A REVIEW ON NATURAL FIBER REINFORCED POLYMER COMPOSITES

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Abstract - *Polymers matrix composites are commonly used in a variety of applications, including aerospace, automotive, marine, and household, due to their design flexibility, light-weight, high modulus, ease of manufacturing to meet specific requirements, when compared to traditional metals composites. However, they possess poor mechanical, tribological and physical properties. In order to improve the aforementioned properties researchers introduced different fibers, flaks, and fillers into polymers. This article presents the recent development of the polymer matrix composites reinforced co-related with the mechanical characteristics (flexural strength, tensile strength, and hardness), Morphological characters (scanning electron microscopic (SEM), X-ray diffraction analysis (crystallinity), and FTIR (chemical compound)) analysis.*

Key Words: Natural Fiber, Polymer Matrix Composites (PMCs), Epoxy, Flexural Strength, Tensile Strength, and Hardness,

1. INTRODUCTION

Polymers are frequently using in a variety of applications, including aerospace, automotive, marine, and household, due to their ease of manufacturing varied forms to meet specific requirements, when compared to traditional metals and composites [1-2]. Polymers have possessed good modulus of elasticity, strength-to-weight ratio, corrosion resistance, less water absorption, electrical conductivity and many more features. Overall, the properties of polymers make them a popular choice for a wide range of applications across different industries. Their ability to maintain strength and durability in challenging environments, along with their cost-effectiveness and versatility, make them a valuable material for various products. As technology continues to advance, the use of polymers is likely to expand even further, offering innovative solutions for a variety of needs [3-4].

One of the key advantages of polymers is their flexibility in design and production. With the ability to be molded into virtually any shape or size, polymers can be customized to meet specific requirements and applications [5-6]. This versatility allows for the creation of complex and intricate designs that may not be possible with other materials. The polymers are classified into thermoplastics, thermosets, and elastomers.

Whatever the polymer type, it can be easily combined with other materials to enhance their properties and performance, further expanding their potential uses in various industries. The combination of matrix and reinforcement phases is merely known as a composite material, where the polymer will be matrix/base material then it is referred as polymer composites [8-9]. PMCs, are classified as either particle, fiber, or flakes reinforced depending on the kind of reinforcement that is integrated into the polymers. Particle reinforced PMCs typically involve the addition of small particles, such as ceramics or metals, to the polymer matrix to improve strength and stiffness. Fiber reinforced PMCs, on the other hand, use longer fibers, such as carbon or glass, to enhance the mechanical properties of the polymer [10-12]. Lastly, flake reinforced PMCs incorporate flat flakes, like mica or graphite, to provide thermal and electrical conductivity to the polymer. Overall, the flexibility and versatility of polymer composites make them a valuable material for a wide range of applications across industries. Nevertheless, the type of fiber is also very important in enhancing PMC qualities.

2. Fibers used in polymer composites

The fibers are majorly classified into two categories as synthetic and natural fibers as shown in Fig. 1. Normally, the man-made (synthetic) fibers derived from synthetic materials enhance the load-carrying capacity and mechanical properties of PMCs, but they have poor energy dissipation capabilities and are not environmentally friendly. Due to this, Mother Earth is facing several issues. The unsustainable use of synthetic fibers in PMCs has led to increased pollution and waste that is harming the environment. As a result, there is a growing need for more sustainable alternatives that can still provide the necessary strength and durability without causing further damage [8, 13]. Researchers are now exploring natural fibers and bio-based materials as potential solutions to reduce the negative impact on the planet while still meeting the performance requirements of PMCs. By making these changes, we can help protect Mother Earth and create a more sustainable future for generations to come. As a result of polymers' inability to degrade, the study shifts to the development of green products (bio-degradable products) as well as the reduction of natural fibers' (NFs) carbon footprints [14-15].

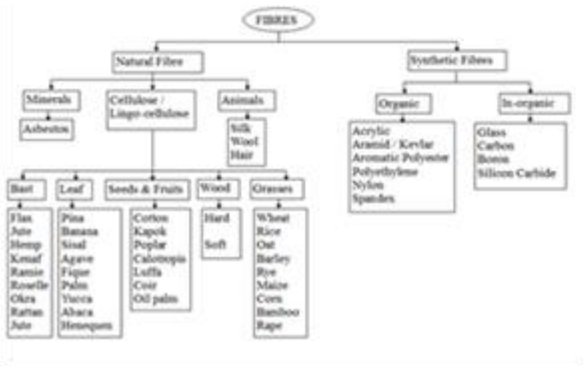

Figure 1. Classification of Fibres

Natural fiber reinforced polymer matrix composites (NFRPMC) came into existence because the NFs are biodegradable in nature and possess good energy dissipating features. Such NFs are directly harvested from the living organism, which consists of ignocellulose. NFRPMC are aimed to develop for intermediate and low-slung load applications. There are different kinds of NFs are available (Ref. Fig. 1) [14]. The cellulous/lingo-cellulous are classified as Plant fibres (jute, talipot, hemp, coir, sisal, palmyra, pineapple, banana, etc); Stem or Bast fibres (banana, baggase, jute, mesta, etc.); Fruit fibres (coir, oil palm, cotton etc.); and Leaf fibres (pineapple, sisal, screw pine etc.) are wide range of exploration as fibers utilized in production of NFRPMCs to improve the environmental sustainability for industrial materials, [15]. These natural fibers are not only renewable and biodegradable but also possess good mechanical properties, making them suitable for a variety of applications. By utilizing these plant-based fibers in NFRPMCs, industries can reduce their reliance on non-renewable resources and decrease their environmental footprint. In addition, these fibers can also help in enhancing the performance and durability of the composite materials, making them a viable alternative to traditional synthetic fibers. Overall, the utilization of natural fibers in NFRPMCs is a step towards creating more sustainable and eco-friendly industrial materials.

2.1 Influence of fiber orientation

These NFs are available in dissimilar arrangements such as short, randomly oriented, and continuous forms. Incorporation of short and randomly oriented NFs in polymers found difficulty in obtaining uniform distribution of fibers thereby non-uniform stress distribution will occur due to fiber discontinuity and prone to early failure of the PMCs. In addition, agglomeration of fibers with high-density polymers generates poor stress transfers between the fiber-matrix and prone to affects the stiffness of the composites as well as diminishes the mechanical properties [16]. Also, increase in fiber content and loading of fibers decreases the stiffness of the PMCs, whereas increase in length of NFs enhances the properties. Therefore, many researchers concluded that fiber orientation, loading, and length plays crucial role in obtaining exceptional properties of the composites [17]. The NFs are weaving in diverse patterns like plain, twill, baskets, braided, stain, knitted, and other patters [16, 18]. Among them, the woven fabrics (WFs) are in forefront in enhancing the modulus of NFPMCs for variety of structural applications. Also, woven fabrics reinforced NFRPMCs improves the natural frequency owing to free vibration characteristics and orientation of the fibers within the yarn.

3. Recent developments of NFRPMCs

Chkala et al. (2024), investigated the effect of incorporating different amounts of date palm fiber (DPF) on the mechanical, physical, and structural properties of geopolymer composites. These composites were formulated by utilizing mining residue as the geopolymer matrix and DPF as a reinforcing agent. The synthesis procedure involved activating the mining residue with a highly concentrated NaOH solution to form the geopolymer matrix. Subsequently, the resulting matrix was blended with different proportions of DPF, ranging from 1% to 20% (wt/wt), and underwent a 28-day curing period under ambient conditions. Mechanical properties were assessed through compression (CS) and flexural (FS, FM) tests, while water absorption (WA) and thickness swelling (TS) were employed to evaluate physical properties [1].

Ekpechi et al. (2023), developed novel composite materials using coconut shell fiber municipal solid waste (MSW), silicon carbide (SiC), aluminum oxide (Al2O3), and epoxy, using hand-layup and compression molding process. The developed specimens were subjected to mechanical, thermal, and water absorption tests using suitable apparatus. From the result obtained, specimen S1 which polymer material (epoxy) was reinforced with coconut shell fiber, displayed the impact of natural waste fiber on improving the polymer material's thermal and mechanical strength. 50.45MPa, 32.33, and 0.25W/mK values of tensile, hardness, and thermal conductivity strength respectively, were observed on the resulting test on sample S1, which is satisfactory compared to the value results from sample E, having only polymer material. Although sample E possesses the highest impact strength (15.2 J/m2) and water absorption values, due to the absence reinforce fiber. Natural synthetic fibers incorporation in the specimens had a huge impact on thermal and mechanical strength, such as seen from specimen S2 - S4 having a thermal conductivity of 0.45W/mK and hardness value of 44.52 [25].

Rana et al. (2023) investigate the bio-composites with reinforced natural sisal (Agave sisalana) fibres by hand lay-up method. Sisal fibre loading was kept constant (30 wt%) with varying fibre lengths (5, 10, 15 and 20 mm) incorporated in epoxy composites to study their effects on mechanical properties & Thermal stability. Mechanical testing (Tensile, Flexural and Impact) and were performed to identify mechanical properties. A remarkable improvement in tensile, flexural and impact strength were noticed in composites incorporated with sisal fibers of 15 mm. The significant enhancement in tensile, flexural and impact strength was evaluated by 20.15%, 39.95% and 47.27% respectively as compared to neat epoxy composite [5].

Deeban et al. (2023), utilized plant leaf fibers as reinforcements in thermo-plastic resins to produce affordable and light-weight composites. Although, these fibers have several advantages over synthetic fibers, mechanical characteristics of composites such as moisture absorption, poor wettability, and insufficient adhesion between the matrix and the fiber cause disadvantages. To overcome these issues, in this experimental study, two leaf-based plant fibers are hybridized and the composites have been fabricated by hand lay-up process. The composites were subjected to several tests. The results showed that the hybridization of sisal and pineapple leaf fiber (PALF) increases the mechanical strength of the composite by a maximum tensile strength of 3.59kN, a little lower flexural strength than the individual fiber, and a noticeably higher compressive strength. The results further showed that the decreased affinities for moisture content and the aged composites seem to be prone to be hydrophilic. Findings of the experiments reveal that the hybridization of sisal and PALF has a significant influence on the properties of the composites. The scanning electron microscopy micrographs of fractured surfaces have been examined, and the findings have effectively been investigated[3].

Sankarlal and Balaji (2022), demonstrated that comprises fabrication of Sisal Fibre Reinforced composite material in six different compositions and analyzing their mechanical properties for determining effective composition of composite materials. The optimal combined material can be replaced with materials for conventional wheel rim, bumper, and door panels in automobiles [4].

Sinitsky et al. (2022), investigated the effective elastic properties and strength of materials composed of unidirectional sisal fibers within a thermosetting polymer matrix, containing 20%, 40% and 60% fiber-volume fraction. Experiments with axial and off-axis loads in conjunction with finite-element modeling were utilized to determine the effective mechanical response of the composites. Analytical and numerical models were considered, using both isotropic- and anisotropic-fiber approaches. It is shown that only by considering the sisal-fiber anisotropy can the experimental results of the off-axis experiments be reproduced. A total of 15 tensile tests were performed on different sisal-fiber bundles: five for each bundle group, which contained different quantitative content of the fibers. During the loading, at first the fibers were stretched, then some of the fibers began to break before the load reached the maximum measured value; the bulk of the fibers broke after this in the strain range of 1.5–2%, and only some of the fibers reached a strain of 2.5%. The critical value of the load increased with an increase in the number of fibers: the 44, 88 and 132 g specimen bundles, on average, withstood 419, 807 and 1197 N, respectively. Thus, with an increase in the number of fibers, the load-bearing capacity also grew close to a linear relationship[27].

Gobikannan et al. (2021), studied on mechanical properties of composite board made from waste paper, wood dust, and sisal fibers with various weight proportions. The obtained result is compared with those of the conventional ceiling board results and it is observed that these composite materials can be used for internal low-cost construction work for separation, and acoustic & thermal insulation purposes[18].

Ayyappa et al. (2021), studied on caryota, sisal fiber-based epoxy resin hybrid composites were developed by using the hand layup technique, and the mechanical properties were investigated. Experimental results stated that hybrid composites showed superior properties. From the tensile test, it was found that 15C/25S hybrid composites have shown 38 MPa whereas single fiber composites (0C/40S, 40C/0S) showed 25 and 22 MPa respectively. From flexural properties, it was found that the hybrid composites showed improved flexural properties than single fiber composites. The 15C/25S hybrid composites showed flexural strength and flexural modulus as 89.16 MPa and 3.40 GPa. Single Caryota fiber composites showed the least strength and modulus as 64.09 MPa and 2.14 GPa. Coming to the impact strength 15C/25S composites showed as 97 joules and in single sisal fiber composites, it was observed that 83.5 joules. in all the tests hybridization effect was observed clearly except the hardness test. In the hardness test, single fiber composites showed superior properties to hybrid composites. The reason could be fabrication errors or poor bonding between matrix and reinforcement material[24].

Nagamadhu et al. (2019) studied that influence on dynamic mechanical and water absorption behavior of epoxy composites with three different woven fabric sisal fiber natural fiber. In that study results showed that decreasing the yarn diameter, the storage and loss modulus increased. Water absorption is less in plain type of fabric compared to other type of textile fabric weaving pattern[10].

Khalid et al. (2021), researched lowering the harmful effects of advanced materials on the environment the complete degradation of the materials for this purpose, researchers should consistently search for those materials which are completely combustible or biodegradable. It is concluded that these NFRPCs are superior to the synthetic fiber reinforced composites due to the following attributes. These NFs are present abundantly in nature, which makes them cheap and sustainable materials. There are different techniques like chemical treatments, coating of different materials on NFs and hybridization technique, which enhance the mechanical and physical properties of NFRPCs. NFRPCs, are best suited to ballistics applications due to their high-impact properties [30].

Arputhabalan et al. (2020), developed sandwich panel with dissimilar natural fiber like aloevera, sisal, kenaf, jute, flax as reinforcements and epoxy LY556 and GY250 as matrix. AA6061 facing sheets is placed between the natural fiber and compared. The epoxy GY250 and LY556 based epoxy composites[25].

Gupta, M. K., & Deep, V. (2019). Effect of water absorption and stacking sequences on the properties of hybrid SF/glass fibre reinforced polyester composite. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 233(10), 2045-2056.

Betelie et al. (2019), investigated mechanical properties of sisal fiber reinforced epoxy composites are developed using hand layup process with 15, 25, 30, 35, and 40 wt% sisal fiber to epoxy ratio. Tests for the properties indicated were made using the Instron material testing system. Test results demonstrated, among the samples, that 30 wt% of sisal fiber-reinforced composites have the maximum tensile and flexural strength of 85.5 MPa and 85.79 MPa respectively. The impact strength has been found to be maximum for 40 wt% sisal fiber which is 24.5 kJ/m2. As the result show, and compared with other researcher findings, the mechanical properties are acceptable as substitutes for applications demanding low-cost engineering applications such as automotive internal parts including interior door panel, back seat, and body panels[11].

Rajan et al. (2019), studied processing and characterization of sisal fiber reinforced epoxy composites. Based on the experimental results, it is observed the increase in volume fraction of fiber in composites tends to increase the tensile strength, flexural strength, and impact strength. Tensile strength, flexural strength, and impact strength of 30% volume fraction is higher than 10% and 20%[12].

Ravi Teja et al. (2019), explored the mechanical properties of hybrid composite materials reinforced with jute and sisal fibers. Mechanical testing, including tensile, flexural, and impact tests, revealed promising results in terms of strength, stiffness, and toughness. The hybridization exhibited synergistic effects, demonstrating improved mechanical properties compared to single-fiber composites. These findings suggest that jute and sisal fiber-reinforced hybrid composites have great potential for various engineering applications, offering a sustainable alternative to synthetic fiber composites with comparable or even superior mechanical performance[26].

Krishnasamy and Thiagamani et al. (2019), investigated the mechanical, water absorption and thermal behavior of hemp, sisal fibres were fabricated by hand lay-up technique, followed by hot press with different stacking sequences. The experimental results indicate that hybrid composites with sisal fiber as top and bottom layer exhibited optimized mechanical properties. Major variation in tensile strength, when the stacking sequence was altered[9].

Niranjan et al. (2019), conducted a comparative analysis and optimization of footrests by replacing aluminium with composite sisal fiber. Mechanical tests, including tensile and flexural evaluations, highlighted the potential of sisal fiber composites to meet the required strength criteria while significantly reducing weight. Furthermore, finite element analysis and design optimization methods were employed to refine the footrest's geometry and material distribution. The findings suggest that sisal fiber-reinforced composites offer a viable alternative to aluminium, achieving weight reduction without compromising functional performance in footrest applications[28].

Senthil Kumar et al. (2016) prepared two different fibers short banana (B) and naturally woven coconut sheath (C) was hybridized in polyester matrix composites using

compression molding. Static mechanical and dynamic characteristics were studied. The results revealed that the maximum mechanical properties are obtained at the highest

relative amount of banana fiber in the composite. There is also vary in the mechanical properties with a change in a layering pattern. The CBC layering pattern showed the greatest damping, indicating better energy absorption capability[19].

Kamaraj, et al. (2018), studied the epoxy composites reinforced with SiC particle and sisal fiber by using hand layup process. The mechanical performance of the produced composites was investigated and the results shows that addition of SiC particles into sisal fiber/epoxy composite reduced the ultimate tensile strength and percent elongation. When the wt. % of SiC was increased up to 10 %, the ultimate tensile strength and elongation was reduced from 18 MPa and 1.192 % to 10.94 MPa and 0.729 % respectively[13].

Munde and ingle et al. (2018) studied experimentally investigate the effect of fibre weight fraction (0–30 %) on vibrational damping and acoustic characteristics. Polypropylene composites are fabricated using extrusion–injection moulding technique. In that work modal analysis shows that incorporation of sisal fibres by 30 wt.% to polypropylenes made the natural frequency superior when compared with other compositions[6].

Kumar et al. (2017), studied the effect of chemical treatment on the tensile properties of sisal fiber reinforced epoxy composites It is clearly observed that the alkali (NaOH) treatment improves the tensile properties. The 3% NaOH treated sisal fiber composite has optimum tensile strength[8].

Vieira et al. (2017), investigated and comparing various the mechanical properties between sisal fiber composites and sisal fiber reinforced aluminum laminates. The results in that study showed that huge improvement in specific tensile strength, specific flexural strength and modulus. delamination was observed during bending[14]

Ayyappa et al. (2021), Studied on Caryota and sisal fiber-based epoxy resin hybrid composites were developed by using the hand layup technique and the mechanical properties were investigated. Experimental results stated that hybrid composites showed superior properties. From the tensile test, it was found that 15C/25S hybrid composites have shown 38 MPa whereas single fiber composites (0C/40S, 40C/0S) showed 25 and 22 MPa respectively. From flexural properties, it was found that the hybrid composites showed improved flexural properties than single fiber composites. The 15C/25S hybrid composites showed flexural strength and flexural modulus as 89.16 MPa and 3.40 GPa. Single Caryota fiber composites showed the least strength and modulus as 64.09 MPa and 2.14 GPa. Whereas the impact strength of 15C/25S composites showed as 97 joules and in single layer sisal fiber composites, it was observed that 83.5 joules. In the hardness test, single fiber composites showed superior properties to hybrid composites. The reason could be fabrication errors or poor bonding between matrix and reinforcement material[7].

Sivakandhan et al. (2019) studied the mechanical properties of the hybrid composites of sisal and jute fiber combination. The results suggest that the impact properties of sisal fiber/epoxy composite are better than the jute fiber epoxy composites and also addition of sisal fiber decreases the tensile, flexural, compression properties but increases its impact properties[16].

Parandaman and Jayaraman (2016) studied that the mechanical properties of jute/sisal fiber/glass and jute/banana/glass hybrid composite materials. The results shows that the high strength hybrid composite made of jute-banana-glass (JBG) provides better mechanical properties and it could be used for a wide range of applications like structural, aerospace and automobile industries[15].

James et al. (2019) concluded the influence of mechanical behavior on different stacking sequence of bagasse and sisal fiber hybrid epoxy composites. In that study composites were prepared with four different proportions and tested the mechanical and morphology behavior of composites. Results showed that stacking sequence with s-s-s (three SF) is having good properties compared to the other stacking sequences[20].

Rajesh Krishna and Chandramohan (2019), studied that the surface treatment and stacking sequence on mechanical properties of basalt/glass epoxy composites. In the present work, sandwich hybrid composites have been fabricated using hand layup technique followed by compression moulding process. This fabric was used in both untreated and treated conditions using hydrochloric acid and sodium hydroxide solutions. The results show that hybridization and surface treatment improve tensile strength and hardness in all the composites[2].

Soundhar and Kandasamy (2019) demonstrated the mechanical, morphology and chemical properties of sisal natural fibers and epoxy blended with different weight percentage of crab shell. The experimental results showed that on increasing crab shell weight percentage up to four in sisal fibers there is considerable increase in tensile and flexural properties[17].

Girisha et al. (2012), Studied the mechanical properties of chemically treated husk of arecanut fruit and tamarind fruit fibers reinforced with epoxy composites the novel composites are developed by manual hand layup technique the results found that treated fiber shows better results than the untreated fiber composites. Further, it is noticed that the strength of hybrid composites increases with increase in volume fraction of fiber[22].

4. CONCLUSION

In conclusion, Natural fiber composites represent a promising material solution that combines sustainability, mechanical performance, and economic viability. As the demand for eco-friendly and cost-effective materials continues to grow, sisal fiber composites are poised to play an increasingly vital role in various industries, contributing to a more sustainable future while meeting the ever-evolving material requirements of modern applications.

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