Manufacturing Science and Education 2025

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 68, Issue Special II, July, 2025

ADVANCING GREEN COMPOSITES: A COMPARATIVE ANALYSIS OF SISAL, COIR, AND GLASS FIBER-REINFORCED POLYMERS

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Abstract: *The research explores the mechanical, thermal, and aging properties of coir and sisal fiber-reinforced polymer-based composites and compares them to glass fiber-reinforced composites. From tensile testing, sisal composites were found to be more tensile than coir but less than glass fiber composites. Thermogravimetric analysis (TGA) found sisal to exhibit an onset decomposition temperature of 380°C, higher than glass fiber at 320°C, reflecting better initial thermal stability. Thermal shock aging tests did, however, report severe mechanical degradation for natural fiber composites, with 53.20% loss being experienced by coir. SEM analysis confirmed the occurrence of good fiber-matrix adhesion for glass and sisal composites, whereas voids and non-bonding were observed for coir. Sisal fibers, in spite of mechanical drawbacks, do have potential in sustainable automobile, aerospace, and lightweight structural applications, whereas research in fiber-matrix adhesion, hybridization, and improvement in durability is to be pursued for future progress.*

Keywords: *natural fiber composites, coconut fiber, sisal fiber, mechanical properties, thermal stability, microstructural analysis, sustainable materials, aging resistance.*

1. INTRODUCTION

1.1 Background: Why Natural Fiber Composites?

The demand for eco-friendly and bio-degradable materials has increased research on bio-fiber reinforcement such as coconut, sisal, hemp, and flax to substitute glass as well as carbon fibers in polymer composites.[1] Natural fibers, being low-density, biodegradable, renewable, and cost-effective, therefore, are attractive for structural, aerospace, and automotive applications.

Natural fibers are more sustainable but also come with limitations, such as inconsistent mechanical properties, hydrophilicity, and their ability to bond to the polymer matrix is greatly inferior with respect to synthetic fibers. Biomaterials must be assessed as suitable for high-performance uses through extensive tests of their mechanical strength, thermal stability, and structural integrity.

1.2 Motivation: Sustainability and the Limitations of Synthetic Fiber Composites

Due to their high strength-to-weight ratios, high durability and resistance to most environmental hazards, glass or carbon fiber-reinforced polymer (FRP) composites dominate engineering applications today. [2]

Yet these materials can be quite detrimental to the environment and economy:

- High energy consumption and carbon footprint: The production of carbon and glass fibers involves high processing intensity, resulting in a large amount of CO_2 emissions and energy consumption. [3]
- Disposal and recyclability problems: Synthetic fibers do not biodegrade, and are not easy to recycle, creating problems for landfills. Carbon fiber composites are usually burnt instead of reused, for example. [4]
- Toxicity and health hazards: Particulates from glass fiber production are toxic, requiring strict safety measures for workers in the industry. [1]

In contrast, natural fibers are biodegradable and renewable, and also need far less energy in their processing. Other works like [5] have indicated that sisal and coconut fibers have moderate tensile strength and satisfactory thermal stability; therefore, these fibers have great potential to be used in automotive and lightweight structural applications. Nonetheless, a significant challenge that this study like other [6] seeks to address is their long-term structural integrity under mechanical loading, thermal aging, and environmental exposure.

1.3 Objective of the Study: Investigating Mechanical, Thermal, and Structural Properties

This paper aims to study the mechanical, thermal, and microstructural behavior of polymer-based composites reinforced with coconut and sisal fibers. Tensile, compression, TGA, DMA, and SEM were performed to analyze the following:

1. **Mechanical Strenght**: Effect of Coconut and Sisal Fibers on Tensile & Compressive Strength of Polymer Composites
2. **Thermal Stability:** These materials can tolerate a lot of heat without loss of quality.
3. **Aging Resistance**: Do they still behave well when cycled 100 times between -40°C and 120°C?)
4. **Microstructural Performance** — How does fiber-matrix adhesion influence the performance of the composite as a whole?

1.4 Research Questions & Hypotheses

This research compares the mechanical, thermal, and aging properties of coconut and sisal fiber-reinforced polymer composites with glass fiber composites. The main research questions and hypotheses are:

Q1: What is the comparison between the mechanical and thermal properties of natural fiber composites and glass fiber composites?

H1: Glass fiber will possess greater strength and thermal stability than coir and sisal. Sisal may have relatively better characteristics than coir but will still degrade faster and have poorer mechanical performance than glass fiber.

Q2: How does thermal aging affect the durability of natural fiber composites?

H2: Thermal cycling (-40°C to 120°C) will result in fiber-matrix debonding and strength reduction in all composites, with natural fibers losing more compared to glass because of the absorption of moisture and low thermal resistance.

Through tensile testing, TGA, thermal aging, and SEM imaging, the viability of natural fiber composites as green alternatives to synthetic counterparts is assessed in this research.

2. MATERIALS AND METHOD

2.1 Materials

Matrix: Polymer Resin

The matrix material used was a two-component polymer resin named Pro-Klar, produced by company Vosschemie GmbH, in Uetersen, Germany. Pro-Klar is a transparent, solvent-free, and self-leveling polymer resin. It has a mixing ratio of 100 parts of resin (component A) to 40 parts of hardener (component B) by weight, a pot life of about 240 minutes at 23°C. This resin was selected for its great mechanical properties, such as shore D hardness of 75, chemical resistance and affinity with the fibers.

Fibers: Glass, Coconut and Sisal

The reason of selection for natural fibers have already mentioned above where as for a more clear perspective of their performance, it was felt as a necessity to have a comparison with the most significant giant in the industry: the glass fibres. As reinforcements for the polymer matrix, natural fibers (coconut (coir) and sisal fibers) were used.

- **Glass fibers**: The glass fibers used in this study were purchased from BestTool, Brașov, specifically produced for use as a filler in composites. Fibers are of 10 mm-12 mm in length.
- **Coconut Fiber (Coir)**: Coir fibers came from the husk of coconut fruits. Their density is 1.36 g/cm³ and they were cut at 10-12 mm length.
- **Sisal Fiber**: The sisal fibers are mostly obtained from the leaves of Agave sisalana plant. But in this research, the fibers were purchased from of company FloraSelf. They have a density of about 1.45 g/cm3. Cut manually at 10-12 mm.
- **Pretreatment of Fibers**

The fibers were subjected to an alkali treatment procedure to improve their interfacial adhesion with the polymer matrix. Specifically, the NaOH-treated modification was achieved by soaking in a 2% NaOH solution at room temperature for 4 hours. If not, alkali treatment facilitates the elimination of fractionation material like lignin, hemicellulose and other types of extractives from fiber surfaces, resulting in a rough surface and enhancing the adhesion with the matrix, as other study [7], have already proven. The fiber color was also altered; this is especially noticeable in the coir fiber, which was brown before treatment and almost white after. This could be visible in Figure 1 below.

Fig. 1. Effect of Alkali Treatment on Coir Fibers
a) Before treatment b) After treatment

After treatment with alkali, the fibers were rinsed thoroughly with distilled water to remove any unreacted NaOH, and dried in a Vötsch VT 4002 thermal chamber at 60°C for 24h to remove any moisture content.

2.2 Composite Fabrication

Natural fibers, coconut and sisal as well as glass fibers were loaded into the polymer matrix at a 30% mass fraction with uniform distribution. The resulting mixture was mechanically stirred for 30 seconds to ensure homogenous dispersion throughout the polymer resin without polymerization of the resin itself. As a result, the finished specimens incorporated 30% organic fibers, which implemented a randomly arranged, amorphous structure without a preferential direction of orientation of the fibers. For the check of normal distribution were used untreated/unbleached fibers present in Figure 2.

Fig. 2. Coir fibers distribution through the matrix

This distribution contributes to an isotropic mechanical behavior in the composite material.

In order to create the base specimen for testing, silicone molds were developed following the ASTM D638 standard tensile test specimen etalon, as displayed in Figure 3 below, defining the standard geometry and dimen-sions for polymeric and composite specimens.

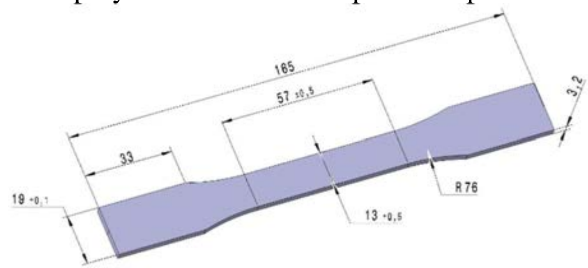

Fig. 3. Test specimen dimensions

The free-pour technique was used to fill the molds and after they were placed in a 7.4 L vacuum chamber connected to a 4.5 CFM vacuum pump to degas trapped air. By eliminating air pockets that are significant stress concentrators, the degassing process improves fiber-matrix adhesion and contributes to the overall integrity of the composite structure.

The overall dimensions (length, width and thickness) of each specimen was precisely measured with a Mitutoyo digital caliper to conform to standard testing requirements.

2.3 Testing Procedures

Mechanical Testing

The mechanical performance was chara-cterized by carrying out tensile tests according to ASTM D638. The experiments were per-formed using a SAUTER TVM20KN120N Motorized Vertical Test Stand. The crosshead speed was fixed at 20 mm/min and load-extension data were continuously recorded over the duration of the test. From the recorded data, tensile strength, modulus of elasticity and elongation at break were calculated, but only the breaking force and displacement will be considered.

Thermal Analysis

A thermogravimetric analysis (TGA) was conducted using a BAXIT BXT-TGA-1600 thermogravimetric analyzer (Glomro Industrial Co., Ltd., Shanghai, China) to study the thermal stability and degradation behavior of the composites. Few milligrams small pieces were prepared from the composite samples and analyzed in a natural air atmosphere. Samples were heated gradually to 750 °C and weight loss as a function of burning time was determined to establish the degradation profile of the composites. Table 1 shows the process parameters.

Table 1

TGA parameters

Nr. crt.	Temperature [°C]	Heating rate [°C/min]	Holding time [min]
1	250	35	1
2	450	20	1
3	750	20	0

Aging & Durability Testing

To analyze the durability of the composites in extreme temperature variations, thermal shock aging tests with a Vötsch VT 4002 Temperature Test Chamber were performed. According to the applicable standards in the automotive sector, the test samples were subjected to 100 thermal conditions, varying from -40°C to +120°C every 30 minutes. This period was long enough for the samples to equilibrate thermally with the atmosphere of each stage. The tensile test was conducted again to see if the mechanical properties were degraded after the 100 cycles.

Microstructural Analysis

The microstructural characteristics of the composites were analyzed using a Phenom Pure G6 Desktop Scanning Electron Microscope (SEM) (Thermo Fisher Scientific, Waltham, MA, USA). Fiber-matrix adhesion, fiber pull-out, void creation, and failure mechanisms were studied by examining the fracture surfaces of tensile-tested samples.

3. RESULTS AND DISCUSSION

Through the investigation of natural fiber reinforced polymer composites, the experimental findings highlight useful mechanical and thermal properties that contribute to the overall understanding of the performance of composite structures subjected to load.

3.1 Mechanical performance: tensile strength and comparison with synthetic composites

Tensile tests were performed on neat polymer, glass fiber, coir fiber and sisal fiber. The results, including the mean force, maximum force, and standard deviation, are presented in Table 2.

Table 2

Tensile Test Force Comparison

Fiber Type	Mean Force (N)	Max. Force (N)	Standard Deviation (N)
None	1207.0	1211	±4.83
Glass	2808.4	2836	±23.63
Coir	2551.4	2561	±9.07
Sisal	2707.6	2713	±5.41

It was revealed that glass fiber-reinforced composites showed the highest tensile strength (mean force 2808.4 N), underlining their high load-bearing capacity. Conventional composite demonstrates again such a good performance like in previous studies. The mean force for sisal fiber-reinforced polymer was found to be 2707.6 N and it was determined to be the closest to synthetic reinforcement among natural fiber alternatives. Compared to sisal, the coir fiber composites with a maximum tensile strength of 2551.4 N is also significant, demonstrating significant reinforcement of neat polymer (1207.0 N).

Standard deviation values demonstrate scattering with which tensile performance varies. The standard deviation for the glass fiber composites (±23.63 N) was larger than other materials due to the inconsistencies of fiber alignment and bonding, whereas the sisal fibers demonstrated the most repeatable properties with a standard deviation of ±5.41 N, indicating that the fibers were evenly distributed and adhered. The standard deviation of coir fiber composites was ±9.07 N which was comparatively larger.

The mechanical properties of sisal fibers more closely resemble synthetic glass fibers, as shown in the Figure 4.

This contributes to being a better candidate for high-performance applications, as well as other study [9], [10] showed that a mixture of synthetic fiber and sisal fibers has given very good results. Nevertheless, both type of natural fiber composites are still interesting eco-friendly alternatives for commonly used synthetic composites.

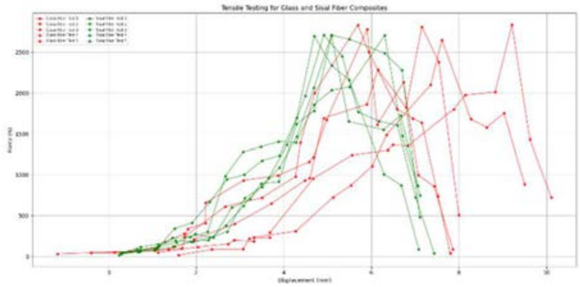

Fig. 4. Tensile test for glass and sisal fiber composites

3.2 Thermal Stability: TGA/DMA Results

In terms of TGA, the thermal stability of glass fiber-reinforced polymer, coir fiber-reinforced polymer, and sisal fiber-reinforced polymer were investigated.

Table 3 displays the data obtained which shows the degradation behavior and mass retention as well as the decomposition temperature ranges of the composites.

Table 3

Thermal Stability Comparison of Composites

Type	Start & 50% Mass Loss (°C)	Max & Decomposition Range (°C)	Residual Mass
Glass	320 → 480	480 (350-590)	8.02
Coir	335 → 455	460 (370-550)	4.52
Sisal	380 → 470	470 (425-550)	3,12

Although glass fiber composites are still providing the maximum value of temperature at 50% mass loss and highest value of residual mass, which is not an advantage at all from ecodesign perspective (due to difficult recyclability, higher density, ecological impact), but the sisal fiber composite beat the glass fiber in the onset of decomposition temperature, may be due to thermal shielding effects. This isn't entirely unexpected since other studies [11] also found similar scalar results in a different application. Sisal performed comparable to, or even better than, coir among the natural fibers, with significant higher thermal degradation temperature, delayed initial degradation, and a broader degradation range.

The result indicates that natural sisal fibers could be engineered to further improve their thermal stability, thus increasing their potential as sustainable alternatives to synthetic fibers. Performance on high-temperature applications can be improved through optimized fibers treatments accordingly with other scientific work as [6] or hybridization with other reinforcements as in [12] or improve the matrix.

The weight of glass fiber composites (8.02 mg) is high due to the inorganic nature of glass fibers, which do not burn on heating. Unlike coir and sisal, which are natural-based and biodegrade, glass fibers go through the polymer matrix burning off, and leave a much higher amount of solid residue. This is also consistent with the less residual mass of coir (4.52 mg) and sisal (3.12 mg) in the thermogram (Table 3), as the organic part of the fibers is completely thermally decomposed.

Why Did Sisal Show a Higher Decomposition Temperature?

Natural fibers, such as sisal and coir have been already studied in the scientific literature [13], [14] among others, identifying their application in composite material, but also for their use in stand-alone applications. The genuine cause may be plotted underneath:

- Char Formation & Heat Shielding: As sisal chars, it creates a protective layer that delays heat penetration; this is not the case with glass fibers, which, unlike sisal, do not char.
- Higher Cellulose Crystallinity: Sisal has higher cellulose (>70%) which imparts better thermal resistivity, and glass fibers are non-interacting with matrix on chemical basis.
- Stronger Fiber-Matrix Bonding: The presence of hydroxyl (-OH) groups in sisal allow sisal to form hydrogen bonds with polymer thus promote a stronger fiber-matrix interfacial interaction as compared to glass fibers, which forms only compound bond with polymer.
- Stepwise vs. Single-Stage Decomposition: Sisal deteriorates continuously (hemi-cellulose → cellulose → lignin), whereas glass fiber composites undergo cleavage upon breaking down during polymer degradation.
- Carbon Residue Effect: Sisal produces carbon residues, making a thermal barrier, like the carbon fiber, whereas glass does not have this effect.

Sisal's onset decomposition temperature is unexpectedly high, which can be attributed, as evident in the Figure 5, from char formation, cellulose crystallinity and very strong fiber-matrix bonding.

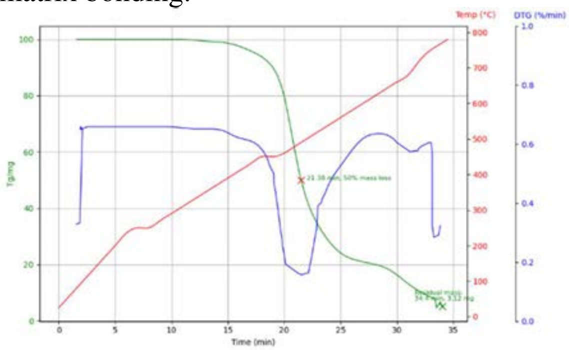

Fig. 5. Thermogravimetric analysis for Sisal composite

Glass fiber retains more mass, whereas sisal exhibits higher thermal resistance than other natural fibers, making it a candidate for high-temperature applications. However, to observe the long-term thermal opposition, the aging through thermal shock must be investigated.

3.3 Evaluation of the aging resistance of composites under extreme temperature conditions

For testing composite durability at extreme temperatures (both hot and cold), thermal shock aging tests were performed using a Vötsch VT 4002 Temperature Test Chamber. Each specimen was cycled 100 times between temperatures of -40°C and +120°C, with each temperature being uniformly held for a time of 30minutes, ensuring complete thermal equilibration. The test profile is shown in Figure 6.

All specimens underwent mechanical testing before and after thermal aging, in which respective material types showed a substantial decrease in mechanical properties. The tensile strength test results are shown after aging and outlined in Table 4.

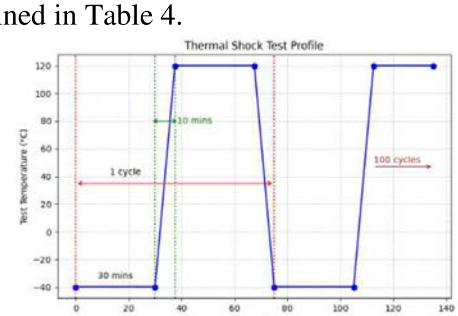

Fig. 6. Aging resistance test parameters

Table 4

Tensile Strength Reduction After Thermal Shock

Type	Mean Force Before (N)	Reduction (%)	Mean Force After (N)
None	1203.0	49.61%	606.1
Glass Fiber	2808.4	37.11%	1766.2
Coir Fiber	2551.4	53.20%	1194.2
Sisal Fiber	2707.6	46.20%	1456.8

Analysis of Tensile Strength Degradation

The polymer matrix without fibers showed the greatest tensile strength reduction (49.61%), suggesting severe polymer degradation, microcracking, and embrittlement. The repeated thermal expansion/compression cycles generated internal stresses which caused structural failure. Conversely, the reduction of glass fiber composite was the lowest (37.11%), which demonstrated enough thermal resistivity. The main reason is because glass fiber is inorganic and thermally stable that does not degrade, although the polymer matrix experienced damage.

Out of all the natural fiber composites, the coir fiber composite exhibited the highest degradation (53.20%) providing an indication of the considerable occurrence of thermal degradation, fiber fracture, and matrix debonding of coir fibers. Coir fibers had a higher hemicellulose and lignin composition, which probably caused them to be less resistant to thermal aging. For the case of sisal fiber composite, it lost approximately 46.20% of its strength whereas the loss of strength of the coir fiber composite was more. The enhanced heating reduction was attributed to the improved fiber-matrix adhesion structure and the increase in cellulose crystallinity, which enhanced the thermal degradation resistance. Both natural fiber composites experience noticeable mechanical property loss despite this, suggesting that more extensive thermal stabilization or fiber treatments need to be investigated for improved durability across a wide temperature range.

From this, it can be concluded that glass fiber composites had the best aging resistance but natural fiber composites had considerable strength reductions, especially that of coir composites.

Similar results were obtained in the study of natural fiber-reinforced composites [15], [16] as well. For instance, the study conducted in [15] showed that natural fiber composites face high reductions of tensile strength due to thermal aging, in the same manner as the 53.20% decrease observed in the coir composites in this study, while the thermal cycling led to better mechanical properties retention in glass fiber mats. Moreover, the hydrothermal aging effects reported in [16] revealed that fiber-matrix adhesion is the most important factor responsible for mechanical retention, which is consistent with our finding that sisal composites performed better than coir (46.20% reduction) owing to a higher interfacial bonding strength and higher cellulose crystallinity.

3.4. Microstructural Observations (SEM Analysis): Fiber Pull-Out, Voids, and Adhesion

The analysis of the fracture surfaces was performed by scanning electron microscopy (SEM) for glass fiber-reinforced, coir fiber-reinforced, and sisal fiber-reinforced composites. To correlate the increased fiber breakage observed in damaged and aged interfaces with the drop in tensile values in aged composites, fiber-matrix adhesion, voids, and polymer integrity were evaluated.

Glass Fiber-Reinforced Composite: Strong Adhesion but Matrix Degradation

Before thermal shock test, the glass fiber composite sowed really good fiber-matrix adhesion, and it is very clear that all the fibers embedded firmly in the polymer, as can be seen in Figure 7.

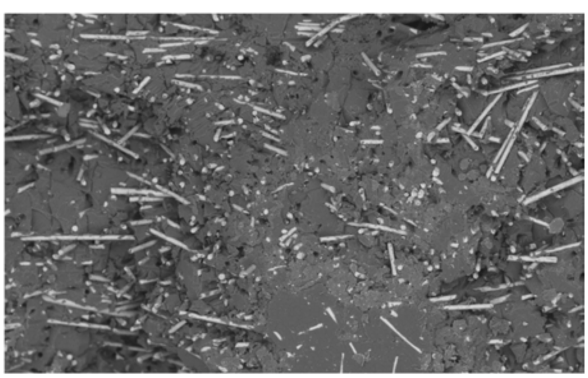

Fig. 7. SEM analysis for glass fiber composites

The fracture surface was compact, with minimal voids or but a lot of fiber pull-out. However, after thermal shock aging, significant polymer degradation was observed like in Figure 8, which consists a very big issue.

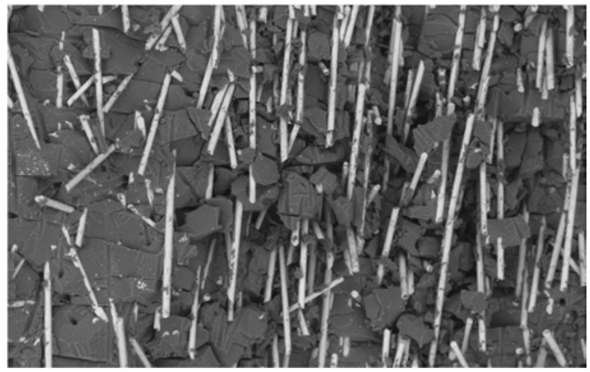

Fig. 8. SEM analysis for glass fiber composites after TS

The resin shows a lot of cracks, like a general decomposition, which reduced the composite's load-bearing capability. Despite this, glass fibers remained well-anchored into the matrix, and this is why glass composites had the lowest tensile strength reduction (37.11%) compared to natural fibers.

Coir Fiber-Reinforced Composite: High Void Content and Weak Bonding

Even without thermal shock, the composite with coir fibers exhibited large pore spaces and poor adhesion between fiber and matrix and for this, Figure 9 shows a SEM image of a part of coir fiber embedded in the matrix.

Fig. 9. SEM analysis for coir fiber composites before TS

The fiber-matrix interface also showed large gaps on the interface, and the center hole was significantly larger than the fiber thickness indicating incomplete resin infiltration. Thermal shock resulted in significant cracking and embrittlement of the polymer matrix, including details outlined above that exacerbate fiber pull-out. The leading degradation percentage (53.20%) experienced by coir fibers was due to the poor bonding, which further caused them to fail prematurely under tensile loads.

The study [17] performed before by Truong et al., investigated the hydrothermal aging effects on PP/PLA biocomposite, and the SEM images, just like in here, confirmed that fiber pull-out and matrix cracking occur, resulting in lower mechanical properties.

Sisal Fiber-Reinforced Composite: High Porosity but Excellent Adhesion

The sisal fiber composite had a porous structure, but fibers were well-integrated with the matrix, showing strong interfacial bonding and no voids or gaps, as Figure 10 prove.

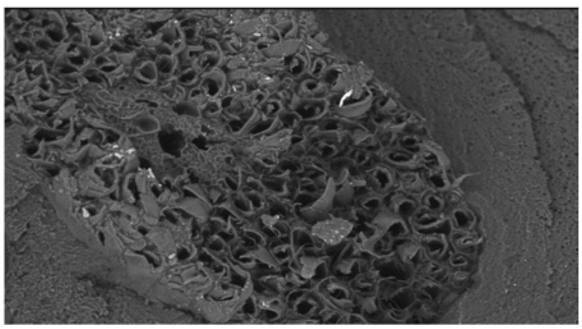

Fig. 10. SEM analysis for sisal fiber composites

Rough surfaces of the fiber also helped in the bonding, and the fiber did not pull out. This important result is not new, because similar thing has been shown previously as well in [18]. In this study, the mechanical properties of sisal and banana reinforced epoxy composites were analyzed and found similar results to that of this study during SEM analysis.

After aging, the polymer matrix cracked, but the sisal fibers were well-anchored and reduced the stress concentration. This could be the reason why sisal fibers displayed superior aging resistance as compared to coir fibers even though the former also showed the reduction in tensile force.

4. CONCLUSION

Summary of Key Findings

In this study, the mechanical, thermal, and microstructural performance of coir and sisal fiber-reinforced polymer composites was evaluated, and the results were compared to glass fiber composites.

- Tensile tests suggested that natural fiber composites provide moderate strength, but sisal composites outperformed coir even if it is still lower than glass fiber.
- The TGA analysis suggested sisal composites exhibited a higher initial degradation temperature (380°C) than glass fiber (320°C), implying an enhanced thermal stability during initial heating.
- Aging tests confirmed that the synthetic fibers exhibit better long-term mechanical properties stability, where tensile strength loss for coir, sisal, and glass fiber was 53.20%, 46.20%, and 37.11%, respectively.
- SEM analysis indicated more fiber-matrix adhesion for glass and sisal composites and significant voids present in coir composites, which caused premature failure.

The results indicate potential for natural fiber biocomposites in targeted applications yet suggest that lower durability, fiber-matrix adhesion, and mechanical performance must improve to compete with synthetic alternatives.

Implications for Applications

Natural fiber composites, especially sisal-reinforced polymer composites, could be used in fields where lightweight and sustainable materials are important.

- Automotive Industry: Appropriate for non-structural components like door panels, dashboards and interior reinforcements, where reduced weight and sustainability have high priority
- Aerospace Applications: In thermal insulation panels, secondary interior structures and lightweight composite materials requiring moderate mechanical performance.

Their durability over time and mechanical constraints limits them from being used for primary load-bearing structural elements, requiring additional material refinements.

Future Research Directions

Future research should focus on the following to enhance the easily available natural fiber composites:

- Fiber Surface Treatments: Assessing chemical treatments (e.g., better alkali, silane or hybrid) before spinning of fibers to improve fiber-matrix adhesion and reduce moisture absorption.

- Particle Reinforcements: Incorporating natural fillers within a polymer matrix to improve mechanical and thermal properties.
- Next-generation polymer matrices: The generation of novel biodegradable or high-temperature resistant resins to improve thermal stability and environmental resistance.
- Sisal-based composites can be used in non-structural automotive components, but require improvements in thermal aging resistance for long-term applications

Natural fibers composites have the potential to improve material properties and function through high-performance hybridization, making them a competitive sustainable alternative to synthetic composites and promoting sustainable innovations in high-performance industries.

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Dezvoltarea compozitelor ecologice: studiu comparativ asupra compozitelor polimerice ranforsate cu fibre de sisal, cocos și sticlă

Acest studiu analizează performanțele mecanice, termice și de îmbătrânire ale compozitelor polimerice armate cu fibre de cocos și sisal, comparativ cu cele armate cu fibră de sticlă. Testele de tracțiune au arătat că materialele compozite pe bază de sisal au o rezistență superioară față de cele cu fibre de cocos, dar inferioară celor cu fibră de sticlă. Analiza termogravimetrică (TGA) a indicat o temperatură de descompunere inițială mai ridicată pentru sisal (380°C) comparativ cu fibra de sticlă (320°C), sugerând o rezistență termică superioară. Totuși, testele de șoc termic au evidențiat o degradare mecanică semnificativă, în special pentru compozitele cu fibre de cocos (pierderea de 53,20%). Analiza SEM a confirmat o aderență superioară fibră-matrice pentru compozitele cu fibră de sticlă și sisal, în timp ce cele cu fibre de cocos au prezentat goluri și aderență slabă. Deși prezintă limitări mecanice, fibrele de sisal demonstrează un potențial ridicat pentru aplicații sustenabile în industria auto, aerospațială și a structurilor ușoare. Optimizarea aderenței, hibridizarea și îmbunătățirea durabilității sunt esențiale pentru consolidarea poziției compozitelor din fibre naturale ca alternative competitive la materialele sintetice.

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