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EFFECT OF ACCELERATED WEATHERING ON TENSILE PROPERTIES OF KENAF REINFORCED HIGH-DENSITY POLYETHYLENE COMPOSITES

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ABSTRACT

In this study, a high-density polyethylene composite reinforced with kenaf (*Hibiscus Cannabinus L.*) bast fibres (K-HDPE) was fabricated and tested for durability with regard to weather elements. The material consists of 40% (by weight) fibres and 60% matrix. Other additives, such as ultraviolet (UV) stabiliser and maleic anhydride grafted polyethylene (MaPE) as a coupling agent were added to the composite material. The biocomposite was subjected to 1000 hours (h) of accelerated weathering tests, which consisted of heat, moisture and UV light, intended to imitate the outdoor environment. The tensile properties of the K-HDPE composite were recorded after 0, 200, 400, 600, 800 and 1000 h of exposure to the accelerated weathering. Compared with neat high-density polyethylene (HDPE), the K-HDPE composite has 22.7% lower tensile strength when produced but displays a less rapid rate of strength deterioration under weathering (After 1000 h of exposure the tensile strength of K-HDPE drops 29.4%, whereas, for neat HDPE, it falls rapidly by 36%). Due to better stiffness, the Young's modulus of the K-HDPE composite is much higher than that of neat HDPE. The fibres on the surface of the K-HDPE composite gradually start to whiten after 200 h of exposure and become completely white after 600 h of exposure. For neat HDPE, micro-cracking on the surface can be observed after 200 h of exposure and the stress-strain curve obtained from the tensile test indicates its increase in brittleness proportional to the amount of weathering time.

Keywords: Kenaf bast fibre, high-density polyethylene, tensile properties, accelerated weathering, natural fibre polymer composites.

INTRODUCTION

Non-wood plant fibres, obtained from sustainable sources of agricultural plants, have been utilised in polymer composite materials because they provide sustainability and cost reduction in composite fabrication (Mohanty, Misra, Drzal, Selke, Harte, & Hinrichsen, 2005; Bachtiar, Sapuan, & Hamdan, 2010; Adebisi, Maleque, & Rahman, 2011). In Malaysia, one potential source of agro-based fibres that is becoming one of the national economic agendas is kenaf fibre (Mat Daham, 2005). Kenaf plants provide good strong fibres derived from its bast. This is the stem's outer layer that traditionally, has been used for cordage products (Akil, Omar, Mazuki, Safiee, Ishak, & Abu Bakar, 2011). One major advantage of kenaf fibres for biocomposites is that it has the appearance of wood but possesses plastic processing properties, which means it can easily be fabricated like other plastic products. These so-called environmentally friendly composite materials have been developed into numerous applications both for indoor and outdoor use (Misri, Leman, Sapuan, & Ishak, 2010; Maleque, Belal, & Sapuan, 2007; Merah, Nizamuddin, Khan, Al-Sulaiman, & Mehdi, 2010; Rowell & Stout, 2007). However, biocomposite materials intended for outdoor applications are exposed to weather elements that deteriorate the integrity of the composite's mechanical properties (Maleque et al., 2007; Merah et al., 2010; Pritchard, 2000; Brennan & Fedor, 2006).

Determining the material durability with regard to the damaging effect of weathering provides essential information for product makers, in understanding the material's lifespan for outdoor applications. Choosing a material that has good mechanical properties is not satisfactory if the material cannot endure the degrading elements of weathering. The effect of high temperature, exposure to the ultraviolet (UV) radiation of sunlight, rain and humidity causes deterioration to a composite material and consequently, reduces its mechanical performance (Brennan & Fedor, 2006). Therefore, the accelerated weathering study helps researchers to predict the service life of a newly developed material without going through years of natural weathering (Pritchard, 2000). In this study, a kenaf bast fibre reinforced high-density polyethylene (K-HDPE) composite was subjected to 1000 h of exposure in an accelerated weathering chamber. The tensile properties of the K-HDPE composite specimens were analysed and compared with those of neat high-density polyethylene (HDPE).

METHODOLOGY

Kenaf bast fibres were purchased from KEFI (Malaysia) Sdn. Bhd. The bast fibre supplied was farmed in Wakaf Gelam, Terengganu, Malaysia and comes from the kenaf variety V36. The bast fibres were separated from the core by a water retting process. The long bast fibres were pulverised to 250 microns long. This length was chosen because it allows the fibres to blend into the polymer melt with a better distribution but still retain an acceptable length over diameter (*L*/*D*) ratio, which is approximately 10:1. Figure 1 shows the dimensions of the pulverised kenaf bast fibre. A common and cheap plastic material, HDPE (with density of 0.95 g/cm^3) was purchased in the form of pellets and used as the matrix of the composite. The fibre loading of the composite was 40% (by weight). Other additives, such as UV stabilisers (1%) and maleic anhydride grafted polyethylene (MaPE) (3%) were also added to the processing of the K-HDPE composite. The inclusion of MaPE acts as a coupling agent between the fibres and matrix.

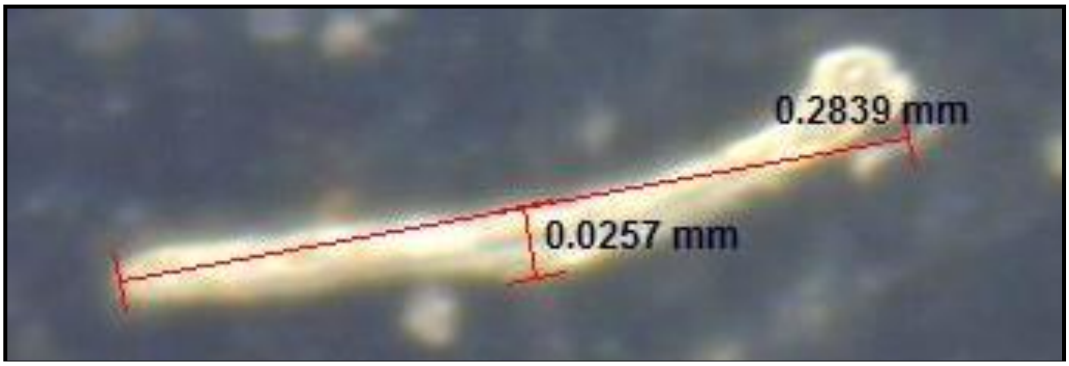

Figure 1. Dimension of the pulverised kenaf bast fibre.

The processing of the composite begins with the melting of the HDPE pellets, UV stabilisers and the MaPE in a melt mixer machine with the temperature set to 180 °C and a screw rotation speed of 50 rpm. As the torque of the mixing screw reaches a constant value, this indicates that the plastic pellets have totally melted and the mixture is ready for the kenaf fibres to be added. Immediately, after the kenaf fibres are added, the torque of the rotating screw spikes up, then gradually declines and stabilises at a constant value as the fibres become homogeneously blended within the polymer matrix. The mixture is then placed in a 150 × 150 mm square-shaped metal mould with a thickness of 1 mm. The compression moulding process of the composite was set to 5 minutes of hot pressing at 50 bars of pressure at a temperature of 180 °C. After the hot press is complete, the composite undergoes cold pressing to allow the composite to solidify. Using a specimen cutter, the K-HDPE composite boards were cut into tensile test specimens with dimensions according to the Japanese Industrial Standard, JIS K-7113 (Figure 2).

Figure 2. Tensile specimens of neat HDPE (below) and K-HDPE composite (above).

The fabricated specimens were placed in a Q-Sun Xenon test chamber for the accelerated weathering test. The accelerated weathering test in this research was conducted according to the standard ASTM G 155–00 (Standard practice for operating xenon arc light apparatus for exposure of non-metallic materials). The details of the weathering cycle used for the test are below:

- UV irradiation set to 0.55 $W/m^2/nm$
- UV wavelength is 340 nm
- Exposure Cycle:
    - 40 min light, 50 (65.0) % relative humidity (RH), at 70 (62)°C Black Panel Temperature
    - 20 min light and water spray on specimen
    - 60 min light, 50 (65.0) % RH, at 70 (62)°C Black Panel Temperature
    - 60 min dark and water spray on specimen, 95 (+5.0) % RH, 38 (62)°C Black Panel Temperature

After every 200 hrs of weathering, a group of specimens was removed for tensile testing. Therefore, a correlation between the tensile properties and the exposure time of weathering can be developed. The tensile properties of unweathered specimens were also tested in this study. The tensile test was conducted with a 30kN INSTRON Universal Test Machine with a crosshead speed set at 3mm/min.

RESULTS AND DISCUSSION

Figure 3 presents the tensile strength of weathered and unweathered HDPE and K-HDPE composite. The tensile strength of unweathered HDPE was recorded at 22.2 MPa, which is 22.7% higher compared with the unweathered K-HDPE composite. The results show that both the HDPE and K-HDPE composite undergo a slight drop in strength after 200 hrs of exposure. However, after 400 hrs of exposure, the tensile strength of HDPE drops a significant 35.1%, nearly the same strength of the K-HDPE composite after 400 hrs of exposure. After 800 hrs of the weathering experiment, the HDPE tensile strength increases slightly before dropping back again after 1000 hrs of exposure. However, the tensile strength of the K-HDPE composite drops at a constant rate throughout the weathering test and loses about an average of 1 MPa for every 200 hrs of weathering.

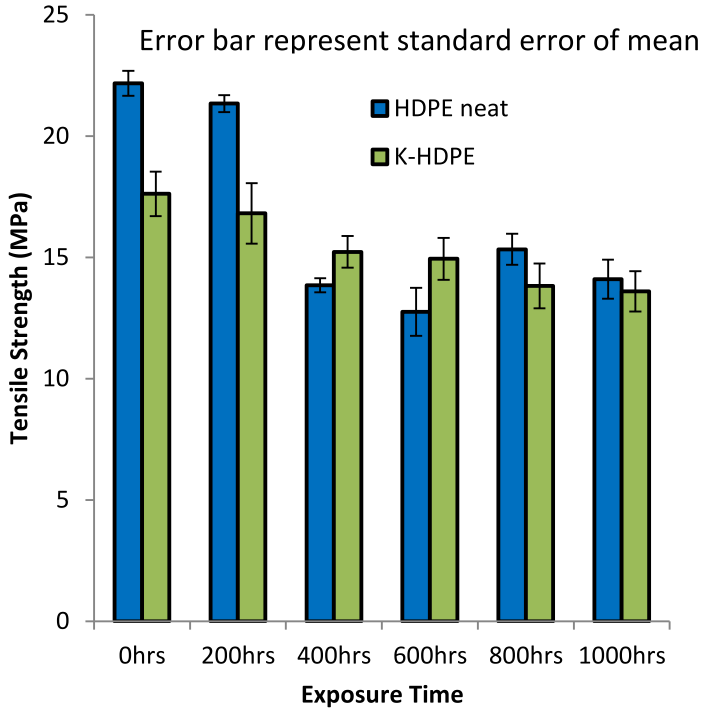

Figure 3. Tensile strength of weathered and unweathered HDPE and K-HDPE composite.

HDPE gains its mechanical strength from its long chains of polymer. The UV radiation of sunlight attacks the polymer by breaking it into smaller chains, typically known as chain-scission (Brennan & Fedor, 2006). This can be proven by the faint cracks that appear on the surface of the HDPE specimens and from scanning electron microscopy (SEM) images of the surface at 500× magnification (Figure 4). Micro-cracking of the polymer causes the weathered HDPE specimens to fail under a much lower loading compared with the unweathered specimens. During the tensile test, the micro-cracks develop into larger cracks before the specimen totally fails (Figure 5).

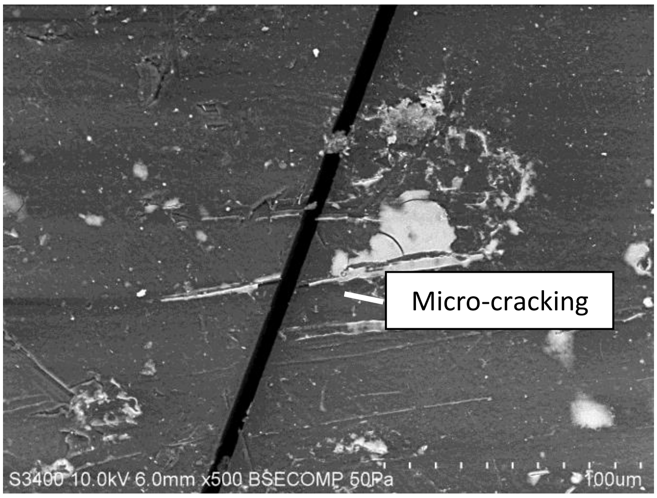

Figure 4. Micro-cracking on weathered HDPE specimens.

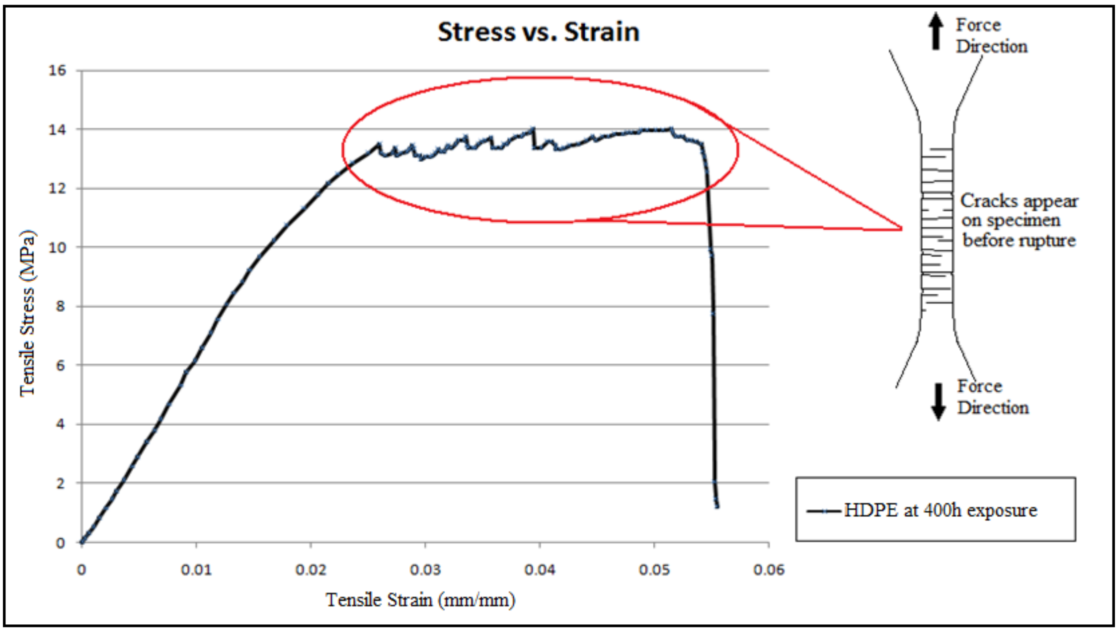

Figure 5. The stress-strain curve of the weathered HDPE at 400 h of exposure.

The UV stabilisers in the K-HDPE composite countered the effect of the UV light that causes the polymer chain-scission and micro-cracking (Brennan & Fedor, 2006). However, the most possible cause of deterioration of the K-HDPE composite was due to the effect of high humidity produced from water vapour inside the accelerated weathering chamber. Hydrophilic kenaf fibres attract water molecules into the K-HDPE composite and cause fibre-matrix debonding (Merah et al., 2010). As the exposure time increases, the moisture creeps deeper into the K-HDPE composite creating more fibre-matrix debonding, which decreases the tensile strength of the composites (Figure 6).

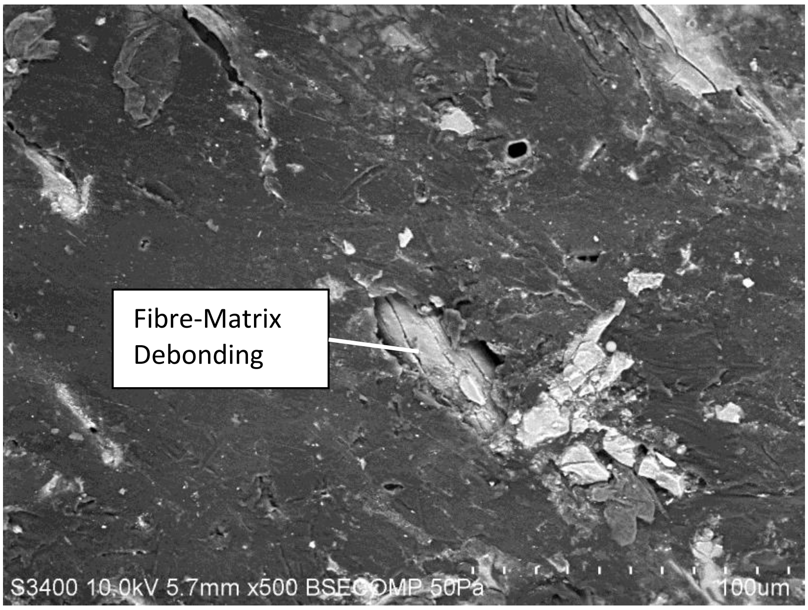

Figure 6. Fibre-matrix debonding on composite surface.

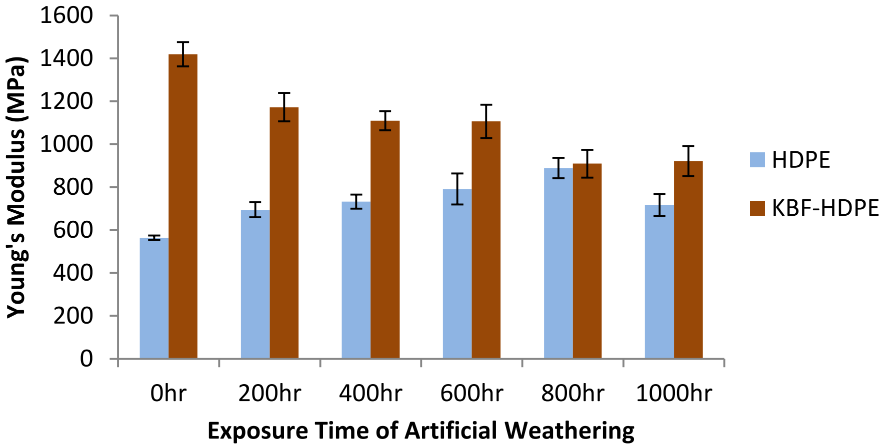

Figure 7. Young's modulus of HDPE and K-HDPE composite.

Figure 7 represents the downgrading of the K-HDPE composite's Young's modulus (YM). The kenaf fibres provide stiffness to the composite but fibre-matrix debonding due to weathering causes the tensile stress failure to be transferred from the matrix to the fibre (Rowell & Stout, 2007). However, the weather elements cause the HDPE's YM to increase when exposed to longer times of weathering. As chain-scission happens in the polymer chain, HDPE loses it ductility and becomes stiffer but brittle and weaker in terms of tensile strength (Brennan & Fedor, 2006). The unweathered HDPE does not experience rupture or breakage when reaching the ultimate tensile strength (UTS) but it experiences a common behaviour called 'necking', where the specimen tends to elongate further while the cross-section of the specimen becomes thinner. However, for weathered HDPE, the material becomes brittle, cracks begin to appear under stress and the material abruptly breaks (Figure 8). For K-HDPE composite, the tensile strength may not be higher or equivalent to HDPE but the YM recorded was more than double that of HDPE. This higher value of YM is achieved because the fibres support the stress from the matrix. As seen in Figure 9, the K-HDPE stress vs. strain curve, which represents rigidity or stiffness, immediately breaks when reaching its UTS. The characteristic of the K-HDPE composite's strain-stress curve is dominated by the kenaf fibres, which provide stiffness that causes breakage of composites at UTS (Rowell & Stout, 2007). The UV stabiliser in the K-HDPE composite protects the material from UV radiation, so that it does not show any sign of polymer degradation, such as chalking and micro-cracking.

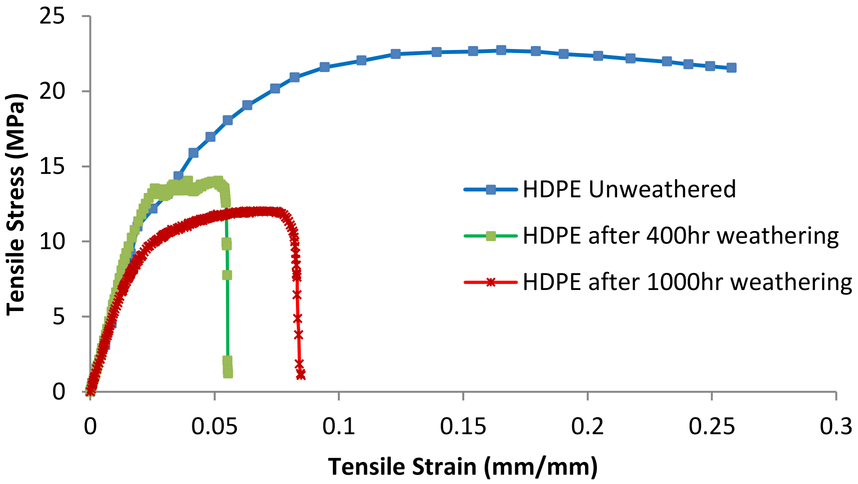

Figure 8. Stress-strain curves of weathered and unweathered HDPE.

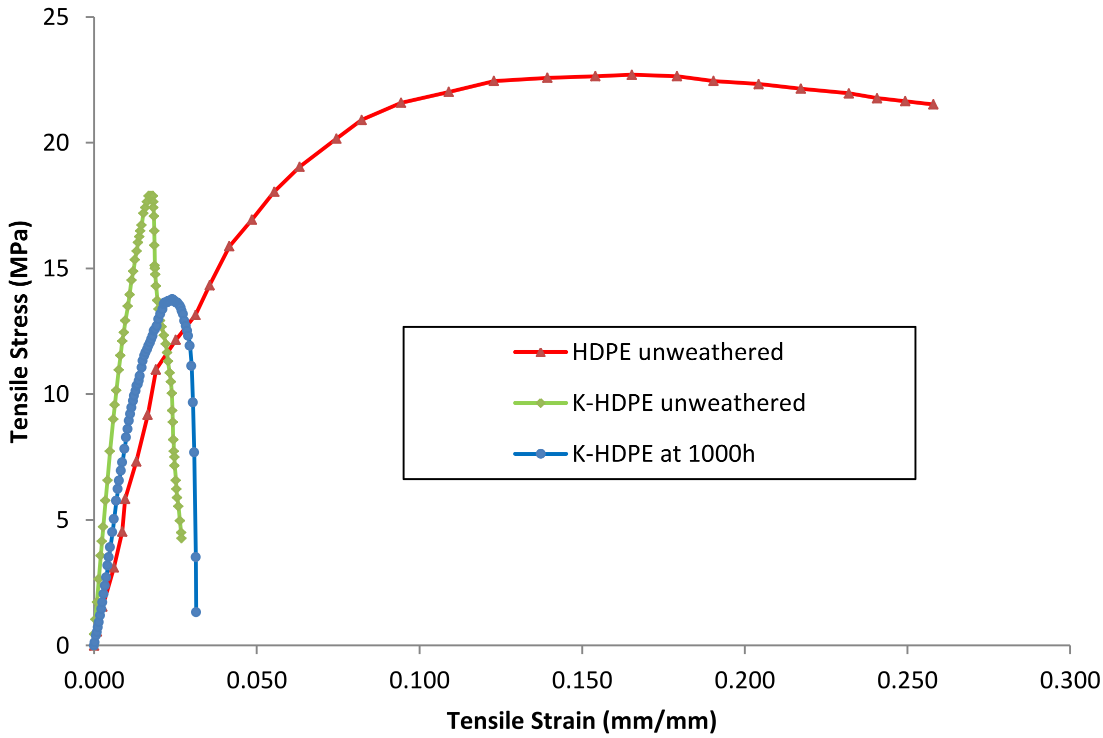

Figure 9. Stress-strain curves of unweathered HDPE with K-HDPE composites.

CONCLUSIONS

Kenaf fibres do not improve the tensile strength of composites but do provide better stiffness, as indicated by the higher Young's modulus when compared with HDPE. The exposure of accelerated weathering deteriorates both the HDPE and K-HDPE composites. The tensile strength of unweathered HDPE was 22.7% superior to that of the K-HDPE composites. However, HDPE tensile strength falls drastically at after 400 hours of weathering, showing similar values to that of the K-HDPE composite at the same time of exposure. Due to the deteriorating tensile properties of K-HDPE composites, the tested material in this weathering experiment may not be safe for use outdoors in load-bearing applications but could be applicable for non-load-bearing applications. However, the appearance of the weathered K-HDPE composite possibly may not be satisfactory because the composite surface starts to whiten and lose its appearance of wood-like texture.

REFERENCES

Adebisi, A. A., Maleque, M. A., & Rahman, M. M. (2011). Metal matrix composite brake rotor: historical development and product life cycle analysis. *International Journal of Automotive and Mechanical Engineering*, 4, 471-480.

Akil, H. M., Omar, M. F., Mazuki, A. A. M., Safiee, S., Ishak, Z. A. M., & Abu Bakar, A. (2011). Kenaf fiber reinforced composites: A review. *Materials and Design*, 32(8-9), 4107-4121.

Bachtiar, D., Sapuan, S. M., & Hamdan, M. M. (2010). Flexural properties of alkaline treated sugar palm fibre reinforced epoxy composites. *International Journal of Automotive and Mechanical Engineering*, 1, 79-90.

Brennan, P., & Fedor, C. (2006). Sunlight, ultraviolet, and accelerated weathering. In A. A. Tracton (Ed.), *Coatings Technology Handbook*. Boca Raton: CRC Press.

Maleque, M. A., Belal, F. Y., & Sapuan, S.M. (2007). Mechanical properties study of pseudo-stem banana fibre reinforced composite. *The Arabian Journal for Science and Engineering* 32(2B), 359-364.

Mat Daham, M. D. (2005). Kenaftanamanindustriberpotensitinggi. *Agromedia*, 18: 4-13.

Merah, N., Nizamuddin, S., Khan, Z., Al-Sulaiman, F., & Mehdi, M. (2010). Effects of harsh weather and seawater on glass fiber reinforced epoxy composite. *Journal of Reinforced Plastics and Composites*, 29(20), 3104-3110.

Misri, S., Leman, Z., Sapuan, S.M., & Ishak, M. (2010). Mechanical properties and fabrication of small boat using woven glass/sugar palm fibres reinforced unsaturated polyester hybrid composite. *IOP Conference Series: Materials Science and Engineering*, 11(1), 012015.

Mohanty, A. K., Misra, M., Drzal, L. T., Selke, S. E., Harte, B. R., & Hinrichsen, G. (2005). *Natural fibres, biopolymers, and biocomposites: An introduction. In Natural Fibres, Biopolymers, and Biocomposites*, Boca Raton: CRC Press, pp. 1-36.

Pritchard, G. (2000)**.** *Environmental testing of organic matrix composites**.** In mechanical testing of advanced fibre composites*. Eds. Hodgkinson, J.M. Cambridge: Woodhead Publishing Ltd, pp. 269-270.

Rowell, R. M., & Stout, H. P. (2007). *Jute and kenaf in handbook of fiber chemistry*. Boca Raton: CRC/ Taylor & Francis.