INVESTIGATION ON MECHANICAL, DMA ANALYSIS AND FRACTOGRAPHY ANALYSIS OF HYBRID NANOCLAY-BAMBOO FIBER / HYBRID RESIN COMPOSITES

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Abstract

Natural fiber-based composites are fundamental to human life from the simplest building elements to those utilized in the automotive and construction industries. This study examined the effects of adding nanoclay to epoxy Lannea Coromandelica (ELC) resins composites made with reinforcement of bamboo fiber. A mechanical stirrer is used to thoroughly mix the ELC resin after adding nanoclay (N) as reinforcement in weight fractions of 0, 1, 2, 3, 4, and 5. The material used for secondary reinforcement as woven bamboo (B) fiber mat. Hardener (HY951) is introduced in a specific volume fraction (1%) while stirring the nanoclay-ELC resin mixture.

Then, using the hand layup process, composites made of bamboo fiber reinforced epoxy lannea coromandelica (BFRELC) are created. The impact, water absorption, DMA analysis and thermal conductivity of the specimens are all evaluated. The SEM as the research tool, the Fractography analysis of fracture in ELC hybrid composites is examined. For bamboo fiber reinforced ELC resin nanocomposites with a nano "N" concentration of 3 wt%, the best impact characteristics are noted.

Key words: Epoxy Lannea Coromandelica resin, Bamboo Fibers, Mechanical Testing, SEM, Nanoclay, etc.

1. Introduction

The mixing of clay particles of a certain quantity can greatly improve the polymer's characteristics [1-3]. Polymer clay nanocomposites have gained a lot of attention. Numerous studies in thermoset polymer systems including epoxy [4], polyesters [5–6] and others, as well as thermoplastics including polypropylene [7] have been conducted based on this concept. Natural sisal fiber, resin and nanocomposites have many advantages including low cost, high thermal conductivity properties and reduced processing power requirements. In recent times, attempts have been made to use hybrid bio – nano materials in place of synthetic materials [8]. Because of their specific morphological features and cell membrane, bamboo fibers are becoming more and more well-liked because they provide more mechanical strength than other natural fibers including sisal and straw etc. [9]. Alkali treatment resulted in the partial elimination of non-structural components such lignin, pectin, and hemicellulose, according to a SEM and FTIR investigation of bamboo fibres [10].

Due of their high aspect ratio and platy appearance, layered silicate clays from the Smectite group are typically used as fundamental reinforcing elements [11]. Organo-modified bentonite can be uniformly dispersed into biopolymers to greatly improve the mechanical and physical characteristics [12–13]. It had been documented [14] how the addition of nanoclay affected the vibration behaviour of hybrid clay - glass fiber infused nanocomposites. In unidirectional glass fiber reinforced epoxy composites, Manfredi et al. investigated the impact of nanoclay on the water properties and mechanical properties [15]. According to Ayemerich et al., study's [16], adding nanoclay considerably increased the glass fiber - epoxy composites' ability to absorb energy. The impact of adding nanoclay on the mechanical property and thermal property of fiber infused epoxy composites had also been the subject of numerous research studies [17–19].There haven’t been much research reports on nanoclay and bamboo fiber reinforced ELC resin composites, in contrast to the previous works on nanocomposites mentioned above. Bamboo reinforced EPL resin nano composites are created in the current work using a hand layup compression approach as a follow-up to this research.

The aim of this research project is (1) Bamboo fiber mats with weight fractions of 0%, 1%, 2%, 3%, 4% and 5% are the main materials used in this research project. Each mixture enhanced ELC matrix's nanoclay (N) loading is created manually and compressed using a moulding machine. (2) To investigate the specifically impact properties and physically the water absorption. (3) To evaluate the storage (Pa) modulus and damping (δ) factor for composites for bamboo fiber mats resin nanocomposites, DMA tests is carried out. (4) To identify and analyze the morphological examination of the hybrid bamboo fibre matting resin nanocomposites, SEM is used. (5) The thermal conductivity of hybrid nanocomposites made of bamboo fiber mats and ELC resin is also examined.

2. Experimental Methods

2.1 Materials

The materials used for creating the bamboo fiber mats resin nanocomposites: Epoxy (E) resin (LY556), Bentonite (N) nanoclay (pH-value 8- 9.5), Bamboo (B) fiber of 425 GSM (fiber mat roving), Hybrid (ELC) resin (pH 2 -2.5) and Hardener - (HY951).

2.2 Preparation of Hybrid (ELC) Resin

Ten days are spent for drying the Lannea (LC) coromandelica at ambient temperature and then an hour is spent for drying it at 30 degrees Celsius in an oven. Coarse gum is processed into fine powder using a mechanical dynamic mixer for five minutes. By employing a mechanical mixer for combining the LC powder and Epoxy (E) resin matrix in the 1: 1 ratio, hybrid (ELC) resin is produced [20].

2.3 Preparation of laminates for hybrid bamboo fiber mats resin nanocomposites and ELC resin

Four layers of bamboo fiber mat laminates (300 X 300 X 3.2 mm) are arranged in order. Hybrid bamboo fiber mats resin nanocomposites are created by high shear mixing ELC resin in a 12:1 ratio of hardener (HY951) with 0% weight fraction of nano clay (N) for 25 minutes at an speed of (1100) revolutions per minute. . In order to keep the pressure (10 bar), which impact the over layers of composites, the necessary quantity of ELC resin - (N) clay mixture is put into the mould, and a strong plate weighing 1000 N is then held on the mould. According to Table.1, compression hand lay-up is used to create different hybrid nano ELC resin composites in the similar manner.

Table 1 – Details of composition of bamboo fiber mats reinforced ELC nano composites

Basic Material	**Composites' Specification**	**ELC Matrix (300 ml)**	**Reinforcement Roving Mat - RM N – Nano Clay (0 – 5) wt %**
Hybrid Resin	ELC	ELC	---
Bamboo	B1	ELC	B RM + 0 wt %
Fiber mats	B2	ELC	B RM + 1 wt %
(B) or (BFM)	B3	ELC	B RM + 2 wt%
	B4	ELC	B RM + 3 wt%
	B5	ELC	B RM + 4 wt%
	B6	ELC	B RM + 5 wt%

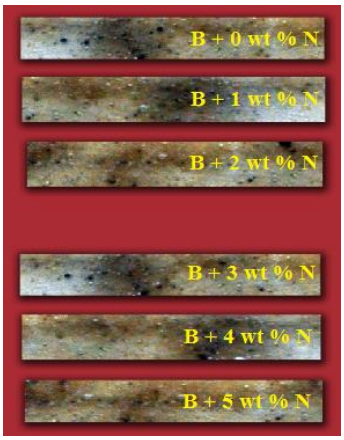

Fig. 1 Laminates of bamboo fiber mats reinforced ELC nano composites

2.4 Impact Test

Specimens of Hybrid (ELC) resin and hybrid nano ELC resin composites are examined for compressive characteristics (ASTM D695) using the Universal (Olsen) testing machine.

2.5 Dynamic Mechanical Analysis (DMA) Test

The DMSC 6100 (SEIKODMAI) test is conduct to find the qualities of Hybrid (ELC) resin and hybrid nano ELC resin composites with tensile load applying temperature being maintained in the span of (25 – 240) °C and increment of 5° centigrade per minute at amplitude of 2 Hz.

2.6 Thermal Conductivity Test

Hybrid (ELC) resin and hybrid nano ELC resin composites are evaluated for 12cm diameter specimens using Lee - method for detecting the thermal conductivity.

2.7 Water Absorption Test

The tests (ASTM D570) are evaluated to find the weight loss percentages of the hybrid nano ELC resin composites and Hybrid (ELC) resin composites. The dimension utilized for the test specimen is 25.5 X 7.6 X 3.2 mm.

Weight absorption in percentage = $[(W_B - W_A) / W_A] \times 100$

where W_A - Initial Weight "A" of specimen

W_B - Final Weight "B" of specimen

2.8 Fractography Study

Hybrid nanocomposite specimens with gold coatings are kept in the sputter coating machine for up to one hour. Hybrid nano ELC resin composites are analyzed (SEM model : Apreo S (Alternating current voltage: (0.1-30 kV), magnification range (50 x - 25000X), and frequency maximum 2 nm) to find the microstructure for analyzing the impact fracture properties and fractography behaviors.

3. Results and Discussion

3.1 Impact strength

The impact strength of hybrid nano ELC resin composites is depicted in Figure 2. Impact strength for ELC Resin is 1 J. In comparison to other hybrid nano ELC resin composites and hybrid ELC resin, bamboo fiber mats reinforced ELC resin with 3 vol% nanoclay composites have a greater impact strength of 2.82 J. A composite's ability to withstand energy was referred to as having the higher impact strength [21]. The impact strength is proceeding to deteriorate after intensifying steadily up to 3 weight's percent of nanoclay, despite the fiber inducement being raised to 4 & 5 weight percent of nano-filler. The results show that huge nanoclay was induced to the resin that could easily be absorbed by the fibers, which led to defective joining and reduced impact strength [22]. It was also known that the fragmented and impacted nano - filler dispersed in the ELC matrix induced the strengthening mechanisms in various matrix materials [23].

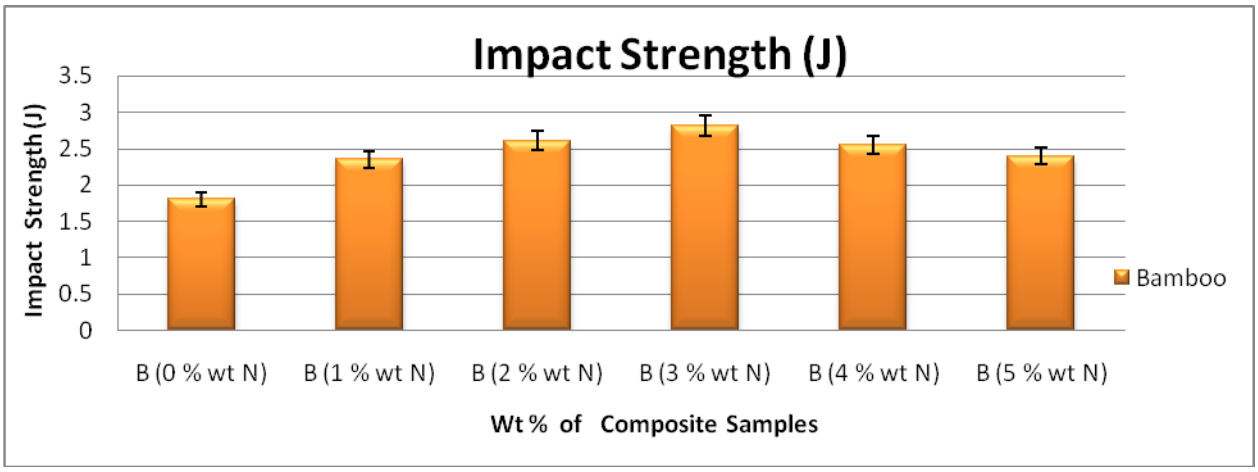

Fig. 2 Comparison of impact property of bamboo fiber mats (BFM) reinforced ELC nano composites

3.2. Fractography Observation

Composites made from hybrid nano ELC resin carry the structural morphology. Composites' impact strength is increased when bamboo fiber mats with a 3% weight percentage of Nano(N) clay mixed with ELC resin. The cross sectional area of Fig. 3(a) shows that nano clay is uniformly dispersed throughout the Hybrid ELC resin matrix in natural fiber. As seen in Figs. 3(b) SEM's micrographs of the bamboo fiber (BFM) mats with 5% weight percentage N mixing in the ELC resin, the bamboo fibre mats' and the hybrid (ELC) resin matrix's bonding strength are weak. The fiber removal had shown the poor strength between the fiber and resin matrix interacted with one another. As an added bonus, the fundamentals of energy loss during the contact process were discovered [22, 23].

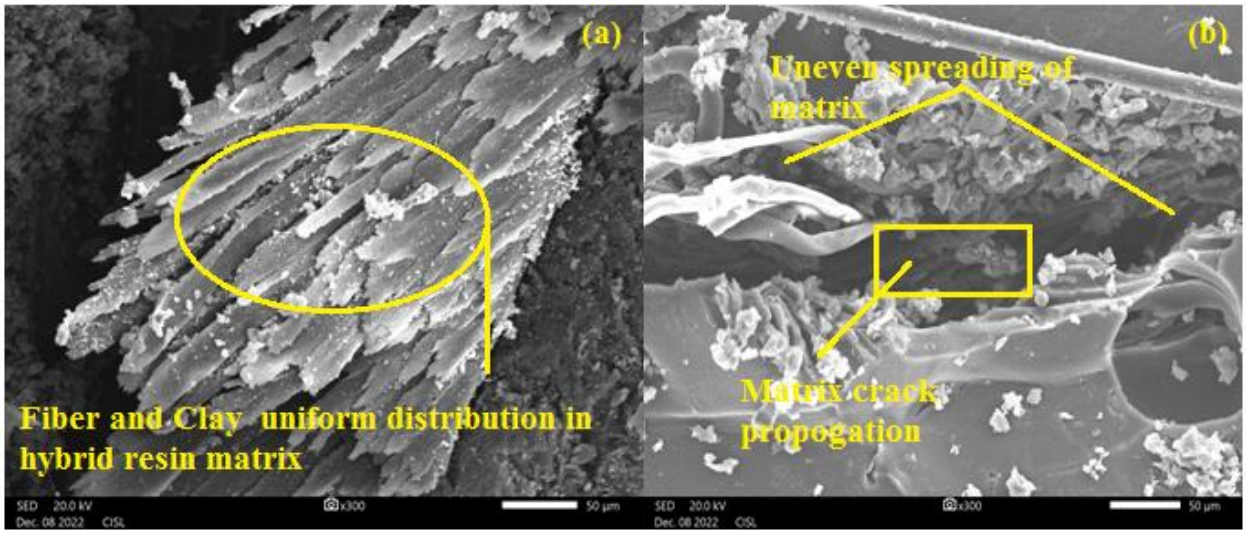

Fig. 3 SEM Images of ' cross-sectional areas of (a) bamboo fiber mats (3 wt %) reinforced ELC nano composites and (b) bamboo fiber mats (5 wt %) reinforced ELC nano composites

3.3. Dynamic mechanical analysis

3.3.1Storage modulus

Figure 4 shows the storage (Pa) modulus of bamboo fiber mat-reinforced ELC resin nanocomposites at a frequency of 2 HZ and temperatures varying from 28 °C to 185 °C. The same conditions are also applied to ELC resin. In comparison to other hybrid nano ELC resin composites, hybrid ELC resin has the lowest storage modulus value indicating the lowest rigidity. The heat stability of the bamboo fiber mats infused with N percent (3 wt) in each composition of ELC resin composites is noticeably higher than that of the ELC resin and other nano ELC resin composites. . Until the temperature reaches 135°C, the energy storage is superior for ELC resin and hybrid nano ELC resin composites and above this temperature, the energy loss is about to be identical. The results show that huge nanoclay is induced to the resin that could easily be absorbed by the fibers, which led to defective joining and reduced impact strength. It was also known that the fragmented and impacted nano - filler dispersed in the ELC matrix induced the strengthening mechanisms in the various matrix materials [22, 24- 26].

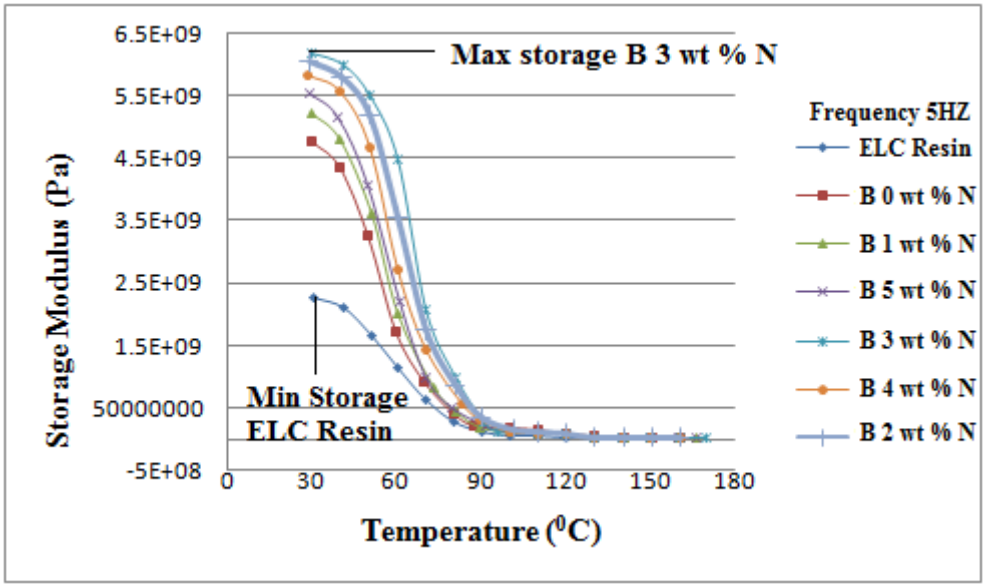

Fig 4 Storage modulus(Pa) of bamboo fiber mats reinforced ELC nano composites

3.3.2 Damping Factor

Figure 5 illustrates the evaluation of the material energy loss (Damping factor Tan δ) for composites made of ELC resin and hybrid nano-ELC resin. When compared to other hybrid nano ELC resin composites and ELC resin, bamboo fiber reinforced with Nano 3 wt% mixing in every composition has lesser peak height, which indicates the reduced power loss. More resistance between the interfaces of resin matrix, filler and fiber suggests the less energy loss. This implies that when compared to hybrid ELC resin, the hybrid resin nano composite material including nanoclay (N) loses less energy [10, 27].

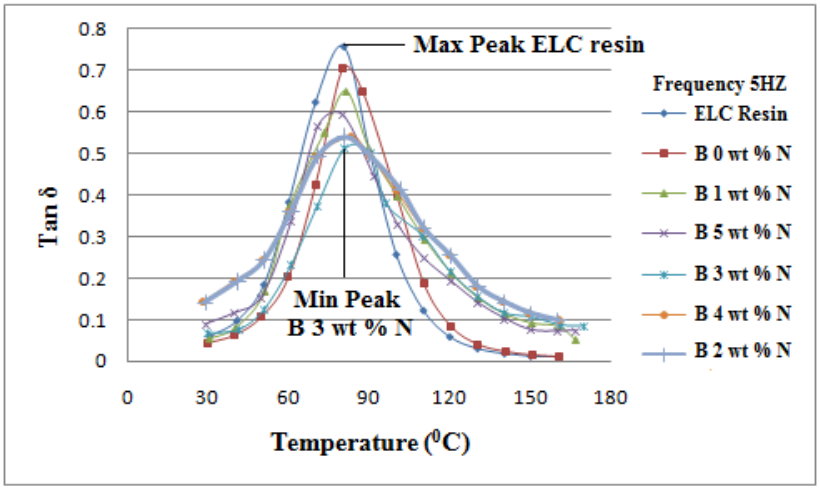

Fig. 5 Damping (δ)factor of bamboo fiber mats reinforced ELC nano composites

3.4. Thermal conductivity

The heat conductivity of bamboo fiber composites is depicted in Figure 6. It is important to note that ELC resin has a thermal conductivity of 0.21 W/mK. The inclusion of Nano N particles enhances heat conductivity. With a thermal conductivity of 0.26 W/mK, composites infused with 4% N particles and bamboo fiber mats have the highest thermal conductivity. The "N" particle effectively creates the heat transfer in to bridges as a result of these significant improvements in thermal conductivity. Despite the fiber's large pores, effective carbonization during the manufacture of laminates improves heat bond transmission. The heat conductivity of composites was greatly raised by employing nanoclay (NCF) particles [28].

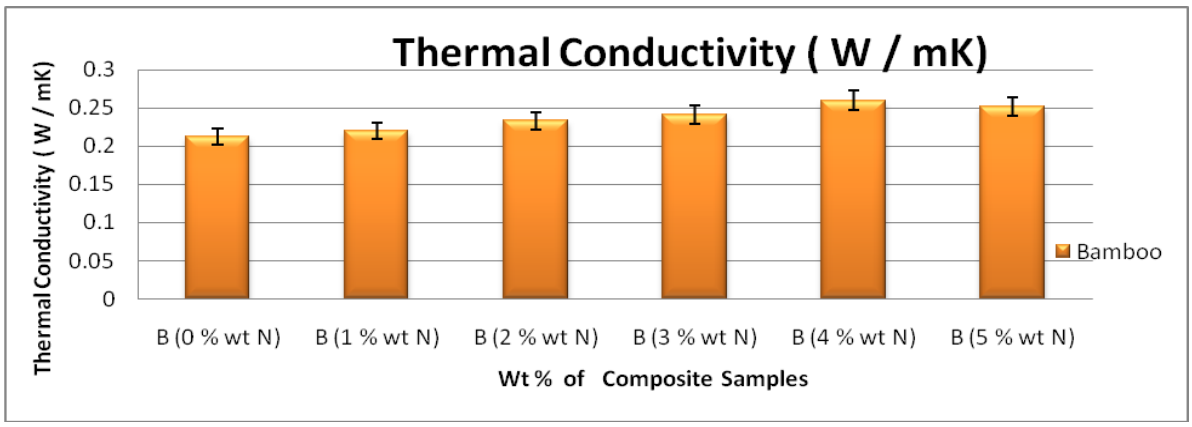

Fig. 6 Comparison of thermal conductivity of bamboo fiber mats infused ELC nano composites

3.5 Water Absorption

Figure 19 shows the percentage of bamboo fiber reinforced ELC resin nanocomposites that absorb water. When 3% nano clay feeding is used in ELC composites, the least value for water absorption in bamboo fiber mats is 6.5% higher than it is for other fiber composites. It has been found that bamboo fiber mats with zero nanoclay feeding has the highest capacity to absorb water up to 12.3%. In general, natural fibres showed a

significant capacity to absorb water [21]. The amount of water absorbed in percentage of bamboo fiber reinforced ELC resin nanocomposites and the deterioration of mechanical (impact) strength brought on by water's impacts may both be significantly influenced by the natural fibers/resin matrix interface [22, 28-29].

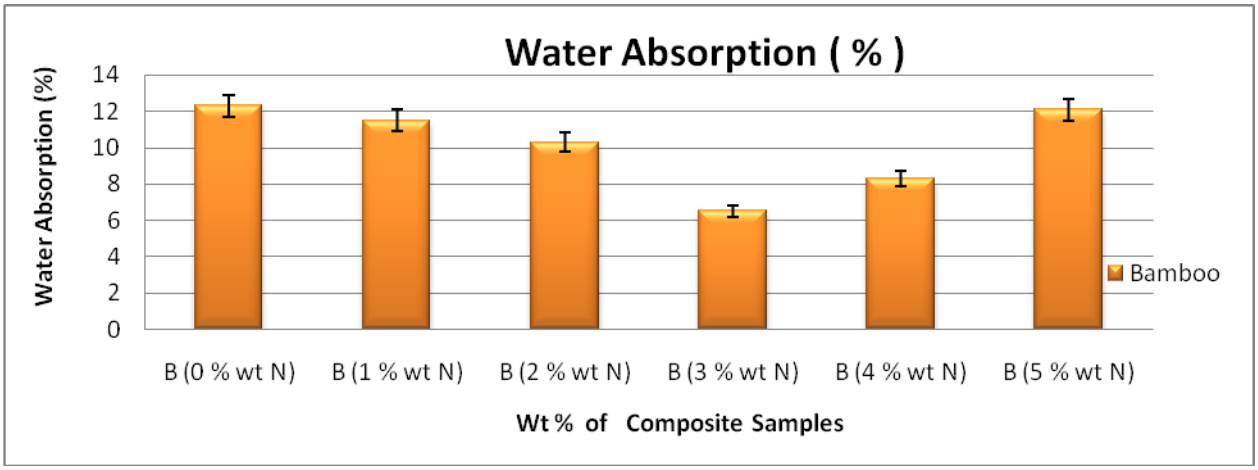

Fig.19. Comparison of water absorption of bamboo fiber mats reinforced ELC nano composites

4. Conclusion

- ELC resin and ELC resin nanocomposites of bamboo fiber mats with wt % (0, 1, 2, 3, 4 and 5) of Nano (N) particles mixing in each composition in ELC matrix) are made by HLU compression technique.
- The results of the impact tests demonstrate that the presence of 3 wt% N in the ELC matrix of bamboo fiber mats (BFM) of composites has greatly increased the impact strength. The highest impact strength of bamboo fiber (BFM) mats of composites with 3 wt percent Nano (N) particles infused in ELC matrix is 2.82 J compared to other hybrid nano ELC resin composites.
- Microstructural research affirms that the improved adhesion strength between cotton fiber, ELC resin and Nano N filler in hybrid composites of bamboo fiber mats / 3% wt nano particles reinforcement in ELC matrix composites which has played a major role in the most cohesive composites to improve the impact strength.
- The introduction of nanoparticles and bamboo fiber in the ELC matrix enhances the storage (Pa) modulus and reduces power loss of bamboo fiber composites, according to the comparative result of DMA analysis of ELC resin and other ELC resin nanocomposites.
- The maximum thermal conductivity of bamboo fiber mats of composites with 4 wt percent “N” of Nano filler infused in ELC matrix is 0.26 W/mK compared to other hybrid nano composites.
- The least value obtained in taking the water in bamboo fiber mats 3% nano clay infusing in ELC resin composites is 6.5 % compared to other hybrid nano ELC composites.
- I highlight that because they are environmentally beneficial and higher impact strength, the available hybrid natural polymer composites can be used in more useful applications (for wind screens, side panels etc.).

References

1. *P Prabhu, M Siva Kumar, S Mohamed Iqbal, A Balaji and B Karthikeyan, "Research and review of clay and glass fiber reinforced polyester nanocomposite materials using optimization techniques," Surf. Rev. Lett., 2250014,1-22 (2021).*
2. *V. Jayaseelan, S. Vijayananth, J. Francis Xavier, S. Ajith Arul Daniel, Nallapaneni Manoj Kumar, X.X. Jiang, Experimental investigation on bi-axial superplastic forming characteristics of AA6063/SiCp with various percentages of SiCp under various temperatures and pressures,Results in Physics,Volume 15,2019,102624, ISSN 2211-3797, https://doi.org/10.1016/j.rinp.2019.102624*
3. *S. Vijay Ananth, R. Srimurugan, V. Jayaseelan, Arunvasantha Geethan, and J. Francis Xavier, Experimental investigation on superplastic forming behavior of AA 6063/SiCp using stir casting, AIP Conference Proceedings 2283, 020118 (2020); https://doi.org/10.1063/5.0025150*
4. *X.Kornmann, H. Lindberg, and L.A.Berglund, "Synthesis of epoxy-clay nanocomposites: influence of the nature of the clay on structure," Polymer, Vol. 42, no. 4 , pp. 1303-1310, 2001.*
5. *P Prabhu, A Balaji, D Jayabalakrishnan, N Velmurugan, P Vimalnathan, B Karthikeyan, V Balaji and S Dinesh, "Study on machining parameters and mechanical properties of hybrid agave sisalana and glass fiber reinforced polyester composites (A/GFRP)," Journal of Natural Fibers., 1-15 (2022).*
6. *X.Kornmann, L.A.Berglund, J.Sterte and E.P.Giannelis, "Nanocomposites based on montmorillonite and unsaturated polyester," Polymer Engineering and Science, Vol. 38, no. 8 , pp. 1351-1358 ,1998.*
7. *N.Hasegawa, M. Kawasumi, M.Kato, A. Usuki and A.Okada "Synthesis of Polypropylene – Clay hybrid," Journal of Applied Polymer Science, Vol. 63, no. 1 , pp. 137 – 138, 1997.*
8. *M. Seeman, D. Kanagarajan, P. Sivaraj, R. Seetharaman and A. Devaraju, Optimization through NSGA-II during machining of A356Al/20%SiCp metal matrix composites using PCD Tool, IOP Conf. Series: Materials Science and Engineering 574 (2019) 012008, doi:10.1088/1757-899X/574/1/012008*
9. *Widiastuti I, Solikhun M, Cahyo DN, et al. Treatment of Bamboo Fibres in Improving Mechanical Performance of Polymer Composites – A Review. AIP Conference Proceedings, 2018, 1977, 030046:1-7*
10. *K.Zhang, F. Wang, W. Liang, Z.Wang , Z. Duan and B. Yang, " Thermal and Mechanical Properties of Bamboo Fiber Reinforced Epoxy Composites, "Polym., 10(6), 1-18 (2018).*
11. *B.Lepoittevin, N.Egepantoustier, M.D. Ckenaeve, M.Alexandre, C. Calberg, R.Jerome, C.Henrist and P.Rulmont, "Polymer/layered silicate nanocomposites by combined intercalative polymerization and melt intercalation: a master batch process," Polymer, Vol. 44, no. 7 , pp. 2033–2040, 2003.*
12. *Dhamotharakannan T, Sivaraj P, Seeman M, Balasubramanian V, "Mechanical and Metallurgical Characteristics of Rotary Friction Welded Low Carbon Steel Plate/Rod Joints." Key Engineering Materials, Vol. 934, pp. 153–160, 2022.*
13. *Dhamothara kannan T, Sivaraj P, Balasubramanian V, Malaravizhi S, Sonar T, Ivanov M, Sathiya S, "Joining different grades of low carbon steel to develop unsymmetrical rod to*

plate joints using rotary friction welding for automotive applications" Forces in Mechanics, Vol. 10, 100153, 2023.

14. *R.A.Vaia, G. Price, P.N.Ruth, H.T.Nguyen, and J. Lichtenhan, "Polymer/layered silicate nanocomposites as high performance ablative materials," Applied Clay Science , Vol. 15, no. 1, pp. 67-92, 1999.*
15. *L.B.Manfredi, H.D.Santis and A.Vazquez, "Influence of the addition of montmorillonite to the matrix of unidirectional glass fibre/epoxy composites on their mechanical and water absorption properties ," Composites Part A Applied Science and Manufacturing , Vol. 39, no. 11, pp. 1726-1731, 2008.*
16. *F.Aymerich, A.D.Via, and M.Quaresimin, " Energy absorption capability of nanomodified glass/epoxy laminates," Procedia Engineering , Vol. 10, no. 1, pp. 780-785, 2011.*
17. *U.K.Shafi, M.Arshad , H.Rizwan, and K.K.Jang, "Fatigue damage behaviors of carbon fiber-reinforced epoxy composites containing nanoclay," Composites Science and Technology, Vol. 70, no. 14, pp. 2077-2085, 2010.*
18. *X.Kornmann, M. Rees, Y. Thomann , A. Necola, M. Barbezat, and R.Thomann "Epoxy-layered silicate nanocomposites as matrix in glass fibre-reinforced composites," Composites Science and Technology, Vol. 65, no. 14, pp. 2259-2268, 2005.*
19. *X.Yuan and V.H. Suong, "Mechanical properties of carbon fiber reinforced epoxy/clay nanocomposites," Composites Science and Technology , Vol. 68, no. 3, pp. 854-861, 2008.*
20. *Lohithasu D, Ramana Murthy KV. Isolation and Evaluation of Binding property of Lannea coromandelica gum. Indian J Pharm Sci 2016; 78: 224-230. https://doi.org/10.4172/pharmaceutical-sciences.1000107*
21. *Balaji A, Karthikeyan B, Swaminathan J (2019) Comparative mechanical, thermal, and morphological study of untreated and NaOH-treated bagasse fiber-reinforced cardanol green composites. Adv Compos Hybrid Mater 2:125–132. https:// doi. org/ 10.1007/ s42114-019- 00079-7*
22. *Amir HH, Ismail G, Behzad B, Ahmad S (2011) Influence of nanoclay on the physical properties of recycled high-density polyethylene / bagasse nanocomposite. Middle East J 8(3):648–651*
23. *D. Kanagarajan, P. Sivaraj, M. Seeman, R. Seetharaman, Evaluation of the reliability on WC-40%Co composites through Weibull analysis, Materials Today: Proceedings 22 (2020) 519–524, https://doi.org/10.1016/j.matpr.2019.08.124*
24. *Amir HH, Ismail G, Behzad B, Ahmad S (2011) Influence of nanoclay on the physical properties of recycled high-density polyethylene/ bagasse nanocomposite. Middle East J 8(3):648–651*
25. *L.Szczesniak, A.Rachocki and J.T.Goc, "Glass transition temperature and thermal decomposition of cellulose powder, "Cellulose., 15(3), 445-451(2008).*
26. *S. Venugopal, M. Seeman, R. Seetharaman, V. Jayaseelan, The Effect of Bonding Process Parameters on the Microstructure and Mechanical Properties of AA5083 Diffusion-Bonded Joints, International Journal of Lightweight Materials and Manufacture 5 (2022) 555-563, https://doi.org/10.1016/j.ijlmm.2022.07.003.*
27. *K. Senthilvel, A. Arul Jeya Kumar, M. Seeman, I. Ashok Kumar, B. Prabu, Studies the effect of halloysite nanotubes on the mechanical and hot air ageing properties of nitrile-polyvinyl*

chloride rubber nano-composites, Materials Today: Proceedings 43 (2021) 1730–1739, https://doi.org/10.1016/j.matpr.2020.10.437

28. *Prabhu, P., Jayabalakrishnan, D., Balaji, V., Bhaskar, K., Maridurai, T., Arun Prakash, VR., Mechanical, tribology, dielectric, thermal conductivity, and water absorption behaviour of Caryota urens woven fibre-reinforced coconut husk biochar toughened wood-plastic composite, Biomass Conv. Bioref.,2022, 1-8,*
29. *Veerasundaram Jayaseelan, Kani Kalaichelvan, Murugesan Seeman and Nallamuthu Ramasamy. "Effect of extrusion ratio and die angle on the microstructure of an AA6063/SiC composite" Materials Testing, vol. 64, no. 6, 2022, pp. 874-883. https://doi.org/10.1515/mt-2021-2114*