

Biocomposites Based on Rice Husk Flour and Recycled Polymer Blend: Effects of Interfacial Modification and High Fibre Loading

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Biocomposites were prepared with rice husk flour (RHF) (raw and alkali-treated) in a recycled polymer blend (RPB) using a co-rotating twin screw extruder. Modifications to the composite were carried out through fibre surface treatment with 4 wt.% sodium hydroxide (NaOH) and 3 wt.% maleic anhydride polyethylene (MAPE) coupling agent. Fourier transform infrared (FTIR) analyses of raw and NaOH-treated RHF were performed. The effects of the interfacial modification (MAPE or/and NaOH) and filler loading (50 to 80 wt.%) on the mechanical, physical, and morphological properties were investigated. Improvements in the tensile strength and Young's modulus as well as reduction in water absorption and water loss were observed for raw RHF composites incorporated with MAPE. Alkalisiation of fibres resulted only in an enhancement in elongation and impact strength. The composite with 70 wt.% RHF modified with only MAPE exhibited the highest tensile strength and modulus, 22.2 and 711.6 MPa, respectively. The general trend of the composite results exhibited some decrease in water absorption and water loss from untreated RHF composites with only MAPE modification as compared to the NaOH-treated composite, although a rougher surface for the treated fibres was revealed in SEM images.

Keywords: High loading biocomposites; Agro residue; Alkaline treatment; Coupling agent; Mechanical properties; Water behaviour

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INTRODUCTION

Biocomposites or green composite materials based on natural fibre reinforcement of thermoplastics have been a worldwide focus of extensive research. Because of increasing environmental and ecological concerns, natural fibres are quickly replacing synthetic fibres as the reinforcing agents used in polymer matrix composites (Chattopadhyay *et al.* 2010). Rice husk (RH) fibre-reinforced thermoplastic composites are now being commercialised in the green furniture, building construction for interior components (such as ceiling linings), window and door frame, wall, partitioning and panelling industries, among others. RH is a lignocellulosic material that is renewable and abundantly available in Malaysia. The raw RH consists of 25 to 35% cellulose, 18 to 21% hemicellulose, 26 to 31% lignin, 15 to 17% silica, 2 to 5% solubles, and 7.5% moisture content (Chen *et al.* 2015b). RH has low density, high specific strength and modulus, and is biodegradable, tough, resistant to weathering, and makes final products cheaper if it is incorporated into composites compared to other fibers (Zhao *et al.* 2009; Kwon *et al.* 2013). The RH-filled composites are increasingly being used in the automotive industry such as door panels and trims, and in the building construction like decks, windows, slidings and green furniture. Compared to wood-based composites, in terms of

performance and ecological, manufacture of RH-filled composites can be considered to have higher novelty due to the higher resistance to termite attack and better dimensional stability besides the limited wood resources in global (Chen *et al.* 2015a).

In the production of natural fibre plastic composites (NFPCs), both thermosets and thermoplastics, in either virgin or recycled form, can be used as the polymer matrices. From a technological standpoint, post-consumer recycled plastic (PCR) is a promising source of raw material for polymer matrices in the production of composites because it is generated in huge amounts and is cost competitive (Najafi and Khademi-Eslam 2011). In 2010, in Peninsular Malaysia with population of 28.45 million inhabitants, the PCR has accounted for 24 % of the total amount of municipal solid wastes (21,100 tonnes per day). The carbon footprint of manufacturing PCR polyethylene terephthalate (PET), such as from water bottles, is much lower than associated with virgin PET. Using PCR such as recycled polyethylene (PE), polypropylene (PP), and PET, the use of virgin plastic could be eliminated, one potential solution to the problem of waste plastic pollution. PCR polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) account for a large amount of all waste plastic materials (Chen *et al.* 2014; 2015c). Many studies have been conducted on the preparation and characterisation of natural fibre composites based on PCR plastics (Lei *et al.* 2009; Fávares *et al.* 2010).

In most natural fibre composites, the incompatibility of the hydrophobic polymer matrix and the hydrophilic natural fibres results in the weak bonding between the components (Robertson *et al.* 2013). Incompatibility of the components leads to agglomeration of fibres during processing, poor dispersion of fibres into the matrix, and poor resistance to moisture, which reduces the use of natural fibres as fillers in polymer matrix (Araújo *et al.* 2008). Mercerisation or alkalisation by sodium hydroxide (NaOH) is a well-known and the most economical surface treatments applied to natural fibres, prior to composites formation. This treatment helps to eliminate non-cellulosic substances such as waxes, impurities, pectin, lignin, and hemicelluloses from the fibre surface. Besides, removal of these substances increases the roughness of the fibre surface, thus opening more hydroxyl groups on the surface of cellulose unit. This has potential to increase fibre surface contact and improve the mechanical interlocking between the polymer matrix and the fibre (Kaewkuk *et al.* 2013). In addition, maleic anhydride polyethylene (MAPE) is a common coupling agent used to improve the interfacial adhesion between the PE matrix and natural fibres. The anhydride group of MAPE acts by covalently bonding to the hydroxyl groups available on the surface of natural fibres, whilst the ethylene of MAPE facilitates the wetting of the polymer chains (Araújo *et al.* 2008; Robertson *et al.* 2013). MAPP performed less effectively when the PE was used as matrix polymer in the composites, and this was due to the incompatibility problem occurred between the PP backbone of MAPP and the PE matrix polymer in the composites (Yang *et al.* 2007).

In spite of these studies, very few reports on the properties of rice husk-reinforced recycled polymer blend using both fibre surface treatment or/and a coupling agent were found. According to Chen *et al.* (2015b), rHDPE/rPET/E-GMA (70/25/5 w/w/w) was extruded via single screw extruder and then used as matrix for producing RH composites with the filler of 30 to 70 wt.% and 3% MAPE using twin screw extruder, the resultant composites showed a great enhancement in modulus properties and thermal stability. On the other hand, 40, 60, and 80 wt.% RH-filled composites (with 3% MAPE), based on treated and untreated rHDPE/rPET 75/25 matrix with 5% E-GMA, were extruded twice via twin screw extrusion; results indicated better mechanical results and dimensional stability for RH composites with treated matrix (Chen *et al.* 2015a). Kaewkuk *et al.* (2013) concluded that fiber treatment (alkali and heat treatment) and adding MAPP contributed to an enhancement the interfacial adhesion between the sisal fibre and the PP matrix. In the present study, the main objective was to evaluate the effect of alkali

treatment and a coupling agent on the mechanical, physical, and morphological properties of the rice husk flour composites. In order to add value for agricultural waste (rice husk) and make the final products more economically competitive, high fibre loading biocomposites, with up to 80 wt.% fiber, were prepared. Composites were fabricated from treated and untreated fibres, recycled polymer blend, and MAPE. The effects of single (NaOH treatment only or MAPE modification only) and double (both the NaOH treatment and MAPE modification) interfacial modifications and fibre loading (50 to 80 wt.%) on composite properties were investigated.

EXPERIMENTAL

Materials

Recycled high-density polyethylene (rHDPE, density, 923 kg/m³; melt flow index, 0.72 g/10 min at 190 °C), and recycled polyethylene terephthalate (rPET, T_g, 74.1 °C; cold crystallisation peak temperature, 119.9 °C; and melting peak temperature, 252.5 °C) used as the polymer blend matrix were obtained from a local plastic recycling plant. An ethylene-glycidyl methacrylate (E-GMA, Lotader AX8840) with 5 g/10 min (190 °C, 2.16 kg) melt index, and 8% glycidyl methacrylate content was utilised as a compatibiliser. The agro filler material was rice husk flour (RHF). RHF was oven-dried for 24 h at 100 °C before use. Maleic anhydride polyethylene (MAPE, melting peak temperature, 135.2 °C) was added as a coupling agent to the rice husk-reinforced composite. All raw materials were supplied by a local factory, BioComposites Extrusion Sdn. Bhd. (Malaysia). For the alkali treatment of the RHF, 4 wt.% sodium hydroxide (NaOH) was used.

Methods

Alkali treatment of fibre

The raw RHF was soaked in a 4% NaOH solution in distilled water (w/v) at room temperature for 24 h. The treated RHF was then rinsed with water several times to eliminate residual NaOH and dissolved impurities. After rinsing, the fibres were oven-dried at 90 °C for 24 h to eliminate the excess moisture trapped in the RHF.

Matrix preparation

The matrix chosen was a recycled polymer blend (RPB) of rHDPE and rPET. The rHDPE/rPET weight ratio used was 75/25 (w/w) and 5 wt.% EGMA, based on the weight of rHDPE and rPET added to the matrix. This matrix composition was chosen from the authors' previous study (Chen *et al.* 2014). As shown in Fig. 1(a), melt-compounding of the RPB was accomplished using a 40-mm laboratory scale co-rotating twin screw extruder (Thermo Prism TSE 16 PC, Thermo Electron Corporation, Germany). The barrel temperature profiles from the feeding to die zones were set as 190, 240, 270, and 250 °C, respectively. The screw rotating speed used was 30 rpm. The extrudates were cooled at room temperature and then pelletized with a crusher. The blend pellets were oven-dried at 90 °C for 24 h before use in preparation of the composite.

Preparation of RHF composites

As shown in Fig. 1(b), RPB pellets and 70 wt.% dried fibres (untreated and NaOH-treated) were melt-blended thoroughly, either with or without MAPE, using the same twin screw extruder. Extrusion temperature profiles of 195, 210, 215, and 170 °C at 30 rpm were used. For further filler loading investigation, RHF fibre loadings of 50, 60, 70, and 80 wt.% of the untreated fibre composite (modified with only MAPE) were used

in composite fabrication. The extrudates were then granulated into pellets after being cooled at room temperature.

Compression moulding

A hot- and cold-press process (compression moulding machine model LP50, Labtech Engineering Company Ltd., Thailand) was used to create the composite board specimen for testing (Fig. 1(c)). The granulated composite pellets were put into a mould with dimensions of 14 mm x 14 mm x 3 mm. The temperatures of the upper and lower platen were 200 °C, and 6.9 MPa pressure was applied. During the hot-pressing process, the periods of preheating, venting, and full pressing lasted 3, 2, and 5 min, respectively, followed by cold pressing for 5 min to cool the specimens. After finishing the moulding process, the specimens were stored at ambient conditions for 40 h to stabilise. The composite samples without NaOH treatment or MAPE modification were coded the 'control'.

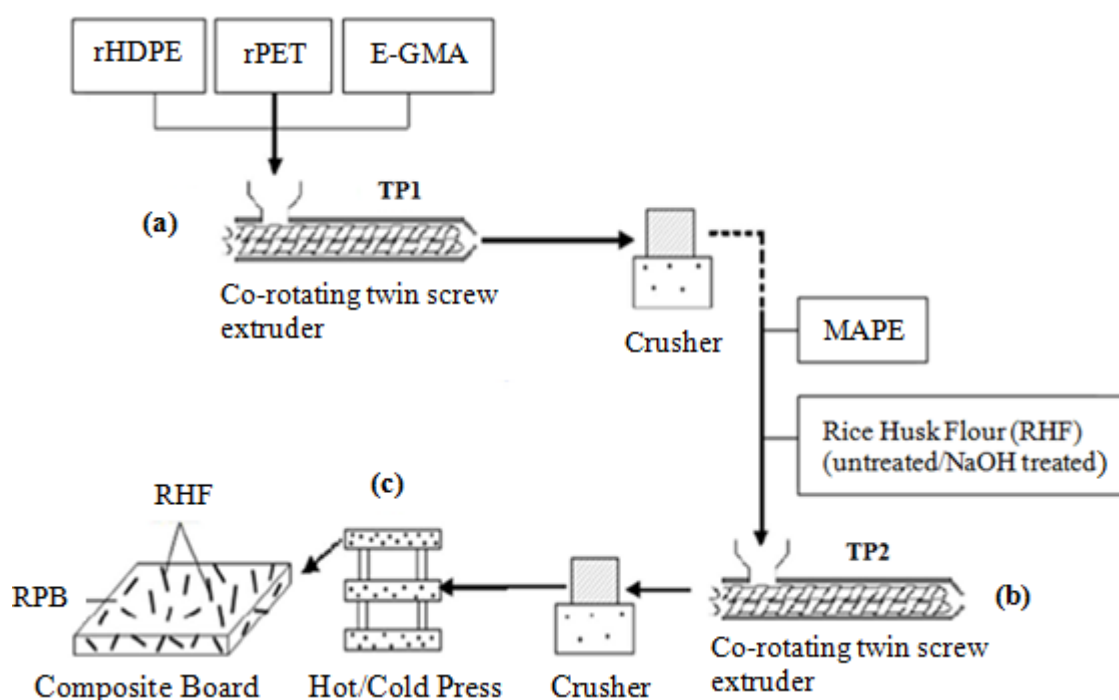


Fig. 1. Scheme for preparing rice husk flour (RHF)-reinforced composites; TP1: temperature profile 1 - 190, 240, 270, and 250 °C; TP2: temperature profile 2 - 195, 210, 215, and 170 °C

Characterisation Techniques

Fourier transform infrared-attenuated total reflectance (FTIR-ATR)

The infrared spectra in the FTIR-ATR of raw (untreated) and NaOH-treated RHF were obtained using an FTIR-near infra-red apparatus with an imaging system (Perkin Elmer Spectrum 400 FT-IR, Perkin Elmer Inc., USA). The samples were analysed over the range of 4000 to 650 cm^{-1} .

Mechanical property measurements

Prior to testing, six replicate specimens were cut in accordance with ASTM D638-03 (type I) (tensile) and ASTM D256-05 (impact) specifications. Tensile measurement was done using a universal testing machine (Model Testometric M350-10CT, Testometric materials testing machines, UK) at a crosshead speed of 5 mm/min at room temperature. Izod impact measurement was done using a Ray-Ran Universal Pendulum Impact System

(Ray-Ran Test Equipment, UK) at room temperature. The Izod impact testing was carried out at a velocity of 3.46 m/s, load weight of 0.452 kg, and calibration energy of 2.765 J.

Water behaviour

According to ASTM D570-98 (Chen *et al.* 2015a), the specimens were cut to a length of 76.2 mm, width of 25.4 mm, and height of 3.2 mm. Prior to immersion, the specimens were dried in an oven at 90 °C for 24 h to eliminate trapped moisture. The weight of the oven-dried specimens was measured using an analytical balance with a precision of 0.001 g. Then, the specimens were immersed in distilled water at room temperature. The specimens were taken out of the water, wiped off to remove surface water, and weighed. The weight gains of the specimens were evaluated periodically for 13 weeks. Finally, all specimens were oven-dried at 105 °C for 1 week and weighed. The water absorption (WA) at any time and water loss (WL) of the composites were calculated using the following equations,

$$WA(\%) = \frac{W_t - W_0}{W_0} \times 100 \quad (1)$$

$$WL(\%) = \frac{W_f - W_0}{W_0} \times 100 \quad (2)$$

where W_0 is the weight of the dry specimen, W_t is the weight of the wet specimen at time t , and W_f is the dried weight of the specimen after immersion for 13 weeks.

Scanning electron microscopy (SEM)

The morphology of the surface of each sample was analysed using scanning electron microscopy (VPSEM LEO 1450VP, Carl Zeiss Inc., Germany) at an accelerating voltage of 10 kV. The samples were sputter-coated with gold using sputter coater (Q150R, Quorum Technologies Ltd., London) before SEM examination at 300 and 500 times magnification.

RESULTS AND DISCUSSION

FTIR-ATR spectra analysis

The FTIR spectra of raw (untreated) and NaOH-treated rice husks are shown in Fig. 2. In the spectrum of the raw RHF, the presence of a medium-intensity, broad absorption band at 3335 cm^{-1} indicates the stretching vibration of hydroxyl (-OH) groups in cellulose fibres. Another -OH vibration peak occurred at 1640 cm^{-1} . After treatment with NaOH, both of these peaks exhibited noticeable growth in intensity. This could be attributed to the removal of surface impurities from the RHF, thus increasing the exposed accessible -OH groups on the RHF surfaces. The absorption band at 2921 cm^{-1} , which was attributed to the vibration of carbon-hydrogen (CH) bonds, was present in both raw and NaOH-treated RHF.

The absorption represented by weak bands at 1727 cm^{-1} appeared in the spectrum of the raw RHF because of the carbonyl stretching vibrations of the aldehyde, ester, acetyl, and carboxyl groups in the hemicelluloses, lignin, and extractives such as natural fats and wax (Kaci *et al.* 2007). Another carbonyl vibration was found at 1550 cm^{-1} , which could be attributed to the stretching vibration of carboxylic groups or the interaction of cell windows. Both of these peaks disappeared after the RHF was treated

with NaOH, which indicates that they may have been removed by alkali treatment (Ndazi *et al.* 2007).

A small, sharp peak at 1230 cm^{-1} in the raw RHF represented the C-O stretching of the acetyl group of lignin, as proposed by Sgriccia *et al.* (2008), or the vibration of silica bonds, as proposed by Ndazi *et al.* (2007). This peak disappeared after NaOH treatment. Another silica vibration band occurred at 785 cm^{-1} , which shifted slightly towards lower frequencies by 1 cm^{-1} in the NaOH-treated RHF. These peaks indicated the removal of lignin from the RHF surfaces or the possibility of NaOH to react with the silica of the RHF by embedding part of the cellulose with silica in the silicon-cellulose membrane form (Ndazi *et al.* 2007; Sgriccia *et al.* 2008).

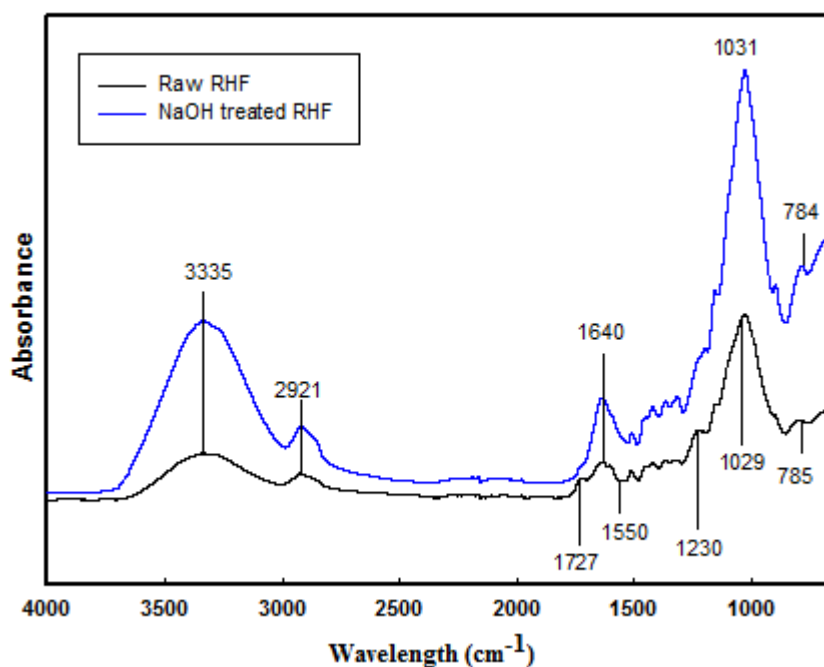


Fig. 2. FTIR-ATR spectra of untreated raw and NaOH-treated rice husks

Mechanical Properties

The effects of interfacial modification on the mechanical properties

The tensile properties and impact strengths of differently modified composites are listed in Table 1. The alkali treatment and coupling agent enhanced the tensile strength, Young's modulus, elongation, and impact strength. Among a range of composites with different interfacial modifications, the increases in the tensile strength and Young's modulus were in the following order: composites without NaOH and MAPE (control) < NaOH only < NaOH-treated with MAPE < MAPE only. The untreated and NaOH-treated fibre composites without the coupling agent exhibited lower tensile strength and modulus. The dewaxing followed by alkali treatment, which increased the surface roughness of treated fibres, promoted better mechanical locking between the fibres and the matrix (Akil *et al.* 2011). Incorporating MAPE into RHF fibre/RPB composites resulted in a superior increase in the tensile strength and Young's modulus as compared to NaOH treatment, which are about 16.8 % and 12.3% respectively. MAPE improved the interfacial adhesion between the less-polar RPB matrix and the more-polar RHF fibres through interactions between the carboxyl groups of the MAPE and the hydroxyl groups of the fibres (Kaewkuk *et al.* 2013). Untreated fibre contained hemicellulose and lignin components (non-polar components) that made it somewhat compatible with non-polar RPB, as compared with the delignified fibre (Chattopadhyay *et al.* 2010). Thus, the improvement

in the chemical adhesion between the fibre and the matrix by the MAPE coupling agent was more effective in untreated fibre composites as compared to treated ones, although the treated fibres had higher strength and modulus. Therefore, the composites modified only with MAPE exhibited the highest tensile strength (22.2 MPa) and Young's modulus (711.6 MPa), which were increased by 35.4% and 16.7%, respectively. On the other hand, the treated fibres provided some resistance to the elongation and impact of the composites. The modified composites displayed more ductile failure with the increasing elongation at break and impact strength in the following order: control < MAPE only < NaOH only < NaOH-treated with MAPE. The superior results for elongation at break and impact strength exhibited by composites with both NaOH and MAPE was attributed to the increased roughness of RH surface and fibre fibrillation by NaOH treatment (Chong *et al.* 2010) which increased the effective surface area available for matrix polymer to effectively adhere to the fibre surface *via* mechanical interlocking. Hence, NaOH treated RH less disturbed the matrix continuity in comparison to the untreated RH, for which the individual filler particle can act as a microcrack initiator.

Table 1. Mechanical Properties of 70 wt.% RHF Composites Subjected to Various Interfacial Modifications

Fibre Treatment / Coupling Agent	Tensile Strength (MPa)	Young's Modulus (MPa)	Elongation at Break (%)	Impact Strength (kJ/m ²)
Control	16.4 (0.413)	609.8 (28.6)	2.52 (0.271)	2.05 (0.158)
NaOH only	19.0 (0.154)	633.8 (39.7)	3.55 (0.205)	2.88 (0.146)
MAPE only	22.2 (0.177)	711.6 (4.5)	3.50 (0.207)	2.58 (0.021)
NaOH & MAPE	20.9 (0.503)	636.1 (19.8)	3.72 (0.251)	3.30 (0.183)

Standard deviations are included in parentheses.

The effects of fibre loading on the mechanical properties

Figure 3 depicts the tensile strength, tensile modulus, and elongation at break of the untreated RHF composites coupled with MAPE at various fibre loadings. The results in Figs. 3(a) and (b) show that the tensile strength and modulus increased with increasing percentage of RHF filler until maximum values were reached at 70 wt.% RHF. This suggests that there was better interfacial bonding between the hydrophilic fibres and the hydrophobic matrix modified with MAPE, in which the fibres effectively took part in stress transfer (El-Shekeil *et al.* 2012). With further addition of RHF fillers at 80 wt.% untreated composites, both the tensile strength and modulus decreased, by approximately 21.6% and 23.1%, respectively.

It is possible that the fibres acted as defects when the amount of RHF filler exceeded a limit (Nourbakhsh *et al.* 2011), which was 70 wt.% in this study. At higher fibre loading, the fibres were not sufficiently wetted by the lesser amount of matrix, causing the agglomeration of fibres and blocking stress transfer (El-Shekeil *et al.* 2012). The incorporation of RHF fillers into the biocomposites markedly decreased the elongation at break, as shown in Fig. 4. A similar trend was exhibited by the impact strength, as shown in Fig. 4.

As is well-known, rice husk is a stiff but brittle organic filler that exhibits relatively low elongation and impact properties (Nourbakhsh *et al.* 2011). Therefore, as the RHF filler loading increased, both the elongation and the impact strength gradually decreased.

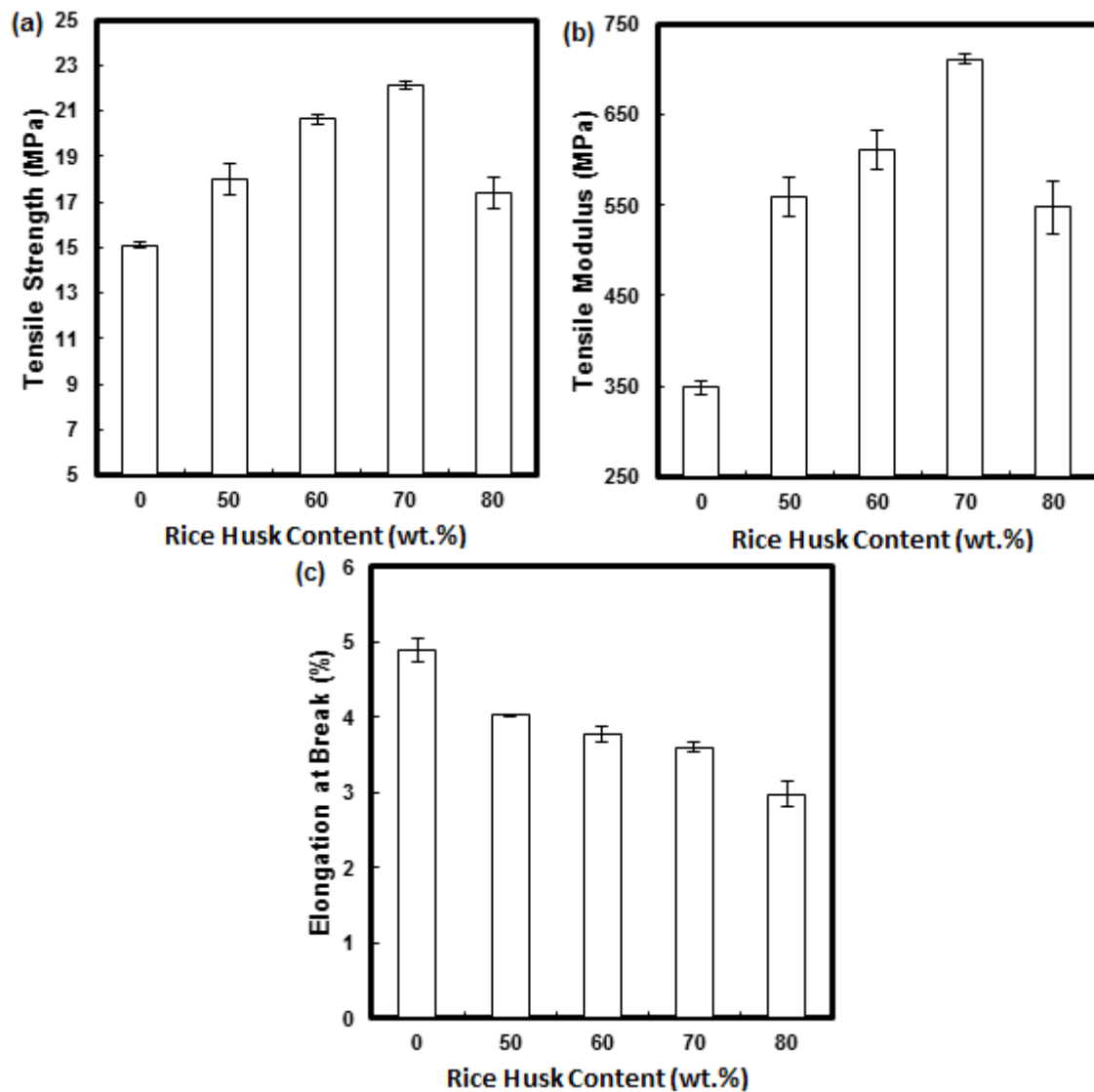


Fig. 3. Effect of filler loading on (a) tensile strength, (b) tensile modulus, and (c) elongation at break of untreated RHF composites coupled with MAPE

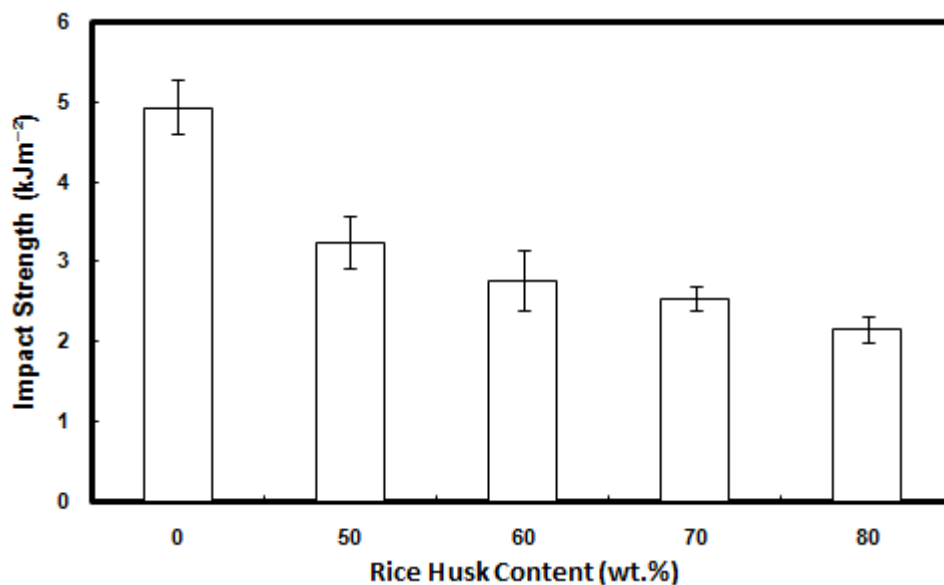


Fig. 4. Effect of filler loading on impact strength of untreated, MAPE-coupled RHF composites

Water Behaviour

Water absorption

Figure 5 shows the water absorptions of composites containing 70 wt.% RHF with various interfacial modifications. The composites modified with only MAPE exhibited the lowest water absorption. The compatibility between the hydrophilic RHF and the hydrophobic RPB matrix was enhanced by incorporating MAPE because of the esterification reaction that occurred between the anhydride moieties in MAPE and the surface hydroxyl groups of the RHF (Adhikary *et al.* 2008). Upon esterification, the ethylene groups of MAPE attach to the fibre surface, blocking pores and lumen; thus, water molecules are prevented from being absorbed. Somehow, the NaOH treatment of the RHF fibres increased the water absorption capacity of the composites. This could be attributed to the enlargement of the specific surface area of the fillers as a result of fibre swelling after mercerisation, which could have increased the accessibility of water molecules to the reactive regions. Hence, the hydrophilicity of the filler was increased (Marcovich *et al.* 1998). Therefore, composites with only NaOH treatment exhibited the highest water absorption, followed by that of the control sample (composites without NaOH or MAPE), both NaOH and MAPE, and only MAPE.

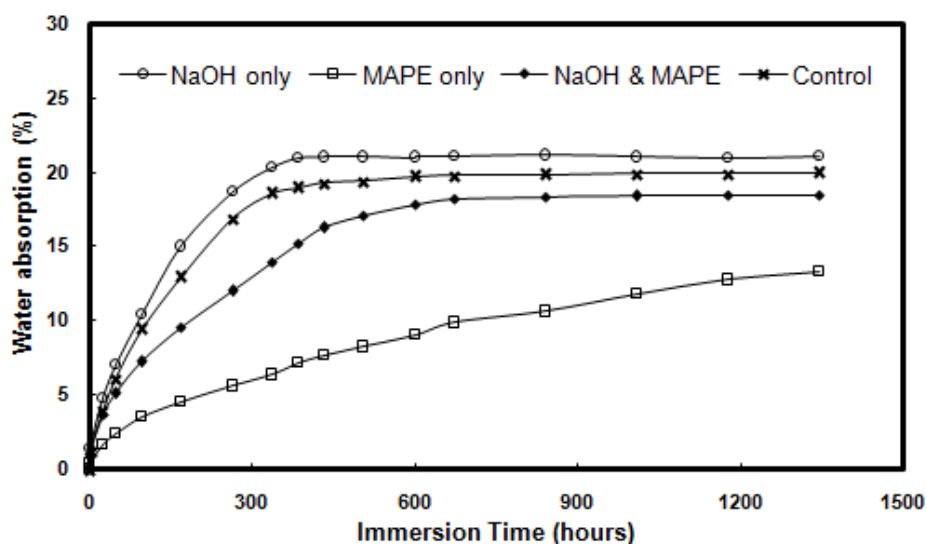


Fig. 5. Water absorption of composites made with 70 wt.% RHF with various interfacial modifications

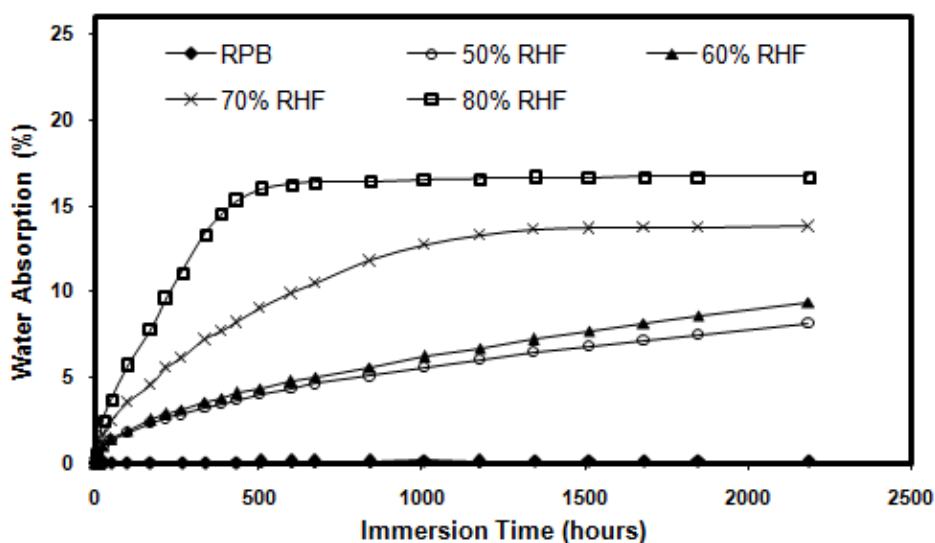


Fig. 6. Water absorption behaviour of raw RHF composites modified with only MAPE at various filler loadings

Figure 6 shows the water absorption behaviour of RHF composites at various filler loadings. RPB is considered a hydrophobic matrix because it is composed of a high weight fraction of HDPE (which is hydrophobic in nature) and only a quarter PET (which is hydrophilic in nature). Therefore, the RPB exhibited negligible water absorption. Hydrophilic rice husk is the main component that causes water absorption in the biocomposite-reinforced RHF. As the RHF content in the composites increased, the water absorption also increased because of the increase in the number of water residence sites in the form of RHF free hydroxyl groups, which attracted water molecules *via* hydrogen bonding (Gu *et al.* 2010).

Water (weight) loss

Figure 7 depicts the water loss of composites made with 70 wt.% RHF with various interfacial modifications. The water loss of composites is related to their water absorption. More water absorbed leads to more water loss. Because of the oven-drying at 105 °C, natural fibre-reinforced composites may also lose a small amount of soluble compounds, including the highly carboxylic groups of low-molecular weight hemicellulose, lignin, and extractives, after 13 weeks of soaking (Gu *et al.* 2010).

The water loss of untreated and treated fibre composites without the MAPE coupling agent exhibited higher water loss as compared to those with MAPE. The NaOH-treated RHF fibre composites seemed to exhibit higher water loss in comparison with that of the untreated RHF fibre. This was due to the higher percentage of water absorbed in the composites after they were treated with NaOH. In the MAPE-treated composites, the anhydride groups may have combined with them and attached to the fibre surface, blocking pores and lumen; thus, the removal of some low-level chemical content could be prevented.

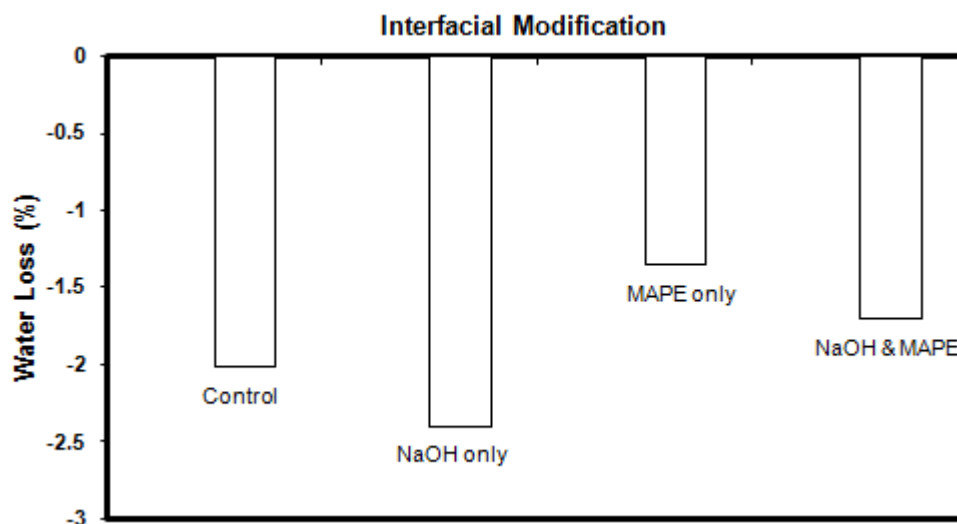


Fig. 7. Water loss behaviour of composites made with 70 wt.% RHF with various interfacial modifications

Figure 8 shows the water loss of the raw (untreated) RHF composites modified with MAPE as a function of filler loading. As the filler loading increased, the water absorption increased; thus, the water loss also increased.

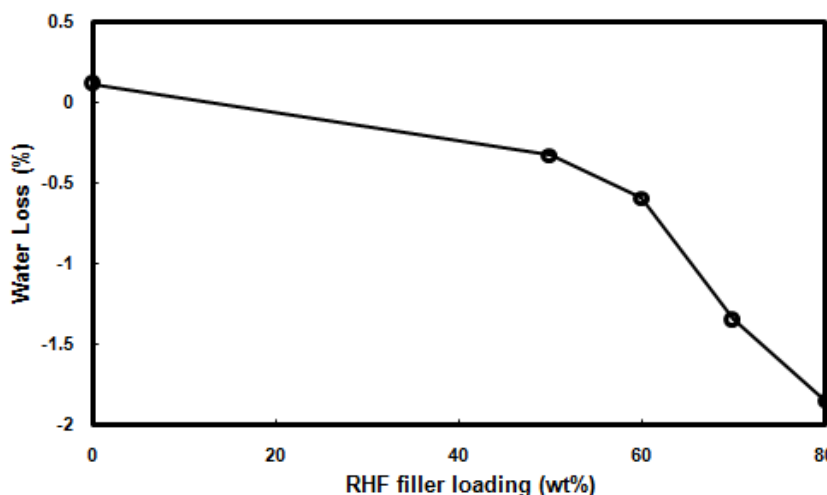


Fig. 8. Water loss behaviour of raw (untreated) RHF composites modified with MAPE at various filler loadings

Scanning Electron Microscopy (SEM)

Figures 9 and 10 show the surface morphology of the untreated and NaOH-treated raw RHF and the composites coupled with MAPE at 70 wt.% filler loading. The untreated raw RHF in Fig. 9(a) had a smooth surface, which confirms the presence of wax and oil and some surface impurities. The NaOH treatment increased the surface roughness because of dewaxing and the elimination of surface impurities, as revealed in Fig. 9(b). As expected, this resulted in better mechanical interlocking between the treated RHF and the RPB matrix, which improved the elongation at break and impact strength. As shown in Fig. 10(b), alkali treatment could lead to fibre fibrillation, destroying the cellular structure and splitting the fibre into filaments (Chong *et al.* 2010). The effective surface area of the NaOH-treated fibre was increased for contact with polymer resins such as RPB. Somehow, the increment in the contact surface area decreased the interfacial adhesion between the filler and the matrix when there was a high weight fraction of RHF (70 wt.%) in the composites. Smooth RHF fibrils can be seen in Fig. 10(b).

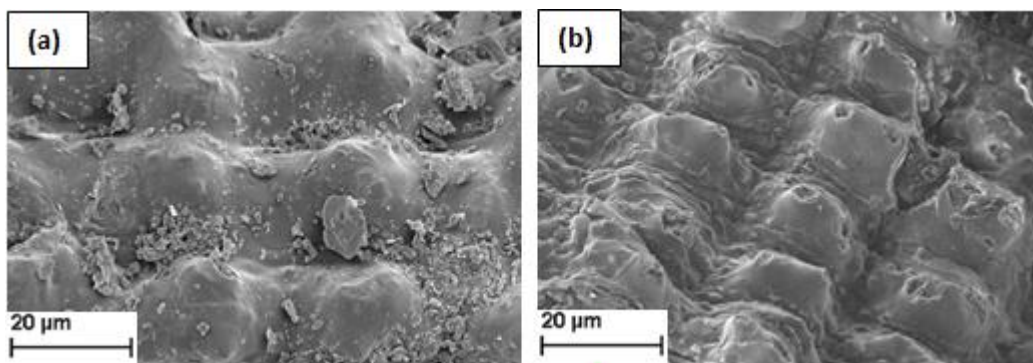


Fig. 9. SEM micrograph of (a) untreated and (b) NaOH-treated raw RHF (500x)

In comparison, the untreated fibre, which had lesser contact surface area, exhibited the rougher surface morphology of RHF, indicating better interfacial fibre-matrix bonding (Fig. 10(a)). This means that the ratio of polymer matrix-to-filler and their effective contact surface area are interrelated and affect the interfacial bonding between both components. In other words, if a coupling agent is incorporated, the alkali treatment of fibre is not necessary for use in high filler loading composites to improve the interfacial adhesion between the polymer resin and the fibre.

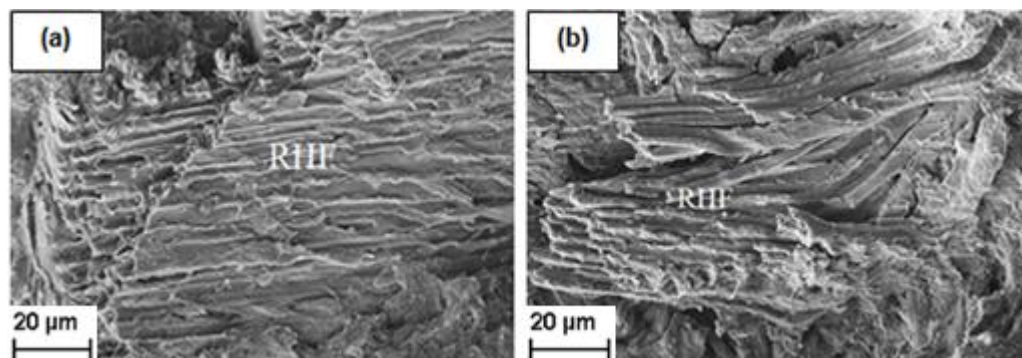


Fig. 10. SEM micrograph of (a) untreated and (b) NaOH-treated composites coupled with MAPE at 70 wt.% filler loading (300x)

CONCLUSIONS

1. The tensile strength and modulus of biocomposites were noticeably increased with increasing rice husk fiber (RHF) concentration up to 70 wt.%, and then decreased when further increasing the filler loading.
2. The elongation at break and impact strength dramatically decreased with the incorporation of RHF into the polymer matrix.
3. In general, the modification of composites by the coupling agent seemed to enhance the tensile strength and modulus, whereas alkali treatment was more effective in improving the elongation and impact strength. The water absorption and loss of composite were only reduced by adding maleic anhydride polyethylene (MAPE) coupling agent.
4. Agricultural residue and industrial wastes such as rice husk could be good reinforcements for recycled high-density polyethylene/polyethylene-terephthalate (HDPE/PET) blends in the future. Using these materials could be an alternative for manufacturing wood-plastic composites because the global wood supply is becoming limited in developed countries. Rice husk flour seems to have the potential to create high-fibre loading composites up to 80 wt.%, which is suitable for use in the construction and green furniture industries.

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