

## Research Article

# Effect of Environmental Degradation on Mechanical Properties of Kenaf/Polyethylene Terephthalate Fiber Reinforced Polyoxymethylene Hybrid Composite

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The main objective of this research is to investigate the effect of environmental degradation on the mechanical properties of kenaf/PET fiber reinforced POM hybrid composite. Kenaf and PET fibers were selected as reinforcements because of their good mechanical properties and resistance to photodegradation. The test samples were produced by compression molding. The samples were exposed to moisture, water spray, and ultraviolet penetration in an accelerated weathering chamber for 672 hours. The tensile strength of the long fiber POM/kenaf (80/20) composite dropped by 50% from 127.8 to 64.8 MPa while that of the hybrid composite dropped by only 2% from 73.8 to 72.5 MPa. This suggests that the hybrid composite had higher resistance to tensile strength than the POM/kenaf composite. Similarly, the results of flexural and impact strengths also revealed that the hybrid composite showed less degradation compared to the kenaf fiber composite. The results of the investigation revealed that the hybrid composite had better retention of mechanical properties than that of the kenaf fiber composites and may be suitable for outdoor application in the automotive industry.

## 1. Introduction

There is a growing interest in the automotive industry to replace fiberglass with natural fiber as reinforcing material in thermoplastic composites. One of the major challenges for using natural fibers in the production of automotive parts is the low mechanical properties due to environmental degradation [1]. The environmental degradation is a major factor affecting the performance of natural fiber reinforced composites when subjected to temperature, humidity, and ultraviolet radiation (UV). Polymer composites used in the automotive industry are mostly affected by photochemical reaction when subjected to severe weather condition [2]. The photochemical reaction is also referred to as photodegradation. In photodegradation process, the strength of the polymers is being affected which may be due to excessive UV penetration and thermal oxidation [3]. In order to reduce the effect of environmental degradation on composites used for outdoor applications, it is imperative

to consider hybridization with hydrophobic thermoplastic fibers due to their high resistance to photodegradation and moisture absorption compared to natural fibers.

Natural fibers can be considered as natural composites because of the presence of cellulosic fibers embedded in lignin and pectin matrix. The cellulose gives the matrix its rigidity with good tensile and flexural strengths due to their orientation along the fiber length. The cellulosic fibers have high specific strength and elastic modulus [4]. Natural fibers like kenaf are prone to high moisture absorption when exposed to high humidity due to the presence of hydroxyl groups in the cellulosic fibers [5, 6]. In photodegradation of natural fibers, the UV penetrations can result in the breaking down of hemicellulose, lignin, and cellulose content of the fiber. This reaction can affect the interfacial bonding between the fiber and the thermoplastic matrix. The poor interfacial bonding will eventually reduce the efficiency at which the composite transfers load in components, resulting in lower mechanical properties [7].

The degradation of PET mainly occurs as a result of exposure to UV light and high temperature. The degradation results in discoloration, reduction in molecular weight, and cross-link. The discoloration is due to the formation of chromophoric systems after a prolong exposure at elevated temperature. Studies conducted on the degradation of PET revealed that the first stage of the thermal degradation process is a random scission of the in-chain ester linkage that results in the formation of vinyl ester and the carboxyl end groups [8]. The next stage is the transesterification of vinyl ester to form vinyl alcohol which is immediately transformed to acetaldehyde. The thermal degradation occurs at elevated temperature in the absence of oxygen. The photodegradation of PET occurs due to exposure to UV light. The degradation leads to cross-linking thereby causing discoloration and making the fibers brittle. Previous studies on infrared and gas chromatographic analysis revealed large changes in hydroxylic regions and widening of carbonyl peaks [9].

The effect of hygrothermal edging on the thermomechanical properties of recycled PET composites was investigated [10]. The samples were subjected to hygrothermal edging at 70°C and 80% relative humidity. The results of the investigation revealed that the tensile properties of the recycled PET matrix remain unaffected after the degradation test under the selected conditions. However, the mechanical properties (tensile and fracture toughness) of the PET composites dropped due to the reduction in molecular weight of the recycled PET during the hygrothermal edging as a consequence of hydrolysis.

The effect of weathering on polypropylene (PP) and its composites was investigated [11]. Three samples were prepared for the study. The first sample was pure PP, the second sample was PP with basic stabilization, and the third sample was talc (10%) filled PP. The samples were produced by injection molding and exposed to natural weathering for a period of 6 months. The results of tensile test showed a decrease in tensile strength for all samples except for the hybrid sample after the first four months of exposure. A decrease in flexural modulus was observed for all samples during the initial period of weathering. This may be attributed to increase in stiffness and brittleness caused by photooxidation.

An investigation on the environmental degradability of self-reinforced composite made from sisal was carried out [12]. The sisal fibers extracted by benzene-ethanol were first treated with NaOH for 1.5 hours. The fibers were then transferred into a jar containing benzyl chloride. The benzylation reaction was carried out at 115°C after which the mixture was dried in an oven to obtain a benzylated sisal fiber. The self-reinforced sisal composite was produced by hot press molding process and the samples produced were immersed in water for a certain period. The results showed about 15% loss in flexural strength, flexural modulus, and impact strength. This insignificant loss was attributed to the hydroxyl groups of the sisal fiber that has been replaced by a benzyl group in the composite.

An accelerated weathering chamber can be utilized to carry out tests on components that are intended to be used for outdoor applications. Some tests conducted using accelerated

weathering chamber confirmed that there was an adverse effect on the mechanical properties of polymer composites reinforced with natural fiber [13, 14]. The studies also showed that there was less emphasis on hybridizing the composites with thermoplastic fibers to reduce the degradation rate arising from UV exposure and moisture absorption. The main objective of this paper is to investigate the effect of the environmental degradation on the mechanical properties of kenaf fiber reinforced POM composite and also to study the effect of hybridizing the composite with PET fiber. The effect of fiber content on the environmental degradation of the composites was also investigated. The selection of kenaf fiber was based on its good mechanical properties, availability, thermal stability with PET fiber, and resistance to thermal degradation. The kenaf fiber is best processed at temperatures not exceeding 200°C to avoid thermal degradation [15]. PET fiber was selected for hybridization with kenaf fiber due to its hydrophobic characteristic, high melting temperature compared to kenaf fiber, good mechanical properties, and resistance to photodegradation. The selection of POM as the matrix was based on its good mechanical properties and thermal stability with kenaf and PET fibers.

## 2. Experimental Methods

*2.1. Materials and Equipment.* A continuous kenaf fiber yarn, PET fiber yarn, and POM resin pellets supplied by Innovative Pultrusion Sdn Bhd were used to produce test samples. The kenaf and PET fibers yarns supplied were 1 mm and 0.05 mm thick, respectively. A compression molding machine with a maximum temperature capacity of 400°C was used alongside a domestic cooling fan to aid in the cooling process during the production of samples. Standard mild steel molds designed according to ASTM D638, D790, and D6110-10 specifications were used for the production of samples [16]. A universal material testing machine with maximum load capacity of 5 kN was used for testing the samples after removal from the weathering chamber. A test chamber manufactured by Q-SUN (model Q SUN Xe-34) was used for the weathering test. Three UV lamps were installed in the machine each with rated power of 1800 W and 800 V, respectively.

*2.2. Production of Test Samples.* The POM pellets were compression-molded at 190°C and cooled under pressure at 150 MPa to produce POM layers (3 mm thick) before the production of test samples. The continuous kenaf and PET fibers were cut into smaller sizes to a length of about 0.5 mm for the production of the short fiber composites. In the production of the long fiber POM/kenaf composites, the kenaf fibers were placed in between two layers of POM in a standard mold as described above. The assembly was compression-molded at 190°C with a pressure of 150 MPa maintained for 10 minutes before cooling under pressure to 80°C. The same production process was used to produce hybrid composite of both continuous and short fiber composites (POM/kenaf/PET). The weight percentage composition of POM/kenaf/PET was maintained at 80/10/10 and 70/15/15 in order to determine the effect of increasing fiber content on the environmental

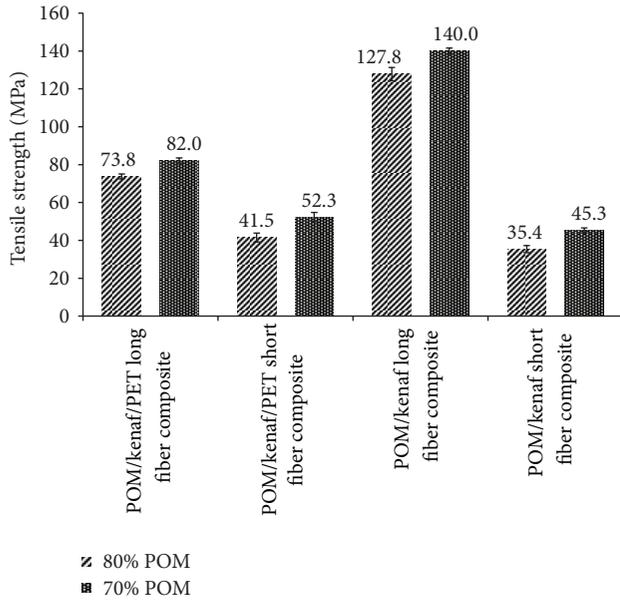


FIGURE 1: Tensile strength of the controlled samples.

degradation, as an increase in weight percentage significantly improves mechanical properties of polymer composites [17]. The 50/50 weight percentage between kenaf and PET fibers was maintained to achieve balanced mechanical properties in the composite since the high elongation fiber (PET) contributes more to raise the composite strength while the low elongation fiber (kenaf) contributes more to raise the composite stiffness [18, 19].

**2.3. Weathering Test.** The experiment was conducted according to ASTM D2565 standard for weathering tests of plastic composites. The samples were placed inside the test chamber and the machine was set to run on three cycles. During the first cycle, the specimens were exposed to UV light for 45 minutes; the second cycle operated in a dark environment and spray water on the specimens at 60°C for 1 hour, and the third cycle operated in a dark environment with a relative humidity set at 70% for another 1 hour. The black panel temperature of the chamber was set at 55°C during the first cycle and at 35°C during the second and third cycles. The irradiance was maintained at 0.8 w/m<sup>2</sup> and measured at 420 nm. The chamber air temperature used during UV exposure was 60°C. The total test duration was 1344 hours. At the end of every 672 hours, selected specimens were removed and subjected to mechanical testing.

### 3. Results and Discussion

**3.1. Tensile Properties.** Figures 1 and 2 show the results of tensile strength before and after the weathering test. The results of tensile test show a reduction in tensile strength for POM/kenaf samples after exposure for 672 hours. A 40% drop in tensile strength from 140 to 83 MPa can be observed from Figure 2. However, the hybrid composite showed 8% drop in tensile strength from 82 to 76 MPa. This suggests that

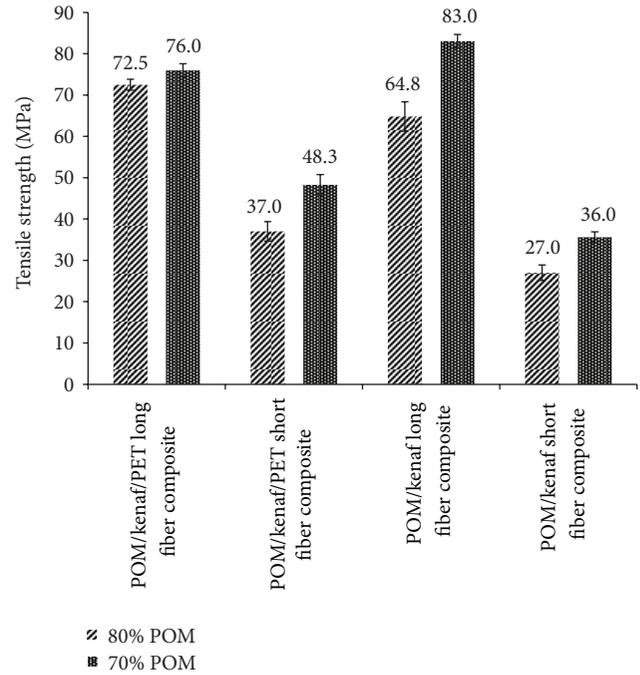


FIGURE 2: Tensile strength of the weathered samples.

the hybrid composite has higher resistance to environmental degradation than the POM/kenaf composite. This may be due to the hydrophobic characteristics of PET fiber in the composite and its high resistance to thermooxidative degradation [20]. The degradation of PET fiber may be attributed to UV penetration and thermal weight loss. The UV light provides the energy that is required to initiate the incorporation of oxygen atoms into the polymer [21]. This may further reduce its crystallinity and elasticity due to long time exposure in the weathering chamber. Previous study on recycling of the hybrid composite also explained why a reduction in molecular weight and thermal degradation affected the mechanical properties of the hybrid composite [22]. The degradation of the kenaf fiber may be due to the effect of high humidity and UV on cellulose, hemicellulose, and lignin content of the fiber during exposure in the accelerated weathering chamber. The cellulose is the fibrous part of the kenaf fiber embedded in hemicellulose and lignin matrix [23]. The hemicellulose is responsible for thermal degradation and moisture absorption of the fiber while the lignin is responsible for ultraviolet degradation. The breaking down of cellulose fiber, hemicellulose, and lignin may result in poor interfacial bonding between the thermoplastic matrix and the natural fiber [24].

Figures 3 and 4 show the elastic moduli of the controlled samples and the weathered samples. It can be observed from Figures 3 and 4 that the elastic modulus of the long fiber POM/kenaf (80/20) composite dropped by 20% from 4.0 to 3.2 GPa while that of the hybrid composite dropped by 19% from 4.7 to 3.8 GPa. Similarly, the elastic modulus of the short fiber POM/kenaf (80/20) composite dropped by 35% from 7.1 to 4.6 GPa while that of the hybrid composite dropped by 19% from 4.3 to 3.4 GPa. The fractured surfaces and porosity in

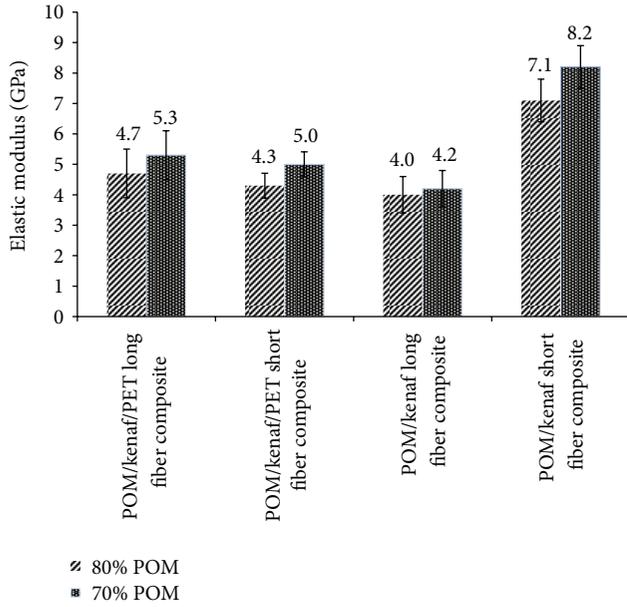


FIGURE 3: Elastic moduli of the controlled samples.

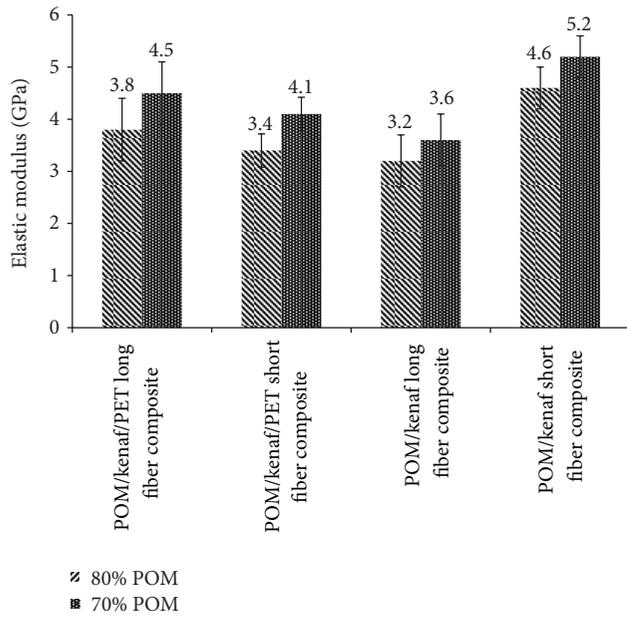


FIGURE 4: Elastic moduli of the weathered samples.

the specimens accounted for the loss in elastic moduli. The high void content in the specimens may be due to prolonged exposure to moisture during the weathering test.

The field emission scanning electron microscopy (FESEM) of the weathered kenaf composite in Figure 5 shows more fiber pullout, debonding, and matrix cracking compared to the controlled sample [25]. The phase morphology of the hybrid composite in Figure 6(a) showed less fiber debonding compared to the composite microstructure shown in Figure 6(b). With severe fiber-matrix debonding, stress cannot be effectively transferred in the composite and may eventually result in low mechanical properties.

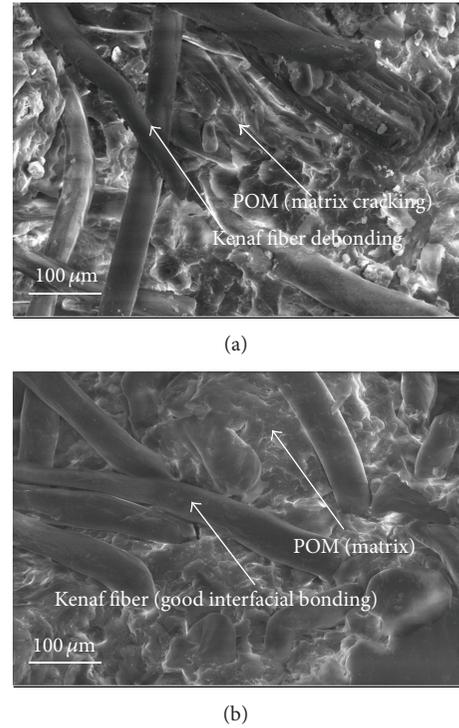


FIGURE 5: FESEM micrograph of POM/kenaf composite of (a) weathered samples and (b) controlled samples.

The degradation of POM also resulted in poor fiber-matrix interfacial bonding due to loss of hydrogen atoms in the polymer chain during thermal degradation [26, 27]. This may lead to the creation of unstable polymer free radicals and hydrogen atoms with unpaired electrons. The free radicals may react with oxygen molecule to form a peroxy radical which may further remove hydrogen from one of the polymer chains to form hydroperoxide. The continuation of these processes may lead to the formation of another polymer molecule.

**3.2. Flexural Properties.** Figures 7 and 8 show the results of flexural strength and modulus of the composites. The results of the three-point bending tests show a significant drop in flexural strength after exposure for 672 hours in the test chamber. The yield stress was computed based on an assumed maximum bending stress corresponding to about 4% strain. The flexural strength of the kenaf fiber composite dropped by 18% from 75 to 62 MPa while that of the hybrid composite dropped by 33% from 140 to 94 MPa. This loss in flexural strength may be attributed to high UV penetration and moisture absorption during the weathering test [28]. The 60°C hot chamber air-supplied during the second cycle may be responsible for kenaf fiber brittle behavior in the composite. The short fiber formulations of both POM/kenaf and the hybrid composites showed about 25% loss in flexural strength which is low compared to that of the long fiber composites. The results obtained confirmed that the long time exposure of natural fiber composites to UV and high humidity adversely affects its flexural strength due to the

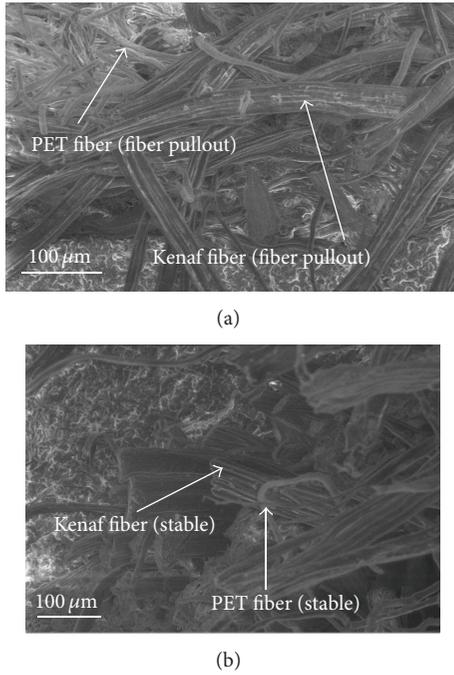


FIGURE 6: FESEM micrograph of the hybrid composite of (a) weathered samples and (b) controlled samples.

degradation of cellulose, hemicellulose, and lignin which are the major constituents of the natural fiber. The hybrid samples of both long and short fiber composites have better retention of flexural strength than that of the composites of POM/kenaf. This may be due to the high resistance of PET fiber to photodegradation compared to kenaf fiber.

The results in Figures 9 and 10 show the flexural moduli of all the composite formulations before and after exposure in the weathering chamber for 672 hours. A 30% loss in flexural modulus from 32.2 to 2.3 GPa was observed for POM/kenaf composites. This may be attributed to the degradation of kenaf fiber in the composite [29]. However, only 10% loss from 3.8 to 3.4 GPa was observed for the hybrid composite formulation due to hybridization with hydrophobic PET fiber. The only little change in microstructure can be observed from the FESEM micrograph in Figure 6 which is not very significant to cause much loss in flexural moduli [30]. Increasing the kenaf fiber content did not decrease the degradation rate but rather increased moisture uptake and UV penetration which eventually reduced the flexural strength and moduli of the composites. It can be observed from Figure 9 that the degradation is high in samples with 30% kenaf fiber. Samples with 15% PET fiber showed higher resistance to degradation than those with 10% PET fiber. This explains why increasing PET fiber content increases the composite resistance to environmental degradation. Previous studies have shown that polymers with pure carbon backbones have higher resistance to degradation than those with heteroatoms in their backbone [31, 32]. Studies on the degradation of aromatic polymers showed that such polymers are resistant to degradation despite the presence of bonds that may easily be hydrolyzed [33, 34]. This explained why

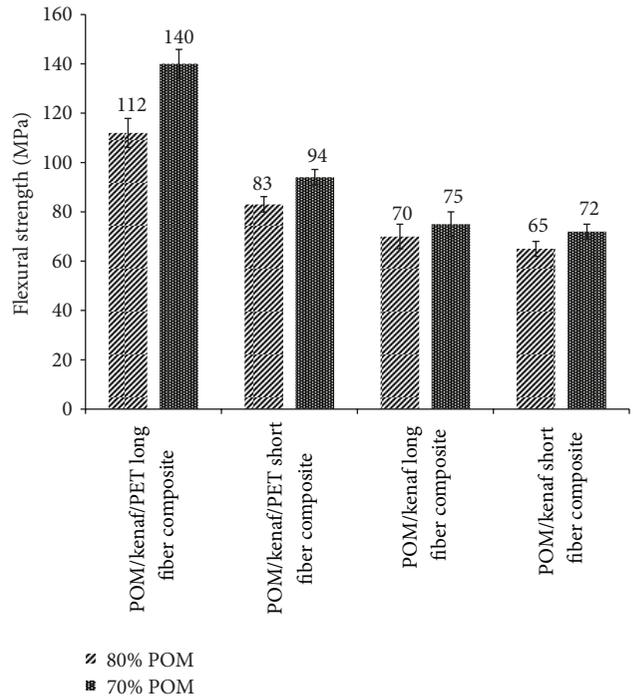


FIGURE 7: Flexural strength of controlled samples.

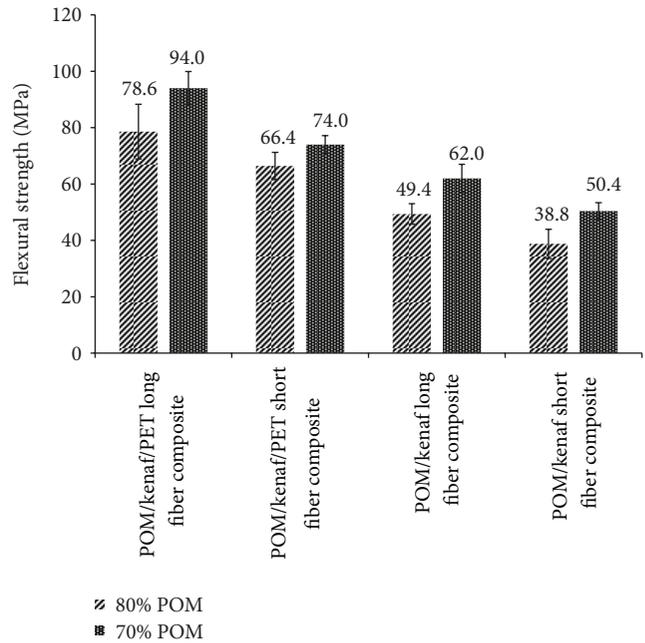


FIGURE 8: Flexural strength of weathered samples.

PET fiber in the composite has high resistance to degradation despite its aromatic structure.

**3.3. Impact Strength.** The results in Figures 11 and 12 show the impact strength of the composites before and after the weathering test. The results generally showed a significant loss in impact strength compared to the controlled samples. The impact strength of the long fiber POM/kenaf (80/20)

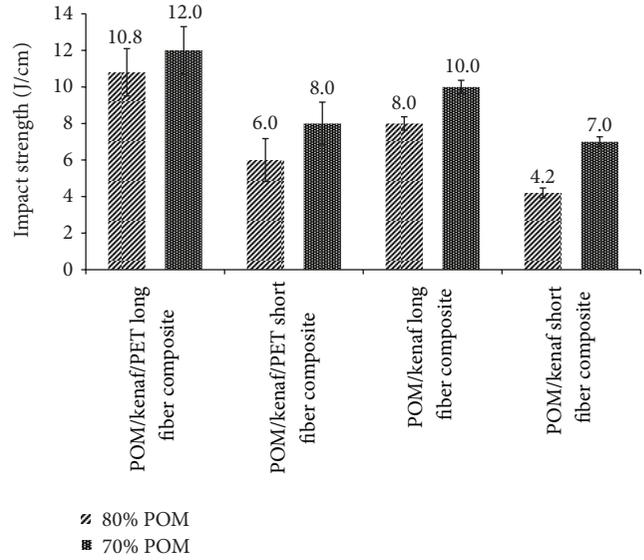
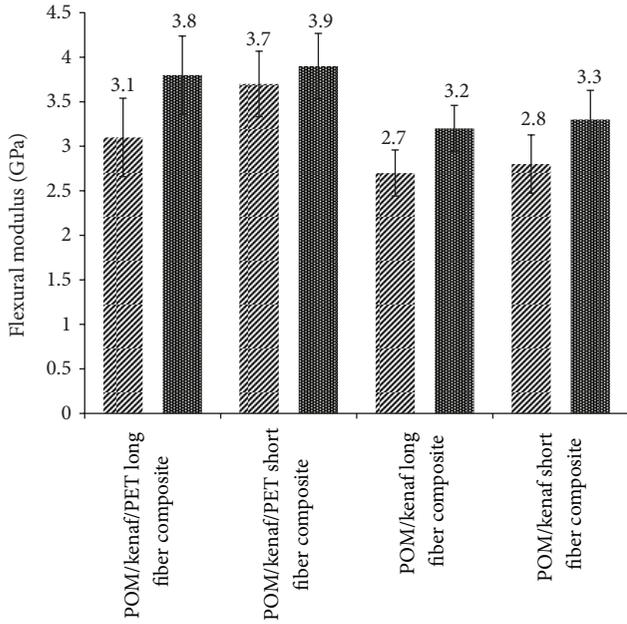


FIGURE 11: Impact strength of the controlled samples.

80% POM  
70% POM

FIGURE 9: Flexural moduli of the controlled samples.

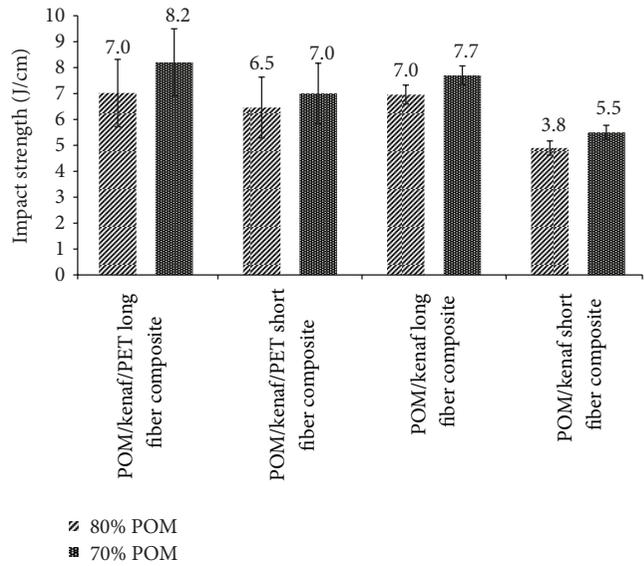
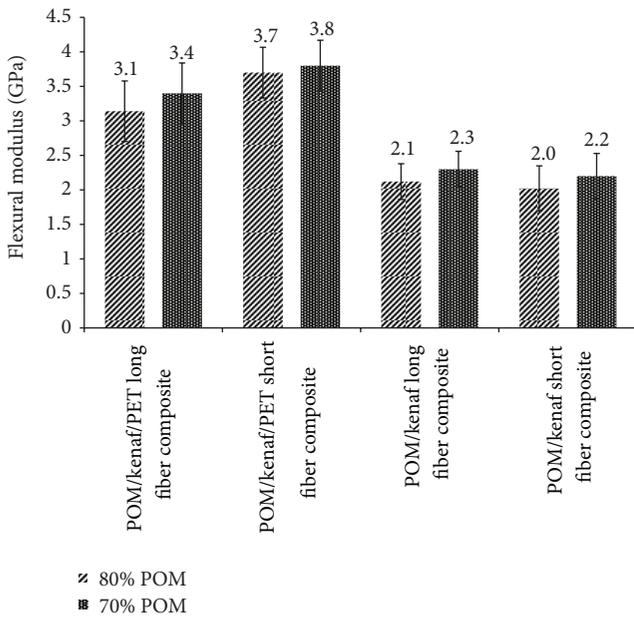


FIGURE 12: Impact strength of the weathered samples.

FIGURE 10: Flexural moduli of the weathered samples.

dropped by 13% from 8.0 to 7.0 J/cm while that of the hybrid composite dropped by 35% from 10.8 to 7.0 J/cm. The results also show that increasing the fiber content further reduced the impact strength after the weathering test. A 30% drop was observed for the long fiber composites while about 20% drop was observed for the short fiber composite formulations. The PET fiber has high impact strength compared to kenaf fiber due to its high elastic properties. The degradation of the PET fiber in the composite may be attributed to chain cuts

at the level of the ester function located on both sides of the aromatic ring in the PET molecular structure [35]. Increasing the water spray temperature in the test chamber may increase water diffusion into the hybrid composite which may further accelerate the aging of the composite, but the rate of water diffusion is higher in kenaf fiber due to its hydrophilic nature and porosity.

#### 4. Conclusion

The environmental degradation test of the composites for all formulations was carried out after exposure for 672 hours in an accelerated weathering chamber. The samples were exposed to moisture, water spray, and UV penetration.

Tensile, flexural, and impact tests were conducted after removing the samples from the test chamber. The results from tensile test showed a significant drop in tensile strength. A 40% reduction in tensile strength was observed in the long POM/kenaf composite which is low compared to about 8% loss for the long fiber hybrid composite. The reduction may be attributed to the degradation of cellulose, hemicellulose, and lignin content of the kenaf fiber resulting from exposure to moisture and UV. A 33% drop in flexural strength was observed for the hybrid composite while 18% drop was observed for the kenaf fiber composite. However, only a 10% drop in flexural modulus was observed for the hybrid composite while a 30% drop was observed for the kenaf fiber composite. The results above confirmed that exposing the natural fiber composite to moisture and UV penetration resulted in degradation of the composite, but the hybrid composites had better retention of mechanical properties than the POM/kenaf composites. This suggests that the hybrid composite will be more suitable for outdoor application compared to the kenaf fiber composite. The results also revealed that increasing the PET fiber content significantly improved the composite resistance to environmental degradation.

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