Optimization of the Major Factors Affecting the Recycling of Disposed (LDP) Plastics

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Abstract

Low density polyethylene (LDPE), which is widely adopted in many daily life products, known take hundreds of years to decompose in the landfill. As LDPE continues to expand its limitless use over all fields and industries, it also brings tremendous damages onto land and marine ecosystems. Although various efforts were carried out to recycle LDPE, but the operations were proved to be troublesome due to low demand of recycled LDPE pallets, obstacles to seek demanding markets and difficulties to process contaminated and dyed LDPE wastes. Existing recycling methods are still in research-stage to be able to effectively counter the ever-increasing problems of LDPE. Hence, this study aimed to investigate optimum recycling conditions of disposed LDPE plastics and explore potential green applications for the recycled LDPE. As proposed in this study, disposed LDPE bags are shredded, washed, dried and then inserted into oven for melting at heating temperature of 170^0 to 200^o C for different durations inside the oven to seek the optimum heat recycling conditions. Mechanical tests are conducted onto the recycled LDPE samples, which include hardness test. compression test and tensile test. The recycled LDPE has achieved 90.2 Shore-A hardness point, 9.2599 MPa of compressive strength and tensile strength of 9.0705 MPa. After comparison with similar available products in the market, this recycled LDPE can be utilized in the manufacturing of skateboard, shopping cartwheels, tabletops, garden paving tiles, and substitutes for bricks and woods in construction works.

Keywords: Recycling of LDPE; Shore Hardness; Compressive Strength; Tensile Strength

1. Introduction

Over the past decades, industries worldwide have been widely adopting plastics. Plastics are one of the most versatile materials in the world where the global production of plastic-made products surpassed 335 million tonnes in year 2017 [1]. Study from American Chemistry Council shows that replacing existing plastic packaging in the U.S. with non-plastic alternatives requires 4.5 times raise in packaging materials by weight and may result in 130 percent increase in global warming potential. Large-scale eliminations for use of plastics are basically impossible. To worsen the situation, only a mere one percent of LDPE products is recycled [2], as compared to 27% of recycled rate of HDPE which is the most recycled plastic [3]. Although LDPE products were collected frequently for mechanical recycling [4], only rigid, clean and soft LDPE wastes are collected to be recycled in most of the countries [5]. The contaminated and dyed LDPE must be washed and sorted before undergoing mechanical recycling [6], and hence most companies avoid the collection and recycling of LDPE.

Consequently, the market for the recycled LDPE is infrequent and not consistent with regards to time. Biodegradable bags also caused recycled LDPE to be unwanted. Most governments and company policies encouraged the usage of biodegradable plastic bags, instead of the conventional LDPE plastic bags. Laws and rules are implemented to greatly reduce the application of the conventional LDPE plastic bags in certain states in Malaysia [7].

There are three main available methods to dispose LDPE plastics: mechanical recycling, energy recovery and landfill [8]. Energy recovery operations are hard to maintain since there are multiple technological limitations and high operating costs [9]. Since most of the plastic products are not biodegradable [10], plastics in the landfill will not degrade for hundreds of years. Mechanical recycling is the most environmental-friendly approach in reducing the number of plastics, but it may cause soil contamination [11] and emission of plastic chemicals to the surrounding [12],[13].

Efforts to seek effective recycling procedures for LDPE was done by a few researchers. an investigation on the feasibility of reprocessing low-density polyethylene (LDPE) waste materials was done by Bassey et.al [14]. The targeted product of the research was PVC-liked ceiling tiles by addition of different grain size of sawdust into the LDPE wastes. Researcher Singh et. al has conducted research on the recycling of HDPE solid waste for additive manufacturing applications [5],[15]. Ragaert et.al investigated the topic of upcycling of contaminated post-industrial polypropylene waste by turning plastic waste into FDM filaments [16].

The objective of this paper is to investigate optimum recycling conditions of disposed LDPE plastics by using simple and available equipment and to assess some mechanical properties of the recycled LDPE to find useful green applications.

2. Methodology and Experimental Setup

2.1. *Materials*

Low-density Polyethylene (LDPE) plastics packaging bags are used in this study. The disposed LDPE packaging bags are obtained from a local packaging-bag manufacturing company. The LDPE packaging bags are available in red and white colors, both with thickness of 0.1 mm.

2.2. *Apparatus and Equipment*

The apparatus and equipment used for the research work are electrical oven, metal mould, baking paper, aluminium pans, weighing balance and G-clamps. Test machines utilized for mechanical tests include Teclock durometer, Kenco analog compression machine and Tinius Olsen tensile test machine.

2.3. *Specimen and Preparation*

The recycling procedure practiced in this study has started by shredding the ddisposed LDPE bag into small pieces, washed, and then dried to be used in further steps. To produce cylindrical shaped samples for compression tests, metal cylinder molds are used, whereas aluminium pans are used for the fabrication of board samples. The process has been continued by inserting the molds containing 100 grams of LDPE flakes into the oven and heated under the temperatures and time duration's shown in Table 1. Thorough compression has been used to ensure perfect bonding and homogenizing of samples. The specimens retrieved from the oven are cooled using natural air-cooling treatment at room temperature. Table 1 is showing the recycling conditions practiced in this study.

Table 1 Heat Treatment for Specimen Fabrication

Duration in Oven (min) / ***Oven Heating Temperature (℃)***	*40*	*50*	*60*
170	*X*	✓	✓
180	✓	✓	✓
190	✓	✓	✓
200	✓	✓	*X*

** ✓ indicates that samples are manufactured under the prescribed condition.*
**X indicates that the condition is excluded from sample preparation.*

2.4. *Mechanical Tests*

Mechanical tests are conducted on the produced samples to determine the mechanical properties of recycled LDPE, namely hardness test, compression test and tensile test, and to find the optimum recycling parameters.

2.4.1 Hardness Test

Hardness tests are conducted using Teclock Durometer GS-706G with Shore-A scale in comply to ASTM D2240 standard. The specimens to be tested are measured to ensure a thickness of at least 6mm. The samples are placed in parallel on a well-flattened test surface and ten readings are taken on the top and bottom surface of the sample. The mean hardness value of each condition is used for comparisons.

2.4.2 Compression Test

Kenco Compression Test Machine has been used to determinee the compressive strength of the recycled LDPE samples. All cylindrical samples have been cut and sanded to same height before the compression test to ensure minimum error. In the compression machine, constant speed loading is applied by compression of top and bottom platens. As comply to ASTM D695, the compressing loads are stopped once fracture, breakage or any sign of shearing occurred. Readings of maximum force applied has taken and the test is continued with other samples. The calculation of compressive strength for the samples is stated in ASTM D695, as shown in Eq. (1).

$$Compressive\ Strength, F = \frac{P}{A} \tag{1}$$

where;

P= Maximum load
A= Original minimum cross-sectional area

2.4.3 Tensile Test

Tinius Olsen Tensile Test Machine has been utilized to conduct tensile strength test of the dumbbell LDPE samples. Force against extension graphs were displayed in QMat Software from the connected computer. From the graphs in QMat, the maximum sustainable load for each condition is retrieved to determine the tensile strength of each specimen. Tensile strength is calculated according to formula stated in ASTM D638 standard, which is Eq. (2).

$$Tensile\ Strength, \sigma = \frac{P_{max}}{A_0} \tag{2}$$

where;

P_{max}= *Maximum load sustained*
A_0= *Average original cross-sectional area (gauge length)*

3. Result and Discussion

3.1. *Fabricated Specimen*

Figure 1 shows the fabricated cylindrical specimens fabricated under heating temperatures of 170℃ to 200℃ with time durations of 40 to 60 minutes. The cooling treatment performed in this study is natural air-cooling at room temperature. All samples prepared in this study possessed smooth outer surfaces and fully took the shape of the metal cylinder mould. Since red and white colour LDPE flakes are used in this study, all samples are looking marmoreal or marble-like patterns.

Fig. 1 Specimens fabricated under different heating temperatures and duration

Conducted experiments have shown that LDPE packaging bags can only start melting at a temperature of 170℃, with heating duration over 40 minutes. Similarly, it's found that the LDPE plastic is unable to be fully melted in the core part at heating temperature of 160ºC and heating duration of 50 minutes. The recycled LDPE has shown shrinkage after heating for 60 minutes at temperature of 200ºC.

Figure 2 shows the flat board shaped samples fabricated using aluminium pans and compression force. Part of the board samples are used to produce dumbbell-shaped test samples for tensile strength tests. The temperature range for the fabrication followed the conditions shown in Table 1.

Fig. 2 Board samples fabricated

3.2. *Mechanical Test Result*

3.2.1 Hardness Test

Hardness values have been taken using Teclock Durometer GS-706G with Shore-A scale in comply to ASTM D2240 standard. The average hardness values are obtained from the mean of ten hardness measurements on different points on each of the specimens.

Figure 3 is presenting the relationship between hardness values, heating temperature and time duration. From the figure, the highest hardness value is 90.2 point, and it's achieved by the sample prepared under 190℃ and 50 mins. A general trend can be observed from the figure that the sspecimens fabricated using the heating temperature of 190℃ generally have higher Shore-A hardness values as compared to other temperatures. The lower hardness values for samples prepared with temperature of 170℃ is due to incomplete homogeneity of melted LDPE flakes during the heating process. The decrease in hardness values of samples manufactured under 200℃ can be attributed to thermal degradation.

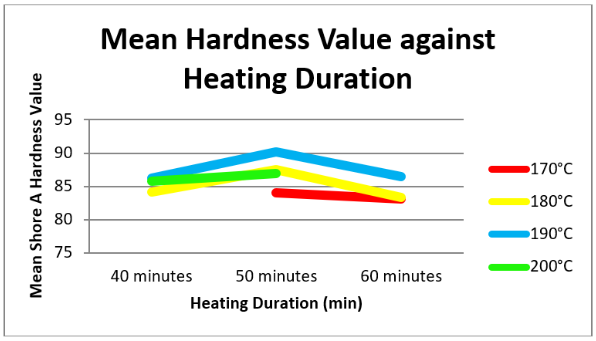

Fig. 3 Relationship between hardness value, temperature and time duration

3.2.2 Compression Test

Kenco Compression Test Machine has been used to determine the compressive strength of the recycled LDPE samples. The diameter of all specimens produced is 55 mm and thus the cross-sectional area of recycled LDPE samples is 2375.83 mm^2. The Compressive strength has been calculated using Eq. (1) and following the ASTM D695 standards.

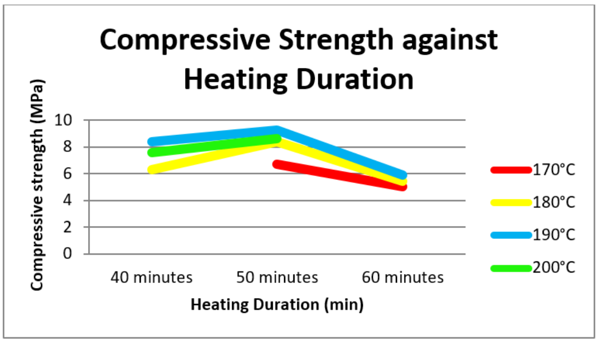

Fig. 4 Relationship between compressive strength, temperature and time duration

Figure 4 shows the relationship between compressive strength, temperature and time duration. It can be noticed that heating temperature of 190ºC and heating duration of 50 mins produced the sample with highest compressive strength of 9.26 MPa. Generally, samples fabricated with the duration of 50 min. have higher compressive strength when compared to time duration of 40 min. and 60 min. of the same heating temperature. Heating duration of 60 minutes and above may cause polymer degradation on the samples, thus breaking the long chain branching of LDPE and reduce its mechanical properties.

3.2.3 Tensile Test

The tensile strength of recycled LDPE for each recycling condition is determined by using Eq. (2) and is shown in Figure 5.

Figure 5 is showing the results of tensile strength, heating temperature and time duration. The highest attained tensile strength is 9.071 MPa. It is achieved by sample prepared under 190°C and 50 mins. The trend shown in tensile test is roughly like trend illustrated in Shore A hardness test and compression test. This phenomenon may be explained by the correlations between indentation hardness value with tensile and compressive strength [1].

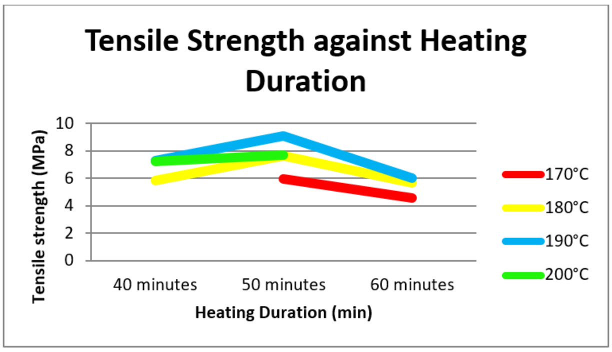

Fig. 5 Relationship between tensile strength, temperature and time duration

3.3. *Potential Applications*

With regards to the results obtained from the mechanical tests conducted, thereupon the recycled LDPE samples are found comparable with materials such as virgin LDPE, virgin polyurethane (PU), ultra-high-molecular-weight polyethylene (UHMW-PE) and ethylene propylene rubber (EPR). Although the obtained hardness value is found lower than virgin LDPE, the recycled LDPE is still comparable to certain classes of PU and EPR. The proposed applications in terms of hardness value includes idler rollers, shopping cartwheels, skateboard's wheels and O-rings.

The recycled LDPE specimens are comparable with C62 grade bricks, light bricks, brickwork's and D70-grade Hardwood. The obtained compressive strength of 9.26 MPa for the recycled LDPE is higher than the materials mentioned. Since all the mentioned materials are commonly utilized as construction materials, as partitioning and manufacturing of doors and door frames. Thus, recycled LDPE has the potential to be utilized for the same applications.

The recycled LDPE samples have shown an optimum tensile strength of 9.071 MPa, which is comparable to glass, wood, medium density fiber-wood, marble, limestone and alumina boards. All the mentioned materials are commonly used in the manufacturing of furniture and fixtures, where strength and long shelf-life are the most considered parameters.

4. Conclusion

By interpreting the data obtained and the graphs plotted for the mechanical tests conducted, it can be concluded that recycling at heating temperature of 190°C with heating duration of 50 minutes and natural air-cooling treatment are the best conditions for recycling of disposed LDPE plastic using the method introduced in this study in accordance with ASTM standards. Specimens fabricated using the heating temperature of 190°C in 50 minutes achieved 90.2A in Shore hardness test, 9.26 MPa for compressive strength and 9.071 MPa for tensile strength.

Potential green applications which can be suggested according to the mechanical properties obtained, are manufacturing of skateboard, shopping cartwheels, tabletops, garden paving tiles, and substitutes for bricks and woods in construction works.

It can be concluded that the promising results obtained are a good implementation towards achieving the Sustainable Development Goals (SDG's).

Acknowledgment

The authors would like to express the gratitude towards the school of engineering at UCSI University for the support throughout the research. Special thanks would be extended to CERVIE office at UCSI University for the endless support to research.

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