A Domestic Plastic Waste Recycling Procedure to Find the Optimal Heat Treatment for Better Hardness and Compression Properties

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Abstract. The optimal recycling temperature and the time duration inside the oven to produce quality recycled plastic waste has not been standardised. This research focuses on finding the optimal heat treatment procedures for the recycling of wasted plastics as a common guide for the recycling of wasted plastics by using basic domestic tools. Mechanical tests have been conducted on the recycled samples of HDPE and LDPE plastics to find the hardness and compression stress. It has been found that at oven temperature of 180\textdegree{}C, with a heating duration of 50 minutes inside the oven, yields an optimal hardness and compressive properties for LDPE. A temperature of 230\textdegree{}C, with a heating duration of 60 minutes, has been found to give the optimal properties for the HDPE.

1. Introduction
Implementation of plastic recycling became very important to the current era where disposed plastics are more than recycled or reused plastics. In this research, using simple domestic tools for recycling of High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE) have been studied. Due to chemical properties of plastics, it takes decades to degrade and usage are on worldwide commercial scale, with the current amount, it can cause substantial environmental issues if not properly disposed of. Common household used plastics are contributing to that factor as most plastic wastes are discarded without being recycled [1].

Global production of plastics in year 2015 rose to a staggering amount of 322 million tons, an increased volume of 3.5\% from year 2014. Plastic-waste generated in Europe annually is estimated at 25 million tons on average, with only 29.7\% effectively recycled, 39.5\% used for energy recovery, and the remaining 30.8\% used for landfill [2].

E-waste has generated an estimated volume of 44.7 million tons in year 2016 and with annual growth rate of 3~4\%, expectation will be 52.2 million tons in year 2021. Despite having a staggering volume in millions, overall global e-waste recycling rate is only 15\% [3]. Recycling rates in the United States, China, and Europe are 9\%, 25\%, and 30\%, respectively, and global recycling rate are only at an average of 18\% [4].

Plastic wastes have generated about 6300 million metric tons till the year 2015, 79\% are discarded, 12\% are incinerated, and only 9\% are being recycled. Most unrecycled plastic wastes end up in landfill or incinerated causing more pollutions while recycled plastics can be used to make a variety of things depending on properties of the recycled plastics.

PVC, PP, HDPE, and LDPE are the 4 types of plastics contributed mostly to the consumption of plastics due to their specific useful characteristics. It should be noted that recycled plastics can only be re-...
worked for 2 to 3 times due to its’ decaying strength of virgin plastic. This is attributed to the materials being reduced through thermal degradation for every recycling process [1].

Consumption of plastics will gradually increase and several methods of recycling to recover plastics are required which include mechanical recycling, chemical recycling, pyrolysis, and gasification. The most widely practiced recycling method are mechanical and chemical recycling [4].

In this paper, a simple domestic mechanical method has been investigated by using the kitchen oven to control the recycling heat and to find the optimal recycling temperature and heating duration inside the oven to give the optimal mechanical properties.

2. Experimental set up and procedures

2.1. Experimental set up

Domestic equipment and tools have been used in this research as an approach to benefit common users to recycle rather than throwing out the plastics-waster of the different types.

The procedure consists of a few steps: First, the identification and separation, sorting, cleaning, shredding of the plastic-waste. Second, the heating and molding of the plastic-waste. Then, the materials are first sorted and separated by type according to recycling code. In this case study, HDPE and LDPE have been chosen. Materials are then sorted by colors, allowing single or multiple colors to be added into the mold [5]. Next, the sorted plastic-waste will be shredded and categorized into small pieces and flakes to ensure easier melting and handling.

2.2. Procedure and flow chart

The main purpose of this study is to promote common practice of recycling wasted plastic with widely available domestic tools. This encouragement is in line with the Sustainable Development Goals (SDGs) – an environmental agenda by the United Nations’ initiative. The normal kitchen oven which is available at most of the houses in Malaysia has been used for the heating of the shredded wasted plastics [6-7]. The flow chart in Figure 1 explains the main steps used. The setting temperature of the oven for effective melting without burning and the duration time inside the oven are the main factors studied throughout this research.

![Flow Chart of recycling shredded wasted plastic](image-url)
2.3. Materials
Two categories of plastics have been chosen for this study, the High Density Polyethylene (HDPE) and the low Density Polyethylene (LDPE) with recycling number code 2 for HDPE and recycling number code 4 for LDPE. Properties of HDPE such as high stiffness, strength, chemicals and moisture resistance and permeability to gas, make ease the process of forming the recycled plastic. Some product applications of HDPE can be made into bottles, milk jugs, dish and laundry detergent bottles, trash and retail bags, chemical bottles and etc. LDPE also has the properties for easy processing such as barrier to moisture, high strength and flexibility, easing sealing characteristics, of which can be applied to films or bags and squeezable bottles [8-9].

3. Recycling procedure
The main factors studied in this research have been the oven setting temperature and the duration of heating process. A higher temperature or longer duration is required to melt the HDPE flakes, hence variable temperatures and durations have to be tested. Similarly, LDPE films is the alternate material selected to be used in conducting this research [10]. Temperature required for both materials to melt has been found different and tested with the sensitivity of 10℃ from the working temperature.

3.1. HDPE Material
HDPE working temperatures ranges from 210℃ to 230℃, varying with different time duration inside the oven. Few tests have been implemented to produce the few recycled specimens. Literatures recommend a time duration of 40, 50 and 60 minutes inside the oven to be tested for each sample [11]. All temperatures and time durations are shown in Table 1.

| Table 1. Experimented temperature and duration of HDPE. |
|-----------------------------------------------|
| Duration (Minutes) | Temperature (℃) |
|-------------------|-----------------|
| 210               | 220             | 230 |
| 40                | Specimen 1      | Specimen 2 | Specimen 3 |
| 50                | Specimen 4      | Specimen 5 | Specimen 6 |
| 60                | Specimen 7      | Specimen 8 | Specimen 9 |

3.2. LDPE Material
Temperatures of 170℃ and 180℃ have been implemented in this experiment to melt the shredded LDPE. A duration of 40 minutes has been found necessary to completely melt the material. This experiment has been conducted at variation temperature of 170℃ and 180℃ with time durations of 40 and 50 minutes. All temperatures and durations are shown in Table 2.

| Table 2. Experimented temperature and duration of LDPE. |
|-----------------------------------------------|
| Duration (Minutes) | Temperature (℃) |
|-------------------|-----------------|
| 170               | 180             |
| 40                | Specimen 1      | Specimen 2 |
| 50                | Specimen 3      | Specimen 4 |

4. Results and discussion
Mechanical testing has been conducted on the recycled specimens to determine the physical properties. The tests have been conducted to observe the effects of different recycling heating temperatures and the durations subjected to recycled plastics. Hardness and compression tests have been conducted, where hardness test has been conducted on all specimens with 10 points on each specimen. Compression test has been conducted on specimens using Kenco E-Series Analog compression machine [12].

4.1. Shore hardness test results
Hardness of specimens have been measured using a Teclock Durometer GS-706G, a Shore A category durometer. Shore A durometer is used to measure flexible mould rubber hardness ranging from soft to
hard, flexible to rigid bodies. Semi rigid plastics can be measured using Shore A hardness scale as the values are still within range of the scale. The hardness test is conducted on specimens according to ASTM D2240 standards [13], each reading is 12mm from the edges and 6mm in between each point. All data has been recorded and tabulated according to the recycling process.

A sheet of baking paper has been used on the tray and the shredded plastics have been set on the baking paper. The tray is inserted into the oven with temperature and time have been set to the desired values with sensitivity intervals of 10 minutes from 50 minutes. The Molten material will then be formed to the desired shapes through compression in a wooden prepared mould. Specimens will be left for 30 minutes of air-cooling time in its' compressed state to prevent deformation. Figure 2 and Figure 3 show the sample of the recycled plastics specimens.

![Figure 2. HDPE recycled specimen.](image1)
![Figure 3. LDPE recycled specimen.](image2)

4.2. Hardness test results for HDPE

Results for HDPE hardness are shown in Tables 3, 4 and 5.

| Duration (Minutes) | Average Hardness (A Shore Units) |
|-------------------|----------------------------------|
| 40                | 91.1                             |
| 50                | 90.8                             |
| 60                | 91.1                             |

| Duration (Minutes) | Average Hardness (A Shore Units) |
|-------------------|----------------------------------|
| 40                | 93                               |
| 50                | 91.8                             |
| 60                | 93.3                             |

| Duration (Minutes) | Average Hardness (A Shore Units) |
|-------------------|----------------------------------|
| 40                | 95.5                             |
| 50                | 92.9                             |
| 60                | 95.8                             |

Based on the average of the tabulated data. The highest average Shore A hardness value was found to be 95.8 at 230°C and 60 minutes duration. Consequently, it has been found that exceeding temperature
or exceeding heating duration yield signs of burnt on the recycled plastics. In comparison, all tests are shown in Figure 4, results from 40 minutes heating yield almost similar characteristics of Shore A hardness. At such, further structural analysis should be performed on samples from 40 and 60 minutes heating.

![Figure 4. HDPE Hardness comparison of different duration and temperatures.](image)

Hardness value between virgin HDPE and recycled HDPE has been compared. Virgin HDPE has Shore D value in between 60 to 70, to which Shore D is used to measure hardness of hard plastics. Recycled HDPE had a Shore A value of 95.8 which is equivalent to Shore D value of 48. A lower hardness value was obtained from recycled HDPE due to thermal degradation from heat exposure in recycling process [14].

4.3. Hardness test results for LDPE
Different temperatures have been used for the LDPE recycling, and the temperatures used were lower than that of HDPE. Hardness test results can be shown in Figure 5.

![Figure 5. LDPE hardness values comparison for different durations and temperatures.](image)

The graph showed increased hardness value at 180°C at both heating durations. Highest hardness value was recorded at 96.9 with 180°C and 50 minutes heating duration. Exceeding the temperature of 180°C or the heating duration beyond 50 minutes has shown signs of burn of the LDPE.

Hardness value between virgin LDPE and recycled LDPE has been compared to show the differences of physical properties obtained in this research. Virgin LDPE has Shore D value in between 40 to 50 minutes, which Shore D is to measure hardness of hard plastics. Recycled LDPE had a Shore
A value of 96.9 which is equivalent to Shore D value of 40.5. A lower hardness value was obtained from recycled LDPE due to thermal degradation from heat exposure in recycling process.

4.4. Compression tests
Cylindrical specimens have been prepared according to ASTM D2240 for the compression tests. Tests have been conducted by using Kencol E-Series Analog compression test machine. HDPE and LDPE exhibited ductile characteristics as specimens show barrelling from the sides. Cracks occurred on HDPE at stress > 20 MPa and experiment was stopped [15]. LDPE specimens continued to barrel with increased load and no cracking has been noticed. Table 6 show compression test result for HDPE. Table 7 is showing the results for the compression tests for the LDPE recycled plastic.

| Heating Duration in Oven (Minutes) | 60 |
|-----------------------------------|----|
| Temperature (°C)                  | 210 | 220 | 230 |
| Compressive strength (MPa)        | 21.04 | 20.42 | 20.20 |

| Heating Duration in Oven (Minutes) | 40 |
|-----------------------------------|----|
| Temperature (°C)                  | 170 | 180 |
| Compressive strength (MPa)        | 8.84 | 10.1 |

The compression yield strength for the recycled HDPE are ranging from a highest value of 21.89MPa to a lowest value of 18.94MPa which are comparable to “Kelempayan” - a Malaysian timber [19]. LDPE has shown a highest compression strength value of 10.1MPa and lower value at 8.84MPa. Comparison to the values for virgin plastics, shows that recycled HDPE and LDPE have lost part of the mechanical properties after the recycling process [15-16], and it would not be advisable for use under compressive loading. Such weakness can be overcome by inserting additives for structural enhancement.

5. Conclusion
The results indicate the recycled HDPE and LDPE formed possess structural integrity suitable for various applications. For the test values obtained, both categories of the recycled plastics can be used for some engineering applications like the skate board wheels, the shopping cart wheels and the workers hard hat [18]. Both HDPE and LDPE, at optimised heating temperature level and time, are compatible and can be used for sustainable replacement for a wide range of mechanical and structural installations. Further research on the inclusion of additives, commercialization, production by economics of scale and testing of specific model will further proof the feasibility of the recycled plastic.

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