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FABRICATION OF NEW FIBER REINFORCED COMPOSITE MATERIAL USING SISAL AND EVALUATION OF ITS MECHANICAL PROPERTIES

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ABSTRACT

In this study, the mechanical properties of untreated and chemically treated materials were analyzed, focusing on tensile strength, Young's modulus, and elongation at break. A range of alkali treatments (1%, 2%, 5%, 10%, and 15% alkali) were compared to untreated samples, as well as samples treated with alkali-silane. The results revealed that moderate alkali treatment significantly enhances tensile strength, reaching a maximum at 2% alkali concentration, while higher alkali concentrations result in a gradual decline. The alkali-silane treated samples demonstrated superior tensile properties, with the highest tensile strength and improved elongation at break, indicating enhanced ductility. The study highlights the critical role of chemical treatment in optimizing mechanical properties, with alkali-silane treatment offering the most substantial improvements in both tensile strength and elongation at break.

Keywords: Composite, Fiber, Strength, Alkali

1. INTRODUCTION

Over the past few decades, the utilization of polymers has significantly increased across various industrial sectors, including automotive, aerospace, medical, railways, electrical and electronics, and consumer goods. This surge in use is attributed to their superior strength, lightweight properties, low cost, corrosion resistance, and ease of processing. Recently, polymer composites have gained considerable prominence. These composites consist of a dispersed reinforcing phase embedded within a continuous binding phase (Sanjay et al., 2002; Paluvai et al., 2014). The reinforcing phase typically comprises fibers, particulates, or whiskers, while the matrix material may be thermosets, thermoplastics, or elastomers. The matrix serves as a medium for load transfer between the fibers or particulates, providing the composite with necessary strength, stiffness, electrical conductivity, and thermal stability. The properties of fiber-reinforced polymer (FRP) composites are largely influenced by the arrangement of fibers within the polymer matrix. FRP composites utilize various fiber forms, ranging from long continuous fibers to woven fabrics, short chopped fibers, and mats. Notably, the load-carrying capacity of FRP composites is maximized along the axis of continuous fibers. Conversely, when the same material is chopped into shorter lengths, it exhibits lower mechanical properties.

Polymers can be derived from both petroleum-based and biological resources. Thermosetting resins, such as benzoxazine, epoxy, polyester, polyurethane, phenolic, and vinyl ester, are commonly used with natural fiber composites. These resins provide exceptional mechanical strength, thermal stability, dielectric properties, chemical resistance, low shrinkage, minimal water absorption, and strong adhesion, rendering them superior to thermoplastic polymers for many applications.

Among thermosetting polymeric materials, epoxy resins hold particular significance in the composite industry. Epoxy resins contain more than one epoxide group, also referred to as an oxirane or glycidyl group (Srivastava et al., 1997). Petroleum-derived epoxy monomers exhibit outstanding mechanical strength, thermal and dimensional stability, chemical resistance, dielectric strength, low shrinkage, and strong adhesive properties, making them versatile for use in applications such as metal coatings, electronics, high-tension electrical insulators, composites, and structural adhesives (Mohan et al., 2012; Ratna et al., 2009).

The oxirane group within epoxy monomers reacts with various curing agents, including aliphatic amines, amidoamines, anhydrides, aromatic amines, phenols, polyamides, and thiols, resulting in a rigid thermoset product. However, the brittleness of cured epoxies, caused by a high degree of cross-linking, often compromises their toughness. To address this issue, numerous studies have focused on modifying epoxy monomers by incorporating flexible polymers, inorganic solid particles (such as nanoparticles), and elastomers (Petrie et al., 2006; Jean et al., 2010).

In this paper, the authors primarily focus on examining the effects of various chemical treatments on the tensile strength and elongation at break of composite materials. Different alkali concentrations (1%, 2%, 5%, 10%, and 15%) were used to treat the samples, as well as a combination of alkali and silane treatment. The primary goal was to analyze how these treatments influence the mechanical properties, particularly tensile strength and ductility, of the materials.

The novelty of this research lies in the combined alkali-silane treatment, which exhibits the best overall improvement in both tensile strength and elongation at break. This dual treatment approach demonstrated significant enhancement in mechanical performance, making the material both stronger and more ductile compared to untreated and purely alkali-treated samples. This work provides new insights into the synergistic effects of chemical treatments on mechanical properties, offering a novel method to improve material performance for various industrial applications.

Epoxy resins have also been used to modify other polymers, such as polyurethanes and unsaturated polyesters, to enhance their physical and chemical properties. Several authors have discussed the synthesis, modification, properties, and applications of epoxy resins (Paluvai et al., 2014; Mohan et al., 2013). Most epoxy monomers are synthesized through the condensation reaction of epichlorohydrin with aromatic amines, diphenyl methane, polyhydric phenols, polyols, or olefinic compounds, or through peracid epoxidation of olefins. Based on their oxirane rings, epoxy resins can be categorized into di-, tri-, and tetra-functional monomers. This section covers the synthesis and preparation of various epoxy monomers.

2. MATERIALS AND METHODS

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

The fibers of 50 cm length were soaked in 1, 2, 5, 10 and 15 wt% NaOH solution at room temperature for 4 h. The NaOH (alkali) treated fibers were washed with distilled water containing a few drops of acetic acid in order to neutralize the excess NaOH, followed by thorough rinsing withdistilled water. The fibers were then dried in the oven at 105 °C for 24 hr (Akram Khan et al 2011).

2.3. Alkali-Silane treatment of sisal fibers

The alkali treated fibers (ATF) were soaked in a solution containing 6wt% 3-aminopropyltriethoxy silane (APTES) solution mixed with ethanol/water in the ratio of 8:2 for 1 hr. Subsequently, the ethanol-water was drained out and then the fibers were dried in oven for 2 h at 105^0C (Kumar et al. 2012). The interaction of APTES with sisal fibers occurs through the succeeding steps (Bledzki et al. 1999), as represented in Figure 2.6. Similar behavior has also been reported by several authors between silane coupling agent and natural fiber (Puglia et al 2013, Sgriccia et al. 2008).

2.4. Mechanical Characterization (Tensile testing)

Tensile strength and modulus of fibers were determined using Universal Testing Machine (UTM), INSTRON 3382 (UK) as per ASTM-D- 3379 test method, at 2 mm/min cross-head speed and gauge length of 40 mm and fiber length of 0.05 m. above properties for the matrices and composites of dimensions 200×25×3mm were determined using UTM, INSTRON 3382 (UK) as per ASTM-D-5083 test procedure at a crosshead speed of 5mm/min and a gage length of 50mm.

3. RESULTS AND DISCUSSION

3.1. Scanning electron microscopic images

It is noted that in case of UTF, there are traces of impurities along the longitudinal surface of the fiber. As can be seen from Figure 1 and 2, the chemical treatment tends to remove wax and other essences on the fiber surface.

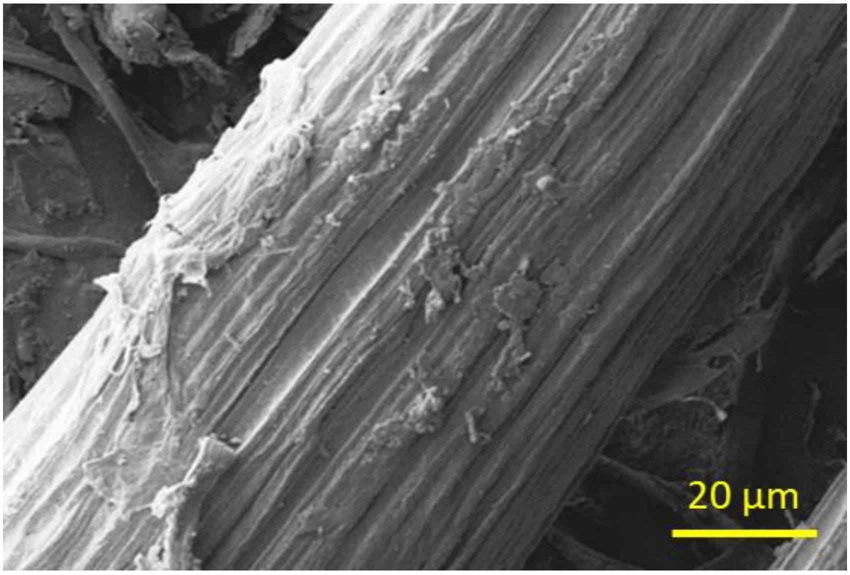

Figure 1. SEM micrograph of UTF

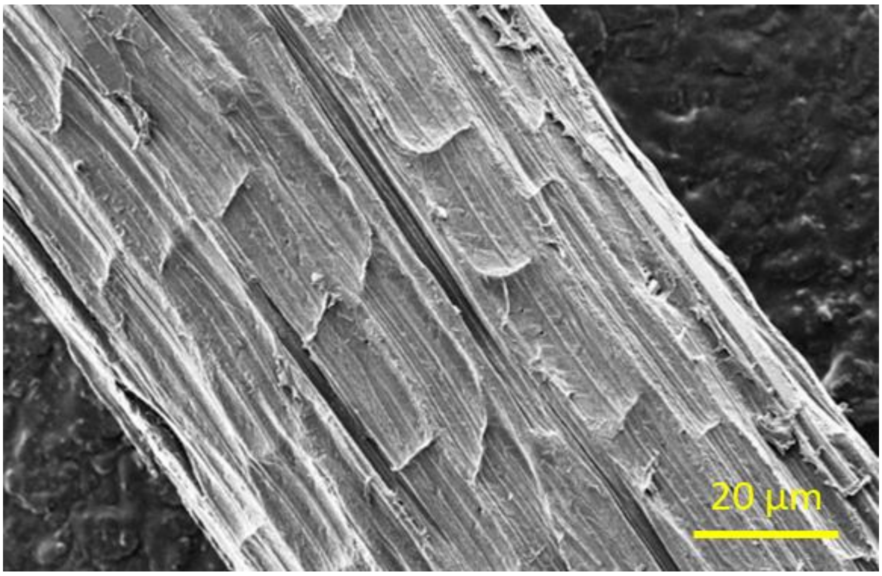

Figure 2. SEM micrograph of ATF

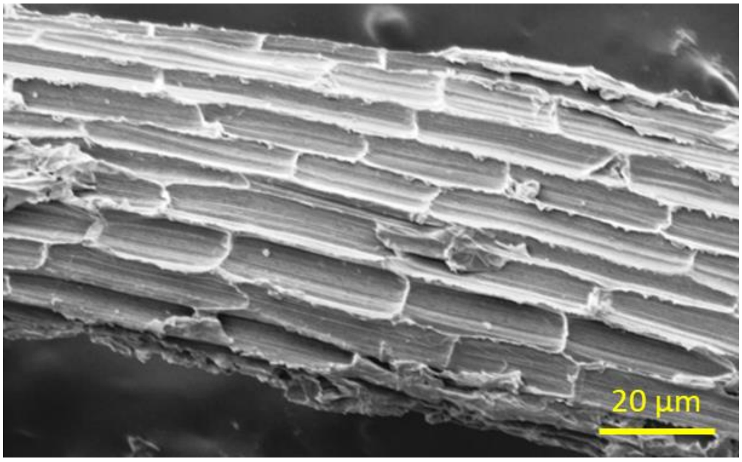

Figure 3. SEM micrograph of ASTF

The ATF sample displays fibrillation and a coarser morphology, which is clearly visible from the microporous structure. Unlike the UTF, the ASTF showed a rough surface due the removal of hemicelluloses and pectin groups that render uniform arrangement of the less dense and rigid fibrils in the tensile direction. Similar phenomenon was observed in the case of ASTF, which demonstrate the presence of macrospores, fibrillation as well as rougher fiber surfaces. It is assumed that the moisture in the fiber hydrolyzes the silanes to form silanols, which finally forms covalent bonds or H-bonds with the OH group of sisal fiber (Singh et al. 1996, Ghosh et al. 1990). These results concluded that the chemical modification of sisal fiber improves the surface characteristics such as wetting, adhesion, surface tension, and porosity.

The variation in mechanical properties of UTF, ATF, and ASTF is illustrated in Figures 1, 2, and 3. The results clearly show that alkali treatment enhances the mechanical properties of UTF. A significant increase of approximately 21% in tensile strength and 23% in Young’s modulus was observed at a NaOH concentration of 2 wt.% compared to the untreated fibers (UTF). This improvement is likely due to the removal of impurities from the fiber surface through alkali treatment, which causes fibrillation of the sisal fibers, resulting in a rougher surface topology and enhanced tensile properties relative to the untreated fibers.

However, when the NaOH concentration exceeded 2 wt.%, the fiber strength began to decrease due to delignification. At a higher alkali concentration of 15 wt.% NaOH, the fibers lost a significant amount of lignin, the cementing material, leading to a reduction in tensile strength and tensile modulus by 23% and 3%, respectively, compared to those at 2 wt.% ATF. Additionally, the alkali-silane treatment further improved the tensile properties of ATF. The tensile strength increased from 503 MPa to 531 MPa, and the tensile modulus rose from 17,320 MPa to 19,629 MPa compared to the 2 wt.% ATF. This enhancement is attributed to the formation of hydrogen bonds and covalent bonds between 3-aminopropyltriethoxy silane and the sisal fiber, making the fiber surface more hydrophobic and rougher than with alkali treatment alone.

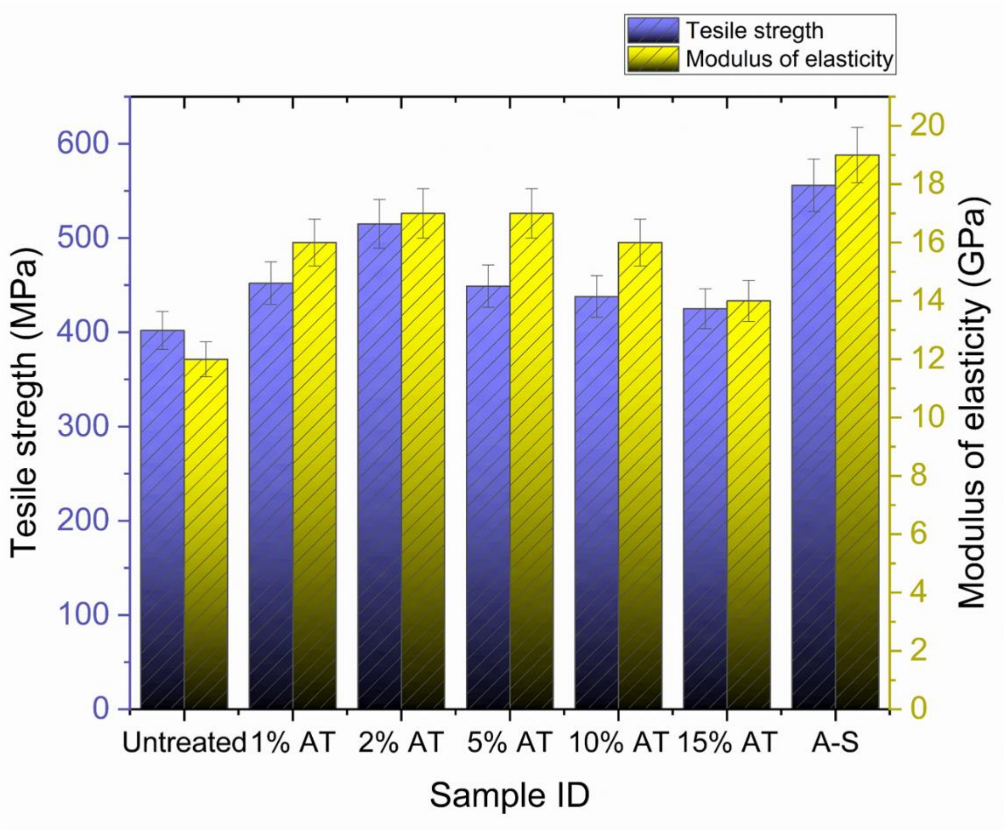

Figure 4. Tensile strength and Young’s modulus of untreated and treated fibers

Fig. 4 revealed that moderate alkali treatment (around 2%) and the alkali-silane treatment are beneficial for improving tensile strength, while higher alkali concentrations (above 5%) may have a diminishing effect.

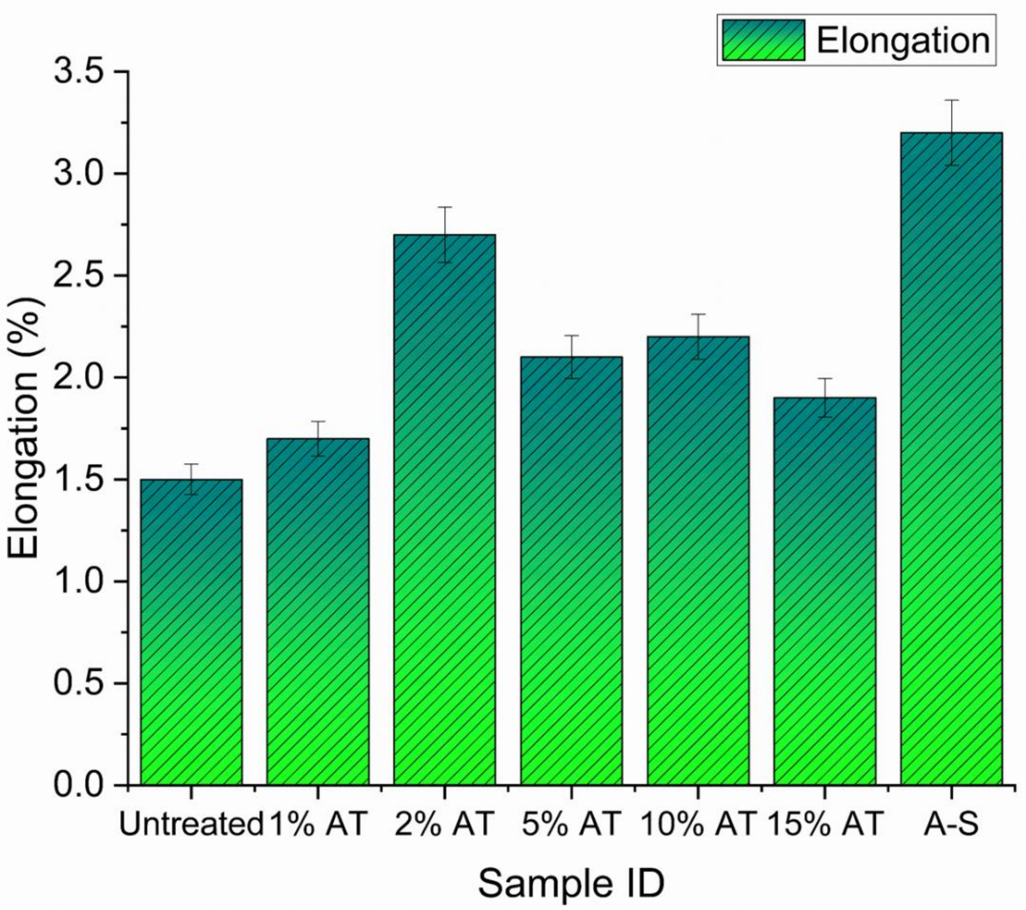

Figure 5. Elongation at break of untreated and treated fibers

Fig. 5 showed that the overall, the 2% alkali treatment and alkali-silane treatment offer the most beneficial effects on the material's elongation, enhancing its ductility, while higher concentrations of alkali have diminishing or negative effects.

4. CONCLUSION

This research demonstrates that chemical treatments significantly affect the mechanical properties of materials. Moderate alkali treatment (2%) enhances both tensile strength and elongation at break, providing an optimal balance between strength and ductility. However, excessive alkali treatment (above 5%) results in diminishing tensile strength and reduced elongation, indicating a potential loss of material flexibility. Alkali-silane treatment outperforms all other treatments, offering the highest tensile strength and elongation at break, suggesting its potential for enhancing mechanical performance. These findings emphasize the importance of selecting appropriate chemical treatments to optimize material properties for various engineering applications.

CREDIT AUTHORSHIP CONTRUTION STATEMENT

Dheeraj Singh: Conceptualization, Data curation, Methodology, Investigation, Resources, Writing – original draft, review and editing.

Sohail Bux: Conceptualization, Methodology, Supervision, Writing – review and editing.

DECLARATION OF COMPETING INTEREST

According to the authors, they are not aware of any financial conflicts of interest or close personal relationships that might have appeared to have influenced the work detailed in this study.

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