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Enhancements in crystallinity, thermal stability, tensile modulus and strength of sisal fibres and their PP composites induced by the synergistic effects of alkali and high intensity ultrasound (HIU) treatments

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ABSTRACT

In this investigation, sisal fibres were treated with the combination of alkali and high intensity ultrasound (HIU) and their effects on the morphology, thermal properties of fibres and mechanical properties of their reinforced PP composites were studied. FTIR and FE-SEM results confirmed the removal of amorphous materials such as hemicellulose, lignin and other waxy materials after the combined treatments of alkali and ultrasound. X-ray diffraction analysis revealed an increase in the crystallinity of sisal fibres with an increase in the concentration of alkali. Thermogravimetric results revealed that the thermal stability of sisal fibres obtained with the combination of both alkali and ultrasound treatment was increased by 38.5 °C as compared to the untreated fibres. Morphology of sisal fibre reinforced composites showed good interfacial interaction between fibres and matrix after the combined treatment. Tensile properties were increased for the combined treated sisal fibres reinforced PP composites as compared to the untreated and pure PP. Tensile modulus and strength increased by more than 50% and 10% respectively as compared to the untreated sisal fibre reinforced composite. It has been found that the combined treatment of alkali and ultrasound is effective and useful to remove the amorphous materials and hence to improve the mechanical and thermal properties.

1. Introduction

Over the last few decades, more attention is given to cellulose-based fibres as reinforcement fillers in the polymer composites owing to the environmental pollution caused by the extensive usage of synthetic fibres such as glass fibres to produce composite materials [1]. Unlike synthetic fibres, natural fibres possess light weight, high strength, and are readily available, environmentally friendly and biodegradable. Utilisation of natural fibres for the generation of composites has many advantages, for example, recyclability, eco-friendly products etc.

Many different types of natural fibres are being exploited for the production of biodegradable polymer composites [2–6]. More than thousand types of natural fibres are already available [7]. Among these, sisal fibres are one of the best reinforcing materials for polymer composites owing to their higher cellulose content (78%), good tensile strength (>600 MPa), easy availability and low cost [8]. However, similar to other natural fibres, sisal fibres are poorly compatible with the matrices of thermoplastics, due to their hydrophilic surface which in turn reduces the thermal and mechanical properties of sisal fibres reinforced thermoplastics. Especially in the fibre-matrix interfaces, hydrophilicity of the fibres causes poor mechanical strength and hence limits their applications [9,10]. Parparita et al. [11] studied the mechanical and rheological properties of different lignocellulosic fibre materials reinforced polypropylene composites. It has been observed that using different types of fibrous materials tensile modulus improved by more than 10% for fibre reinforced polypropylene composites.

Surface modification of natural fibres is often the followed method for the removal of amorphous materials from the fibre surface which increases the compatibility between fibre-matrix interfaces in the fibre-reinforced polymer composites. Alkali treatment reduces the fibre diameter by removing the amorphous materials from the fibre surface and increases the rough morphology. Thus, the removal of amorphous materials exposes cellulose and its hydroxyl groups and leads to more hydroxyl bonding between

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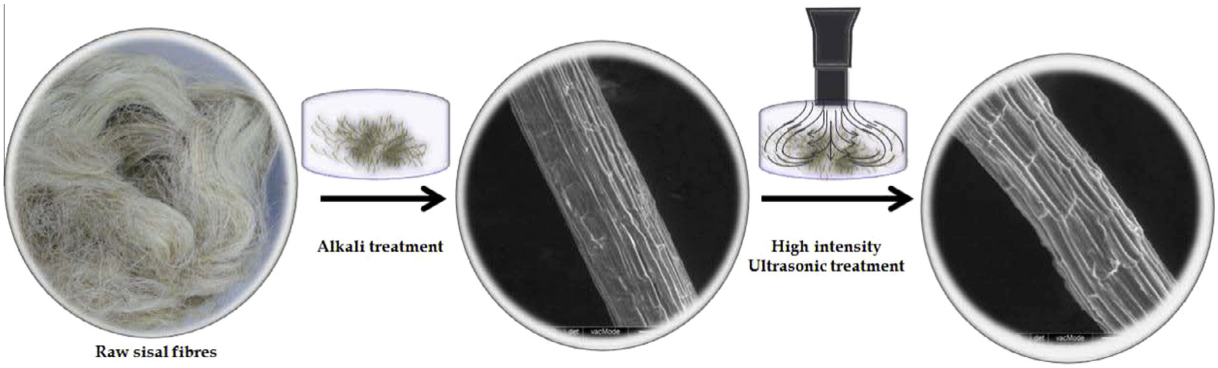

Fig. 1. Alkali and HIU treatments on the sisal fibres.

fibre surface and polymer matrix thereby enhancing the mechanical and thermal properties of the fibre reinforced polymer composites. Sisal fibres were treated with an alkali solution (NaOH) and the thermal and mechanical properties of sisal fibres reinforced cardanol-based biocomposites were studied. Treatment with 5% NaOH improved the thermal stability up to 12 °C, whereas with 10% NaOH the thermal stability increased by 18 °C [12]. Cyras et al. [13] studied the alkaline and acetylene treatments on sisal fibres and observed that the alkali treatments on sisal fibres increased the thermal stability due to the removal of lignin from the fibre surface. Asumani et al. [14] studied the alkali and silane treated kenaf fibre reinforced polypropylene composites. It has been noted that the tensile strength and modulus increased significantly by 25% and 11% respectively after treatment with 5% alkali.

High intensity ultrasound (HIU) treatment is the application of sound waves to the liquids in the frequency range from 20 to 1000 kHz [15]. It is well known that ultrasonication is one of the important and eco-friendly methods for various technological applications [16]. Ultrasonication induces cavitation which is the formation, growth and violent collapse of bubbles. Millions of formed bubbles collapse in the solution simultaneously which generates very high temperatures and pressures locally. The resultant effects of stable cavitation cause the etching effects on the fibre surface and results in the removal of amorphous materials from the fibre surface. The effect of ultrasound in degrading the linkages of cellulose and amorphous materials on the surface of fibres has been reported [17]. It has been proved that the removal of hemicellulose and lignin from lignocellulosic materials could be improved by applying HIU [18–21].

Moshiul Alam et al. [22] and Akindoyo et al. [23] studied the simultaneous effects of both alkali and ultrasound treatments on oil palm empty fruit bunch fibres and reinforced with poly (lactic acid), where they observed a significant improvement in the mechanical, thermal and interfacial properties of the resultant composites.

Looking at the fruitful effects of ultrasound, in this investigation, sisal fibres were treated with different concentrations of alkali, HIU as well as simultaneous application of both the alkali and HIU treatments (Fig. 1) and their resultant effects on the morphology and thermal properties were studied and also the tensile and impact properties of untreated and treated short sisal fibres reinforced polypropylene composites were investigated.

2. Experimental

2.1. Materials

General purpose injection moulding grade polypropylene (Titanpro 6331) was used with the melt flow index of 14 g/cm^3 and with the density of 0.9 g/cm^3. Sisal fibres were obtained from vibrant nature, Chennai, India. Commercial grade NaOH and acetic acid were used for the alkali treatment.

2.2. Treatments on the fibre surface

2.2.1. Alkali treatment

The alkali solution was prepared with different concentrations of NaOH (w/v) (0%, 3%, 5%, 7%, 9% and 15%) with distilled water. At first, the clean and dried sisal fibres were soaked in an alkali solution at room temperature for 24 h with constant stirring. The fibres were then washed several times with distilled water containing 1% of acetic acid to neutralise the remaining NaOH in the fibres and then dried at 100 °C for 24 h using hot air oven.

2.2.2. Treatment with high intensity ultrasound (HIU)

Untreated and sisal fibres that were treated with different concentrations of alkali were subjected to HIU for 90 min. An ultrasonic processor (Hielscher UIP1000hd, transducer tip diameter of 24 mm) with the frequency of 20 kHz, output power of 1000 W has been employed. Distilled water was used as the medium and the weight of fibres to water solution ratio was maintained as 1:20 (w/v). The total volume of the solution was 1000 ml and the transducer tip was dipped approximately 50% inside the solution medium. The temperature was maintained between 25 and 30 °C by using an ice/water bath. The optimization of ultrasound irradiation time and the temperature were also carried out as described in the literature [22,24]. The fibres were then washed with distilled water and dried at 100 °C in a hot air oven for 24 h and the resultant sisal fibres were then studied for their morphological and thermal properties.

2.2.3. Preparation of sisal fibres/PP composites

PP and different weight percentage of untreated, ultrasound, alkali (7 wt%) and the combination of alkali (7 wt%) and ultrasound treated sisal fibres (Table 1) were mixed with an internal mixer (Brabender Plasticoder PL2000-6 equipped with co-rotating blades and a mixing head with a volumetric capacity of 69 cm^3). The rotor speed, blending temperature and mixing time were set at 50 rpm, 175 °C and 15 min respectively. All the samples were dried under vacuum at 60 °C for 4 h before mixing to remove any moisture. Materials obtained from the internal mixer were compression moulded to obtain the test specimens. The compounded materials were placed onto a steel frame mould covered by aluminium plates on both sides. The materials were pressed into sheets of 1 and 3 mm thickness at 175 °C. The moulding cycles involve 3 min of preheating without any pressure, 20 s of venting and 3 min of compression under 100 bar pressure using hot and cold pressing