The Effects Of Accelerated Weathering On The Tensile Properties Of Kenaf Reinforced Biocomposites

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Abstract. HDPE/soy powder/kenaf biocomposites with and without compatibilizer were prepared by the incorporation of kenaf core filler at different loadings into HDPE/soy powder biocomposites with an internal mixer. The prepared specimens were exposed to ultraviolet light in a weathering chamber for 500, 1000, and 2000 hours with scheduled water sprays to simulate the rain condition. The effects of accelerated weathering on the composite samples were investigated by tensile test, colour change analysis, and field emission scanning electron microscopy. The analysis conducted on the samples showed reductions in the tensile strength and considerable change in colour with the increasing accelerated weathering time.
Keywords: kenaf; biocomposites; accelerated weathering; tensile properties; colour change

1. Introduction

The increasing awareness of environmental problems has resulted in the development of sustainable and environmental-friendly green composite materials that are renewable, recyclable, and biodegradable. Various types of green biocomposite materials have been produced either by using natural fibers as a filler or by employing various types of bioresins as a matrix. These types of materials show great prospect as replacements for various types of conventional construction materials due to their relative high strength, high stiffness, low density, and low cost. Most importantly, they come from a renewable resource [1-3]

Despite all the advantages, the green composite materials still undergo low acceptance in the industrial markets. Their utilizations have been limited to nonstructural applications due to persistent concerns over their long-term durability and susceptibility to moisture in outdoor applications, which involve the exposure to sunlight and rains.

Both ultraviolet radiation and moisture absorption have adverse effects on the mechanical properties of polymeric resins and cellulosic fibers. Fiber swelling due to moisture uptake can lead to surface instability, which is the major cause of deterioration in mechanical properties and cosmetic appearance of composite materials throughout the weathering process. The formation of cracks in polymer composite can be observed from the swelling of the natural fibers, which then results in the loss of

mechanical strength and discolorations of the composites [4-5]. Hence the effects of degradation to the composite samples must be well understood and addressed before the materials can be used and gain acceptance in the industry.

Under natural weathering conditions, the testing of polymeric composite materials usually takes a very long period (1-5 years). The weathering effect on the samples depends on the geographical and weather conditions of a particular testing site and is hardly reproducible even if we conduct the experiments at the same site. Nevertheless, the artificial weathering method condition is easily reproducible by applying the constant cyclic exposure of certain levels of UV irradiation, temperature, and water spray [6-7].

Colorimetry is one of the cheapest and fastest methods in order to measure the degradation progression and to quantify the color changes in term of numeric data [8]. The numerical data obtained from this study can be used as an input for the future numerical simulation in order to correlate the discoloration/degradation of the composite surfaces with the reduction of mechanical properties [9]. The existence of such correlation will be very useful tool that can be used to estimate the composite integrity after the weathering process.

The objectives of this study are to quantify the changes in the physical, mechanical, morphological, and visual properties of kenaf core-reinforced HDPE/soy powder biocomposite samples resulting from accelerated weathering exposure. The effects of maleic anhydride polyethylene (MAPE) as a compatibilizer and its influences on the biocomposites properties under the accelerated weathering are also investigated.

2. Materials and methods

2.1. Materials

High density polyethylene (HDPE) was supplied by Polyethylene Malaysia Sdn. Bhd. The melt flow rate (MFR) and density of the material were 0.25 g/10 min (at 190 ºC and 2.16 kg load) and 0.9540 g/cm³ respectively. Soy powder was purchased from Hasrat Bestari (M) Sdn. Bhd. Figure. 1 shows the SEM micrograph of the soy powder and Table 1 shows the composition of the soy powder. Kenaf core was donated by Forest Research Institute Malaysia (FRIM) and the kenaf core chips were ground in a table type pulverizing machine (Rong Tsong Precision Technology Co. Product Id: RT-34) with a rotor speed of 2850 rpm and sieved with 70 mesh size sieve to produce homogeneous fractions. The compositions of kenaf core are shown in the Table 2 and Figure. 2 shows the kenaf core powder that had been ground to the size of 150-212 µm. Maleic Anhydride Polyetylene (MAPE) was purchased from Sigma Aldrich and its properties are listed in Table 3.

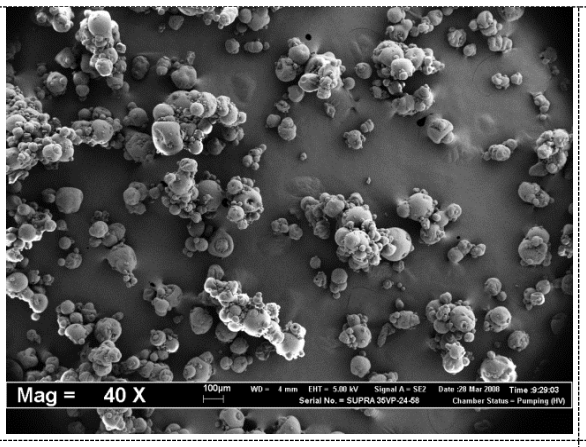

Figure 1. Micrograph of soy powder (40X).

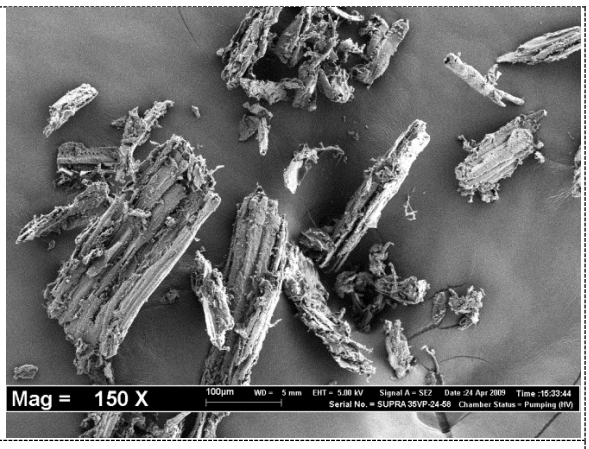

Figure 2. Micrograph of kenaf core powder (150X)

Table 1. Compositions of Soy Powder

Compositions	%
Soluble carbohydrates	15
Oil	18
Moisture, ash, other	14
Insoluble carbohydrates	15
Protein	38

Table 2. Compositions of Kenaf Core

Compositions	%
α-Cellulose	46.1
Hemicellulose	29.7
Lignin	22.1
Ash	1.6

Table 3. Properties of Maleic Anhydride Polyethylene (MAPE)

Compositions	Maleic anhydride, ~0.5 wt. %
Viscosity	500 cP (140 °C)(lit.)
Saponification value	6 mg KOH/g
Transition temperature	T_m (DSC) 107 °C (at peak)
Density	0.92 g/mL at 25 °C

2.2. Compounding

Melt compounding of the composites was done in an internal mixer (Haake PolyLab) at a temperature of 180 ºC and a rotor speed of 50 rpm for 12 minutes. Prior to compounding, all materials were dried by using a vacuum oven at 80 °C for 24 hours. The composition of each of the composite samples is shown in **Table 4.**

Table 4. Formulation of HDPE/Soy Powder/Kenaf Core Composites

	HDPE (phr)	Soy Powder (phr)	Kenaf Core (phr)
Sample 1	95	5	0
Sample 2	95	5	20
Sample 3	95	5	40

2.3 Sample Preparation

The compounded samples were compression-moulded in a GoTech compression moulding machine at 180 ºC using a pressure of 6.9 MPa for 3 min and cooled under pressure for 3 min. The moulded samples were cut into dumbbell and specimens according to ASTM D638 by using a dumbell cutter.

2.4 Tensile Test

Tensile testing was done according to ASTM D638 by using an Instron universal testing machine (Model 3366). The crosshead speed was set at 5 mm/min and tests were performed at 25±3ºC. Tensile strength, Young's modulus, and elongation at break were measured. Five specimens were used for each test and the average data were reported.

2.5 Scanning Electron Microscopy (SEM)

The morphologies of kenaf powders and tensile fracture surfaces of the composites were observed under a Leo Supra-35VP Field Emission Scanning Electron Microscope (FESEM). The kenaf powders and fracture surfaces of the composites were coated with thin layer of gold to avoid electrostatic charging during evaluation.

2.6 Accelerated Weathering

The accelerated weathering tests were conducted in Q-SUN (Model Xe-1-S) equipped with UVA-340 fluorescent lamps according to ASTM D 2565 for 2000 hours. The accelerated weathering test conditions are shown in **Table 5**.

Table 5. Test Condition for Weathering Test

Cycle Name	Step	Function	RH (%)	Irradiation W/m^2	Black Panel Temperature (ºC)	Air Temperature (ºC)	Time (Minutes)
ASTM D 2565 Cycle 1	1	Light	50	0.35	63	48	102
	2	Light + Water Spray	50	0.35	63	48	18
	3	Repeat Step 1 & Step 2					

A Minolta CR-400 Chroma Meter (Minolta Corporation, Ramsey, NJ) was used to measure color using the CIELAB color system. CIELAB is a three-dimensional color space measuring the lightness of the sample (L^*) and color coordinates (a^* and b^*). L^* ranges between 0 and 100 (black and white, respectively). An increase in L^* means the sample is lightening. The color coordinates a^* and b^* range from −150 to +150. They are defined as the red/green coordinate, a^* (+Δa^* signifies a color shift toward red, −Δa^* toward green) and the yellow/blue coordinate, b^* (+Δb^* toward yellow, −Δb^* toward blue). Color was measured for five replicate samples.

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

ΔE_{ab}^{*} is a single number that represents the "distance" between two colors. It can be calculated by using the equation above where L_1, a_1, b_1 is the color coordinate for control samples and L_2, a_2, b_2 is the color coordinate for target samples.

3. Result and Discussion

3.1 Tensile Test

Figure 3 shows the comparison of tensile strength of weathered and unweathered of HDPE/soy powder/kenaf core biocomposites with and without MAPE as a compatibilizer. It can be seen that the tensile strength of the both biocomposites was decreasing with prolonged accelerated weathering time. For the biocomposites without compatibilizer, the deterioration in tensile strength was due to the breakage of the biocomposites at the matrix-kenaf core interface. The weak interactions between the hydrophobic matrix and the hydrophilic filler contributed to the extent of this failure. Furthermore, the interactions became weaker because of swelling of filler due to water uptakes during the water spray cycle. At the same filler loading, the biocomposites with MAPE showed higher value of tensile strength when compared to the biocomposites without MAPE. The addition of MAPE as a compatibilizer improved the matrix-filler interactions, thus reducing the water penetration into the biocomposites during the water spray cycle. This resulted in less swelling in the biocomposites [10].

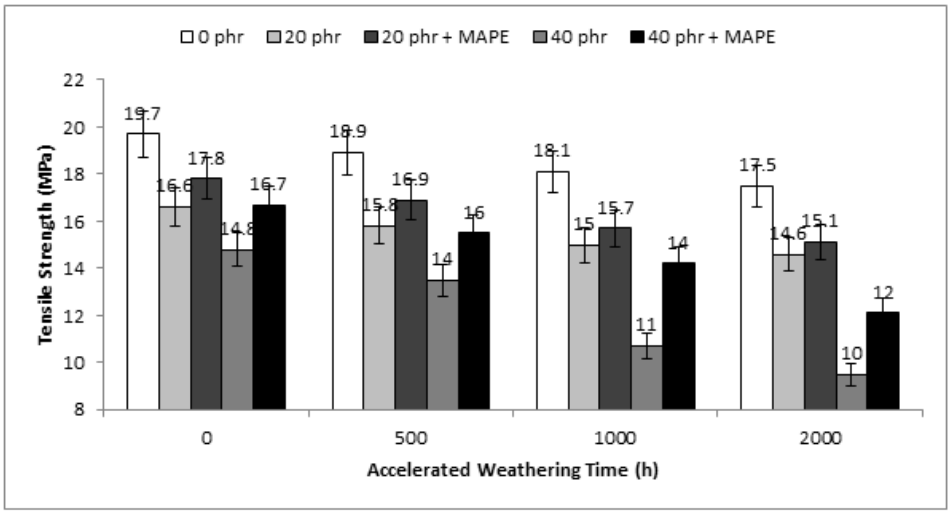

Figure. 3. Tensile strength of biocomposites

Figure 4 shows the elongation at break of weathered and unweathered of HDPE/soy powder/kenaf core biocomposites with and without MAPE. It can be seen that the elongation at break decreased with accelerated weathering time for all biocomposites formulation. The accelerated weathering processes that involved wetting and drying cycles led to the increase of the brittleness of the biocomposites samples. However, at the same filler counterparts, the biocomposites with MAPE exhibited higher elongation at break for the entire accelerated weathering time compared to the biocomposites without MAPE.

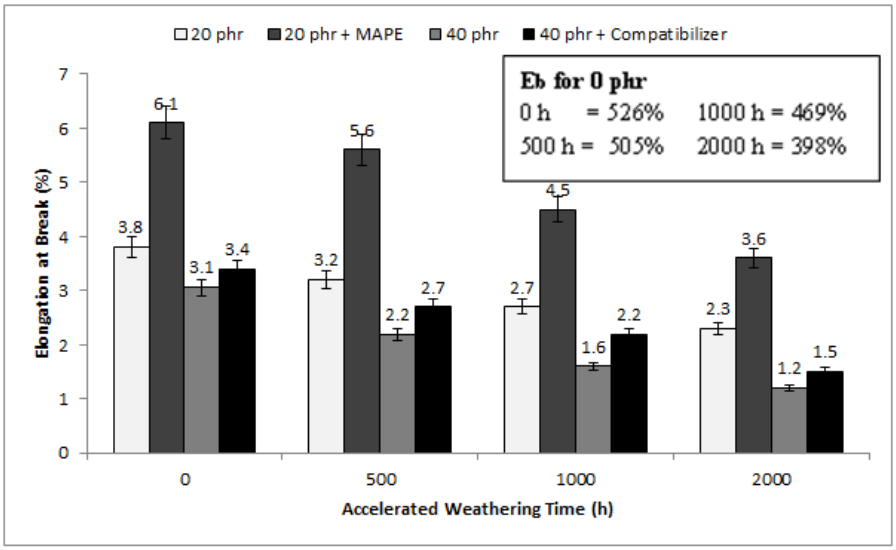

Figure 4. Elongation at break

3.2 Field Emission Scanning Electron Microscopy

Figure. 5 shows the SEM micrographs of weathered and unweathered surfaces of HDPE/soy powder/kenaf core biocomposites without MAPE at 40 phr filler loading. **Figure. 5(a)** shows a very smooth surface compared to **Figure. 5(b)**, **Figure. 5(c),** and **Figure 5(d)**. Cracks formation was observed in **Figure. 5(b)** after 500 hours exposure to UV light and water spray. The frequency and size increased upon extended weathering, and cracks propagation was observed in **Figure. 5(c)**. Cracks and grooves increased and became greater after 2000 hours of exposure to UV light and water spray as shown in **Figure. 5(d)**. The ultraviolet irradiation aggravated the degradation of biocomposites and caused surface erosion and disconnection in the filler and matrix, which then caused the crack across the composite surfaces. This phenomenon is in agreement the findings of Fabiyi et al. [11]. The lignin was degraded by UV radiation leaving loose fibres at the surface of the biocomposites, and during water spray cycle, the loose fibres was removed away by the water, exposing the materials at the inner layer of the biocomposites for degradation [12].

On the other hand, **Figure 6** shows the SEM micrographs of weathered and unweathered surface of HDPE/soy powder/kenaf core biocomposites with MAPE at 40 phr filler loading. Less cracks and grooves were observed for the accelerated weathering samples and this prove the good interaction at the interface of matrix-kenaf fiber, which prevented the crack propagation from occurring.

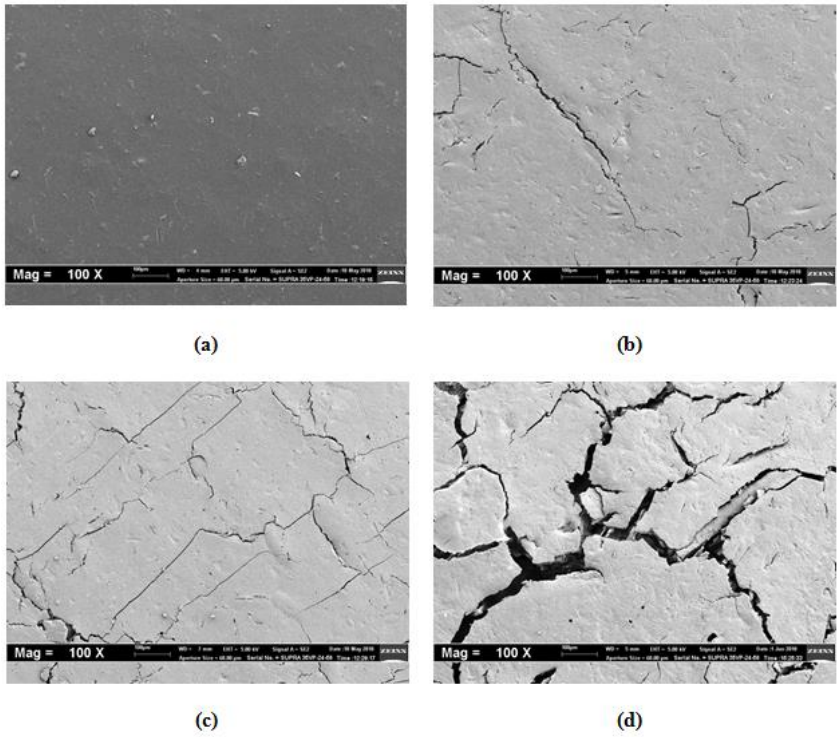

Figure 5. SEM micrographs of weathered sample's surface for HDPE/soy powder/kenaf core biocomposites without MAPE at 40 phr filler loading (a) 0 Hour, (b) 500 Hours, (c) 1000 Hours, and (d) 2000 Hours

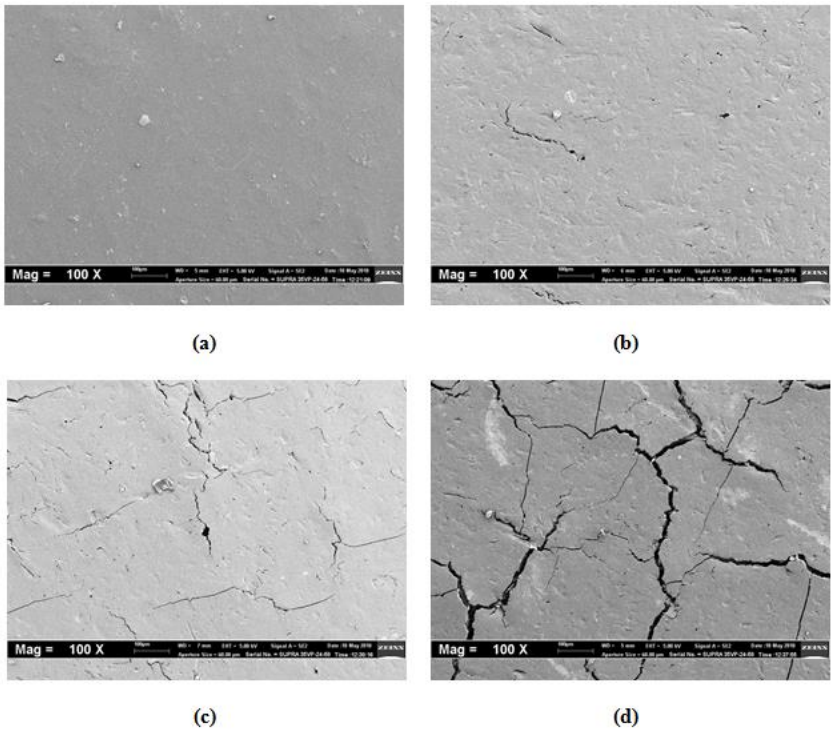

Figure 6. SEM micrographs of weathered of sample's surface for HDPE/soy powder/kenaf core biocomposites with MAPE at 40 phr filler loading (a) 0 Hour, (b) 500 Hours, (c) 1000 Hours, and (d) 2000 Hours

3.3 Colorimetric Analysis

Figure 7 and **Figure 8** show the comparison of total colour change (ΔE_{ab}) and lightness change (ΔL) for HDPE/soy powder/kenaf core biocomposites with and without MAPE as a function of weathering time. Total colour change (ΔE_{ab}) and lightness change (ΔL) increased with the increases of kenaf core filler loading in both composites. It can also be seen that the total colour change and lightness change increased with accelerated weathering time. This is a clear indication that the incorporation of natural fibers will cause lightening effect to a biocomposites system, and the oxidation of lignin and hemicelluloses when exposed to UV radiation was responsible for this phenomenon. Furthermore, during the water spray cycle, the oxidized wood extractives were washed out leaving the cellulose which is naturally white in colour [10,12].

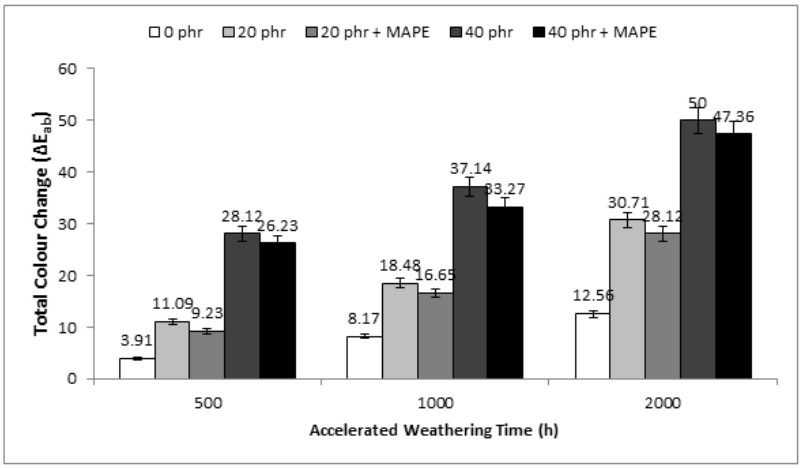

Figure 7. Total change in colour vs. weathering time

After 2000 hours of accelerated weathering time, it was observed that the higher the percentage of filler incorporated into the composites, the higher was the reduction for tensile strength and the higher was the change of total colour and lightness. The radiation and the absorption of water also caused cracks on the surfaces of composites as observed in the morphological analysis. The use of MAPE as a compatibilizer increased the strength of composites and lowered down the total colour change in the composites caused by the UV irradiation.

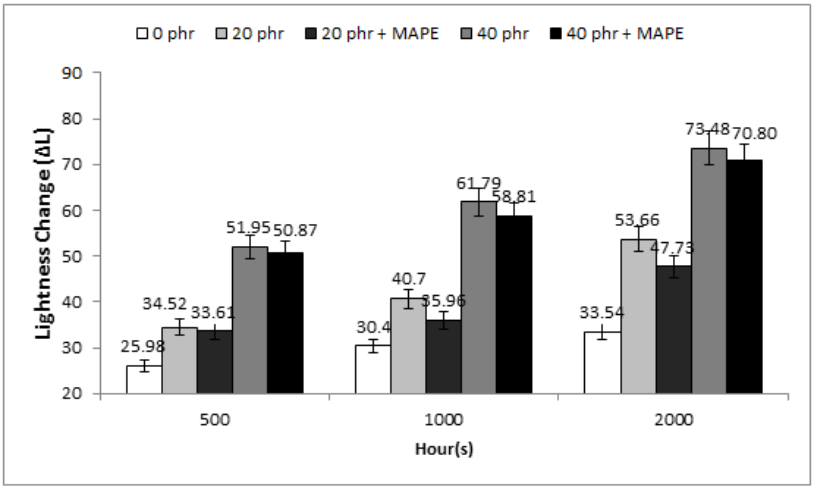

Figure 8. Lightness change vs. weathering time

4. Conclusions

After 2000 hours of accelerated weathering time, it was observed that the higher the percentage of filler incorporated into the composites, the higher was the reduction for tensile strength and the higher was the change of total colour and lightness. The radiation and the absorption of water also caused cracks on the surfaces of composites as observed in the morphological analysis. The use of MAPE as a compatibilizer increased the strength of composites and lowered down the total colour change in the composites caused by the UV irradiation.

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