Mechanical Performance Evaluation of Moringa Oleifera Reinforced Biopolymer Composites under Static and Dynamic Loading

Jesudas Thangaraju[1], Dr. Abhinav Sharma[2]
[1]Post Doctoral Researcher, Lincon University College, Malaysia;
[2]Designated Professor, Tokushima University, Japan.
Email ID: pdf.Jesudas@lincoln.edu.my

Abstract: The study investigated the impact of Moringa Oleifera filler-blended epoxy resin and varying filler loading (ranging from 10% to 30% volume) on the mechanical, dynamic mechanical, biodegradability, and thermal properties of the epoxy composite. The composites were fabricated through compression molding. Optimal mechanical properties, storage modulus, and glass transition temperature were observed in the composite with 20% natural filler content. Concurrently, Tan's peak height was lower for this sample, suggesting enhanced stiffness. Thermal analysis revealed that incorporating natural Moringa Oleifera as filler contributed to improved thermal stability in the composite. In a soil burial test, the addition of bio resin resulted in weight loss, as indicated by biodegradability tests. These findings collectively signify the positive effects of Moringa Oleifera filler and bio resin on the composite's mechanical, dynamic mechanical, thermal, and biodegradable characteristics. The 20% filler loading emerged as a particularly promising configuration for overall performance.

Key words: Mechanical properties, Epoxy resin, composite, polypropylene and polylactic acid

Introduction

Natural filler materials can be employed as reinforcement in polymer composite materials in addition to synthetic filler materials. Natural filler materials have the benefit of being inexpensive and biodegradable, as well as being readily available. The usage of three different filler materials in composite materials made of polypropylene (PP) and polylactic acid (PLA) has been explored by Liu et al. (2014). Particles of cellulose and lignin were separated from the wood powder and employed as various fillers in polymer products. The thermal and physical qualities were assessed by mechanical tests. According to the experimental findings, lignin particle filled composites had superior thermal stability and water resistance but worse mechanical qualities than those supplemented with cellulose powder. The heat deterioration of the wood powder reinforced composite was likewise subpar, and it had a hydrophilic nature. The morphological examination showed that lignin particles and polypropylene adhered to each other more tightly than other materials. Chun et al. investigated how coconut shell powder (CSP) affected the mechanical and thermal characteristics of PLA biocomposite (2012). Utilizing both untreated and treated coconut shell powder, composites were created, and the effects of chemical treatment and filler loading were investigated. According to reports, adding coconut shell powder decreased tensile strength while increasing tensile modulus. The composite's tensile strength increased as a result of being treated with a silane coupling agent. Coconut shell powder has been investigated by Sareena et al. (2012) as a useful reinforcing for natural rubber. Various particle sizes and volume fractions of CSP, both modified and unmodified, were used to create natural rubber composites.

The composite's tensile strength, hardness, and rip strength were investigated. According to reports, 10% CSP reinforcement has superior qualities to other volume fractions. Silane coupling agent was used to modify CSP, which produced better physical and mechanical properties. Fractography was used to examine the surface morphology using SEM images. In order to create composite materials, Navaneethakrishnan et al. (2016) used several reinforcements in vinylester resin. Sisal fibre, coconut shell powder, and both sisal fibre and coconut shell powder were used to create three different types of composite materials. Measurements were made of the thrust force and torque created in response to drilling parameters. It was discovered that the production circumstances, feed, cutting speed, and tool shape all had an impact on the thrust force and torque. Sisal fibre reinforced composite had demonstrated higher thrust and torque among all of these composites. Onegbu et al. produced composites with varying volume fractions of powder filler in a polypropylene matrix using snail shell powder as filler material (2011). By taking into consideration a reference filler material of talk with a particle size of 0.15 micrometre, investigations were carried out utilising different volume fractions and particle sizes of the powdered snail shell. The experimental findings showed that adding more filler to a polypropylene composite increased its tensile modulus, flexural strength, and impact strength. The mechanical qualities were negatively impacted by the particle size. Polypropylene green composites were filled with banyan tree sawdust. According to Ramesha et al. (2016), the addition of banyan tree sawdust powder enhanced the composite's mechanical qualities. It was also demonstrated that the presence of filler material has an impact on abrasive water jet machining. On the machining properties, the impact of coupling agent and mineral filler material addition was documented. By Bootkul et al. (2017) composites were made utilising saw dust at 7 various volume fractions, including 10%, 20%, 30%, 40%, 50%, 60%, and 70%, and the influence of volume fraction on the mechanical characteristics was documented. Teak wood sawdust was used as filler material in high density polyethylene. The findings showed that an impact strength reduction of more than 30% occurred with a filler content. The exterior decorating for the Thai spirit house was later built using the composite samples. By Lette et al., wood polymer composite was created (2018) Saw dust and rice husk were employed as reinforcements in powder form, with phenolic resin serving as the matrix material. The filler to matrix ratio was set at 60:40. Sawdust powder, rice husk powder, and both powders combined were used to create composite materials. The impact of UV light exposure on the water stability and mechanical characteristics of composites made of sawdust and rice husk is included in the experimental analysis. The findings showed that saw dust and phenol resin composites have superior mechanical characteristics over rice husk composites. It has been noted that saw dust adheres to the phenolic resin more effectively than the particle rice husk filler material. Jaya et al. (2018) investigated how wood dust powder affected the unsaturated polyester matrix's mechanical characteristics. According to the findings, the composite containing 6% sawdust powder performed better mechanically. According to a report, wood powder can be utilised as a more effective reinforcing and to create composite materials for mass production.

Krishna et al. employed sawdust and fly ash as filler materials in epoxy resin (2018) By adjusting the ratio of fly ash to sawdust, a hybrid composite was created, and the impact of filler loading on hardness, compressive strength, and moisture absorption was researched. The findings showed that the properties began to decline with filler loading above the threshold level as a result of inadequate epoxy resin wetting of the reinforcements. Suthan et alinvestigations .'s on the mode 1 fracture toughness of an epoxy composite material reinforced with sawdust powder and jute fibres were done in 2019. Different volume percentages of woven jute fibre and sawdust were combined with an epoxy matrix to create composite materials. Glass fibre reinforced composite containing egg shell powder as a filler ingredient was created by Hiremath et al. (2018). In their research, the composite materials were created utilising 50% glass fibre, 5% to 10% egg shell powder as filler material, and the rest polymer matrix. The composites were created using the hand layup method. The study of mechanical and physical qualities. The outcomes showed that 10% eggshell powder can increase stiffness, and 10% eggshell powder integration also showed a similar trend. Using a polyester matrix, Ganesan et al. (2018) created a jute fibre reinforced composite. Jute fabric that has been NaOH-treated and untreated were combined to create composite materials. Egg shell powder and nano clay's impact were investigated. Studying the mechanical and morphological qualities revealed that the composite material that included 1.5% egg shell powder and 1.5% nanoclay had superior properties to other compositions. Better mechanical properties were obtained as a result of the chemical treatment, and good interfacial adhesion was also noted as a result of the chemical treatment of the reinforcement. The composites based on poly lactic acid (PLA) and eggshell powder were created by Ashok et al. (2014). The fabrication of the composite poly lactic acid films utilized egg shell powder at a weight fraction of 0.1 to 0.5. The final composite was put through a number of tests, including X-ray, tensile, and micrograph analyses. Tensile strength and tensile modulus values increased with the addition of egg shell powder up to 4%. The addition of eggshell powder enhanced the composite's crystallinity. The SEM images had demonstrated that the particles were evenly dispersed at a loading of 4% and that adding egg shell powder in amounts greater than 4% caused the particles to aggregate. Bootklad et al. (2013) produced biodegradable thermoplastic starch (TPS) composite materials using egg shell powder. The characteristics of the composites made from egg shell powder and TPS were compared to those of commercial calcium carbonate. According to the test results, calcium carbonate-like characteristics are produced when eggshell powder is added. Additionally, the composite that contained egg shell powder decomposed more quickly than the composite that contained calcium carbonate. The addition of eggshell powder to thermoplastic starch significantly improved the material's thermal stability and moisture resistance. The research mentioned above demonstrates the importance of filler particles and the characteristics of polymer matrix composites. By influencing strength favourably through a number of physical factors, including particle volume fraction, particle size, and the interaction of the particle with the matrix, are filler particles. The three elements mentioned above have a significant impact on the composites' overall mechanical and thermal properties. Additionally, fillers are employed to improve the composite material's surface characteristics, such as its hardness and tribological characteristics (Friedrich et. al. 2005).

EXPERIMENTAL DETAILS

In this investigation, LY 556 Epoxy resin and Moringa Oleifera filler-blended epoxy natural resin were both used. According to calculations, the filler made from Moringa oleifera has a density of 1.06 g/cm3. Using a ball mill, the natural resin material from the Moringa oleifera filler was ground to a fine size of 7-13 microns over the course of four hours. Then, it was mixed with epoxy at various volume percentages (10, 15, 20, 25, and 30 percent by volume). For 45 minutes, both the natural and synthetic resins were continuously swirled in a mechanical mixer to achieve uniform dispersion. Laminates made of Moringa oleifera filler and epoxy hybrid polymer materials were produced using the compression molding technique. The laminates were sliced for several tests after curing in accordance with ASTM standards. Tensile and flexural testing procedures were executed using the Instron Universal Testing Machine. Following the ASTM D-638 standard, the tensile test was performed at a rate of 2 mm/min. To assess flexural strength, a three-point bending test was conducted in accordance with ASTM D-790. The impact strength was determined using the Izod method, following the guidelines outlined in ASTM D-256. Each of these tests involved the use of five samples, and the average values were computed to derive representative measurements. This approach adheres to standardized testing protocols, ensuring consistency and reliability in the evaluation of tensile, flexural, and impact properties. Using the SEIKODMAI-DMSC 6100 under hot and dynamic loading conditions, the dynamic characteristics of an epoxy hybrid material, including Cark filler, were examined. Dynamic mechanical analysis tests were conducted in a Nitrogen environment under tensile mode at temperatures ranging from 30 to 180°C at frequencies of 10 Hz with a 5°C/min increase. The thermal stability of the composite specimen was assessed across a temperature spectrum of 0-800°C, employing a heating rate of 20°C per minute. This analysis was conducted using a TG/DTA 6200 SEIKO TGA analyzer. The specimen was subjected to heating in a nitrogen environment to prevent oxidation, ensuring a controlled and inert atmosphere during the thermal testing process.

Biodegradability Test: Soil burial remains the traditional and widely adopted method for evaluating degradation, aligning with real waste disposal conditions. Soil, as a dynamic and intricate ecosystem, hosts a diverse array of organisms, creating a dynamic and complex environment conducive to active degradation processes. The biodegradability of the sample was assessed by monitoring its weight loss over time in a soil environment. The methodology involved weighing the samples before burying them in the ground. Subsequently, the buried samples were carefully unearthed at specific intervals: 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120 days. Following extraction from the soil, the samples underwent a rinsing process with water before being weighed again to quantify the extent of weight loss. This comprehensive approach provides valuable insights into how the material responds to the dynamic conditions of a soil environment and allows for an accurate assessment of its biodegradability over the specified time intervals. To determine the dispersion of the filler from Moringa Oleifera throughout the polymer matrix, morphological investigations were conducted using a scanning electron microscope (SEM). The experiment utilized a Hitachi S 3400 N scanning electron microscope. To prevent charging, gold was sputter-coated onto composite samples.

Results and Discussion

This paper proposes the blending of epoxy resin with Moringa oleifera filler to enhance the qualities of hybrid polymer composites. A comprehensive study was conducted to compare the results with those obtained using pure epoxy resin. The mechanical properties of hybrid polymer composites, manufactured with epoxy resin and Moringa Oleifera filler, are depicted in Figures 1-3. Figure 1 illustrates the impact of adding natural resin to epoxy resin on the composite's tensile properties.

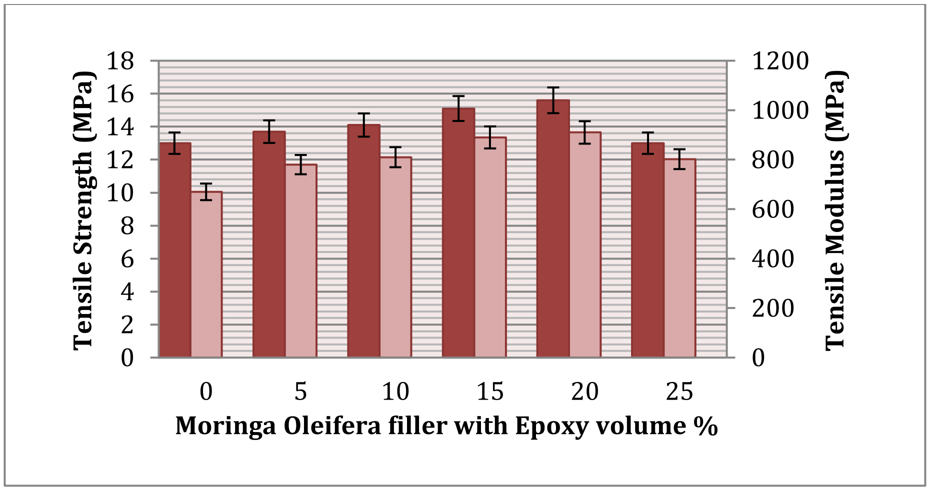


Figure 1 Tensile property of Moringa Oleifera with Epoxy Blender Hybrid Material

Pure epoxy resin exhibits tensile strength and modulus measurements of 17.5 MPa and 1200 MPa, respectively. Upon incorporating a 25 volume percent of Moringa Oleifera filler into the blended epoxy resin, the strength and modulus values of the epoxy bio-resin increased by 12.26% and 31.97%, respectively. However, both strength and modulus decrease from 21.17 MPa to 22.13 MPa with a further increase to 25 volume percent. Micrographs of hybrid polymer composites with 20% and 25% natural resin additions are presented in Figures 4-5.

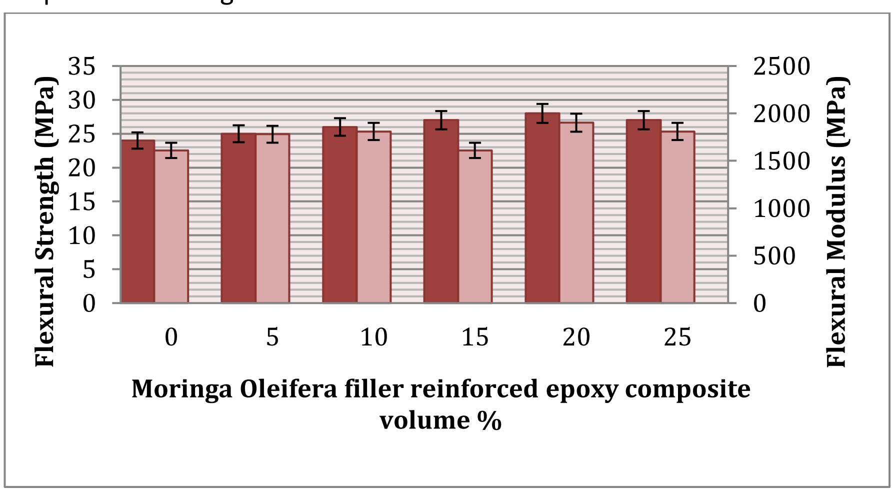


Figure 2 Flexural properties of Moringa Oleifera filler blended epoxy with Epoxy Blender Hybrid Material

The composite's flexural properties are shown in Figure 2. Flexural strength and modulus of epoxy resin are 27 and 1700 MPa, respectively. The composite with 30% Moringa Oleifera filler blended epoxy increased in flexural strength and flexural modulus by 15.37 and 22.70 percent, respectively. Flexural values of hybrid polymer materials made from Moringa oleifera and epoxy show improvements of up to 30% volume percent, which are comparable to tensile qualities.

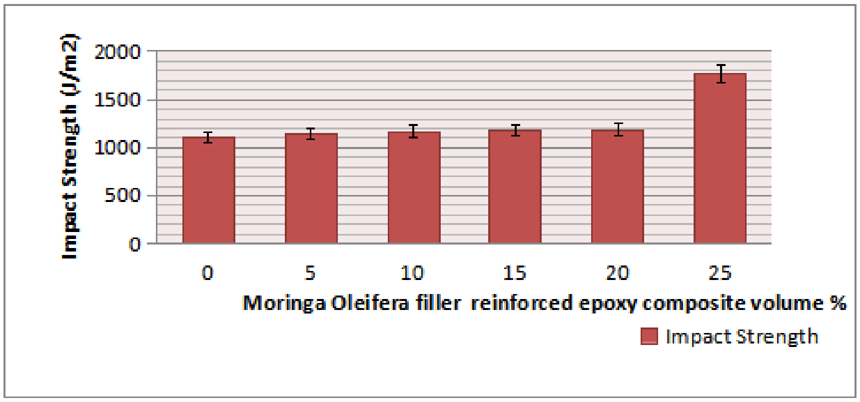


Figure 3 Impact properties of Moringa Oleifera filler blended epoxy with Epoxy Blender Hybrid Material

Figure 3 displays the impact strength of the cark filler and epoxy hybrid composite. Epoxy resin has an impact strength of 2 J/m2, but hybrid polymer composites with 10, 15, 20, 25, 30, and 35 volume percent have impact strengths of 2,469, 2,557, 2,648, 2,687, and 2718, 2,671 J/m2. The greatest impact strength of the hybrid polymer composites with a 30 volume percent Moringa oleifera filler blended epoxy was 2,718 J/m2. The decreased impact strength of the epoxy resin is due to its brittleness, but the Moringa Oleifera filler blended epoxy has better adherence to the epoxy resin. The composite's ductility has grown as a result, and its impact strength has gone up by 18.4%.

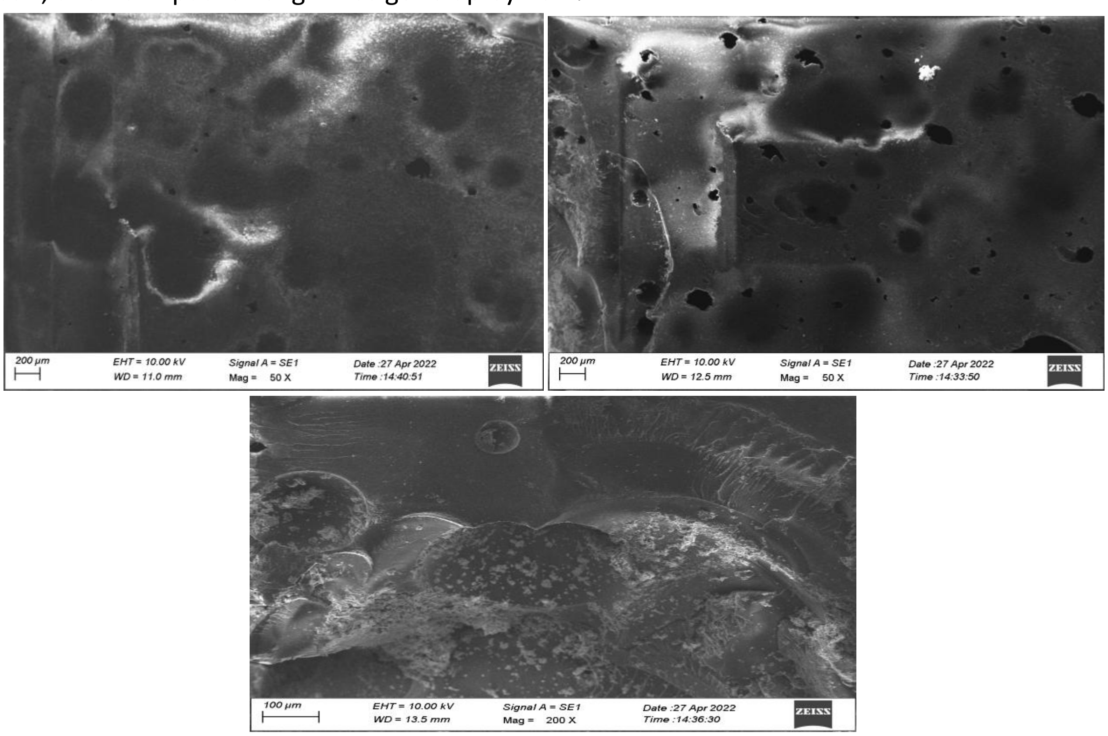


Figure 4 25 vol % Moringa Oleifera filler blended epoxy with epoxy resin evenly dispersion

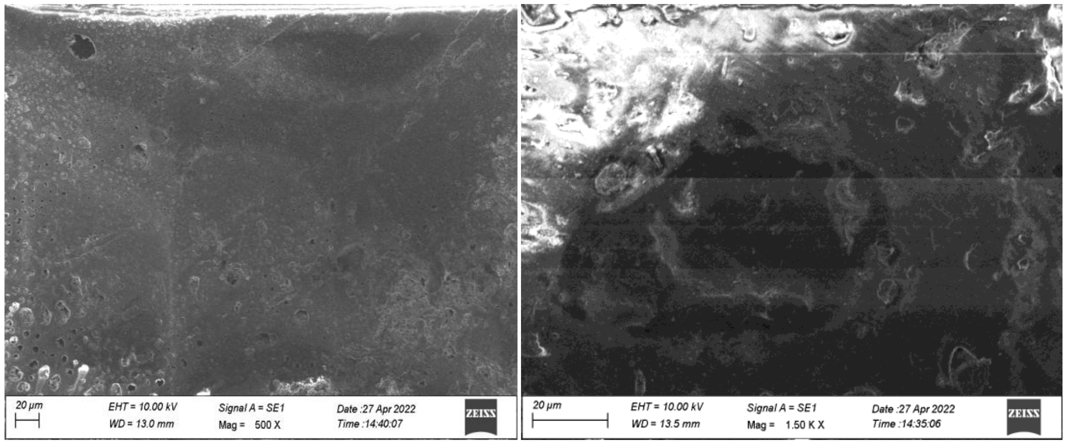


Figure 5 30 vol % Moringa Oleifera filler blended epoxy with epoxy resin agglomeration

The hybrid polymer materials in Fig. 4's SEM image have natural resin added at a 25 volume percent concentration. It proves that the natural resin is dispersed uniformly. The load carrying capacity of hybrid polymer composites is enhanced by this equal dispersion. Fig. 5 also displays the SEM image of a 20 volume percent hybrid polymer material. Agglomeration results with the addition of a volume percent of natural resin, as shown in the SEM images. Agglomeration prevents natural resins from equally dispersing load, which causes the degradation of their mechanical properties.

Dynamic Mechanical Analysis

Using dynamic mechanical analysis, the polymer's viscoelastic behaviour is evaluated. It gauges the polymer material's damping capabilities during cyclic loading. It is measured how much energy is lost. This study investigates the impact of the storage modulus and damping factor of the hybrid polymer material on the volume percent of Moringa Oleifera filler blended epoxy natural resin. The impact of frequency on the storage modulus of hybrid polymer materials is also covered. Figures 6 and 7 show how temperature and the loading of an epoxy resin with a blend of Moringa Oleifera filler affect a hybrid polymer composite's storage modulus at 10 Hz frequencies. The results showed that the absorption energy of the hybrid polymer material was boosted by the addition of Moringa Oleifera blended epoxy natural resin. This is because adding natural components to the pure epoxy matrix enhances the hybrid polymer's capacity to store energy.

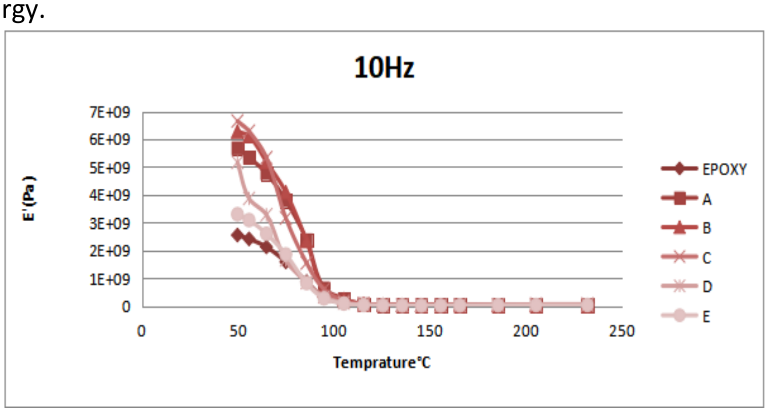


Figure 6 Storage modulus of Moringa Oleifera filler blended epoxy with Epoxy Blender Hybrid at 10 Hz Frequency

Pure epoxy resin is stiffer because it has a lower storage modulus, as seen in Figure 6. Due to free molecular movement in the polymer along the chain, the composite's glass transition temperature (Tg) increases from 70 to 110°C. The rigidity of the Moringa Oleifera filler blended epoxy natural resin using hybrid polymer material, according to researchers, is improved by the addition of a polymer matrix. Another interesting finding from Figures 6 is the usage of mixed epoxy natural resin made from Moringa Oleifera. It raises the storage modulus in both the glassy and rubbery regimes. According to studies, exposure at higher frequencies for a shorter time produces higher storage modulus values than exposure at lower frequencies for a longer time produces lower storage modulus values. This results from the reorganisation of the material molecules to lessen local stressors.

Damping factor (Tan δ)

The damping factor, serving as an indicator of a material's energy dissipation during loading and the molecular mobility within the polymer chain, is computed as the ratio of the loss modulus to the storage modulus. Figures 7 and 8 illustrate the damping factor of the hybrid material composed of Moringa Oleifera, epoxy, and natural resin. These figures provide a visual representation of how the material behaves in terms of energy dissipation and molecular mobility under applied loads. The findings imply that increasing the damping factor by up to 30% by adding Moringa Oleifera blended epoxy natural resin to the polymer mixture. This indicates that there is a greater interaction between synthetic and natural resins in polymer composites with a lower proportion of Moringa Oleifera filler combined with epoxy natural resin. Because of their enhanced contact, natural materials lose more energy. The higher natural resin content (greater than 30% volume percent), however, reduces energy dissipation, as can be shown in Figures 7 and 8. The Tan (damping factor) peak height in neat epoxy resin is comparatively smaller than in the epoxy natural resin hybrid polymer material blended with cark filler. This observation suggests that an increased loading of natural resin enhances the stiffness of the composite material.

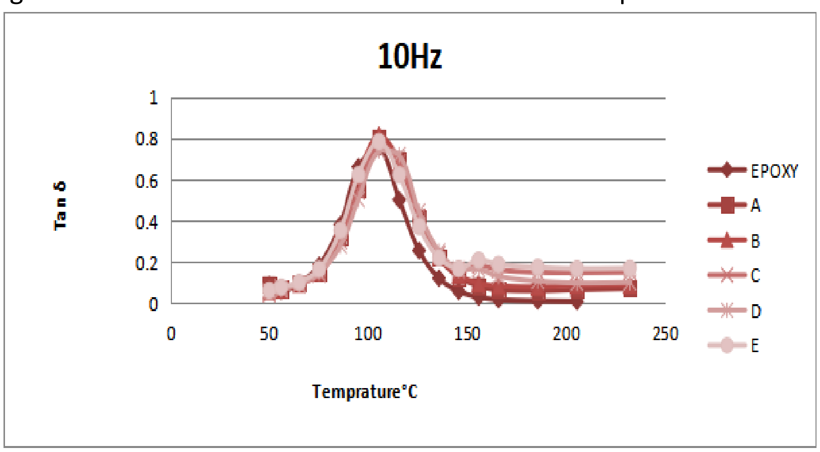


Figure 7 Tan δ of Moringa Oleifera filler blended epoxy with Epoxy Blender Hybrid Material at 10 Hz Frequency

Cole- Cole Plot

To analyze the linear viscoelastic properties of the polymer composite at its glass transition temperature, a Cole-Cole plot is employed. This plot is generated at a frequency of 10 Hz, depicting the relationship between the loss modulus (E′′) and the storage modulus (E′). The Cole-Cole plot serves as a valuable tool for understanding the viscoelastic behavior of the material, particularly during the transition between its glassy and rubbery states. The cross-linked polymer undergoes structural modifications as a result of the addition of natural Moringa Oleifera filler blended epoxy resin, as demonstrated in this figure. The following curve serves as an illustration, where the characteristics of the curve indicate whether the material is homogenous or heterogeneous.

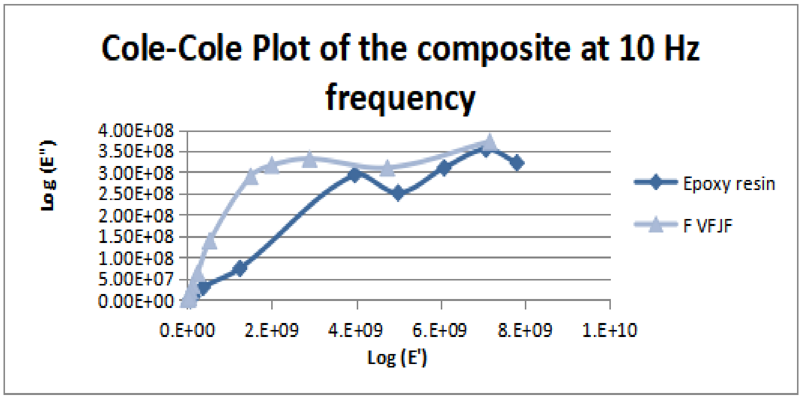
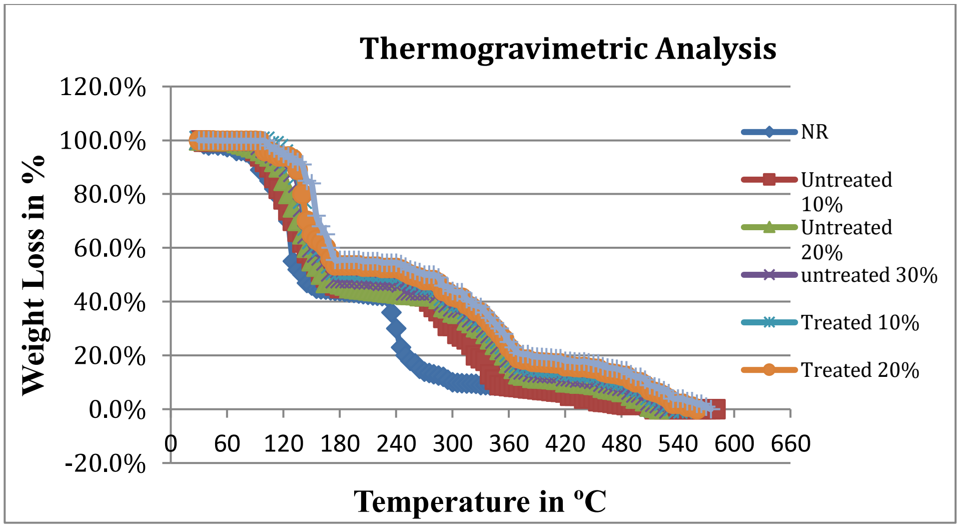


Figure 8 Cole- Cole Plot Moringa Oleifera *filler blended epoxy* with Epoxy Blender Hybrid Material

Figure 8 cole-cole plot demonstrates that the hybrid polymer material's properties are homogeneous. Figure 8 shows how a homogeneous mixture is created by mixing 25% Moringa Oleifera filler with epoxy natural material. When epoxy natural resin combined with 30% Moringa Oleifera filler is introduced, the material's behaviour changes from homogeneity to heterogeneity. The Cole-Cole figure demonstrates that the curve is semicircular for 20% of the volume, and that the composite is becoming heterogeneous if the curve deviates from its semicircular nature.

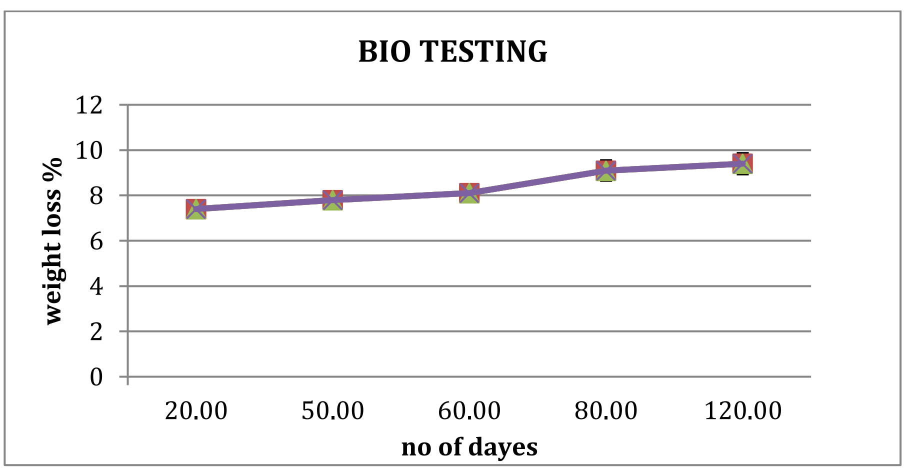
Thermogravimetric analysis

The thermogravimetric analysis (TGA) curves of the hybrid polymer material and neat epoxy resin are displayed in TABLE 1. The thermal stability of pure epoxy was shown to be higher than neat epoxy resin when Moringa Oleifera blended epoxy resin was added. The outcomes demonstrate that the thermal stability is unaffected by the presence of cark blended epoxy hybrid material in the epoxy matrix. However, there was only a very slight increase in TGA values when the Moringa Oleifera blended epoxy natural resin components were used. The initial phase of weight loss was brought on by the evaporation of water from the sample. As a result, adding Moringa Oleifera blended epoxy natural resin to the epoxy matrix enhances the thermal stability of the hybrid polymer composites. The stability of the epoxy resin up to 491°C is shown in Figure 9. At this temperature, the resin dissolves quickly and leaves only 0.3 percent of residues; in contrast, Moringa Oleifera combined epoxy leaves no residue. It contains a residual content of 9% and is stable up to 25%.



Biodegradability Test

In evaluating the biodegradability of hybrid Moringa Oleifera-epoxy polymer materials, a material sample was subjected to burial in wet soil, as illustrated in Figure 10. The initial weight of the sample was recorded before burial, and subsequent measurements were taken at specified intervals to monitor any changes in weight. After 120 days of exposure, the sample exhibited a weight loss of 5.2%, indicating a degree of biodegradation. Interestingly, the observed trend in weight variation showcased an initial increase attributed to moisture absorption. However, this rise was followed by a subsequent decline, suggesting a dynamic interplay between the material and its environment over the assessment period. Such nuanced insights into the biodegradability characteristics contribute valuable information for understanding how the hybrid Moringa Oleifera-epoxy polymer materials interact with and respond to environmental conditions.



The observed weight loss in the composite sample was attributed to its interaction with both micro- and macro-organisms over an extended period. When compared to the biodegradation results of other natural fiber and filler-reinforced polymer composites, the epoxy hybrid material with Moringa Oleifera filler blend demonstrated higher biodegradability. These findings suggest that the incorporation of

Moringa Oleifera filler into the epoxy matrix enhances the environmental friendliness of the polymer. This underscores the potential of the hybrid material to undergo natural degradation processes more effectively than comparable composite materials, making it a more sustainable and eco-friendly choice.

Conclusion

This investigation focused on assessing the impact of varying volumes of Moringa Oleifera filler blends on the mechanical, thermal, biodegradable, and dynamic properties, including storage modulus and damping factor, of epoxy composites. Notably, the incorporation of 20% filler content in the epoxy matrix containing Moringa Oleifera resulted in notable enhancements in tensile, flexural, and impact strength, as per the findings from mechanical tests. The dynamic mechanical analysis further substantiated this improvement, indicating an elevation in storage modulus and glass transition temperature with the 20% filler addition, suggesting heightened stiffness between the matrix and filler components. Furthermore, examination of scanning electron microscopy (SEM) images highlighted non-uniform distribution of the filler within the epoxy matrix, presumably due to the composition of the dark filler and matrix blend. This non-uniform distribution was observed to impact the material's overall properties. In terms of biodegradability, the conducted test revealed a recurring occurrence of 6.2% weight loss after 120 days, suggesting a degree of degradation within this time-frame. These findings collectively contribute valuable insights into the multifaceted effects of Moringa Oleifera filler and its loading volumes on epoxy composite properties, shedding light on potential improvements in mechanical strength and highlighting aspects that warrant further consideration in achieving optimal composite performance.

Reference

1. Berthelot, J. M. (2006). "Damping analysis of laminated beams and plates using the Ritz method," *Composite Structures* 74(2), 186-201. DOI: 10.1016/j.compstruct.2005.04.031

2. Bodros, E., Pillin, I., Montrelay, N., and Baley, C. (2007). "Could biopolymers reinforced by randomly scattered flax fibre be used in structural applications?" *Composites Science and Technology,* 67(3–4), 462-470. DOI: 10.1016/j.compscitech.2006.08.024.

3. Boopalan, M., Niranjanaa, M., and Umapathy, M. J. (2013). "Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites", *Composites Part B: Engineering,* 51, 54-57. DOI: 10.1016/j.compositesb.2013.02.033.

4. Dhawan, V., Singh, S., and Singh, I. (2013). "Effect of natural fillers on mechanical properties of GFRP composites", *Journal of Composites*, 2013, 1-8. DOI: 10.1155/2013/792620.

5. Haq, M., Burgueño, R., Mohanty, A. K., and Misra, M. (2008). "Hybrid bio-based composites from blends of unsaturated polyester and soybean oil reinforced with nanoclay and natural fibers", *Composites Science and Technology*, 68(15–16), 3344- 3351. DOI:10.1016/j.compscitech.2008.09.007.

6. Joshi, S., Drzal, L., Mohanty, A., and Arora, S. (2004). "Are natural fiber composites environmentally superior to glass fiber reinforced composites?," *Composites Part A: Applied Science and Manufacturing*, 35(3), 371-376. DOI: 10.1016/j.compositesa.2003.09.016

7. Kokta, B. V., Raj, R. G., and Daneault, C. (1989). "Use of wood flour as filler in polypropylene: Studies on mechanical properties," *Polymer-Plastics Technology and Engineering*, 28(3), 247-259. DOI: 10.1080/03602558908048598

8. Lee, S. H., and Wang, S. (2006). “Biodegradable polymers/bamboo fiber biocomposite with bio-based coupling agent,” *Composites Part A: Applied Science and Manufacturing*, 37(1), 80-91. DOI: 10.1016/j.compositesa.2005.04.015.

9. Monteiro, S. N., Terrones, L. a H., and D’Almeida, J. R. M. (2008). “Mechanical performance of coir fiber/polyester composites”, *Polymer Testing,* 27(5), 591-595.DOI:10.1016/j.polymertesting.2008.03.003.

10. Rajesh, M., Jeyaraj, P., and Rajini, N. (2016a). “Mechanical, dynamic mechanical and vibration behavior of nanoclay dispersed natural fiber hybrid intra-ply woven fabric composite”, in: Nanoclay Reinforced Polymer Composites: *Natural Fibre/Nanoclay Hybrid Composites*, M. Jawaid, A. el K. Qaiss, and R. Bouhfid, eds., Springer

11. Liu, E. K., He, W. Q., & Yan, C. R. (2014). ‘White revolution’ to ‘white pollution’—agricultural plastic film mulch in China. *Environmental Research Letters*, 9 (9), 091001.

12. Liu, W., Chun, E., Thompson, A. A., Chubukov, P., Xu, F., Katritch, V., & amp; Stevens, R. C. (2012). Structural basis for allosteric regulation of GPCRs by sodium ions. Science, 337(6091), 232-236.

13. Sareena, C., Ramesan, M. T., & Purushothaman, E. (2012). Utilization of coconut shell powder as a novel filler in natural rubber, *Journal of Reinforced Plastics and Composites*, 31(8), 533-547.

14. Venkatachalam, N., Navaneethakrishnan, P., Rajsekar, R., & Shankar, S. (2016). Effect of pretreatment methods on properties of natural fiber composites: a review. *Polymers and Polymer Composites*, 24(7), 555-566.

15. Onuegbu, G. C., & Igwe, I. O. (2011). The effects of filler contents and particle sizes on the mechanical and end-use properties of snail shell powder filled polypropylene. *Materials Sciences and Applications*, 2(07), 810.

16. Mathieu, M. F., Zhao, J. J., Zhao, J., Ramesh, A., Sprechmann, P., & LeCun, Y. (2016). Disentangling factors of variation in deep representation using adversarial training. *Advances in neural information processing systems*, 29.

17. Bootkul, D., Butkul, T., & Intarasiri, S. (2017). Physical and mechanical properties of wood plastic composites from teak wood sawdust and high density polyethylene (HDPE). In Key *Engineering Materials*,Vol. 751, pp. 277-282. 18. Suthan, R., Jayakumar, V., & Madhu, S. (2019, July). Investigation on Mode I Interlaminar Fracture Toughness of Chemically Treated/Untreated Saw Dust Powder Based Jute Fabric Reinforced Epoxy Composite Structure. In IOP Conference Series: *Materials Science and Engineering*,vol. 574, No. 1, p. 01,2023.