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A Case Study: Assessment of Characterization and Development of Polymer Composites Reinforced with Natural Fibers

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Abstract:
Polymer composites that are composed of synthetic resources are toxic and non-biodegradable. Additionally, they contain petroleum-grounded resources, which are greatly detrimental to both humans and the environment. The aim of the study is to assess the characterization and development of polymer composites reinforced with natural fibers. Chemical and thermal characterization (FTIR spectroscopy, XRD analysis, and TGA) were conducted, along with physical aspects (density, vacancy %, and moisture absorption behaviour). The actual density of the bio-Comp. and hybrid Comp.s that were developed was assessed utilising the Archimedes principle-grounded water immersion method. After water immersion, the jute/hemp/epoxy Comp. exhibited a glass transition temp. of 76.2 0C, which is the fourth greatest value were made. The jute/hemp/flax/epoxy hybrid Comp. that was water-saturated attained the lowest value of tan δ (0.401). The mechanical properties of the majority of NFs are satisfactory; however, they are inferior to those of synthetic fibres. Natural fibres, including flax, hemp, jute, has great specific strength and rigidity.

Keywords: *Polymer composites, Natural fibres, Jute, Hemp, Flax.*

INTRODUCTION

Composite materials are composed of two or more constituents that are wholly insoluble in each other and possess unique physical aspects and chemical compositions [1] possess such combinations of aspects [2]. The two primary components of Comp. material are the matrix, which is the continuous phase, and the reinforcement, which is the discontinuous phase. The selection of the fibre and matrix proportion is a critical component of the Comp. material processing procedure [3]. Composite materials with aspects that are distinct from those of their individual constituents should have a proportion of each constituent that is greater than 5% [4]. The matrix surrounds the fibre phase to deliver the correct shape and size to the developed Comp. material, while the reinforcement has a greater strength than the matrix, which delivers reinforcing to the material [5]. In recent years, there has been a surge in the interest of researchers in the field of Comp. material development and characterization [6]. In an effort to boost the performance capabilities of the Comp. material that has been developed, efforts are made to combine numerous fibres with the matrix and to hybridise the fibres [7].

Polymer Comp.s are frequently employed owing to their substantial attributes, including their low weight (wt.) and great specific strength. A polymer composite (PC) material is formed by impregnating fibres with a polymer matrix (poly-mat), which forms a bond across them [8]. The matrix material for PCs can be either thermoset polymer (e.g., epoxy, polyester) or thermoplastic polymer (e.g., poly-lactic acid, polyvinyl alcohol) [9]. Biodegradable ploy-mat and synthetic ploy-mat are also subcategories of ploy-mat. Natural fibres that are reinforced with a synthetic ploy-mat are referred to as partially biodegradable PCs, while those that are reinforced with biodegradable polymer are referred to as fully biodegradable PCs [10].

Natural fibre reinforced Comp.s are produced by reinforcing NFs with a ploy-mat. Depending on the specific needs, plant fibres can be reinforced with either a thermoset or thermoplastic ploy-mat [11]. The incorporation of plant fibres into a ploy-mat can take on numerous forms, like cut fibres, uni-directional fibres, mats, bi-directional woven mats, and arbitrarily oriented mats. Natural fibres are excerpted from numerous natural resources, including plants, animals, and minerals [12]. Wood fibres (soft and hard woods) and non-wood fibres, like straw fibres (rice, wheat, maize, etc.), seed fibres (cotton, coconut, etc.), leaf fibres (sisal, pineapple, etc.), and grass fibres (bamboo, elephant grass), are the four categories into which NFs can be divided. The formation of bio-Comp.s is facilitated by the utilisation of a thermoset matrix (epoxy, polyurethane, polyimides, phenolic, etc.) and six thermoplastics (poly-lactic acids, poly-vinyl chlorides, cellulosic, acrylic, polypropylene, etc.) [13]. The MPs of the bio-Comp. that has been developed, including tensile, compressive, flexural, and impact strength, are contingent upon the fiber's rigidity, strength, density, ductility, and roughness, along with the volume fraction of reinforced fibres [14]. Various chemical treatments, including alkali treatment, silane treatment, acrylation, benzoylation, and permagnate treatment, are employed to boost the surface aspects of bio-fibers [15]. The objective of the study is to investigate the case study on the characterization and development of polymer composites reinforced with natural fibers.

Case Presentation

In the present case study, the production of novel natural fiber-reinforced polymer composites is facilitated by the utilisation of nature-based fibre materials. This innovative natural fibre composite has the potential to be used as structural components that are subjected to moderate loads. For instance, it can be used in the construction and manufacturing industry to create panels for separation and fall ceilings, partition boards, walls, floors, window and door frames, roof tiles and pre-fabricated buildings that can be installed in the event of normal calamities such as floods, cyclones, earthquakes, and short-term residents.

The research presented in this case study is broadly divided into four sections: a. The chemical and thermal characterization (FTIR spectroscopy, XRD analysis, TGA, and DTA), along with the physical aspects (density and moisture absorption behaviour), of NF reinforced epoxy Comp.s are examined. b. The MPs of the Comp.s that were developed were assessed before and after one year of water immersion, including tensile, flexural, impact, and hardness tests. SEM was employed to conduct a morphological analysis of the fractured surface during mechanical testing. c. Before and after one year of water immersion, DMA was conducted to evaluate the damping capability, storage Mod., and loss Mod. of all Comp.s that were developed. The DMA analyzer was utilised to record the damping capability (tan δ), storage Mod. (E´), and loss Mod. (E") curves in relation to temp. d. The pin-on-disc test apparatus was employed to investigate the dry sliding friction and wear behaviour of the epoxy-grounded Comp.s that were developed against a steel counterface before and after one year of water immersion.

Mechanical Characteristics

The Comp.s that were developed underwent mechanical characterization (tensile, flexural, impact, and hardness tests) both before and after one year of water immersion. The Comp.s that were developed were immersed in potable water at room temp. for a period of 12 months. After one year of immersion in water, the tensile, flexural, and hardness (shore D) aspects of the samples were assessed and compared to those of the dried specimens. Scan electron microscopy (SEM) was employed to investigate the interface across the matrix and fibre.

The flax/epoxy Comp. exhibited a greater hardness (98 Shore-D) and TS (46.2 MPa) than the jute/epoxy and hemp/epoxy Comp.s, which respectively demonstrated a flexural and impact strength of 85.59 MPa and 7.68 kJ/m2. The results indicated that hybrid Comp.s exhibited superior MPs. Jute/hemp/flax/epoxy hybrid Comp. exhibited the max. TS, Mod., and impact strength, respectively, at 58.59 MPa, 1.88GPa, and 10.19 kJ/m2. The maximal FS of the jute/hemp/epoxy hybrid Comp. was 86.6 MPa. The TS and Young's Mod. of the water-saturated jute/hemp/epoxy Comp. specimen were the most significantly reduced, at 46.9% and 51.8%, respectively.

The specimen of hemp/epoxy Comp. that was saturated with water exhibited the greatest reduction in FS, which was 45.1%. The jute/hemp/epoxy Comp. specimen obtained the greatest reduction in the flexural Mod., which was 39.7%. Moisture absorption did not result in a substantial drop in the values of hardness. The SEM images of the fractured surfaces of these bioComp.s delivered pertinent information regarding the degradation of the fiber/matrix interface.

Analysis of Dynamic Mechanical Systems

The dynamic mechanical analysis of all the Comp.s that were made before and after one year of water immersion, including their damping capability, storage Mod., and loss Mod. The % change in damping capability, storage Mod., and loss Mod. was analysed by comparing the results of dried specimens, and the effect of moisture absorption on these aspects was also examined. At a glass transition temp. (Tg) of 74 0C, neat epoxy demonstrated the max. damping capability (tanδ) of 0.81. The tanδ value of plain epoxy has been almost negligible as the temp. has increased from 0 0C to 60 0C, indicating low damping in this temp. range. The jute/hemp/flax/epoxy Comp. exhibited a maximal attenuation capability of 0.47 at a glass transition temp. of 79 0C, which was slightly greater (5 0C) than that of pure epoxy. The hemp/flax/epoxy hybrid Comp. demonstrated the second max. suspension capability (tanδ) of 0.68 and a minimum glass transition temp. of 60 0C.

The maximal attenuation capability of 0.66 was demonstrated by the jute/hemp/epoxy hybrid Comp. at a glass transition temp. of 62 0C. The results obtained indicate that the glass transition temp. is the most influential parameter, as the PC transitions from a "glassy," rigid state to a "rubbery" state at Tg, which is characterised by elevated molecular activities. The glass transition temp. of all the Comp.s that were developed increased in comparison to the glass transition temp. of dried specimens after one year of water immersion. The jute/hemp/epoxy Comp. that is submerged in water has a maximal increase in glass transition temp. (23.7%) when compared to the dried specimen.

Analysis of Friction and Wear

The wear and friction aspects of epoxy Comp.s reinforced with NFs (jute, hemp, and flax) and their hybrids were examined both before and after one year of water immersion. The friction and wear behaviour of all Comp.s that were developed were influenced by the load, speed, and sliding distance, as demonstrated by experimental investigation.

The frictional characteristics and sliding wear of the bio-Comp.s that were developed were assessed concerning tribological performance under dry contact conditions at varying process parameters, including the applied load (10-50N), sliding speed (1-5m/s), and sliding distance (1000-2000m). In comparison to the plain epoxy polymer, the wear behaviour of the developed NFRP Comp.s was substantially boosted by the incorporation of NFs into the epoxy ploy-mat, as confirmed by experimental results of wear analysis.

Mechanical characteristics following one year of immersion in water

1. The hardness (Shore-D) values of bio-Comp. specimens that are submerged in water indicate that moisture absorption has minimal impact on their hardness.

2. The tensile aspects of the material are significantly impacted by WA, as indicated by experimental results. Moisture absorption results in a reduction in TS values ranging from a minimum of 11% to a max. of approximately 47% in various Comp.s. Water absorption results in a nearly 50% drop in tensile Mod. Different combinations of bio-Comp.s that were made are observed to exhibit a minimum of 40% and a max. of 51% reduction in Mod. values.

3. The Comp. interface has been significantly impacted, as evidenced by the morphology of water-saturated Comp. specimens following tensile and flexural testing. This is a consequence of the hydrophilic nature of NFs, which causes debonding, dislocation, and fibre fracture by absorbing moisture.

Dynamic mechanical analysis prior to immersion in water

1. The stability of plain epoxy under dynamic loading conditions has been significantly boosted by the reinforcement of NFs, as demonstrated by the dynamic mechanical analysis of the developed Comp.s. The results indicate that the dynamic MPs (damping capability, storage, and loss Mod.) are significantly influenced by the type of NFs and their hybrid configurations that are reinforced with epoxy polymer.

2. The apex of damping (tanδ), storage Mod., and loose Mod. were all reduced by the incorporation of NFs (jute, hemp, and flax) with epoxy polymer. In comparison to other hybrid Comp.s, the jute/hemp/flax/epoxy hybrid Comp. obtained the greatest glass transition temp. with a lesser attenuation value (tanδ) and a greater storage Mod. The dynamic mechanical performance of the jute/hemp/flax/epoxy hybrid Comp. was improved by a greater storage Mod. and a low value of damping.

3. The dynamic MPs of the Comp.s that were made are boosted by the hybridization of NFs, as indicated by the results.

4. The incorporation of NFs has significantly reduced the brittleness of the epoxy matrix, as evidenced by the damping capability results.

Dynamic mechanical analysis following one year of water immersion

1. The results indicate that the dynamic MPs of the Comp.s that were developed were influenced by a year of water immersion.

2. The loss Mod. of each Comp. has increased owing to water immersion. This implies that the Comp. structure's stability is diminished following water immersion, owing to increased molecular displacement.

3. Due to their less affected interface, hybrid Comp.s have once again demonstrated superior DMA results in comparison to nonhybrid Comp.s following water immersion.

4. In comparison to other hybrid Comp.s that demonstrated superior dynamic mechanical performance, the water-aged jute/hemp/flax/epoxy hybrid Comp. obtained the greatest glass transition temp. with the lowest attenuation value (tanδ) and the greatest value of 172 storage Mod.

5. The damping capability of the jute/hemp/epoxy Comp. was reduced by the most (16.03%) when it was saturated with water, as compared to the dried specimens. In comparison to all other water-saturated specimens, the jute/hemp/flax/epoxy hybrid Comp. that was water-saturated attained the lowest value of tan δ (0.401).

Tribological characteristics prior to WA

1. The wear resistance of all the Comp.s that were made has been improved by the incorporation of NFs (jute, hemp, and flax) with epoxy polymer.

2. The degradation performance of epoxy has been significantly improved by the reinforcement of various combinations of NFs. The degradation performance of the Comp.s that were made is significantly influenced by the sliding speed and the applied stresses.

3. The coefficient of friction is nominally affected by speed at greater speeds, while the applied burden has a negligible impact on the coefficient of friction. The average coefficient of friction varies depending on the variety of Comp. This implies that the friction conditions of the Comp.s that were made are influenced by the variety of NF.

4. The specific attrition rate of the Comp.s that were made has initially dropped as the applied strain increases from 10N to 30N. Weight loss increased beyond 30 N load, leading to an increase in the specific wear rate of all Comp.s at varying sliding velocities. However, the specific wear rate of the Comp.s and their hybrids was significantly lesser than that of the plain epoxy in all conditions.

5. The research demonstrated that the tribological performance of the Comp. specimens is significantly influenced by the development of interfacial temp. during wear analysis.

After one year of WA, the tribological aspects are as follows:

1. The coefficient of friction increased swiftly up to 30 N load at each sliding speed after one year of water immersion. However, after 30 N load, the coefficient of friction either marginally dropped for some specimens or remained approximately constant.

2. At a gliding speed of 1 m/s, the coefficient of friction of flax/epoxy attained the greatest increase (46.9%) in comparison to its dried specimen. The jute/hemp/flax/epoxy mixture demonstrated the greatest increase in coefficient of friction (13.5% and 19.9%) when compared to its dried specimen at a gliding speed of 3 m/s and 5 m/s.

3. Specific wear rate increased continuously from 10 N to 50 N load for each sliding speed in water-immersed specimens. The sliding speed increased from 1 to 5 m/s, resulting in an increase in the specific wear rate for all Comp. specimens.

4. In comparison to the dried specimen, the specific wear rate of the hemp/flax/epoxy attained the greatest increment (228.9% and 51.56%) at 1 m/s and 3 m/s sliding speeds when immersed in water.

5. The max. increment (102.9%) was attained by the water-aged flax/epoxy Comp. at 5 m/s in comparison to the dried specimen

DISCUSSION

The commercial and domestic sectors have experienced a significant increase in the demand for products that are made from bio-Comp. materials over the past decade [16]. The researchers have devised numerous processing techniques to ensure the successful production of bio-Comp. components. The simplest and most cost-effective method for the fabrication of relatively basic shapes is hand lay-up technique. Fibre and polymer resin are applied onto a reusable open mould in spray lay-up [11]. the bio-Comp.s that utilise woven jute fabric as reinforcement and unsaturated polyester resin as a matrix. The authors deduced that the curing of the polymer and the resistance to fracture propagation were boosted by this fabrication procedure [13, 14].

For Comp.s that are rather intricately shaped, the compression moulding technique is also greatly prevalent. A hybrid bio-Comp. grounded in polyester that employs short, irregularly oriented banana and sisal fibres as reinforcement. The authors employed the compression moulding technique and determined that Comp.s produced through compression moulding exhibited a greater impact strength than those produced through resin transfer moulding [8, 9]. MPs of bio-Comp.s produced through the compression moulding process. The authors employed polyester as the matrix and sisal fibre as reinforcement. The MPs of compression moulded Comp.s were compared to those of resin transfer moulded Comp.s by the authors. In contrast to resin transfer moulded Comp.s, compression moulded Comp.s have a reduced strength, according to the authors. lactic acid thermoset polymer is employed to reinforce bioComp.s with flax and flax/basalt fibre [6,7].

The authors initially impregnated fibres into resin through manual lay-up. Basalt/flax reinforced Comp.s exhibited superior mechanical and thermodynamic aspects in comparison to pure flax fibre reinforced Comp.s, owing to the superior wettability of basalt fibre [16]. The injection moulding process is typically employed for the production of Comp.s in large quantities. By employing the injection moulding technique, bio-Comp.s were produced with pineapple and cassava flour as fillers and polylactic acid as the matrix material [14]. The Comp.s developed utilising the injection moulding process exhibited a great degree of interfacial adhesion across the fiber/matrix interface and a reduced count of cavities. This, in turn, contributed to the increased tensile and flexural strength of the Comp.s. injection moulding of polybutylene succinate (PBS) bioComp.s grounded in lignin [3].

CONCLUSION

The jute/hemp hybrid Comp. in comparison to other hybrid Comp. combinations, has demonstrated superior wear performance. The analysis of interfacial temp. during attrition demonstrates that the temp. at the interface continues to rise as the applied load increases. The tribological performance of the Comp. specimens is significantly influenced by the development of interfacial temp. during wear analysis.

There is a vast amount of potential for future researchers to investigate numerous additional aspects of the refining of natural fiber-reinforced PCs, as evident in the current research. The following are some suggestions for future research: a. A future investigation may involve the examination of the bearing of various chemical treatments on the aspects of the Comp.s that were made. b. Under lubricated conditions, the wear analysis of the Comp.s that were made can be conducted. c. Available simulation software may be employed to conduct FEM modelling on numerous processing aspects for these Comp.s.

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