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EFFECT OF WEATHERING ON THE PROPERTIES OF RECYCLED HIGH DENSITY POLYETHYLENE BASED NONMETALLIC PRINTED CIRCUIT BOARDS WASTE COMPOSITE

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Abstract: The weathering performances of nonmetallic printed circuit boards (PCB)-filled recycled high-density polyethylene (rHDPE) was investigated in this study. The compression molded rHDPE/PCB composite was exposed to both natural and accelerated weathering attacks. The durability of rHDPE/PCB composites was compared to neat unfilled rHDPE and virgin HDPE (vHDPE). When the exposure time increased, the color of rHDPE faded faster than vHDPE. The surface of composites with 30 and 50 wt% nonmetallic PCB flaked off after being exposed to both weathering conditions. Prolonged weathering exposure also caused loss of impact strength of all the samples with and without nonmetallic PCB filler. In general, composites with 30 and 50 wt% nonmetallic PCB is more resistible to weathering attacks as compared to unfilled rHDPE.

Keywords: *Nonmetallic printed circuit board, recycled HDPE, composites, weathering, impact strength*

1.0 Introduction

The ever increasing tonnage of plastic waste has driven the need for sustainability of renewable resources through plastic recycling. Nowadays, many products are manufactured using recycled plastic, including vineyard posts, garden sleepers, and decking boards for children’s playgrounds (PACIA, 2004). However, there exist disadvantages in the use of recycled plastic when compared to virgin polymer or timber as raw materials. Generally, they exhibit lower stiffness and strength (LaMantia, 2003), which limits their use in high load-bearing applications. However, materials can be incorporated into the polymer matrix of recycled plastics to restore their mechanical properties and extend the life spans of the composites; these materials are often called fillers. Thus, in this research, nonmetallic fraction from Printed Circuit Board (PCB) waste has been utilized as filler material in recycled High Density Polyethylene (rHDPE). In general, waste nonmetallic PCBs mainly consist of thermoset resins and glass fibers (Goosey and Kellner, 2002). The glass fibers in nonmetallic PCB waste are considered very useful since it can act as reinforcing agent. The composites made from nonmetallic PCBs are intended for outdoor applications. Thus, this article aims at investigating the structure-property degradation of compression molded nonmetallic PCB-filled recycled HDPE composite under natural and accelerated weathering exposure. The composites were subjected to natural outdoor and accelerated weathering to determine the extent of surface colour changes and loss of impact strength.

2.0 Materials and Methods

2.1 Materials

Recycled HDPE was obtained from a local plastic recycling plant at Johor, Malaysia. Nonmetallic PCB waste used as a filler material in this work was an industrial solid-waste byproduct from PCB recovery process obtained from METAHUB Industries Sdn Bhd (Johor, Malaysia). This was in the form of powder and without electronic elements. The powder was sieved and particle sizes from 0.07 to 0.3 mm were selected to produce composite.

2.2 Compounding and Preparation of Composites

The nonmetallic PCBs were added to the rHDPE substrate at levels of 10, 30, and 50 wt% and the blends were prepared with a co rotating twin screw extruder Brabender Plasticoder PL 2000. Adding larger amount of nonmetallic PCBs (>50 wt %) to rHDPE worsened the processibility of the composite material, and created great difficulty for molding process. The rHDPE and the nonmetallic PCBs were dried at 80°C for 24 h prior to extrusion. The barrel temperature profile adopted during compounding of all blends was 210°C at the feed section, decreasing to 200°C at the die head and the screw rotation speed was fixed at 50 rpm.

2.3 Test Methods

Weathering performance of rHDPE/PCB composites was compared against virgin HDPE and recycled HDPE properties. The tests were conducted in two different environments which are outdoor natural weathering and accelerated xenon-arc weathering. The details of the testing methods are as follows.

2.4 Outdoor Weathering

The outdoor weathering test was conducted at Universiti Teknologi Malaysia, Skudai, Johor state in country Malaysia where geographically located at latitude 1°33’23” North of the Equator and longitude 103°38’13” East of the Prime Meridian. The samples were exposed for a 6-months period to study the environmental effects on the surface color and impact performance of the samples. The test was performed according to ASTM D 1435-05. The samples were mounted on 45° racks and located far from buildings or obstacles (Figure 3.6). Samples were removed for optical, color, and impact tests after the accelerated weathering exposure.

2.5 Accelerated Weathering

The test samples were mounted in Q-Sun Xenon Test Chamber (Figure 3.7) and subjected to a cycle of exposure, as recommended by ASTM D 4329-05. This included intense of UV radiation, moisture exposure, and condensation. The cycle of exposure was set at 8 hours of UV exposure at 70°C and followed by 4 hours of condensation at 50°C. These cycles were continued for 2000 hours. Samples were removed for optical, color and impact tests.

2.6 Color Measurement

The colour changes at the composite sample surfaces were measured during the UV exposure at preset exposure times, using a method outlined in ASTM D2244. A Spectrophotometer (Minolta CM-2500d) was used to measure the colour according to the Commission International d’Eclairage (CIE) colour system (CIE 1976). As defined by the CIE, L* is used to represent the lightness, and a* and b* are the chromaticity coordinates. The colour coordinates for each composite were measured for three replicate samples before and after exposure to the accelerated weathering. Colour change (HE) of the weathered samples was then calculated from the following equation:

$$\Delta Eab = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2} \qquad (1)$$

Where ΔL, Δa, and Δb represent the difference between initial and final values of L*, a*, b*, respectively.

Increase in L* indicates the samples are lightening. Increase in a* represents a colour shift towards red, whereas decrease in a* represents a colour shift towards green. On the other hand, the increase in b* means a colour shift towards yellow and decrease in b* represents a colour shift towards blue.

2.7 Notched Izod Impact Test

Izod impact tests were carried out on notched impact specimens, by using a Toyoseiki (Tokyo, Japan) impact testing machine according to ASTM 256 under ambient conditions. All the samples were notched using an automatic notching machine prior to testing. Five specimens of each formulation were tested and the average values reported.

3.0 Results and Discussion

3.1 Natural Weathering

Weathering effects was first manifested by the changes in colour of the samples. Figure 1 shows the samples without weathering while Figures 2 and 3 show samples after 18 and 32 weeks of outdoor weathering exposure, respectively. Visually, vHDPE did not show any severe changes over 32 weeks of outdoor exposure. Only a few black spots were seen on the surface of the virgin HDPE (Figures 2a and 3a) after 18 and 32 weeks of weathering, respectively. The colour of unfilled rHDPE faded to silvery grey after 32 weeks of exposure to natural environment, as shown in Figure 3(b). Addition of nonmetallic PCB into rHDPE matrix makes the colour of composite darker (Figure 1e). Therefore, it can be pointed out that, adding larger amount of nonmetallic PCBs into the rHDPE matrix turned the colour of composites from lighter to darker. The dark colours of the composites are believed to be resulted from the greenish colour of nonmetallic PCB powder itself. All the outdoor weathered composite samples lightened initially for the first 18 weeks of exposure as can be seen in Figure 2(a-e), and then darkened as mildew/mold and dirt were deposited on the surface as can be seen in Figure 3(a-e) after 32 weeks of outdoor exposure.

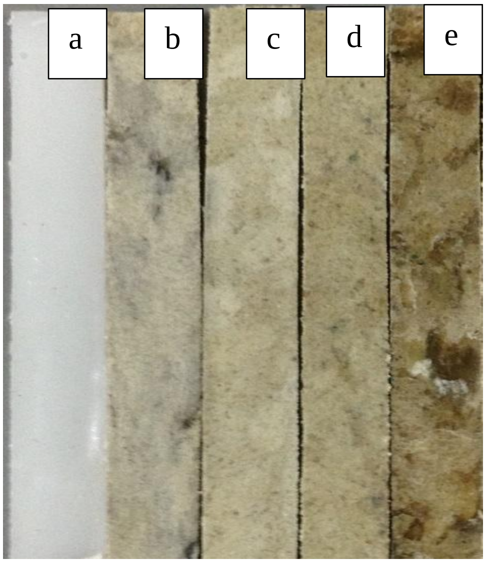


Figure 1: Flexural samples before weathering (a) vHDPE, (b) rHDPE, (c) 10 wt% PCB, (d) 30 wt% PCB, (e) 50 wt% PCB

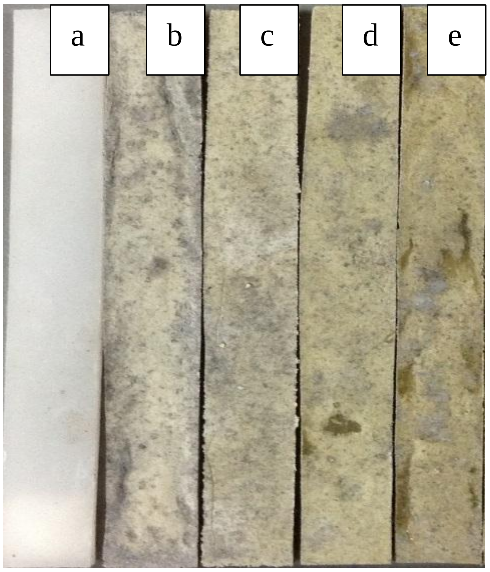


Figure 2: Flexural samples after 18 weeks of outdoor weathering (a) vHDPE, (b) rHDPE, (c) 10 wt% PCB, (d) 30 wt% PCB, (e) 50 wt% PCB

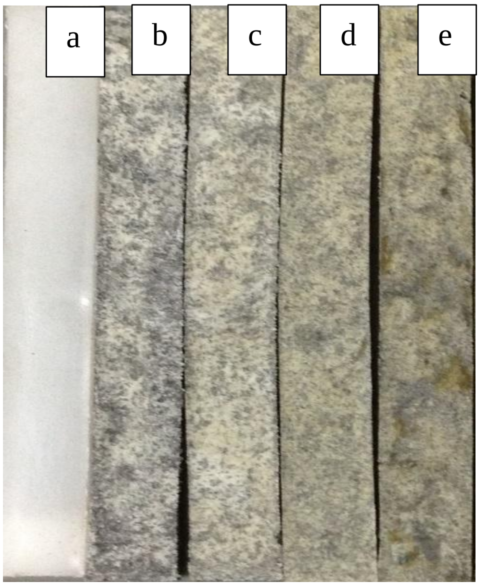


Figure 3: Flexural samples after 32 weeks of outdoor weathering (a) vHDPE, (b) rHDPE, (c) 10 wt% PCB, (d) 30 wt% PCB, (e) 50 wt% PCB

Figure 4 shows the intensity of the reflected light of each sample after exposure to natural weathering for a period of 32 weeks. The differences of colour losses of samples were measured by the lightness factor (intensity of reflected light). Nearly all exposed specimens experienced fading after 32 weeks of outdoor exposure. The exposed specimens generally exhibited greater fading between 6 and 18 weeks than between 24 to 32 weeks. It is apparent from Figure 4 that the unfilled rHDPE faded at a more rapid rate than the rHDPE based nonmetallic PCB composites. In addition, the specimens with higher content of nonmetallic PCB waste faded to somewhat more than specimens with lower nonmetallic PCB. It is believed this has to do with the tendency of the nonmetallic PCB particles to bleach with UV exposure. At loading content of 10 wt% nonmetallic PCB, there is not much difference can be seen. At loading content of 30 and 50 wt% nonmetallic PCB, the intensity of the reflected light were increased and reached maximum at the 18th weeks of exposure, and started to drop slightly and remained constant for rest of the exposure periods. The drop was rationalized by the explanation that the composites lightened until 18 weeks of exposure and started to darken due to the dirt deposited on the surface of the composites. The prolonged heat from outdoor exposure environment was also reported to darken the colour of composites.

Figure 5 shows the impact strengths of weathered samples vs. exposure time. Prior to weathering test, the impact strength of rHDPE and its composites was lower than vHDPE because the incorporation of nonmetallic PCB in rHDPE matrix has caused imperfection of the structural adhesion. All the rHDPE and its composites showed a drop in strength after 6 weeks of exposure which continued for over 32 weeks, indicating that embrittlement has occurred extensively with continued exposure to outdoor weathering.

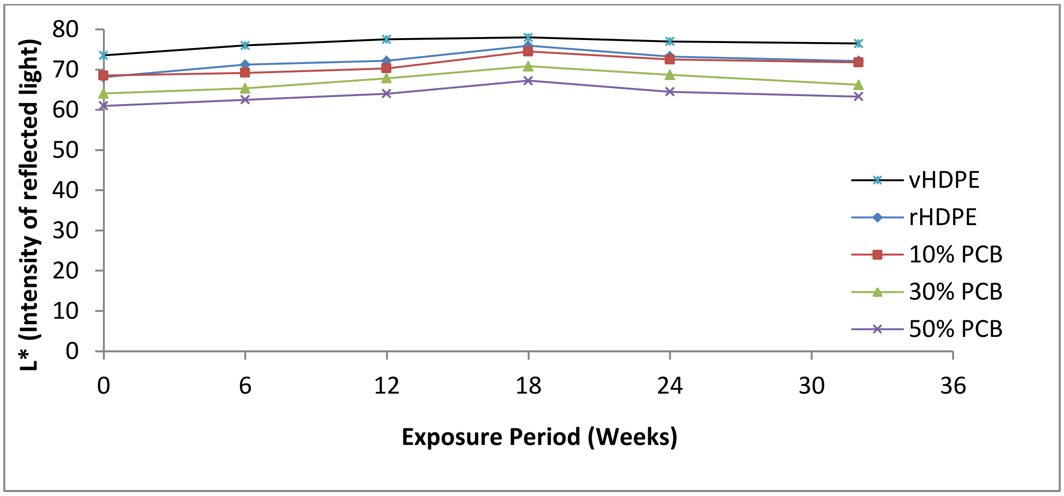


Figure 4: Lightness (L*) of vHDPE, rHDPE, 10 wt% PCB, 30 wt% PCB and 50 wt% PCB composites after outdoor exposure

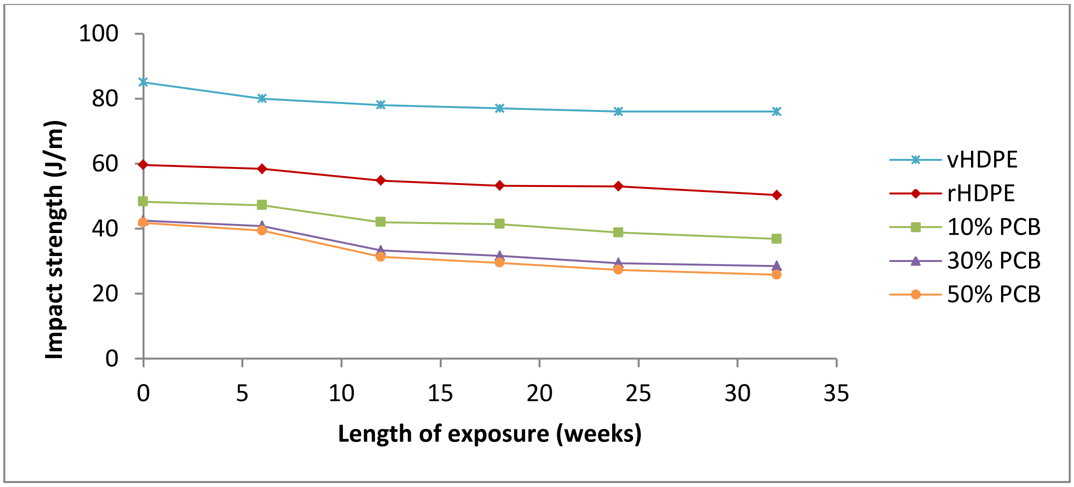


Figure 5: Impact strengths of vHDPE, rHDPE and rHDPE/PCB composites corresponding to length of exposure in natural weathering

3.2 Accelerated Xenon-arc Weathering

Figure 6 shows the changes of vHDPE, rHDPE and rHDPE/PCB composites after 2000 h exposure to accelerated xenon-arc weathering. Visual inspection showed that accelerated (xenon-arc) weathered composites whitened upon exposure as can be seen in Figure 6(a-e). It was noted that, vHDPE was unlikely to be affected by length of UV exposure as the colour of the sample does not change much after 2000 h. Obviously, rHDPE surface colour lightened after 2000 h xenon light exposure (Figure 6b). The surface became rough and powdery due to the matrix degradation. The adsorption and desorption of moistures promoted void formation and initiated cracks. As the exposure times prolonged, cracks started to propagate and eventually deteriorated the interfacial properties of matrix and fiber. As a result, the surface of the rHDPE composite apparently began to flake after 2000 h. This was because the high energy of UV- rays has deeply penetrated to initiate the degradation of HDPE. Such undesirable low surface quality was also reported by Stark and Matuana. (2005) for wood flour filled HDPE composites.

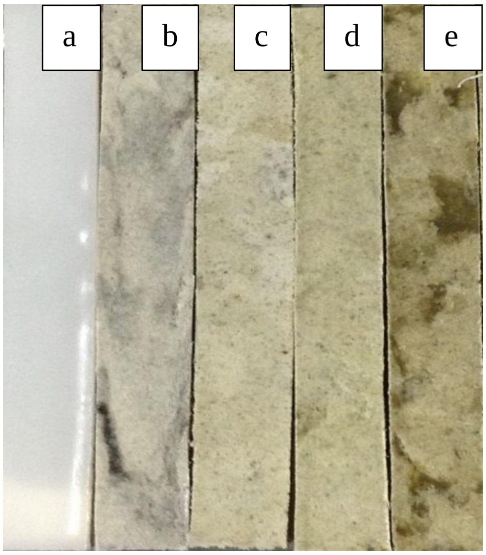


Figure 6: Samples after 2000 hr accelerated weathering (a) vHDPE, (b) rHDPE, (c) 10 wt% PCB, (d) 30 wt% PCB, (e) 50 wt% PCB

As can be seen in Figure 7, in the early stage, rHDPE surface color lightened as the duration of exposure increased. vHDPE was unlikely to be affected by length of UV exposure as it faded rapidly within 500 h of exposure with minimal changes in intensity of reflected light. Beyond 500 h of exposure, the intensity of vHDPE began to remain constant. Thus, vHDPE was capable of withstanding UV light penetration. Stark and Matuana (2007) found that the colour lightening of virgin HDPE sample at initial stage was due to the molecule chain scissioning and subsequently it led to change in molecular weight distribution. However, the UV resistance of rHDPE was worse than vHDPE. The rHDPE specimen exhibited an increasing movement to lighter colour as the colour faded proportionally with the exposure time until 1000 h. After 1000 h of exposure, the intensity of rHDPE remained constant until 2000 h of exposure.

Same as reported for rHDPE/PCB composites with outdoor weathering, the specimens with higher nonmetallic PCB particles faded somewhat more than did specimens with lower nonmetallic PCB content. It has been stated that composites are subjected to a lower degree of lightening when they are exposed to only UV light, compared with exposure to a combination of UV light and water spray (Stark and Matuana, 2005). Water accelerates oxidation reactions and causes the fiber to swell, creating more openings for light penetration. Additionally, water can also remove some water-soluble extractives that impart color to the filler particles (Stark and Matuana, 2007).

Presence of some impurities in the rHDPE also can contribute to the higher moisture absorption at initial stage. Moreover, photodegradation is much greater in the present of water and that the principle of water is to facilitate light penetration into previously inaccessible regions (Hon, 2011).

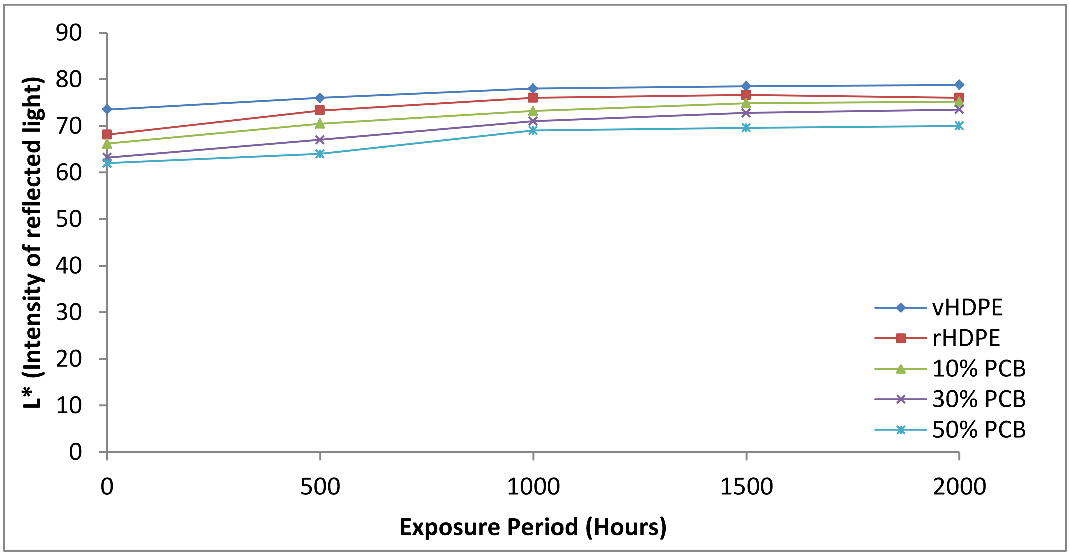


Figure 7: Lightness (L*) of vHDPE, rHDPE, 10 wt% PCB, 30 wt% PCB and 50 wt% PCB composites after accelerated weathering exposure

Figure 8 indicates great drop of the vHDPE impact strength throughout 2000h of exposure time. While, the impact strength of the rHDPE and its composites decreased proportionally with the exposure time. It was found that the changes in the impact strengths for accelerated weathering specimens had similar trend to the specimens for natural weathering. The loss in impact strength can be related to the prolonged degradation to weathering has created weak points on the sample surfaces and when the composites were subjected to impact force, the existed cracks and weak points would propagate and break.

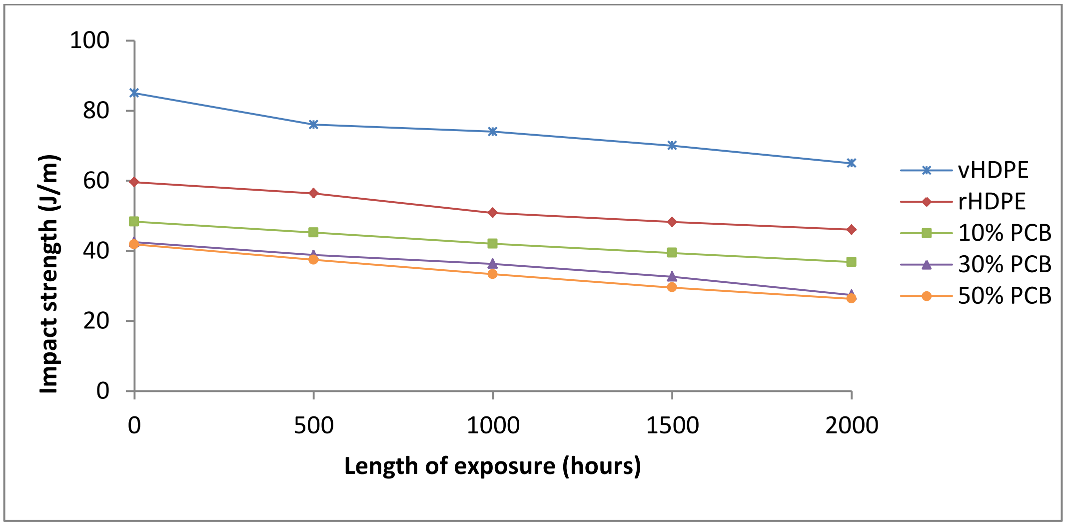


Figure 8: Impact strengths of vHDPE, rHDPE and rHDPE/PCB composites corresponding to length of exposure in accelerated weathering

3.3 *Microstructure Characterization*

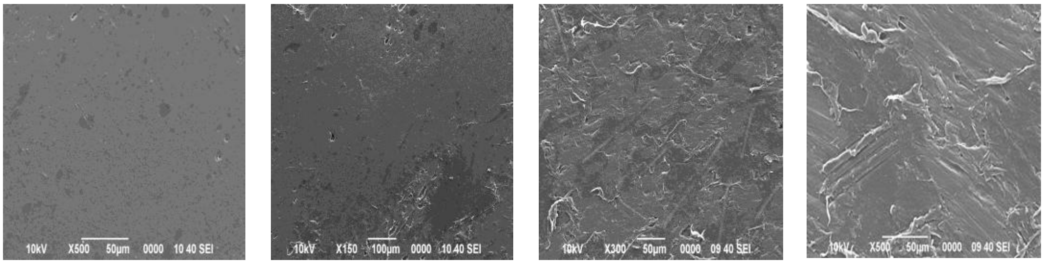
The microstructure of the surfaces of UV weathered composites was compared with the control samples as shown in Figure 9. For the control samples of vHDPE and rHDPE, prior to the weathering test, the surfaces of both the samples were smooth. However, with continued weathering until 32 weeks, more and more cracks appear on the surface and caused the surface of composite to flake and peeled off.

While, for composites with 30wt% and 50wt% nonmetallic PCB prior to weathering, it was found that a considerable amount of matrix breakage and fiber tearing off was observed with little intact material on the surface. This indicated good interface bonding between the nonmetallic PCB fibers and polymer matrix. Conversely, with UV weathering, the interface bond was degraded with intact glass fibers contained in nonmetallic PCB materials being completely separated and pulled out from the matrix.

This also supports the belief that degradation due to UV weathering weakened the interface bonding with some glass fibers being pulled out and thus adversely affected the properties of the composites. The polymer matrix is also seen to tear off form the composite with continued weathering. Similar phenomenon was observed for accelerated weathered composites (Figure 10). Before the weathering test, the glass fibers are randomly oriented on the surface. Furthermore, it is observed that glass fibers almost cover the whole surface of specimens, acting as a protective layer. It can thus prevent exposure of the polymer surface to direct UV irradiation, slowing down the photo-degradation reaction. After 2000 hours of accelerated weathering, it is obvious that some cavities and cracks appear on the surface. Such cracks and cavities would attribute to a quick loss in mechanical properties under low photo degradation. Weathered samples showed decreased bonding between matrix and fibers as reflected by the numbers of fibers being pulled out from matrix. This trend can also be used to explain the reduction in the mechanical properties of the composites after weathering.

Before (0 day)

vHDPE rHDPE 30 wt% PCB 50 wt% PCB



After (32 weeks)

vHDPE rHDPE 30 wt% PCB 50 wt% PCB

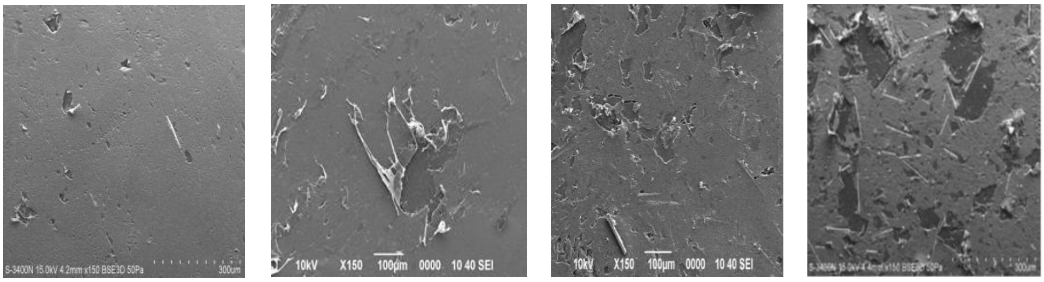
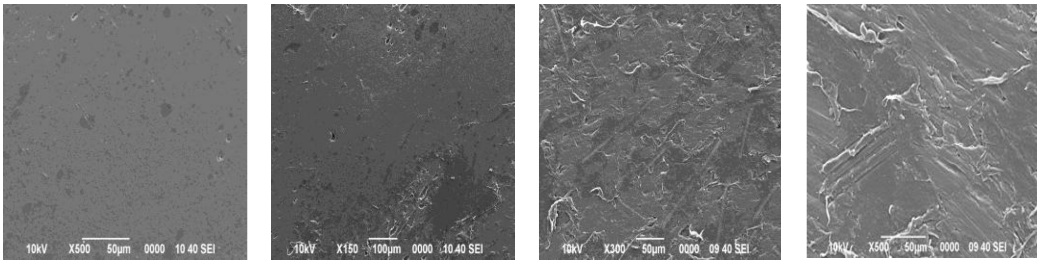


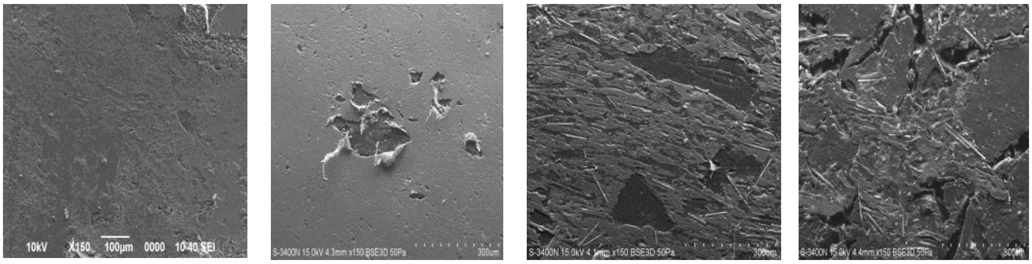
Figure 9: SEM surface of samples before and after exposure to natural weathering

Before (0 h)



vHDPE rHDPE 30 wt% PCB 50 wt% PCB

After (2000 hours)



vHDPE rHDPE 30 wt% PCB 50 wt% PCB

Figure 10: SEM surface of samples before and after exposure to accelerated weathering

4.0 Conclusions

In this study, the effect of weathering on vHDPE, rHDPE and rHDPE/PCB composites colour and impact strength was examined. Weathering of rHDPE and its composites resulted in color change, mainly surface lightening, which occurred through continued exposure time. Composites with nonmetallic PCB material exhibited lesser lightening when compared to unfilled rHDPE samples. While, vHDPE was unlikely to be affected by length of UV exposure as the colour of the sample does not change much for both the weathering conditions. Continued weathering also has caused drop in impact strength for all the composites. Microscopic examination of weathered vHDPE, rHDPE and rHDPE/PCB composite surfaces after extended exposure time revealed crazing and cracks which lowered the mechanical properties of the composites.

5.0 Acknowledgements

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