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Characterization and Optimization of Mechanical Performance of Natural Fiber Composites for Automobile and Spacecraft Applications

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Abstract -

The escalating environmental concerns and the depletion of petroleum resources have intensified research into sustainable and eco-friendly materials. This study focuses on the development, characterization, and optimization of bio composites derived from natural fibers and biopolymers, specifically sisal fiber, palm fiber, corn starch, and glycerol, aimed at enhancing mechanical performance while maintaining environmental sustainability. The mechanical characteristics, including tensile strength, flexural strength, impact resistance, and hardness, were meticulously evaluated. The influence of fiber treatment methods, such as alkali treatment on sisal and palm fibers, was investigated to improve the interfacial bonding between the fibers and the matrix. Additionally, the role of glycerol as a plasticizer in modifying the matrix properties for better flexibility and ductility was thoroughly examined.

The study further explores the degradation behaviour and recyclability of the composites, emphasizing their potential as alternatives to conventional plastics in various applications. The findings demonstrate that the optimal composite formulation exhibits significantly improved mechanical properties compared to traditional petroleum-based plastics and untreated natural fiber composites. The enhanced performance is attributed to the effective stress transfer from the matrix to the well-dispersed, surface-treated fibers. This research not only contributes to the body of knowledge on bio-based composites but also paves the way for the development of sustainable materials with applications ranging from automotive to construction, thus offering a promising solution to the pressing environmental challenges.

Keywords**:** Natural fibers, Bio composites, Mechanical properties, Sisal fiber, Palm fiber, Corn starch, Glycerol, Sustainable materials.

1. INTRODUCTION

In recent years, the shift towards sustainable and eco-friendly materials has become a paramount objective in materials science and engineering. This trend is driven by the urgent need to reduce the environmental impact associated with the production and disposal of synthetic materials, which are pervasive in various industries, including automotive, construction, and packaging. Among the plethora of materials being explored, natural fiber composites have emerged as a promising alternative due to their biodegradability, low cost, and relatively high mechanical properties. Specifically, composites made from sisal fiber, palm fiber, corn starch, and glycerol have garnered attention for their potential to replace conventional materials in specific applications.

Natural fibers, such as sisal and palm, are renewable, abundantly available, and possess inherent mechanical strength that can be harnessed in composite materials. When combined with biodegradable matrices, such as those derived from corn starch and glycerol, the resulting composites not only contribute to the reduction of carbon footprint but also offer the advantage of being produced from non-food bio-resources, thus not competing with food supply chains. Despite these advantages, the widespread adoption of such composites is hindered by challenges related to their mechanical performance, moisture sensitivity, and variability in properties, which are influenced by the nature of the fibers, the matrix composition, and the processing conditions. To address these limitations, a comprehensive understanding of the factors affecting the mechanical performance of sisal fiber, palm fiber, corn starch, and glycerol composites is essential. Moreover, optimizing these factors can enhance the applicability of these composites in various industries. Therefore, this paper aims to characterize the mechanical performance of these natural fiber composites and optimize their properties through systematic experimentation and analysis. The study focuses on evaluating the tensile, flexural, and impact strengths of the composites, as well as their moisture absorption behavior, to identify optimal formulations and processing conditions that maximize their mechanical performance while ensuring biodegradability. The contribution of this research is twofold. First, it provides a detailed characterization of the mechanical properties of sisal fiber, palm fiber, corn starch, and glycerol composites, offering insights into the influence of fiber type, matrix composition, and processing parameters. Second, it presents an optimization framework that can be used to guide the development of natural fiber composites with enhanced mechanical performance, paving the way for their increased application in areas traditionally dominated by synthetic materials. Through this work, we aim to contribute to the advancement of sustainable material solutions, addressing both environmental concerns and the technical requirements of material performance.

2. MATERIAL AND METHOD

MATERIALS: The material used in this research Sisal fiber, Palm fiber, Corn starch, Glycerol.

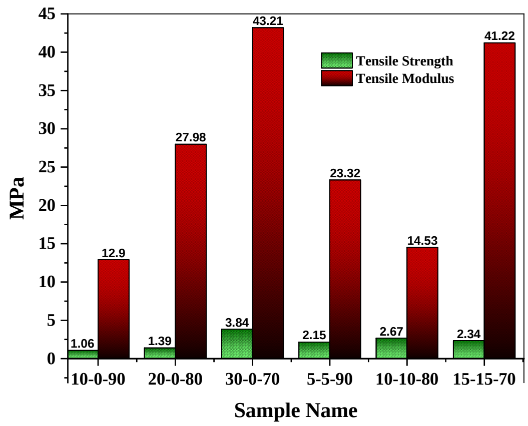
METHODOLOGY: Natural Fibers: Sisal and palm fibers need to be collected. These fibers should be cleaned, dried, and possibly treated to improve their compatibility with the matrix material. Matrix Materials: Corn starch and glycerol are used as the matrix materials. The proportion of corn starch to glycerol can significantly affect the properties of the composite, so this ratio needs to be optimized. Fiber Treatment: Fibers may be treated chemically (e.g., with alkali treatment) to remove lignin, waxes, and oils to increase their surface roughness and improve their adhesion to the matrix. The fibers are cut or ground into the desired length or size. The aspect ratio (length to diameter ratio) of the fibers is crucial for the mechanical properties of the composite. Preparing the Matrix: The corn starch and glycerol are mixed under heat to create a homogeneous gel. The ratio of corn starch to glycerol, the addition of water, and the temperature are key parameters that need optimization. Composite Fabrication**:** Hot Press Technique**:** The mixture of fibers and matrix can also be hot-pressed. The materials are placed in a mold and then subjected to heat and pressure. This method allows for better control over the composite thickness and ensures more uniform distribution of the fibers within the matrix. Curing and Post-Processing: The composites need to be cured, which may involve keeping them at a certain temperature for a specified time to ensure the matrix solidifies. After curing, the samples can be demolded and subjected to any necessary post-processing, like cutting to testing size, surface finishing, etc.

3. RESULT AND DISCUSSION

Mechanical Performance Characterization -Tensile Testing: Measures the composite's strength and elongation at break. This test helps in understanding how well the composite can withstand pulling forces. Flexural Testing: Determines the bending strength and modulus. This is crucial for applications where the composite will be subjected to bending loads. Impact Testing: Assesses the material's ability to absorb energy during a sudden impact, which is essential for evaluating its toughness. Hardness Testing: Measures the surface hardness of the composite, which can be an indicator of wear resistance. Microstructural Analysis: Techniques such as scanning electron microscopy (SEM) can be used to examine the fiber-matrix interface, fiber distribution, and any voids or defects within the composite.

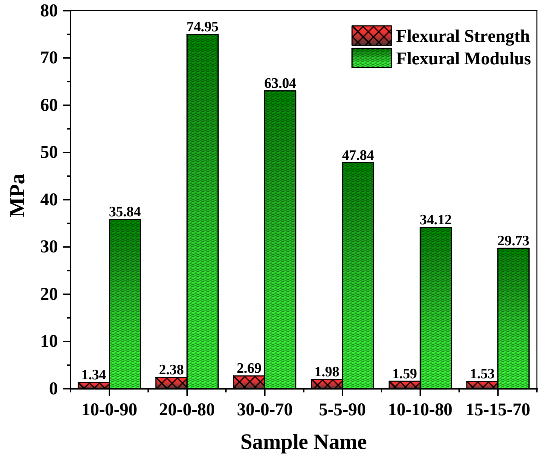
3.1 Tensile Strength and Modulus

For both SFR and BPFR composites, the maximum tensile strength and modulus are found at 30% and 20% of the fiber loading, respectively. This is because the fibbers' reinforcing permits stress to be transferred from the matrix to the natural fibers. It has been noted that in the case of SFR composite, the matrix is not sufficiently restrained by fibers at lower fiber loading, resulting in highly localized strains in the matrix at low stresses. The composite becomes increasingly stiff and the stress is distributed more uniformly as the fiber loading rises. It has been noted in the **Fig-3.1** that the tensile strength and tensile modulus of the composites increase linearly to 242% and 228%, respectively, with an increase in fiber loading from 10% to 30% for BFR composites, while the tensile strength and tensile modulus of the composites increase to 22% and 77%, respectively, with an increase in fiber loading from 10% to 20% for hybrid composites. It has been noted that BFCR hybrid composites have outperformed BFR composites in terms of strength at the same 10% and 20% of fiber loading. When it comes to BFR composites, the tensile strength value rises as the fiber content increases, and for BCFR composites, it can rise by up to 20% of the fiber. Tensile modulus for the 30% of fiber in BFR and BCFR composites has reached its maximum value.



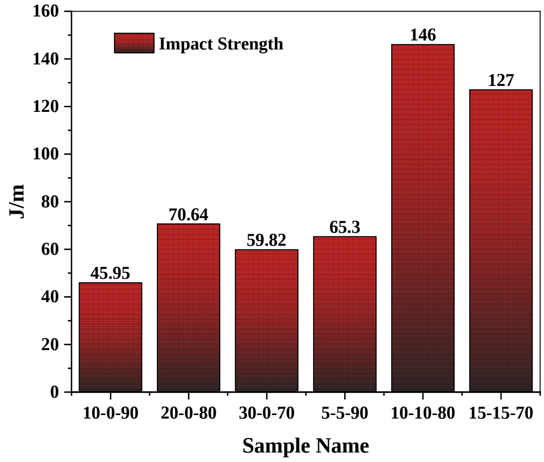
3.2 Flexural Strength and Modulus

Compressive and tensile stresses are combined to create flexural stresses. It is evident that flexural strength and modulus rise with fiber loading, reaching a maximum for BFR composites at 20% and BCFR composites at 10%. At higher loadings, the entanglement of the fibers and the polymer's poor wetting of the fibers cause the flexural strength and modulus to drop. Figure 3.2 illustrates this. For BFR composites, flexural strength increases to 100% as the fiber content increases from 10% to 30%, and modulus increases to 107% as the fiber loading increases from 10% to 20%. In contrast, for BCFR composites, both flexural strength and modulus decrease linearly as the fiber content increases. When fiber loading (30 wt %) is increased in BCFR composites, the flexural characteristics diminish. This can be attributed to inadequate matrix infiltration, increased fiber-to-fiber contacts, and dispersion issues.



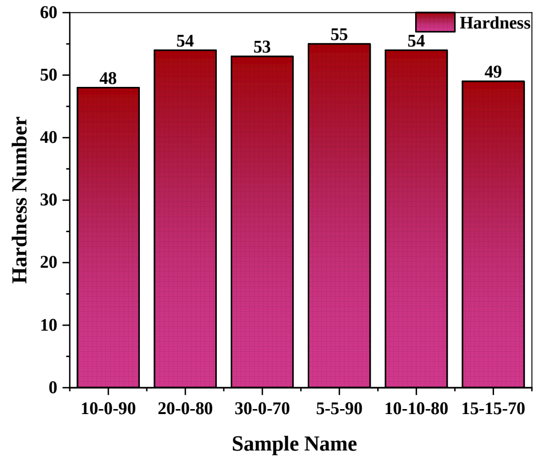
3.3 Izod Impact Test

Impact strength is important in composites because, under service conditions, unexpected loads often create cracks. The application of impact forces (loads) occurs so fast that the molecular structure does not relax in time, leading to a fracture that may involve breaking or interface separation. Numerous variables, including the shape of the composite, test conditions, interfacial area characteristics, and fiber toughness, affect a composite's impact property. The impact strength of the composites improves to 51% and 123% for BFR and BCFR composites, respectively, with a 10% to 20% increase in fiber loading. Impact strength of BCFR composites is 107% higher than that of BFR composites with the same fiber loading (20 wt %). The impact strength of the BFR and BCFR composites increases up to a fiber loading of 20% before it begins to fall somewhat, according to the results of the Izod impact tests shown in the figure 3.3. The introduction of coir fiber significantly improves the composite's impact property.



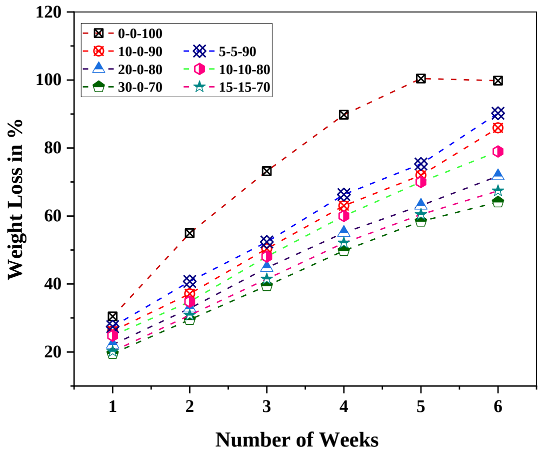
3.4 Hardness Test

The thickness of the specimen is crucial in all hardness testing methods because elasticity is typically assessed as well. It should be emphasized that testing for hardness always gauge the material's surface hardness rather than its interior. The shore D hardness values of BFR and BCFR composites are nearly identical for 20% and 30% and 10% and 20% fiber, respectively, in both scenarios. It has been observed that the Shore D hardness value in BFR composites improved by 12% as the fiber loading climbed by 10% to 20%. Additionally, no discernible difference was detected between BFR and BCFR composites with a 20 wt % fiber loading.



3.5 Biodegradability Test

Using the soil burial approach, the biodegradability of the GC samples and the biopolymer was examined for six weeks. Cut into 70×70 mm pieces, the six composite samples and one biopolymer sample with a 2 mm thickness were buried in the clay pot with soil at a depth of about 50 mm. Water has been sprayed on a regular basis to maintain the soil's humidity and to keep the microorganisms alive. The samples were taken out at regular intervals of seven days, wiped with tissue paper to remove any remaining clay and other particles, and then dried at 50˚C in an oven to study the degradation of the samples.



It can be shown from figure 3.5 that for all seven samples, net weight loss exhibits an approximately linear relationship with degradation time. The addition of natural fibers reduces the rate of biodegradation, and the robust structure of cellulose prevents microbial attack, resulting in a lower rate of breakdown, according to these studies. Because banana fibers had higher cellulose content than coir fibers, BCFR composites degraded more quickly than BFR composites. The biopolymer derived from corn starch demonstrated the fastest rate of disintegration, losing almost 40% of its starting weight within the first week and disappearing entirely by the fourth week. Without a doubt, the obtained results show that the composite samples won't have any detrimental effects on the environment. Stated differently, these composite materials exhibit complete biodegradability.

4. CONCLUSIONS

There are two impacts of the alkaline therapy on fibers: (1) Improves mechanical interlocking by increasing surface roughness; (2) Expands the amount of exposed cellulose on the fiber surface, increasing the number of potential reaction sites. Through SEM research, it has been discovered that the multicellular fiber wall is stripped of cemented components such as wax, pectin, lignin, and hemicelluloses, making individual cells more noticeable and improving the mechanical properties of the composite.

In this experimental investigation, hybrid green composites based on maize starch and reinforced with banana fiber and banana-coir fiber were created using the injection molding technique. Injection-molded composites provide strong interferential bonding between the matrix and reinforcement.

This investigation demonstrates that adding banana fibers up to 30% by weight can produce maximum tensile strength and modulus of 3.84 MPa and 43.21 MPa, respectively. Up to 20% better than BFRC, hybrid composite yields results for the same weight percentage. A higher tensile modulus corresponds to a larger content of banana fiber. For BFR composites, the highest flexural strength and modulus values are 2.38 MPa and 74.95 MPa for 30% and 20% fiber loading, respectively. For hybrid composites, the maximum values are 1.96 MPa and 47.84 MPa for 5% fiber loading of banana and coir fiber, respectively. Flexural characteristics have been found to decrease when coir fiber is added.

It has been determined that up to 20% of fiber loading is all that is needed to attain maximum impact strength. Impact strength then gradually drops down. For BFR and BDFR reinforced composites, it has been recorded at 70.64 J/m and 146 J/m, respectively. Additionally, it has been observed that, in comparison to BFRC, coir fiber significantly boosts impact strength. The experimental result for BFR and BCFR hybrid composites demonstrates that the shore hardness values decrease with fiber loading beyond 20% and 10%, respectively. When fiber loading rises by much than 20%, no discernible change is seen. Thus, we can conclude that a hybrid composite with a smaller percentage of reinforcement can attain the same hardness.

The biodegradation rate demonstrates that, in comparison to pure corn starch, the GC decomposed more slowly as the fiber concentration increased. Samples of biopolymer based on corn starch have broken down in approximately five weeks, losing over half of their weight in just the first two weeks due to the easy microbial attack on starch. Additionally, it has been noted that cellulose content slows down the rate of decomposition as BCFR composites deteriorate more quickly than BFR composites. Green composites are cost-effective and environmentally friendly materials that can be used in a variety of interior automobile components, including the glove box, door panels, dashboard, language mat, shelving, and glove box surfaces.

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