EFFECTS OF ALKALINE TREATMENT AND A COMPATIBILIZING AGENT ON TENSILE PROPERTIES OF SUGAR PALM FIBRE-REINFORCED HIGH IMPACT POLYSTYRENE COMPOSITES

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The effects of alkaline treatment and a compatibilizing agent on the tensile properties of sugar palm fibre-reinforced high impact polystyrene (HIPS) composites were studied. Two concentrations of an alkali solution (4% and 6%) and two percentages of a compatibilizing agent (2% and 3%) were used in this study. The alkaline treatment was carried out by immersing the fibres in 4% and 6% alkali solutions for 1 hour. A 40 wt. % of sugar palm fibre (SPF) was blended with HIPS and the compatibilizing agent using a Brabender melt mixer at 165 °C. All the treated fiber composites showed tensile strength enhancement compared with untreated composites. The maximum strength increase was 35%, which was achieved by 4% alkali treatment; however, there was no improvement in the tensile modulus.

Keywords: Tensile properties; Sugar palm Fibre; HIPS; Alkaline; Compatibilizing agent

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INTRODUCTION

Recently, more attention has been placed on using natural fibres instead of synthetic fibres (glass fibre especially) in fibre-reinforced polymer composites. Polymer composites reinforced with synthetic fibres have negative environmental and health effects. Advantages of using natural fibres in place of synthetic fibres include lower density, better biodegradability, less environmental risk, ease of separation, easy availability, enhanced energy recovery, a non-corrosive nature, and usually lower costs (Singha and Thakur 2007). Various natural fibres such as hemp, flax, abaca, sisal, jute, henequen, kenaf, ramie, oil palm, pineapple leaf, banana pseudo-stem, sugarcane bagasse, coir, rice husk, wood, and bamboo reportedly have been used for the reinforcement of polymer composites (Saheb and Jog 1999).

Sugar palm or *Arenga pinnata* tree is a popular plant in Southeast Asia, in particular in Malaysia and the Philippines, which is a promising source of natural fiber. The black fiber is produced from the mature tree after 5 years (Mogea et al. 1991). Figure 1 shows the location of the fibre on the sugar palm tree. This kind fiber has many applications due to its superior strength and durability.

Fig. 1. Sugar palm tree and the location of the sugar palm fibre

Extensive studies have been reported on the performance of incorporation natural fibre in thermoplastics matrix. George et al. (1993) reported on the processing characteristics and mechanical behavior of pineapple leaf fibre reinforced low-density polyethylene (PALF/LDPE) composites. They studied the effects of fibre orientation, fibre loading, and fibre length on the composites. Hornsby et al. (1997) discussed the mechanical properties of polypropylene composites containing flax and wheat straw fibres. The inclusion of 5% by weight of maleic anhydride-modified PP could enhance the tensile strength, which was shown to promote adhesion between fibres and matrix. Joseph et al. (1999) optimized mixing parameters by varying the mixing time, rotor speed, and chamber temperature when tailoring sisal/PP composites. Their work proved that melt-mixed composites showed better tensile properties than those of solution-mixed composites. Several chemical treatments, i.e. alkali, isocyanate, peroxide, maleic anhydride, and maleic anhydride graft-copolymer treatment had been conducted by previous researchers for the enhancement the mechanical properties of natural fibre reinforced the thermoplastic composites (Joseph et al. 1996; Arbelaiz et al. 2005).

The role of sugar palm fibres in the reinforcement of thermoplastic composites, however, has not been fully studied. This research explores the new concept of combining sugar palm fibres with high impact polystyrene thermoplastic composite materials. High Impact Polystyrene (HIPS) is a type of polystyrene in which polybutadiene is added during polymerization. Polystyrene is used in high-quality goods, and its suggested application in this research is roof tiles. The tensile properties of SPF-HIPS composites were examined, and the chemical treatments of the fibres were carried out to improve the mechanical performance of the composites.

MATERIALS AND METHODS

Materials

The high impact polystyrene (HIPS) used as the matrix polymer was Idemitsu PS HT 50 supplied by the Petrochemical (M) Sdn Bhd, Pasir Gudang, Johor, Malaysia. The sugar palm fibre (SPF) was obtained from Aceh, Indonesia. The fibres were crushed with a pulverisette machine for shortening and sieved through 30 and 50 mesh screens.

There were two types of treatment used in this study: (1) mercerization using an alkali solution and (2) using the polystyrene-block-poly(ethylene-ran-butylene)-block-poly(styrene-graft-maleic-anhydride) as a compatibilizing agent. NaOH and the compatibilizing agent were supplied by Aldrich Chemical Company, Malaysia.

Treatment Processing

The first treatment was mercerization, or alkali treatment. It was carried out by immersing the short fibres in an NaOH solution for 1 hour at room temperature. Two concentrations of NaOH were used: 4% and 6%. The fibre/solution ratio used was 1:20 (w/v).

The treated fibres were then washed with distilled water to remove residual NaOH thoroughly. The drying process of fibres was conducted by oven at 100 ^{0}C during 2 days. The second treatment included applying two different weight concentrations (2 and 3 wt. %) of the compatibilizing agent.

Composite Processing

The sugar palm fibres (40 wt. %) were mixed with the HIPS matrix using a Brabender Plasticorder intensive mixer, model PL2000-6 at 165 °C. The mixing process was performed in the following sequence. The HIPS (58 wt. % and 57 wt. %) and compatibilizing agent (2 wt. % and 3 wt. %) were first premixed at room temperature for 3 minutes. The HIPS and compatibilizing agent were then placed in the mixing chamber for about 2 minutes at 50 rpm, followed by the addition of the SPF for another 10 min. of mixing. The resulting material was then compressed in the mould using a Carver laboratory press with metal frame size 150 mm x 150 mm x 1mm at 100 bar and temperature 165 °C. Thereafter it was subjected to a process of pre-heating for 5 minutes and full press-heating for 5 minutes. The processing pressure is 100 kg/cm^2. This was followed by cooling for 5 minutes using circulated water with 20 ^{o}C temperature, and the final resulting composite was formed into sheets. The same technique was also applied for the alkali-treated sugar palm fibres with a mixing composition of 40 wt. % alkali-treated fibre and 60 wt. % HIPS matrix. Finally, samples were produced by cut using the dumbbell cutter for tensile test according to ASTM Standard size.

Tensile Testing

Tensile testing was carried out on an Instron Tensile model 5569 according to ASTM D 638. The gauge length was set at 50 mm and the cross head speed was set at 2 mm/min. The six specimens of each sample were tested.

Moisture Absorption Behavior

The moisture absorption analysis of neat HIPS matrix, as well as untreated and treated SPF-HIPS composites (40%wg. fibres) was conducted according to the ASTM D570, and the dimensions of test specimens were 25×12.7×3 mm^3. The specimens were placed in oven at 50 C during 24 h, and then they were cooled and immediately weighed to get the initial weight W_0, with 0.1 mg accuracy. The specimens were submerged in a box of water maintained at 25 C during 24 h. Furthermore, the specimens were weighed to get the final weight, W_1. The increase of weight in percentage of the samples was determined by using the formula $(W_1-W_0)/W_0$.

Morphology of Fracture Surfaces

Fracture surfaces were observed with a scanning electron microscope (Hitachi, model, Hitachi High Technologies Inc., Tokyo, Japan) at an acceleration voltage of 5 kV. SEM was used to examine qualitatively the dispersion of fibres in the HIPS matrix and to visually observe the interface of the fibre and matrix composites. The samples were coated with gold using the plasma sputtering apparatus.

RESULTS AND DISCUSSION

Tensile Properties

The effects of the compatibilizing agent (2% and 4%) and alkali treatments (4% and 6%) of short sugar palm fibres on the tensile strength and tensile modulus of SPF-HIPS composites were examined using the treated fibre composites based on 40wt. % fibre loading.

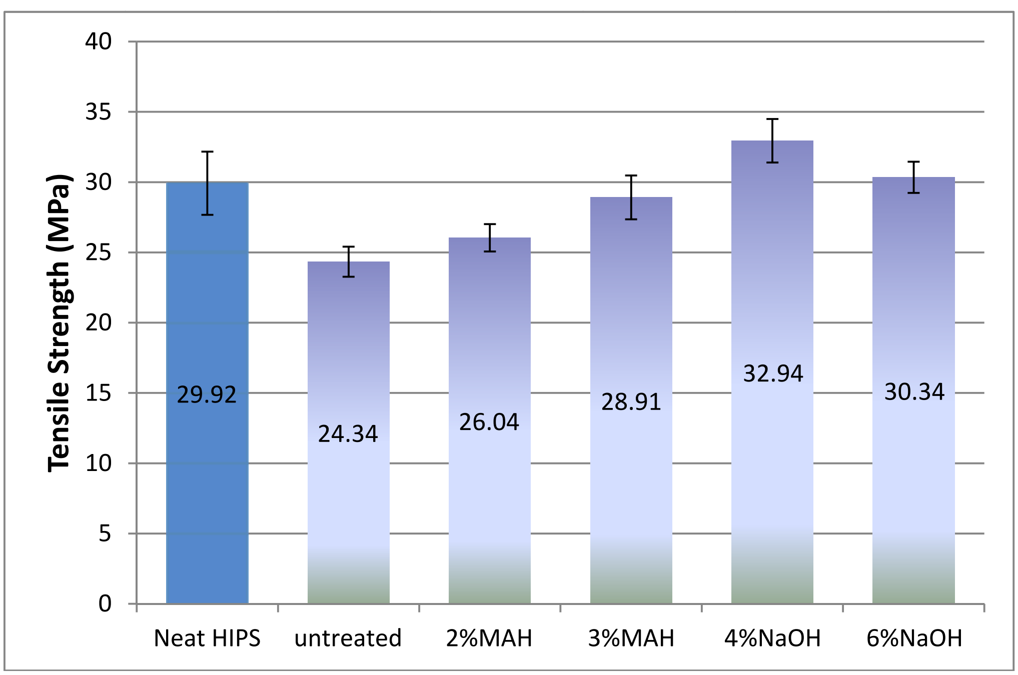

Fig. 2. Tensile strengths of untreated and treated of SPF-HIPS composites

As shown in Fig. 2, all treated composites produced an improvement in tensile strength compared to untreated composites. The 2% MAH, 3% MAH, 4% NaOH, and 6% NaOH treatments improved the tensile strengths by 7%, 19%, 35%, and 25% respectively, compared to the untreated fibre composites. The maximum improvement in tensile strength was observed for the composites treated with 4% alkali. This enhancement may have occurred from enhancement in the adhesion between the fibre surfaces and the HIPS matrixes. Based on literature reports, alkali treatment or mercerize-tion of fibres can cause the following phenomena (Kalia et al. 2009):

1. Fibrillation, which causes the breakdown of fibre bundles into smaller, individual fibres, increasing the surface area exposed to polymer matrix.
2. Reduction in fibre diameter, which increases the aspect ratio, leading to the development of rough surface topography that results in better fibre matrix interface adhesion.
3. Increase in the number of reactive sites, allowing for better fibre wetting.
4. Changes the chemical composition of the fibres, such that cellulose crystallite content in fibres is high due to removal of lignin and hemicelluloses cementing substances.

Mercerization also can decrease the tensile strength of a single fibre under higher alkali concentrations. Edeerozey et al. (2007) investigated the effect of alkali treatment on the strength of a single kenaf fibre. They found that at higher concentrations (9% NaOH), the fibre degraded, decreasing the fiber strength. Referring to Fig. 2, the tensile strength decreased from an alkali concentration of 4% to 6%. It can be argued that a decrease in strength at a 6% NaOH concentration was caused by fibre degradation.

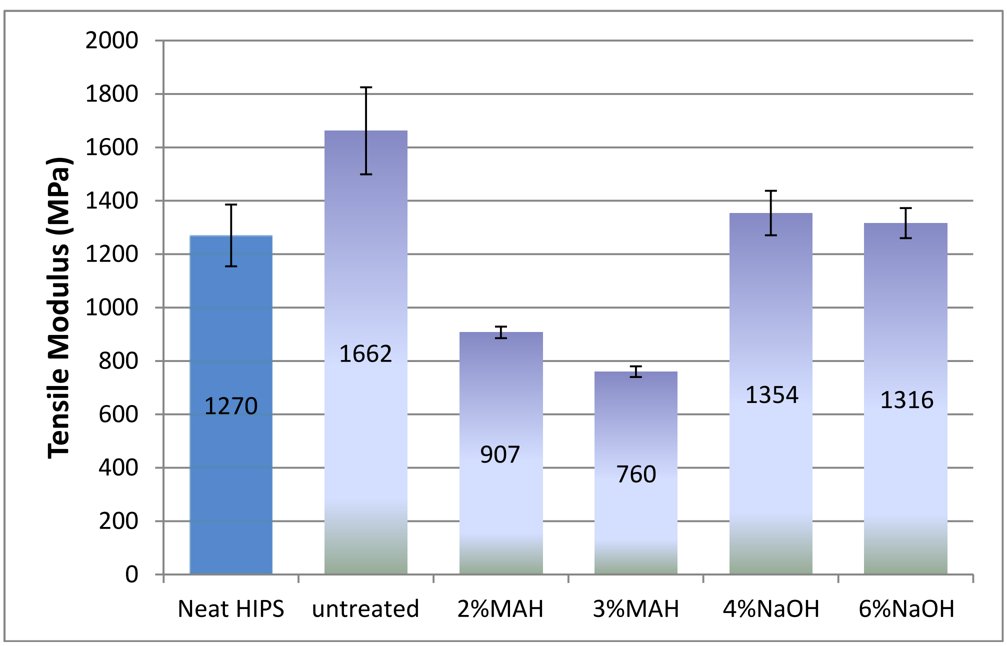

Fig. 3. Tensile moduli of untreated and treated SPF-HIPS composites

Maleic anhydride as a compatibilizing agent was grafted on the mid-block to increase its compatibility with polar coatings and increase its interaction with substrates. The reactive functional groups were able to generate in situ formation of blocks or grafted copolymers at the interface by hot-melting blending. Reactive compatibilization has proven to be an effective method for improving mechanical properties, especially tensile strength, of sugar palm-reinforced HIPS composites.

The tensile moduli of sugar palm fibre-reinforced HIPS composites with chemical treatment, however, showed no improvement compared to untreated composites (Fig. 3). The stiffness of the composites became lower with chemical treatment. Chow and Ooi (2007) also reported the same phenomena; the flexural modulus of polystyrene organo-montmorillonite nanocomposites decreased after the incorporation of maleic anhydride graft polystyrene. A decrease in stiffness from chemically treating composites may be caused by several reasons: (a) Compatibilizer acts as lubricant, which renders the movement of molecules easier than for those without coupling agent due to higher friction, (b) MAH used here was a kind of impact improver that has soft segments and will soften molecules chains, (c) Mercerization will remove some glue/extractives/lignin etc. in fiber bundles, which contributed to lower stiffness of the treated fibers, exhibiting lower tensile modulus.

SEM Analysis

A SEM micrograph was used to qualitatively assess the interfacial adhesion of the fibre and matrix for the composites. Figure 4 shows the fracture surface of untreated SPF-HIPS composites. The fracture model of fiber pull-out and smooth surface can prove there was poor compatibility between native SPF and the matrix. Visuals of treated fibre surfaces of treated composites are shown in Fig. 5 and 6.

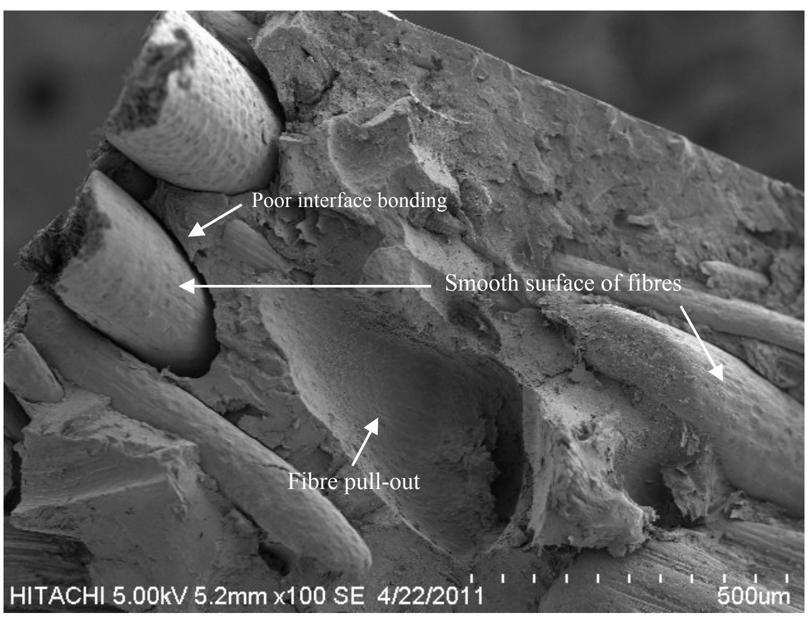

Fig. 4. The fracture surface of an untreated 40%SPF-HIPS composite

Figure 5 shows fracture surfaces of the composites treated with 2% and 3% addition of MAH compatibilizing agent. The thin gap between fibre and matrix indicates good adhesion. This is due to infiltration of maleic anhydride in the HIPS matrix. Figure 6 shows the fracture surfaces of composites treated with 4% and 6% alkali. These photographs also show a thin gap between the fibre and the matrix, indicating the good interfacial bonding that resulted from the alkali treatment. Alkali treatment also produced a rough surface from the abrasion of impurities on the fibre surfaces. Alkali-treated composites also showed higher tensile strengths than composites with MAH addition.

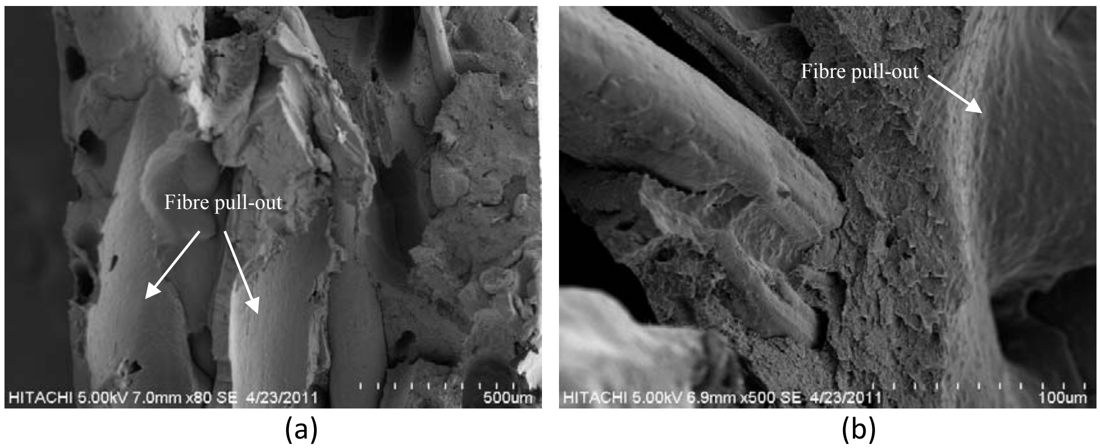

Fig. 5. The fracture surface of a SPF-HIPS composite with (a) the addition of 2%MAH, (b) the addition of 3% MAH

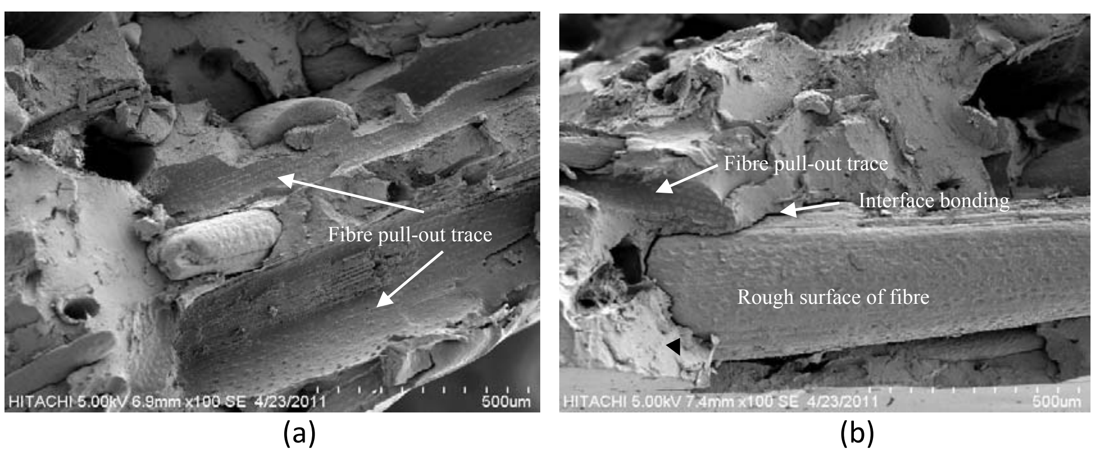

Fig. 6. The fracture surface of a SPF-HIPS composite treated with (a) 4% alkali, (b) 6% alkali

Effect of the Treatments on Water Absorption Behavior of Composites

The effects of the compatibilizing agent (2% and 4%) and alkali treatments (4% and 6%) of short sugar palm fibres on the water absorption behavior of SPF-HIPS composites were examined. Figure 7 depicts the moisture content of the SPF-HIPS composites that had been subjected to several treatments after 24 hours immersion. It can be seen that water absorption behavior of the composites with MAH treatment was almost the same as that of the untreated composites. There was no significantly difference of moisture content between them. However for the alkali treatment, the result shows higher water absorption. Alkali treatment makes the fibre more hydrophilic, due to the change of cellulose I to cellulose II (Alvarez et al. 2003).

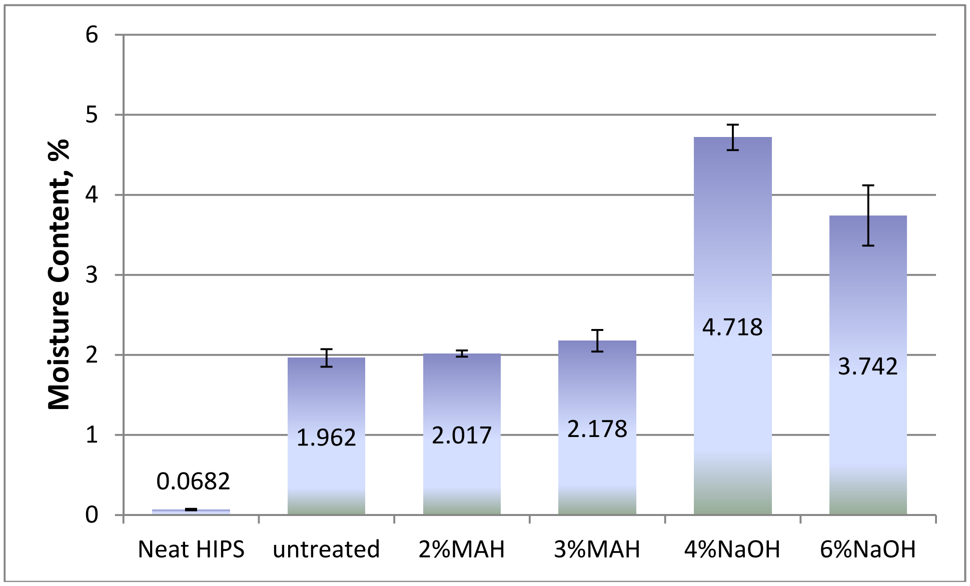

Fig. 7. The water absorption behavior of the SPF-HIPS composites, after 24 hours immersion

CONCLUSIONS

This investigation characterized effects of chemical treatment on natural fibre composites prepared from 40 wt. % sugar palm fibre and HIPS matrix. The aim of this study was to compare the effects alkali treatment and compatibilizing agent treatment on the tensile properties of sugar palm fibre reinforced high impact polystyrene composites. The following conclusions can be drawn:

1. Compatibilizing agent applied to palm fibres decreased composites tensile modulus.
2. Both alkali treatment and compatibilizing agent treatment increased the tensile strength, while the alkali treatment at the 4% level showed the highest tensile strength, improvement of about 35% from untreated composites.
3. Alkali treatment applied to sugar palm fibres increased composites strength more over the neat HIPS tensile strength.
4. Based on this investigation, it is concluded that 4% alkali treatment is the best treatment for enhancing the tensile performance of SPF-HIPS composites.

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