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## **A STUDY ON BIOLOGICAL SISAL FIBERS FOR ENHANCING THE MECHANICAL AND THERMAL PROPERTIES OF COMPOSITES FOR ENVIRONMENTAL SUSTAINABILITY**

**<sup>1</sup>Dheeraj Singh, <sup>2</sup>Sohail Bux**

Research Scholar, RKDF University, Bhopal, India  
Email: [ds.30061979@gmail.com](mailto:ds.30061979@gmail.com)

Professor, RKDF University, Bhopal, India  
Email: [buxsohail@gmail.com](mailto:buxsohail@gmail.com)

\*Corresponding author: [ds.30061979@gmail.com](mailto:ds.30061979@gmail.com)

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### **Abstract**

In order to improve the mechanical and thermal characteristics of sisal fibers, this study looks at surface modification using alkali and alkali-silane treatments. After being thoroughly washed, sisal fibers were treated with a solution containing 3-aminopropyltriethoxy silane (APTES) and different NaOH concentrations. Significant changes in surface morphology were seen by scanning electron microscopy (SEM) examination after treatment. The alkali-treated fibers (ATF) and alkali-silane-treated fibers (ASTF) showed clear evidence of the elimination of contaminants and fibrillation. Mechanical tests revealed a significant improvement in the treated fibers' tensile strength and Young's modulus, especially at the ideal NaOH concentrations. The treated fibers showed improved thermal stability according to thermogravimetric analysis (TGA), with the ASTF demonstrating the strongest resistance to thermal deterioration. These results demonstrate that sisal fibers may be chemically modified to enhance their mechanical qualities, thermal stability, and surface features, thereby improving their suitability for sophisticated composite applications.

**Keywords:** Sisal, Mechanical, Thermal, Chemical, Fiber

## 1. Introduction

Due to their superior strength, light weight, low cost, corrosion resistance, and ease of processing, polymers have been used much more in the last few decades in a wide range of industrial applications, including consumer goods, automotive, aerospace, medical, railways, electrical, and electronics. In recent years, polymer composites have become more and more significant. These consist of the continuous binding phase and the scattered reinforcing phase (Palluvai et al. 2014, Sanjay et al. 2002). Fibers, particles, and whiskers make up the reinforcing phase, whereas thermosets, thermoplastics, and elastomers may be found in the matrix materials. The matrix gives the composite enough strength, stiffness, electrical conductivity, and thermal stability while also serving as a load transmission medium between the fibers and particles. The placement of fibers inside the polymer matrix has a significant impact on the characteristics of fiber reinforced polymer (FRP) composites. FRP composites contain fibers in a variety of shapes, including long, continuous fibers, woven fabric, short, chopped fibers, and mat. The fiber bears the load and its strength is highest along its axis, which is crucial information to keep in mind while working with FRP composites. Zhongguo et al. created the epoxy resin that contains trifluoromethyl groups (2012). Four distinct types of curing agents have been used in the curing studies: 2-methylimidazole (2MI), 4-methylene-dianiline (DDM), phthalic acid anhydride (PA), and poly(propylene glycol) bis(2-aminopropyl) ether (D230). According to reports, at 700°C with 21.8, 19.2, 7.7, and 5.3 (wt%) char, respectively, all cured samples show superior thermal stability in the following order: 3F-PQE-DDM > 3F-PQE-2MI > 3F-PQE-D230 > 3F-PQE-PA. Out of the three, the 3F-PQE-DDM had the highest T<sub>g</sub> (145°C), followed by the 3F-PQE-2MI, 3F-PQE-D230, and 3F-PQE-PA. This was explained by the stiff aromatic groups found in the epoxy resin's backbone after DDM curing. The T<sub>g</sub> sequence, according to the authors, was 3F-PQE-DDM > 3F-PQE-PA ≈ 3F-PQE-2MI > 3F-PQE-D230. Because the spine of 3F-PQE-DDM and 3F-PQE-PA contains hydrophobic fluorine atoms, moisture absorptions of these compounds at 80°C for 24 hours were found to be less than 1% weight %. However, because 3F-PQE-D230 and 3F-PQE-2MI include an imidazole group and an aliphatic chain, it was shown that their water absorptions are greater. Zhiqiang et al. (2007) described the synthesis of 1,1-bis(4-glycidylesterphenyl)-1-(3'-trifluoromethylphenyl)-2,2,2-trifluoroethane (BGTF) epoxy monomer (Scheme 10) in three stages, resulting in a novel fluorinated epoxy monomer. Hexahydro-4-methylphthalic anhydride (HMPA) and diaminodiphenyl-methane (DDM) were used to cure these. In comparison to the

cured DGEBA epoxy resins, the BGTF epoxy resins showed superior mechanical, thermal, and glass transition temperature properties. 47.3 weight percent char yield was detected at 600°C for BGTF/DDM resin and 26.9% for DGEBA/DDM resin. These results indicate that the presence of CF<sub>3</sub> groups in the polymer backbone of BGTF/DDM resin is likely responsible for its better thermal stability. According to the findings, the cured BGTF epoxy resins had superior dielectric qualities and less water absorption than the DGEBA epoxy resins. This is because the network of epoxy resins contains hydrophobic fluorine groups. Yan et al. (2012) used metal-free anionic polymerization and hydrolysis process to synthesize a new dicarboxyl-terminated poly(2,2,3,4,4,4-hexafluorobutyl acrylate) oligomer (CTHFA). The surface qualities of epoxy resin were enhanced by the authors by the use of two distinct forms of CTHFA, each having a different chain length. The CTHFA concentration ranged from 0 to 8 weight percent. The developed fluorinated epoxy resin's surface composition and characteristics were examined using X-ray photoelectron spectroscopy (XPS) and contact angle measurements. While the modified epoxy resin with 5 weight percent CTHFA including shorter chain length did not exhibit good hydrophobic surface qualities, the modified epoxy resin with 5 weight percent CTHFA containing longer chain length did (high water contact angle of about 115° and low surface energy 14.12 mN/m<sup>2</sup>). The fluorinated CTHFA epoxy resin with a long macromolecular chain (5 weight percent) increased the migration of more fluorinated groups to the surface than the fluorinated CTHFA-modified epoxy resin with a short macromolecular chain at the same content, according to XPS studies. Similar to this, Park et al. (2005) provided comprehensive information on epoxy resins and fluorine systems, including modern epoxy composite processing techniques and advancements in epoxy composite materials. The scientists also presented novel uses for epoxy, including the biological, electrical, and other domains. The main goal is to create FRP epoxy composites that are inexpensive and lightweight by utilizing fillers derived from natural resources. The produced bio-based FRP composites must have characteristics that are similar to those of commercially available FRP composites. The materials are anticipated to offer improved interaction and adhesion with the hydrophobic matrix throughout the production process because of the surface-modified bio-fibers' high degree of hydrogen bonding, low density, great mechanical strength, and thermal stability. The natural fiber and matrix, which came from petroleum or plant resources, were used to create the fiber-reinforced composites by hand layup method. The composites were then evaluated using a variety of analytical methods.

## **2. Materials and Method**

### **2.1.Surface Modification of Sisal Fibers**

Prior to surface modification, the fibers were washed for several times with ground water followed by detergent diluted solution at 40-50 °C to remove the wax and other impurities; and then dried for 24 hr.

### **2.2.Alkali treatment of sisal fibers**

50 cm long fibers were soaked for four hours at room temperature in solutions containing 1, 2, 5, 10, and 15% NaOH. After thoroughly washing with distilled water, the fibers treated with NaOH (alkali) were rinsed with distilled water mixed with a few drops of acetic acid to neutralize the excess NaOH. After that, the fibers were dried for 24 hours at 105 °C in an oven (Akram Khan et al 2011).

### **2.3. Alkali-Silane treatment of sisal fibers**

The 6-wt% 3-aminopropyltriethoxy silane (APTES) solution was combined with ethanol and water in an 8:2 ratio to soak the alkali-treated fibers (ATF) for one hour. The ethanol-water mixture was then emptied, and the fibers were dried in an oven at 105 oC for two hours (Kumar et al. 2012). As shown in Figure 2.6, the following processes are how APTES interacts with sisal fibers (Bledzki et al. 1999). Several publications have also documented similar behavior between natural fiber and silane coupling agent (Puglia et al 2013, Sgriccia et al. 2008).

## **3. Results and Discussion**

### **3.1. SEM Analysis**

Figure 1 displays SEM micrographs of UTF, ATF, and ASTF. It is observed that the longitudinal surface of the fiber has residues of contaminants in the case of UTF. Wax and other essences on the fiber surface are often removed by the chemical treatment, as shown in

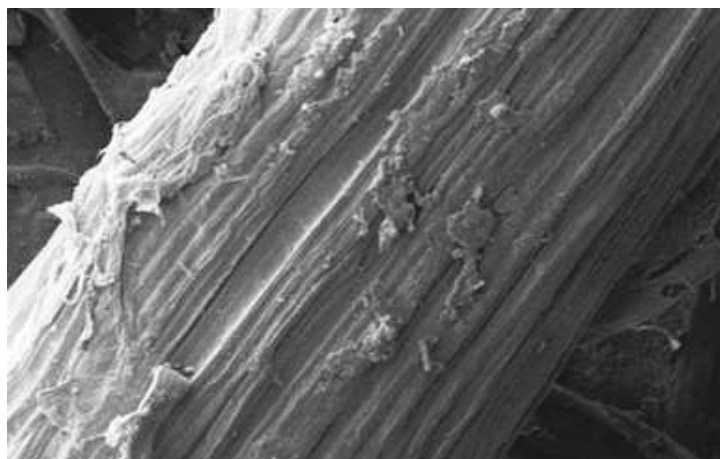


Figure 1(a) SEM micrograph of UTF

Figure 1(b, c). The microporous nature of the ATF sample makes fibrillation and a coarser morphology evident. In contrast to the UTF, the ASTF displayed a rough surface as a result of the elimination of pectin and hemicellulose groups, which cause the less stiff and dense fibrils to organize uniformly in the tensile direction. A comparable occurrence was noted in the instance of ASTF, which exhibits rougher fiber surfaces, fibrillation, and the existence of macrospores. According to Singh et al. (1996) and Ghosh et al. (1990), the moisture in the fiber hydrolyzes the silanes to generate silanols, which in turn form covalent bonds or H-bonds with the sisal fiber's OH group. These findings suggest that sisal fiber may be chemically modified to enhance surface properties including adhesion, surface tension, porosity, and wetting.

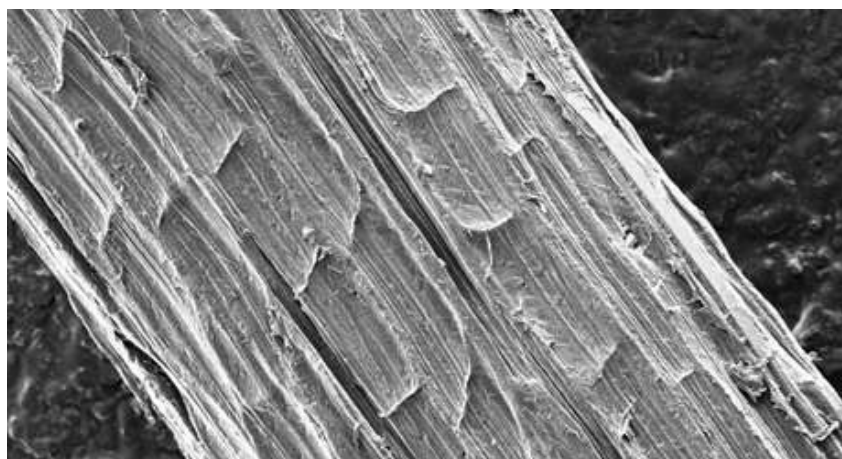


Figure 1(b) SEM micrograph of ATF

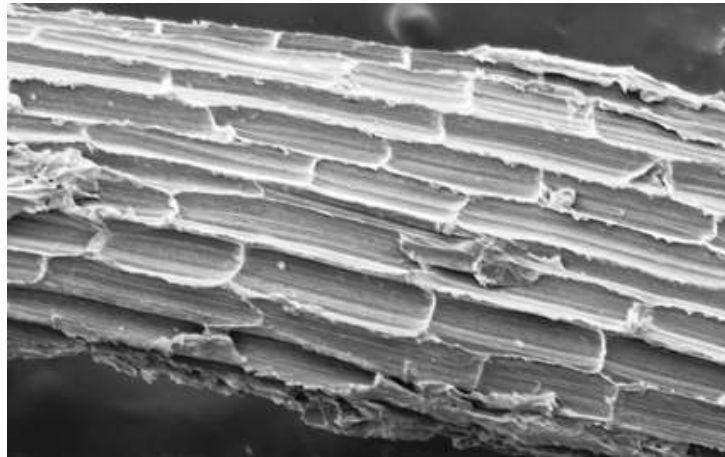


Figure 1(c) SEM micrograph of ASTF

### 3.2. Mechanical Properties

Figure 3 reports the differences in the mechanical characteristics of ATF, ASTF, and UTF. It is clear that the UTF's mechanical qualities are enhanced by the alkali treatment. When compared to UTF values, a 21% rise in tensile strength and a 23% increase in Young's modulus were found at a 2 weight percent concentration of NaOH.

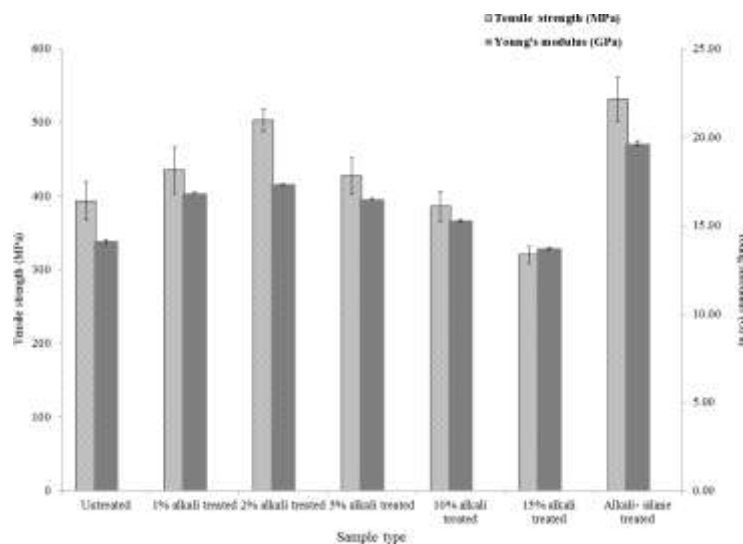


Figure 2(a): Tensile strength and Young's modulus of untreated and treated fibers

This characteristic is most likely caused by the removal of impurities from the fiber surface by alkali treatment, which causes sisal fiber to fibrillate and produce a rough surface topology with

better tensile capabilities than UTF. Nevertheless, delignification caused the fiber strength to decrease beyond a 2 weight percent concentration of NaOH.

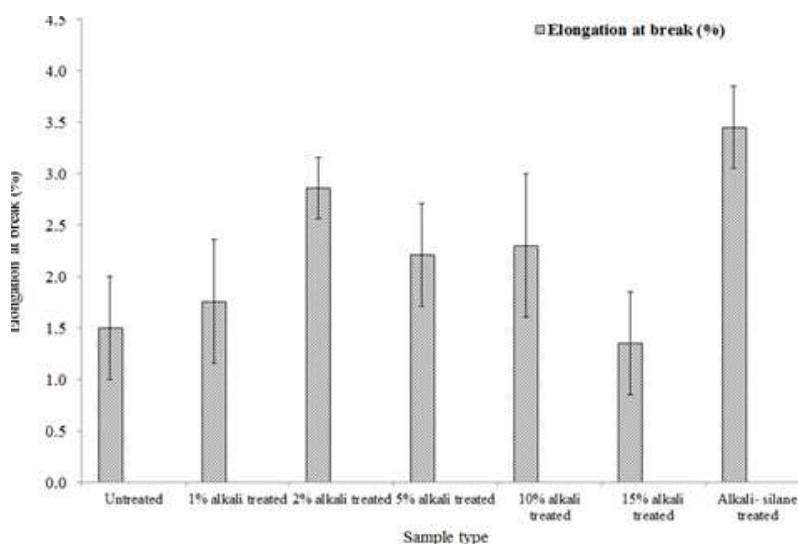


Figure 2(b): Elongation at break of untreated and treated fibers

Tensile strength and tensile modulus drop to 23% and 3%, respectively, at greater alkali concentrations (15 weight percent NaOH) due to the fibers losing their cementing material (lignin). This is in contrast to the fibers that had 2 weight percent ATF. The tensile characteristics of ATF were also improved by the alkali-silane treatment. Comparing the results with those of 2 weight percent ATF, the tensile strength rose from 503 MPa to 531 MPa and the tensile modulus from 17320 MPa to 19629 MPa. This behavior is explained by the formation of covalent and H bonds between 3- aminopropyltriethoxy silane and sisal fiber, which results in a rougher and more hydrophobic fiber surface than that obtained with an alkali treatment.

### 3.3. TGA Analysis

Using TGA at a heating rate of 50C/min, the thermal stability of sisal fibers as a function of alkali and alkali-silane treatments was investigated. As seen in Figure 4, the weight loss of fiber shows a three-stage breakdown as a function of temperature. When compared to UTF, the ATF and ASTF showed a greater thermal breakdown temperature. Moisture and other volatiles are lost when samples are heated from room temperature to 1500C, which results in weight loss. The partial extraction of hemicelluloses, which are very hydrophilic and thought to be the primary cause of

water absorption in lignocellulosic fibers, is the outcome of the alkali-silane treatment. It is observed that both the treated and untreated sisal fibers remained thermally stable up to 2450C, and the sample mass losses were negligible. The samples exhibit a sharp mass loss at 3000C, which is mostly caused by cellulose and hemicellulose breakdown. Delignification of the fibers leads to deterioration over 3700C. The maximum weight loss of 98.82%, 98.93%, and 86% for UTF, ATF, and ASTF was noted at 5150C, 5520C, and 7520C, respectively. This finding also indicates that the ASTF has better thermal stability than the ATF and UTF, with an 86% weight loss seen at 6000C. This demonstrates that the sisal fibers' heat stability was effectively increased by the alkali-silane treatment. Additionally, it demonstrates that the alkali and silane treatment lowers the cementing material and dries out the natural fibers, increasing the fiber's thermal stability compared to ATF and UTF. Additionally, it was discovered that the percentage char for ASTF was 14% greater than that of ATF and UTF, respectively. This demonstrates how surface-modified fiber has better flame-retardant qualities.

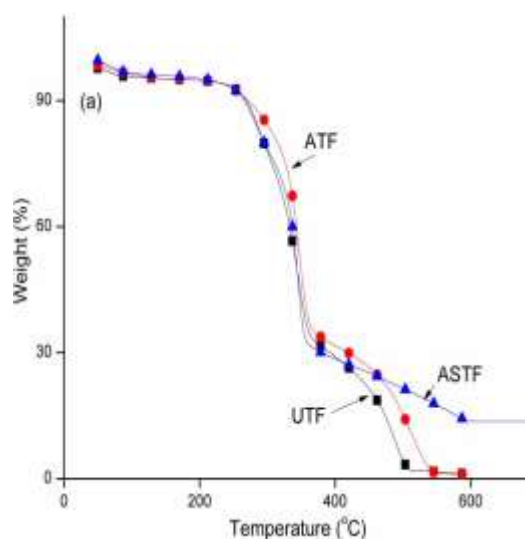


Figure 3. TGA scans of treated and untreated fibers

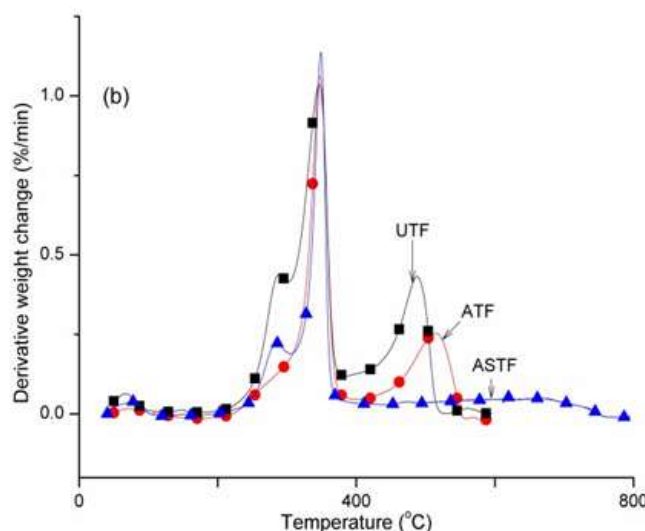


Figure 4. DTG scans of treated and untreated fibers

#### 4. Conclusion

It has been demonstrated that sisal fibers' mechanical and thermal characteristics may be greatly enhanced by surface modification with alkali and alkali-silane treatments. Surface imperfections are efficiently removed by alkali treatment, which also improves fibrillation, resulting in a rougher surface and superior tensile characteristics. Higher concentrations led to decreased strength owing to delignification, but the ideal NaOH concentration of 2 weight percent produced the best tensile strength and Young's modulus. By creating covalent and hydrogen connections between the silane and the fiber, the alkali-silane treatment further enhanced the mechanical characteristics and produced a rough, hydrophobic surface. According to thermogravimetric research, treated fibers—especially ASTF—showed better thermal stability than untreated fibers. The potential of chemically treated sisal fibers in high-performance composite materials is highlighted by these improved qualities. The results of this investigation lay the groundwork for further studies aimed at enhancing fiber treatments for a range of industrial uses.

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