Sugarcane Bagasse Reinforced Polyester Composites: Effects of Fiber Surface Treatment And Fiber Loading on The Tensile And Flexural Properties

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Abstract. The effect of fiber surface treatment and fiber loading on the tensile and flexural properties of untreated and treated fiber-based sugarcane bagasse reinforced polyester (SBRP) composites have been investigated. Sugarcane bagasse fibers were alkalized with 1, 3 and 5% concentration of sodium hydroxide (NaOH) solution combined with different fiber loading formulation 0, 20, 30 and 40 php, and hot-pressed to form natural fibers composite were prepared. The results indicated that the incorporation of bagasse fiber composites alkalized with 3% NaOH solution improved the tensile strength and modulus of reinforced composites meanwhile the untreated bagasse gave the lowest value. However, the elongation at break (\(E_b\)) indicated that treated bagasse fiber composites show a lower value compared to untreated composites. A similar trend also obtained for flexural strength and modulus.

1 Introduction

Fiber-reinforced plastic composites have long performed a leading role in a wide range of applications with their high relative strength and modulus. Fiber integrated plastics were very common because of their versatility, their lightness and the ease of manufacturing complicated shapes with economical savings compared to fiber-reinforced metals/alloys. Therefore, these composites can easily replace traditional materials in various sectors such as the construction industry, transport and consumer goods. Some of the recent attempts to

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use natural fibers by composite material manufacturing have shown their promise in many applications as replacements for traditional materials such as wood and glass fiber reinforced plastics (GFRP) [1].

Natural fillers, including cellulose-based fibers, have largely taken ground on the industry landscape in previous years in replacing synthetic materials [2]. Cellulose-based fibers (natural fibers) arise through relatively affordable and sustainable resources; and the addition of natural fibers such as wood fibers, flax or sisal to polymer matrices can lead to composites that are feasible from a mechanical and economic perspective [3]. Natural fiber-based composites, such as fiberglass, are biologically superior to those based on synthetic fibers. Natural fiber products' incineration requires 45% less energy and leads to lower air pollution as reported in recent studies [4].

Among the diverse agro-industrial residues, sugarcane bagasse is detached to be a highly produced residue containing silica (2.0%), ash (2.4%), fat and wax (3.5%), lignin (19.95%), hemicellulose (24.5%), and cellulose (46.0%) [5]. Bagasse is a plant fiber consisting primarily of cellulose, a glucose polymer with a significantly high modulus, frequently found in association with lignin as a fibrillar portion of many naturally occurred composites (wood, sugarcane straw and bagasse) [6].

Alkali treatment is considered to be one of the commonly used chemical treatment techniques for the surface modification of cellulosic fibers to enhance their adhesion properties with specific thermosetting binders [7, 8, 9]. This treatment involves partial removal from the fiber surfaces of the cementing materials (hemicellulose and lignin) and other impurities [10]. A similar change due to alkali treatment at limited NaOH concentrations has been reported to improve some of the mechanical properties of composites bonded with phenol-formaldehyde [7]. Alkali treatment of cellulosic fibers, also known as mercerization, enhances the fiber's surface adhesive properties by eliminating organic and inorganic impurities, creating a rough topography.

The mechanical properties of sugarcane bagasse reinforced polyester (SBRP) composites were assessed in this work. The effect of NaOH treatments and fiber content has been studied on the tensile and flexural properties of untreated and treated fiber-based composites.

2 Materials and Methods

2.1 Materials and preparation of composites

The bagasse was obtained from the Kilang Gula Felda Perlis Sdn Bhd (KGF) and sieved into a diameter size average of 1.18 mm and 600 μm. Unsaturated Polyester (UP) resin was used with the grade Reversol P9509 supplied by Echemo Trading Sdn. Bhd., Penang. Tert-butyl perbenzoate (Fluka 77200) was used as an elevated temperature curing catalyst supplied by Sigma Aldrich. Sodium hydroxide (NaOH) pellets extra pure obtained from Hamburg Chemicals. Zinc stearate supplied by Sigma-Aldrich and was used as a mould release agent (lubricant).

In each 1, 3 and 5% concentration of NaOH solution, bagasse fibers were soaked at room temperature for 1 hour, maintaining a 20:1 liquor ratio. The fiber was then washed several times with distilled water to remove any NaOH solution that stuck to the fiber and the fibers were oven-dried for 72 hours at 70 °C [11]. The bagasse fibers were then kept in desiccators before compounding.

All materials were weighted by following the formulation to produce composite with percentage fiber that mentioned in Table 1. The composites were then prepared by compounding bagasse fiber, unsaturated polyester, tert-butyl perbenzoate and zinc stearate.
with different fiber loading using high dispersion impeller (Electronic Laboratory Stirrer, Qualtech Products Industry). The catalyst was then put in the beaker and the resin followed. The stirrer was switched on to start the compounding process. The lubricant was then placed in the beaker and the fiber proceeded to obtain a homogeneous compound. The compounding process is conducted for 30 minutes. The compounds were then transferred into the mould for moulding process.

Table 1 Composites Formulation

| Materials                      | Untreated | NaOH Treated |
|--------------------------------|-----------|--------------|
| Unsaturated Polyester (php)    | 100       | 100          |
| Sugarcane Bagasse (php)        | 0, 20, 30, 40 | 0, 20, 30, 40 |
| Tert-Butyl Perbenzoate a       | 1         | 1            |
| Zinc Stearate b                | 6         | 6            |
| NaOH c                         | -         | 1, 3, 5 %    |

a 1 php from the weight of unsaturated polyester  
b 6 php from the weight of unsaturated polyester  
c 1, 3, 5 php from weight filler

The samples were hot-pressed by using a hydraulic hot press machine Technopress 50HC – β model. The compression was done at 110 °C for 5 minutes, and the samples were allowed to cool for 5 minutes by the cooling process. The pressure was set at 1 MPa. A hollow rectangular mold was used in the compression molding, which has a size of 170 mm×135 mm× 3mm.

2.2 Tensile Test

An Instron 5569 tensile tester was employed to determine the tensile properties of the sample according to ASTM D638. The rectangular test specimens were tested at a crosshead speed of 5 mm/min under a cell load of 2500N. A total of 8 samples have been tested for each formulation to ensure consistency.

2.3 Flexural Test

In compliance with ASTM D790 three-point flexural tests were performed. The support range had been set to 50 mm. Tests were carried out at a crosshead speed of 2 mm/min on the same Instron 5569 tensile testing machine used for tensile tests. A total of 8 samples have been tested for each formulation to ensure consistency.

3 Results and Discussion

3.1 Tensile Properties

Figure 1 shows the effect of NaOH solution concentration at 20, 30 and 40 wt % on tensile strength of sugarcane bagasse reinforced unsaturated polyester, respectively. The use of treated bagasse fiber has been found to increase the tensile strength of the polyester composites as opposed to the untreated bagasse fiber. This means that after alkali treatment, most of the pectin, lignin and fat covered by the fiber surface are eliminated, the fiber adhesive character enhanced in combination with the matrix [12].

The results show that all treated fibers have a higher tensile strength from those of untreated fibers, with considerably higher properties shown in 3% concentration of NaOH.
solution treated fibers. The fibrillation of fibers has developed superior interfacial adhesion in the composites [11]. Fiber fibrillation breaks the composite fiber bundle into smaller fibers, thus increasing the optimal surface area available for interacting with the wet matrix [13]. Nonetheless, the mechanical properties decreased with higher fibrillation due to the relatively larger fiber ends necessary for crack initiation for the 5% NaOH treated fiber composites. This could lessen the effectiveness of stress transfer at the interface [11]. The maximum tensile strength improvement was observed in NaOH-treated fiber composites of 3%. Better interfacial adhesion along with better fibrillation of these fibers was considered to have effectively attributed to improving tensile strength.

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![Figure 1](image)

**Figure 1** The effect of different NaOH solution concentration on tensile strength of sugarcane fiber reinforced unsaturated polyester composites with different fiber loading

The effect of NaOH solution concentration at 20, 30 and 40 wt % on elongation at break of sugarcane bagasse reinforced unsaturated polyester composites are illustrated in Figure 2. The graph indicates that elongation at the break of treated bagasse fiber composites has a lower value than untreated composites. There can be two hypotheses; (A) Fibers are failed points which could trigger a crack, and (B) The fibers are sliding in respect of the matrix. The elongated materials have ductile fractures and the composite failure points have the brittle fracture [14]. This was probably because modified fibers were made more hydrophobic and consequently increased compatibility between fiber and matrix resin. Enhancing fiber-matrix bonding will improve composite strength, rigidity and interfacial adhesion. This was also due to the improved adhesion of the fiber-matrix (to give the composites more stiffness) and since modified fiber was susceptible to splitting and falling apart, fiber after modification was more brittle. We can, therefore, infer that improved wetting of the treated fibers through the matrix was responsible in this case [15].
Figure 2: The effect of different NaOH solution concentration on elongation at break of sugarcane fiber reinforced unsaturated polyester composites with different fiber loading.

Figure 3 shows the effect of NaOH solution concentration at 20, 30 and 40 wt % on the modulus of elasticity of sugarcane bagasse reinforced unsaturated polyester composites. The Young’s modulus of the composites increased with increasing the filler loading and NaOH solution concentration. The increase of Young's modulus with an increase in filler loading is expected as the addition of filler increases the composites' stiffness. It can be seen that 40 wt % of bagasse fiber of 3% NaOH solution concentration has the highest value of modulus of elasticity. Here 40 wt % treated bagasse fiber with 3% NaOH solution concentration – reinforced composites showed 28% of the increase in Young’s modulus. Nevertheless, the mechanical properties of the 5% NaOH-treated fiber composites decreased with greater fibrillation due to the relatively larger fiber ends required for crack initiation. This could lower the effective stress transfer at the interface [11].

Such difference can be described as follows: The NaOH reacts with hydroxyl groups of the cementing material hemicelluloses during mercerisation, and it induces the deterioration of the cellular structure, and thus the fibers fragmented into filaments. This phenomenon is called fibrillation, which breaks down the untreated bundle of fibers into smaller ones by dissolving the hemicelluloses. This fibrillation increases the optimal surface area available for matrix interaction [11]. The deletion of lignin and hemicelluloses affects the fibers' tensile characteristics. When the fractions of hemicelluloses are withdrawn, the interfibrillar area is likely to be less dense and rigid, which may make the fibrils more capable of rearranging themselves along the tensile deformation direction. As reported, the alkaline treatment of sisal fibers causes fibrillation and the cellular structure collapsed due to the removal of the cementing materials [16]. Mercerisation also improves the percentage of fibers' crystallinity index due to the removal of cementing compounds, resulting in a better packaging of cellulose chains.
3.2 Flexural Properties

The flexural strength and modulus of bagasse fiber reinforced polyester composite are shown in Fig. 4 and 5. It can be seen from the figure that the flexural strength of the composites increases with the increasing filler loading and the concentration of NaOH solution. The results in Fig. 4 showed that composites with 3% NaOH solution concentration have higher flexural strength than other concentrations. The fibrillation offered a superior interface adhesion in the composites thus enhances the flexural strength compared to the lower fibrillation of 5 percent NaOH solution concentration, due to the relatively larger fiber ends needed for crack initiation.

Figure 5 shows that the composites' flexural modulus increased due to the concentration of the NaOH solution. The effect on the flexural modulus was more substantial than on the flexural strength, as the integration of modified fiber was still able to give the stiffness of the composites. The composites with 3% NaOH solution concentration demonstrated higher stiffness as opposed to those with NaOH modification. This could be attributed to the enhanced compatibility between the resin and the fiber. The increased compatibility leads to a continuous interfacial region, which enabled a better and more stress transfer efficiency in the samples [15].
Figure 4 The effect of different NaOH solution concentration on flexural strength of sugarcane fiber reinforced unsaturated polyester composites with different fiber loading

Figure 5 The effect of different NaOH solution concentration on flexural modulus of sugarcane fiber reinforced unsaturated polyester composites with different fiber loading

4 Conclusions

The following conclusion can be drawn from this study:

a. Tensile strength, Young’s modulus, and flexural strength value were increased with an increasing solution concentration of NaOH. However, 5% NaOH solution concentration modification shows the decreasing value of tensile strength, Young’s modulus and flexural properties of the composites.

b. Elongation at break for the sugarcane bagasse reinforced unsaturated polyester composites decreased with increasing bagasse fiber content in both composites.

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