Assessment of Mechanical Properties of Recycled HDPE and LDPE Plastic Wastes

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Abstract. Most plastic materials can be recycled, and turning them into some useful products can be one of the options in reducing environmental pollutions. In this project, High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE) were used, shredded into smaller pieces and were hot-pressed to become flat plates. Both materials were then mixed with industrial waste sawdust with an aim to investigate their material properties and their suitability to be used in domestic applications such as bricks, pavement and roof tiles. Three destructive and one non-destructive methods have been conducted: tensile, impact, water absorption and ultrasonic testing. It was found that the tensile properties and impact resistance of the recycled HDPE are better than the recycled LDPE, but 10% lower than their virgin polymers. Higher stiffness and lower impact resistance were observed from specimens with additional sawdust filler in comparison to their original polymers. From the ultrasonic measurement, higher wave velocity and lower attenuation in HDPE specimens were observed, compared to the LDPE specimens, attributed by a higher modulus and density of the HDPE specimens. The ultrasonic velocity, which reflects the elastic modulus, and the attenuation that reflect the microstructure inhomogeneity are respectively decreased and increased when more fillers were added to the original specimens. This study reveals that the mechanical properties of the recycled HDPE and LDPE are closer to their virgin materials, and they have huge potential for plastic recycling.

1 Introduction

In 1950 the world produced plastics only 2 million tonnes per year, but then, the annual production has increased to nearly 8 billion tonnes to date [1]. Very little plastic products are recycled or incinerated in waste-to-energy facilities. In 2015, it was estimated that 55% of global plastic waste was discarded, 25% was incinerated, and 20% recycled [2]. Most of them end up in landfills that may take up to hundreds of years to decompose, piling up the land and finally polluting the soil and environment. In one study, it has been estimated that 1/3 of all plastic wastes end up in soils or freshwater, which later disintegrate and break down

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further into nano plastic particles that finally could enter the human food chain [3]. Hence, this plastic waste is such an important issue to be solved quickly.

Apart from cleaning up our oceans or landfills, which is a very significant step, the best way to address this huge plastic pollution is by recycling the plastic wastes [4]. Plastic recycling is the process of collecting plastic wastes and reprocessing the material into useful products. Before reprocessing them, most plastics are sorted according to their resin identification codes. There are represented by Unicode icons and numbered with (1) Polyethylene Terephthalate (PET), (2) High-Density Polyethylene, (3) Polyvinyl Chloride (PVC), (4) Low-Density Polyethylene (LDPE), (5) Polypropylene (PP), (6) Polystyrene (PS), and (7) other plastic types [5]. These resin codes indicate the type of material of each plastic and each of them has a unique material characteristic. Some of them are reusable, some are hazardous after several uses, and some need a more sophisticated reprocessing process. By understanding these seven codes, it will be easier to choose plastics and to know which plastics to be recycled. Due to their differences in material properties and characteristics, it is recommended to use a singular type of plastic in a production of a new product using recycled materials.

In this project, the HDPE and LDPE thermoplastic wastes were used as they are inexpensive, lightweight and durable. HDPE is a very hard-wearing and does not easily break down under exposure to sunlight or extremes heating or freezing [7]. LDPE is normally used as plastic bags, is considered less toxic than other plastics, but it is not commonly recycled [8]. These two plastics are the easiest plastics to recycle. Their unique properties make them suitable to be moulded into a variety of products for many applications, even after they have been recycled into a new form [6]. One research has demonstrated that for the first time that the plastic molding and shredding process have no property-altering effects on the material over the entire period of reuse [7]. In principle, this result means that this plastic can be reused for a long time without diminishing its properties.

Building from this information, the aim of this study is to investigate the material properties of the newly formed HDPE and LDPE from waste bottles and their suitability to be used in domestic applications such as pavements, bricks or roof tiles. A simple processing route will be used, and explained in the following section.

2 Methodology

2.1 Sample preparation

In this study, two types of plastic wastes were used as the specimens: (1) HDPE, collected from recycled detergent bottles, and (2) LDPE, collected from recycled black plastic bags. These trashes were cleaned and washed before cut into small pieces. Then, they were fed into a shredder machine to obtain the plastic pellets. By using a hot-pressed machine, these plastic pellets were placed in a highly tight square-shaped mold to be pressed to a plate. In a separate study, the HDPE and LDPE pellets were individually mixed with wood sawdust as the filler for the plastic plates. They were mixed at a ratio of 80:20 and 70:30. The HDPE/sawdust and LDPE/sawdust mixture were left to bond under hot press machine at 180°C and 160°C respectively. The pressing duration is 1 hour and 2 hours for the HDPE and LDPE specimens respectively. These four types of specimens are shown in Fig. 1. Then, all specimens were cut into a desired shaped for various material testing. The mass of all specimens was measured for a density calculation.
2.2 Tensile test

To conduct the tensile test, the specimens were made according to ASTM 3039 standard, with the dimensions of 200 × 25 × 150 mm. The tensile test was conducted at room temperature with test speed of 5 mm/min using an INSTRON 3382 universal test machine. The specimen was clamped on the testing machine with 50 mm length of the specimen both sides. The mechanical properties such as tensile modulus, the ultimate tensile strength and the total elongation of the specimens were taken. The average values were calculated from five runs for each type of specimen.

2.3 Impact test

This test measures the impact energy, or the energy absorbed prior to fracture, using an Izod Impact testing machine. V-notched specimens were prepared according to the ASTM D6110 standard, with a required length of 65 mm mm and width of 13 mm. The notch has a depth of 2 mm, angle of 45°, and a root radius of 0.25 mm. The radius of curvature at the notched specimen is to serve as a stress concentrator. The weight of pendulum is 0.452 kg. Five specimens were used to determine the average impact resistance for the material sample.

2.4 Water absorption test

Water absorption is expressed as an increase in weight gain percentage of a plastic specimen under the following procedure. Referring to the ASTM D570 standard, the specimens were dried in an oven for 24-hour at 105°C. The specimens were immediately weighed after they have been placed to cool in a desiccator. Then, the specimens were soaked in water for 24-hour at room temperature, and the weight of the patted-dried soaked specimens (soaked HDPE and soaked LDPE) were recorded for the calculation of water absorption, as per equation below:

\[
\text{Water absorption \%} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100
\]
2.5 Ultrasonic measurement

A pulse-echo method was used to measure the properties of longitudinal ultrasonic wave in all specimens. A transducer of 5 MHz center frequency was used, connected to a portable ultrasonic machine GE Krautkramer USM 36. Basic signal parameters such as wave speed and attenuation were recorded. The reflected signals acquired from the measurement setup correspond to the ultrasonic wave velocity that travel twice the thickness of the specimen. The attenuation can be measured by using the reduction in amplitude peaks. Changes in wave speed and energy losses from the interactions with material microstructure are the two key factors in material characterization using non-destructive ultrasonic testing [9]. Both velocity and attenuation can be calculated using Eq. 2 and Eq.3 as below.

\[
\text{wave velocity} = \frac{2(\text{travelled distance})}{\text{time}} \tag{2}
\]

\[
\text{wave attenuation} = \frac{1}{2(\text{travelled distance})} \times \log_{10} \left( \frac{\text{Peak Amp 1}}{\text{Peak Amp 2}} \right) \tag{3}
\]

3 Results and Discussions

3.1 Tensile properties

The stress-strain curves and the bar charts of tensile properties are presented in Fig. 2. From Fig. 2a, the LDPE and HDPE without additional filler shows that there are more ductile and taking a longer time to break than the LDPE- and HDPE- sawdust blend. The HDPE with sawdust shows the most brittleness behavior as they were having less than 5% total elongation during the tensile test (Fig. 2b). As similarly reported in [10], lower elongation at break values was observed with an increase in tensile modulus, which can be seen in HDPE specimens. The effect of the additional filler on the tensile properties can be seen in (Fig 2c and 2d). The elastic moduli of both materials are seen to be increased when they were blended with the sawdust filler, which is in line with the known fact that a stiffer filler particle could enhance the elastic modulus. It is also found that the moduli of both HDPE and LDPE specimens were reduced when they were soaked in water for 24-hrs. The reduction might be due to more water absorption on the interface area between sawdust and polymer, which later caused the reduction in the tensile properties of the composite blend. It is also observed that the tensile properties of all HDPE specimens are higher than the LDPE specimens. Comparing to the literature study [8, 9], there are about 10% differences in the elastic modulus between the recycled products and their virgin materials. Although there is a reduction in the property, the potential of turning these plastic wastes into useful products within the new material property limit is still huge. Overall, the results indicate that recycled HDPE has higher strength, better resistance to deformation, but quite a brittle material when blended with sawdust. In contrast to LDPE, it has a larger elongation rate but weaker in strength compared to HDPE.

3.2 Impact properties

Fig. 3a shows the absorbed impact energy. It can be observed that the HDPE specimens absorbed about 10% more energy compared to the LDPE specimens. This corresponds to the lower elastic modulus (0.38 GPa) and lower density (0.94 g/cm\(^3\)) of the LDPE specimen than the HDPE (0.45 GPa and 0.97 g/cm\(^3\) respectively). For the HDPE with a higher modulus (0.45 GPa) and higher density (0.97 g/cm\(^3\)), it is expected that the high weight and narrow molecular distribution generally improves the impact resistance. The HDPE- LDPE- without any additional fillers captured a higher amount of energy before failure compared to the
HDPE-LDPE composite blend. It is obvious that the impact resistance is reduced with the increasing of the sawdust filler in both HDPE and LDPE composite blend. This suggests that the sawdust filler is not beneficial to the construction of HDPE- and LDPE- composite blend in term of their impact resistance. It should be noted here that when the recycled specimens were soaked in the water, their impact resistance has shown to be greatly reduced, approximately around 50%. This impact test result confirms the mechanical behaviour of all specimens obtained from the tensile test (Fig. 2a), where it indicates a reduced strain rate and displays more brittle behaviour of the composite blend.

![Fig 2. Experimental tensile properties of all specimens: (a) Stress-strain curves, (b) Total elongation, (c) Elastic Modulus, (d) Ultimate tensile strength.](image)

3.3 Water absorption test

From the result, the recycled LDPE specimens absorbed more water compared to HDPE specimens. This could be due to the microstructure of the LDPE, which has more voids and pores [11] that result in water filling the gaps more effectively. Both specimens seem to

![Fig 3. Absorbed impact energy from Izod impact test.](image)
absorb water, but the percentages of the absorption are very small, 0.07% and 0.08% for HDPE and LDPE respectively. Meanwhile, in the composite specimens with the reinforced sawdust, the higher composition of sawdust filler shows higher water absorption capacity. This may be due to the poor mixture between sawdust fibers and the polymer matrix. Furthermore, it is also known that the sawdust particle has a higher ability to absorb water than that the polymer. From a visual inspection, the voids between the fibers and polymers can be clearly seen. If these composites are to be used as roof tiles or bricks, this characteristic is unwanted as they are not waterproof. In addition to that, the composite blend specimens are also floating on the water due to a lighter density compared to their original polymer specimens.

Fig 4. Water absorption capacity of all specimens.

Fig 5. Results from ultrasonic measurement: (a) Wave attenuation, and (b) wave velocity.

3.4 Ultrasonic wave parameters

Two bulk wave parameters, velocity and attenuation coefficient were estimated through pulse-echo measurements. From Fig. 4, the wave attenuation in HDPE specimens are higher compared to the LDPE. Both soaked specimens have higher attenuation than the non-soaked specimens. It can also be seen that adding more filler resulting in higher wave attenuation in both HDPE and LDPE specimens. This attenuation measurement provides valuable information such as material damping property that is directly correlated to the microstructure of the specimens. Higher attenuation means higher inhomogeneity in the grain size distribution, which caused the ultrasonic waves to be absorbed faster and travel slower than homogeneous specimens. This demonstrates that the composites might be good to be used as a soundproofing material or as acoustic absorbers. Meanwhile, the wave velocities of all
specimens show the opposite trends. The velocity in LDPE specimens are lower than in the HDPE. Both soaked specimens have lower velocity compared to the non-soaked specimens. The velocity dropped when more filler was added in both types of specimens, due to the increase in the density. Although the ultrasonic velocity is directly proportional to the elastic modulus, this velocity result is not depending on the elastic modulus (Fig 2b). The additional filler has caused the increment in the density of the specimens, which caused to a lower ultrasonic velocity. However, this non-destructive testing has shown its ability to characterize different types of materials because the ultrasonic wave parameters are shown to be a function of the properties of the material.

4 Summary
In general, the tensile properties, impact and water resistance of recycled HDPE specimens are greater than the recycled LDPE. It was found that the sawdust filler in both types of plastic wastes trigger an increase of elastic modulus and lessening the impact resistance. Using the ultrasonic non-destructive method, the higher wave velocity and lower attenuation were obtained in HDPE specimens. This ultrasonic measurement on the specimens without the additional filler can be correlated to the tensile and impact properties: a higher velocity reflects the higher elastic modulus, and a lower attenuation coefficient corresponds to better impact resistance. As a summary, the characterization of the recycled HDPE and LDPE specimens conducted in this study has provided critical insight in finding their recyclability potential and their suitability to be used in domestic applications such as pavements, bricks, wall partition or roof tiles. Consequently, by recycling plastic wastes, water, land, and air pollution can be reduced, which can bring benefits to everyone for a greener and sustainable future.

The authors gratefully acknowledges the support in funding by Faculty of Mechanical Engineering, Universiti Teknologi Mara (UiTM), Shah Alam, Malaysia.

References
1. J. Payne, et al., A circular approach to plastic waste, Polym. Degrad. Stab., 165, 170-178 (2019)
2. W. L. Filho et al., J. Clean. Prod., 214, 550–558 (2019)
3. M. Compa et al., Sci. Total Environ., 678, 188–196 (2019)
4. Joachim Maris et al., Polym. Degrad. Stab., 147, 245-266 (2018)
5. N. Singh et al., Compos. B. Eng., 115, 409-422 (2017)
6. G. Faraca, and T. Astrup, Waste Manage., 95, 388-398 (2019)
7. Retrieved at https://www.plasticstoday.com/packaging/scientific-tests-prove-hdpe-can-be-recycled-least-10-times/68825031358152
8. M. Alzerreca et al., Polym. Test., 46, 1-8 (2015)
9. M Yamaguchi, S Abe, J. Appl. Polym. Sci., 74, 3153-3159 (1999)
10. F. L. Savio and M. Bonfanti, Polym. Test., 74, 235-244 (2019)
11. A. H. Awad and M. H. Abdellatif, Compos. B. Eng., 173, 106948 (2019)