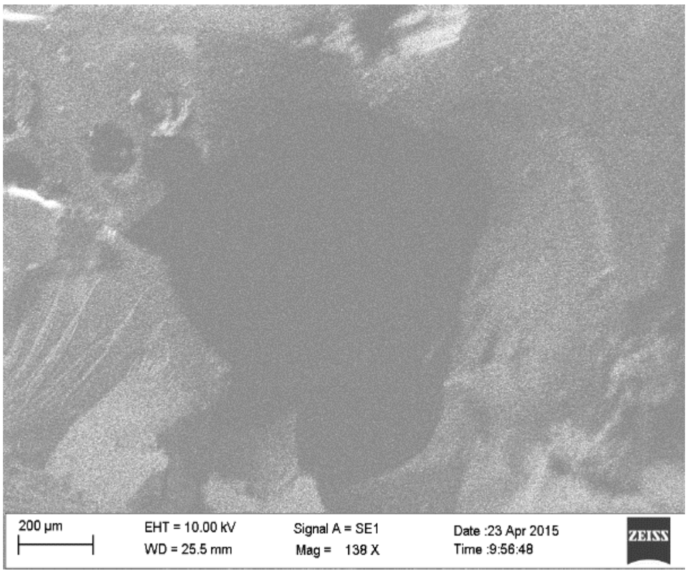
Figure4.17b showsthe fractured surface image of the banana/glass fiber reinforced hybrid polymer composite with 15 wt% fiber content. The uniformity of the sample has increased as compared to sample with 10% fiber content due to the larger fiber content. The image shows a fibers pull out from the resin surface due to poor interfacial bonding. This fiber pull out during tensile test creates large void in composite sample C_2.

The SEM image of the fractured surface of the sample with 20% weight total fiber is shown in figure 4.17c. The random distribution of the fiber further reduces as compared with sample of 20wt% fiber content due to the increase in fiber percentage, which is clearly visible in image. Therefore the amount of voids is also decreasing. More compact structure is seen which results in very less fiber pull out against applied tensile load which leads to better mechanical properties.

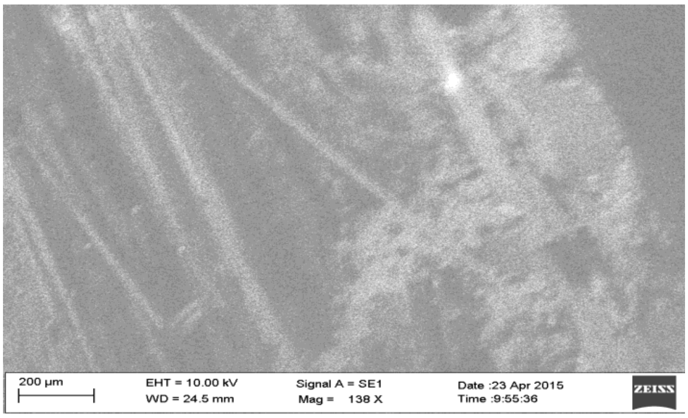
The image for banana/glass-epoxy composite with 25 wt% fiber content is shown in figure 4.17d. The fibers are more evenly distributed due to their high content in the composite resulting in the minimum number of voids among the considered samples 10%, 15% and 20% weight of banana/glass fiber epoxy composites. The surface is seen to be almost saturated with the fiber. It is evident from the figure that surface without much fiber pull out is clearly visible may be due to the better adhesion fiber and matrix which leads to better of strength properties of composites.



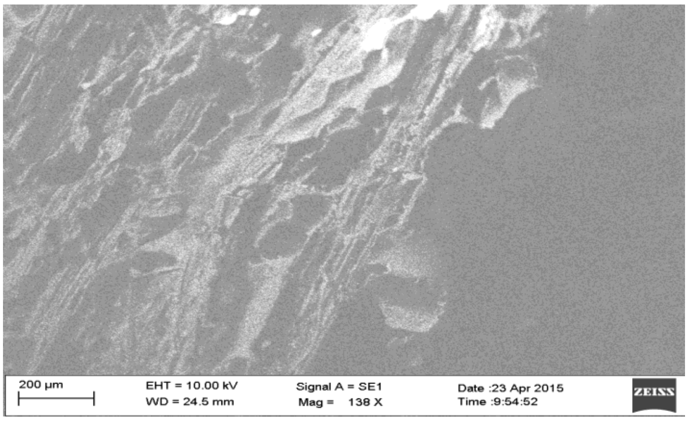
(a)



(b)



(c)

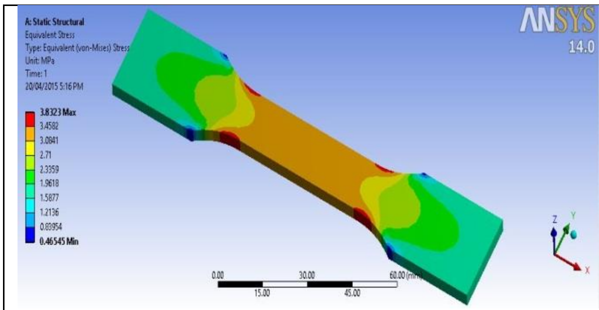


(d)

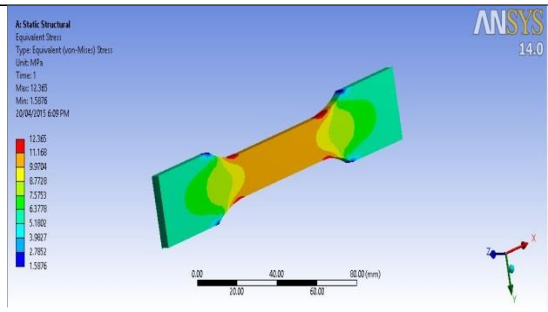
Figure 4.17:Scanning electron micrographs of banana/glass fiber reinforced epoxy based hybridcomposite specimens after tensile test.

4.3 Numerical analysis and theory of finite element method

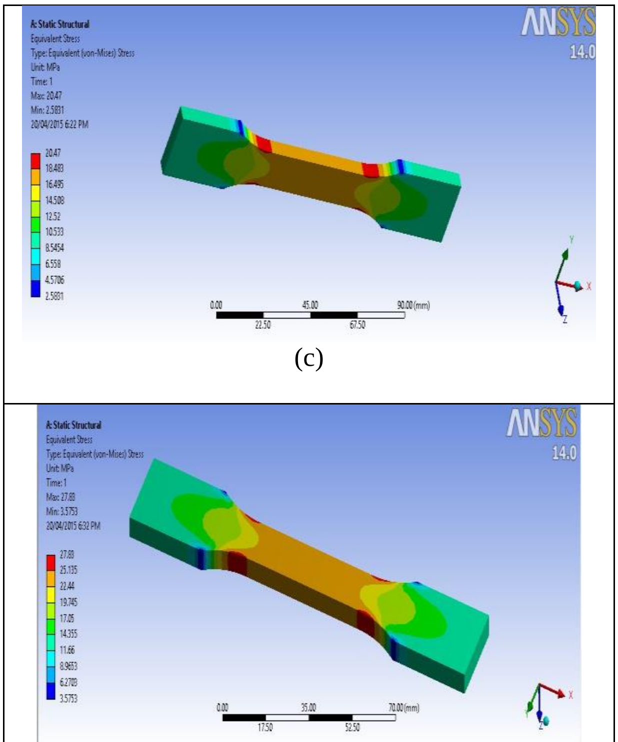
The finite element analysis (FEA) or the finite element method (FEM) is a powerful tool used in numerical methods to arrive at approximate solutions to mathematical problems so that it can simulate the responses of physical systems to various forms of excitation. In the FEM analysis, the complex problems are reduced to simple one by converting the whole domain into a finite number of elements or pieces and for each element an approximate function is associated for the unknown field variables. Now the investigations are concentrated to these elements rather than the whole complex problem. Further, the analysis of tensile and flexural test of the composite is to be done with the help of a well-known FEM package ANSYS. For different fiber loadings, the three dimensional physical model is prepared for the strength analysis. Moreover, the maximum tensile and flexural strength of these prepared epoxy composites reinforced with short fibers ranging from 10 wt% to 25 wt% is numerically determined using ANSYS.



(a)



(b)



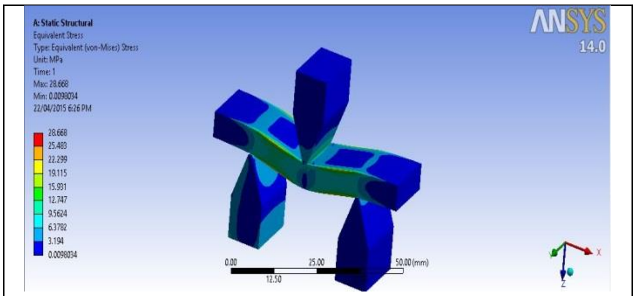
(c)

(d)

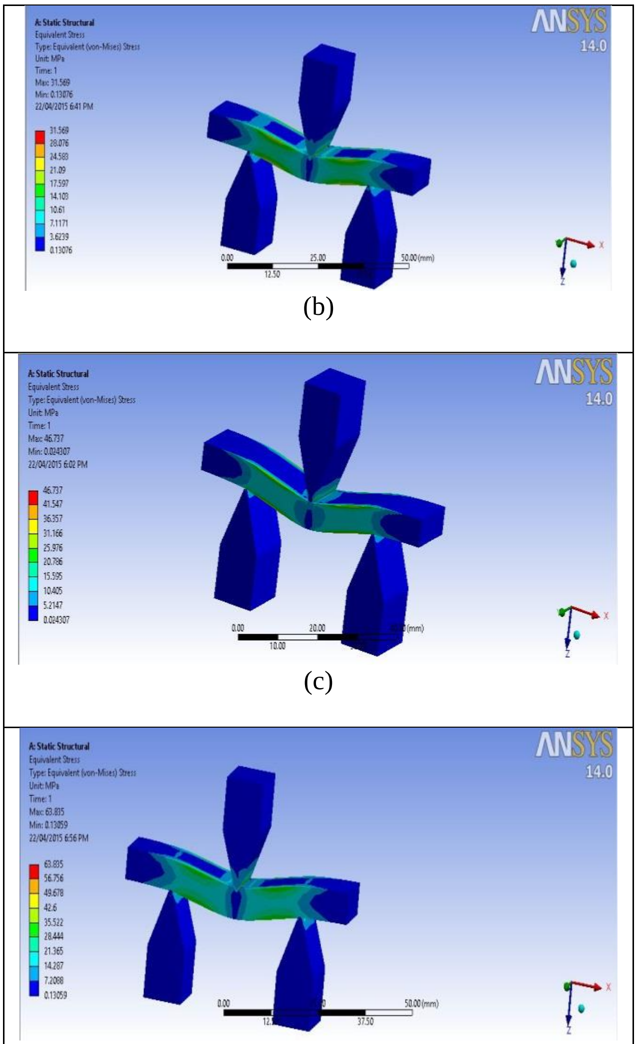
Figure 4.18: Tensile stress distribution.

4.3.2 Flexural test analysis

Three point bending test is to be performed by software. Specimen configuration and applied maximum load for each composition of composite is used in analysis. The effect of fiber loading on the flexural strength with corresponding maximum load are shown in table 4.9, and all the input data required for analysis of flexural strength of various composition of composite are as follows Figure 4.19a, 4.19b, 4.19c, 4.19d shows flexural stress distribution in all samples of composite. All images indicate almost same stress distribution. Failure region is occurring at middle portion of composites samples. This is because; in three points bending test samples are subjected under bending load like simply supported beam under load at middle of span. Composites samples represents same behavior under three point bend test and result in failure occur at middle point of total gauge length.



(a)



(b)

(c)

(d)

Figure 4.19: Flexural stress distribution.

4.3.3 Comparatively study between experimental and simulated results

Table 4.10: Shows the experimental and simulated result on tensile and flexural test. It's percentage difference between both study is also given.

Designation	Composition	Experimental result		Simulated result		% error in tensile strength	% error in flexural strength
		Max. tensile strength MPa	Max. flexural strength MPa	Max. tensile strength MPa	Max. flexural strength MPa		
C_1	90wt% Epoxy + 10wt% Fiber	2.807	25.111	3.8323	28.668	26.75%	12.40%
C_2	85wt% Epoxy + 15wt%	11.550	29.899	12.365	31.569	6.59%	5.28%

	Fiber						
C_3	80wt% Epoxy + 20wt% Fiber	18.991	44.393	20.471	46.737	7.22%	5.01%
C_4	75wt% Epoxy + 25wt% Fiber	25.111	61.961	27.832	63.835	9.77%	2.93%

Figure 4.20 represents the percentage error in tensile strength between experimental and simulated results of all samples of hybrid composite. The maximum deviation is occur with sample C_1(90wt% Epoxy +10wt% Fiber) is 26.75% , rather than this sample percentage deviation are 6.59%, 7.22%, 9.77% with sample C_2, C_3, C_4 respectively. In experiment, the distribution of the fiber is random due to the mechanical stirring process and the preparation of the sample by hand layup method. Some voids are also present due to the irregular distribution of the fibers in the epoxy, result in % difference occur with respect to simulated result.

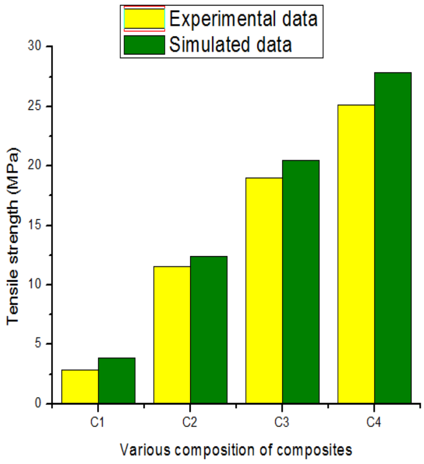


Figure 4.20: Comparison bar chart of tensile strength

Figure 4.21 shows the percentage error in flexural strength between experimental and simulated results of all samples of hybrid composite. Various composition of composite say C_1, C_2, C_3 and C_4 revels 12.24%, 5.28%, 5.01% and 2.93% difference respectively. This difference occurs due to fiber accumulation as well as random distribution of fibers with epoxy in experimental study.

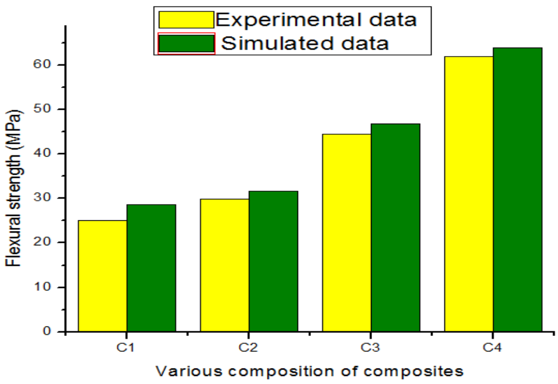


Figure 4.21:Comparison bar chart of flexural strength

Conclusion

The experimental investigation on the mechanical behavior of banana/glass fiber reinforced epoxy based hybrid composites lead to the following conclusions:

1. Epoxy based four hybrid composites (C1, C2, C3 and C4) have been fabricated with fiber loading increase from 10 wt% to 25 wt%, keeping constant contribution of each fiber in total percentage of fiber in each samples of composite. .
2. It has been noticed that the mechanical properties of the composites such as hardness, tensile strength and flexural strength are influenced by the fiber loading. A gradually increase in tensile and flexural strength can be observed with the increase in the fiber loading up to 25 wt% of composites.
3. It can be observed that the tensile modulus increases up to 20 wt% of total fiber then decreasing trend occur from 25 wt% of fibers which shows variation in the tensile modulus irrespective of fiber loading.
4. Hardness value increases continuously by increasing the fiber wt% in composites. Hardness is maximum with composition C4 (75wt% Epoxy + 25wt% Fiber) as compared to pure epoxy.
5. The results obtained from the proposed mathematical model are also in closer approximation with the values obtained by FEM simulation using ANSYS.
6. It is seen that the Finite element method (FEM) can be gainfully employed for determination of tensile and flexural strength of hybrid fiber reinforced polymer composites with different fiber loading.
7. The study shows that the tensile and flexural strength increases as the fiber loading in the composite increases. Both the strength analysis shows approximate same result with experimental one.
8. Finally optimum mechanical properties are obtained for composition C4 (75wt% Epoxy + 25wt% Fiber).
9. XRD analysis of composite identified banana/glass hybrid fiber epoxy composites sample with 10%, 15%, 20% and 25% concentration of total fiber. The absence of any sharp peak confirms the amorphous nature of composites.
10. SEM images of the fracture surfaces of composites after the tensile test shows that the increase in strength properties of composites at 25wt% fiber loading due to the better adhesion between fiber and matrix.
11. Epoxy based banana/glass fiber reinforced hybrid composites can be utilized as structural material.

References

1. Kaw, A. K. “Mechanics of composite materials”, Taylor and Francis,(2006).
2. Vasiliev, V.V. and Morozov, E.V. “Mechanics and Analysis of Composite Materials”, Elsevier (2001).
3. Kelly, A.“The Nature of Composite Materials”,scientific American Magazine pp 161, (1967).
4. Jones, R.M.“Mechanics of composites materials”, Taylor and Francis (1999).
5. Malik P. K. “Fibre reinforced Composites: Materials, Manufacturing and Design.”
6. John M.J. and Anandjiwala R.D., “Recent developments in chemical modification and characterization of natural fibre-reinforced composites” Polymer Composites, vol 29(2), pp. 187-207, (2008).

7. Ronga M.Z., Zhang M.Q., Liu Y., Yang G.C. and Zeng H.M. “The effect of fibre treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites” Composites Science and Technology, vol 61, pp.1437–1447.
8. Filho R.D.T., Scrivener K., England G.L. and Ghavami K “Durability of alkalisensitive sisal and coconut fibres in cement mortar composites” Cement Concrete Composites, vol 22, pp. 127-143.
9. Zhong L.X., Fu S.Y., Zhou X.S. and Zhan H.Y “Effect of surface microfibrillation of sisal fibre on the mechanical properties of sisal/aramid fibre hybrid composites” Composites: Part A, vol 42, pp. 244–252.
10. Acha B.A., Reboredo M.M. and Marcovich N.E., (2007) “Creep and dynamic mechanical behavior of PP-jute composites: Effect of the interfacial adhesion” Composites: Part A, vol 38, pp. 1507–1516.
11. Bledzki A.K., Mamun A.A. and Volk J. “Barley husk and coconut shell reinforced polypropylene composites: The effect of fibre physical, chemical, and surface properties” Composite Science and technology, vol 70, pp. 840-846.
12. Rozman H.D., Tan K.W., Kumar R.N., Ishak Z.A.M. and Ismail H. “The effect of lignin as a Compatibilizer on the physical properties of coconut fibre polypropylene composites” European polymer journal, vol 36, pp.1483 –1494.
13. P.Shashi Shankar, Dr.K.Thirupathi Reddy and V.Chandra Sekhar “Mechanical performance and analysis of banana Fiber reinforced epoxy composites.”
14. Shinji Ochi “Mechanical properties of kenaf fibers and kenaf/PLA composites” Mechanics of Materials, vol 40, pp.446–452.
15. [15] S. Panthapulakkal, A. Zereshkian and M. Sain “Preparation and characterization of wheat straw fibers for reinforcing application in injection molded thermoplastic composites” Bioresource Technology, vol 97 , pp.265–272.
16. [16] Goulart, S.A.S., Oliveira, T.A., Teixeira, A., Miléo, P.C., Mulinari and D.R “Mechanical Behaviour of Polypropylene Reinforced Palm Fibers Composites” Procedia Engineering, vol 10 , pp. 2034–2039.
17. Cristel Onésippe , Nady Passe-Coutrin , Fernando Toro ,Silvio Delvasto , Ketty Bilba and Marie-Ange Arsène “Sugar cane bagasse fibres reinforced cement composites: Thermal considerations” Composites: Part A, vol 41 ,pp.549–556.
18. K. Ramanaiah , A.V. Ratna Prasad and K. Hema Chandra Reddy “Thermal and mechanical properties of waste grass broom fiber-reinforced polyester composites” Materials and Design, vol 40 ,pp. 103–108.
19. Ravindra Mangal, N.S. Saxena, M.S. Sreekala, S. Thomas and Kedar Singh “Thermal properties of pineapple leaf fiber reinforced composites” Materials Science and Engineering ,vol A339, pp. 281-285.
20. M. Ramesh, K. Palanikumar and K. Hemachandra Reddy “Mechanical property evaluation of sisal–jute–glass fiber reinforced polyester composites” Composites: Part B, vol 48 , pp. 1–9.
21. T.P. Sathishkumar , P. Navaneethakrishnan and S. Shankar “Tensile and flexural properties of snake grass natural fiber reinforced isophthallic polyester composites” Composites Science and Technology, vol 72 , pp. 1183–1190.
22. 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,pp. 689–693.
23. H.Venkatasubramanian, C.Chaithanyan, Dr. 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, ISSN: 2319-8753.
24. K. Murali Mohan Rao, K. Mohana Rao and A.V. Ratna Prasad “Fabrication and testing of natural fibre composites: Vakka, sisal, bamboo and banana” Materials and Design, vol 31, pp. 508–513.
25. Al-Qureshi, H.A. “The Use of Banana Fiber Reinforced Composites for the Development of a Truck Body”, in Proc. 2nd International wood and natural fiber composite symposium, 1999.
26. Maries Idicula,N. R. Neelakantan, Zachariah Oommen Kuruvilla Joseph and Sabu Thomas “A Study of the Mechanical Properties of Randomly Oriented Short Banana and Sisal Hybrid Fiber Reinforced Polyester Composites” Wiley InterScience, DOI 10.1002/app.21636.
27. Sevgi Hoyur and Kerim Çetinkaya “Production of banana / glass fiber bio–composite profile and its bending strength” Usak University Journal of Material Sciences, vol 1 , pp.43 – 49, (2012)
28. H.Venkatasubramanian, C.Chaithanyan, Dr. S.Raghuraman and T. Panneerselvam “Evaluation of mechanical properties of Abaca-glass-banana fiber reinforced hybrid Composites” Engineering and Technology, Vol. 3, ISSN: 2319-8753.
29. M. Boopalan, M. Niranjanaa and M.J. Umapathy “Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites” Composites: Part B, vol51,pp. 54–57, (2013)
30. T. Hariprasad, G. Dharmalingam and P. Praveen Raj “ Study of mechanical properties of banana-coir hybrid composite using experimental and fem techniques” Journal of Mechanical Engineering and Sciences, Vol 4, pp. 518-531, June 2013.
31. Sushanta K. Samal , Smita Mohanty and Sanjay K. Nayak “Banana/Glass Fiber-Reinforced Polypropylene Hybrid Composites: Fabrication and Performance Evaluation” Polymer-Plastics Technology and Engineering, vol 48, pp.397–414, 2009.
32. Marco Valente, Fabrizio Sarasini, Francesco Marra, Jacopo Tirillo and Giovanni Pulci “Hybrid recycled glass fiber/wood flour thermoplastic composites: Manufacturing and mechanical characterization” Composites: Part A, vol 42, pp. 649–657, (2011).
33. Chauhan S.R., Gaur B., Das K., (2011).Effect of Fibre Loading on Mechanical Properties, Friction and Wear Behaviour of Vinyl ester Composites under Dry and Water Lubricated Conditions, International Journal of Material Science 1(1), pp. 1-8.
34. James Sargianis and Jonghwan Suhr “Core material effect on wave number and vibrational damping characteristics in carbon fiber sandwich composites” Composites Science and Technology, vol 72, pp. 1493–1499, (2012).

35. M.Ramesha, K.Palanikumar and K.Hemachandra Reddy "Comparative Evaluation on Properties of Hybrid Glass Fiber- Sisal/Jute Reinforced Epoxy Composites" Procedia Engineering, vol 51, pp.745 – 750, (2013).
36. S. Rudzinski, L. Häussler, Ch. Harnisch, E. Mäder and G. Heinrich "Glass fibre reinforced polyamide composites: Thermal behaviour of sizings" Composites: Part A, vol 42, pp.157–164, (2011).
37. Kutty S. K. & Nando G. B., (1993). Effect of processing parameters on the mechanical properties of short Kevlar aramid fibre-thermoplastic polyurethane composite. Plastics, Rubber and Composites Processing and Applications, 19(2), pp.105-111.
38. Jung ju lee and chang suh "Interlaminar fracture toughness and associated fracture behavior of bead-filled epoxy/glass fiber hybrid fiber composites" Journel of material science, vol 30, pp.6179-6191, (1995).
39. Dr. Miller "High Strength Glass Fibers" technical paper, (1996)
40. S. Mridha, S. B. Keng and Z. Ahmad "The effect of OPWF filler on impact strength of glass-fiber reinforced epoxy composite" Journal of mechanical science and Technology, vol 21, pp.1663-1670, (2007).
41. Shao-Yun Fu and Bernd Lauke "Fracture resistance of unfilled and calciteparticle- filled ABS composites reinforced by short glass fibers (SGF) under impact load" Composires Parr A, vol 29A , pp.631-641, (1998).
42. C.M. Manjunatha, A.C. Taylor , A.J. Kinloch and S. Sprenger "The tensile fatigue behaviour of a silica nanoparticle-modified glass fibre reinforced epoxy composite" Composites Science and Technology, vol 70, pp.193–199, (2010).
43. Anine Cristina Detomi , Reniene Maria dos Santos , Sergio Luiz Moni Ribeiro Filho, Carolina Coelho Martuscelli , Túlio Hallak Panzera and Fabrizio Scarpa "Statistical effects of using ceramic particles in glass fibre reinforced Composites" Materials and Design, vol 55, pp.463–470, (2014).
44. Suhara Panthapulakkal and Mohini Sain "Injection-molded short hemp fiber/glass fiber- Reinforced polypropylene hybrid composites— mechanical, water absorption and thermal properties" Wiley InterScience, DOI 10.1002/app.25486.
45. Arun Kumar Rout and Alok Satapathy "Study on mechanical and tribo-performance of rice-husk filled glass–epoxy hybrid composites" Materials and Design, vol 41, pp.131–141, (2012).
46. Valeriu Dulgheru, Viorel Bostan and Marin Guţu "Some research on finite element analysis of composite materials" Mechanical Testing and Diagnosis, vol 3, pp. 79-85.
47. L.T.Harper, I.Ahmed,R.M.Felfel and C.Qian "Finite element modelling of the flexural performance of resorbable phosphate glass fibre reinforced PLA composite bone plates"journal of the mechanical behavior of biomedical materials, vol 15, pp. 13-23, (2012).
48. H. Ku, H. Wang, N. Pattarachaiyakoop and M. Trada "A review on the tensile properties of natural fiber reinforced polymer composites" Composites: Part B, vol 42, pp.856–873, (2011).