High-Pressure Water Cleaning of Degraded Polymers in Preparation for Recycling

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1.0 INTRODUCTION

In Malaysia the average rate of solid waste generation is 1kg per person and approximately 26 million kilograms of solid waste are produced every single day. Plastic waste is the most common waste that is generated in the country accounting for 7 to 12% by weight and 18 to 30% by volume. The plastic industry is one of the fastest growing sectors of the Malaysian economy and is expected to grow by 20% every year over the next five years [1]. The reason for the steady increase in demand for commodity polymers is due to their inherent properties which include low density, low thermal and electric conductivities, good mouldability, high corrosion resistance, high durability and low cost.

Polymers are composed completely of organic compounds; their main disadvantage is that their decaying process takes a very long time and making use of waste polymers is an important economic consideration. Since polymers take a long time to decay, recycling is one of good methods to overcome this problem. Feedstock recycling and mechanical recycling have been used to recycle polymers in develop countries such as in Europe and United States. However, in Malaysia it is still lacking because of the high capital investment involved. Currently, the waste management approach being employed is by landfill disposal, but due to rapid development and lack of space for new landfills, big cities in Malaysia are switching to incineration [2].

Incineration reduces the need for land filling of plastics waste; however, there are concerns that hazardous substances may be released into the atmosphere in the process. For example, PVC and halogenated additives are typically present in mixed plastic waste leading to the risk of dioxins, other polychlorinated biphenyls and furans being released into the environment [3]. Although there are several options of handling plastics waste, recycling is still the best strategy to implement in Malaysia due to the environmental issues related to disposal. Thus, preparation for recycling should not be taken lightly as it obviously contributes towards efficiency of polymer recycling.

Plastic or polymer degradation is a change in the properties such as tensile strength, colour, shape and many other factors. Most polymers degrade when used outdoors leading to molecular chain scission and/or cross-linking. Generally, the major hazard is ultraviolet irradiation, though some polymers are more vulnerable to this than others [4].

When polymers such as polyethylene and polypropylene are exposed to ultraviolet irradiation several changes occur in the molecular characteristics that influence the crystallinity and crystallisability of the material. During ultraviolet exposure, oxidation occurs predominantly in the non-crystalline phase because oxygen can diffuse through such regions relatively freely but is almost excluded from the crystalline regions. There are three principal changes: chain scission, cross linking and the formation of molecular defects such as the carbonyl group [4].

The main aim of this paper is to investigate whether degraded parts in polymer or plastics can be efficiently removed by spraying it with high pressure of water. This study is done as part of research in improving the efficiency of plastics recycling. Experiments started with exposing three different types of plastic bars under UV irradiation, and then all sample bars were sprayed with high pressure of water. Apart from this, crystallinity and weight measurements were also done. The purpose of crystallinity measurement of samples is to determine to what extent that the degraded layer has been efficiently removed while weighing machine is used to measure the percentage of degraded polymer weight successfully removed.

2.0 EXPERIMENTAL

2.1 Materials and Sample Preparation

For differential scanning calorimetry (DSC) analysis, samples were cut using a single point cutter with fly cutting action by milling away material from exposed surface. Before milling operation was carried out, the bed was cleaned thoroughly and the chippings were collected at the end of each cutting pass. Samples were cut at different depths; from 0 to 0.1mm, 0.1 to 0.2mm and 0.2 to 0.3mm. For each DSC run, the sample was weighed on a Mettler AT261 and the amount used was around 10 mg. The weighing machine (Mettler AT261) balance could not read to 0.01mg, yielding an accuracy better than ±0.3% [5].

2.2 UV Exposure

Ultraviolet exposures were carried out at a constant temperature room of 30±1°C using fluorescent tubes type UVA-340 as the UV radiation source. The tubes were chosen because their output in the UV range at wavelengths below about 360 nm coincided with the spectrum of solar radiation at the earth's surface fairly

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Figure 1: Single fly cutting action

Figure 2: Chipping or swarfs

closely. One side of the bars was exposed for a range of times from 2 to 8 weeks before milling away the exposed surface. Exposures were conducted uninterrupted, 24 hours per day. Studies that have been done previously showed that very significant molecular degradation occurs within the chosen periods [2].

2.3 Water Spraying on Degraded Bars

Before water spraying was applied to the exposed surface, each of the bars was clamped at centre as shown below (Figure 3). A water blaster literally blasting water at high pressure was been chosen to carry out the task. The maximum pressure of the water was 95bar and the water flow was 360 l/hour. Further details on specification are shown in Table 1 below.

Table 1: Specifications of the high pressure water washer

Model No.	TRY1350PWB
Electric/Petrol	Electric
Material	Plastic and Metal
Size	Small
Category	Pressure Washers and Sprayers
Water Flow (L/H)	360
Max Pressure Rating (BAR Pressure)	95
Category	Frequent Use Pressure Washers

By using the high-pressure water washer, exposed bars were sprayed using high-pressure water to remove the degraded polymers and dried for three days before successive layers were removed. The degraded layers from the experimental samples were removed using a milling machine with the single fly cutting action method. This method was applied because it produced less heat during cutting. The heat produced during cutting may influence the degree of crystallinity value of the specimen.

2.4 Characterisation

Crystallisation measurements were made by differential scanning calorimetry (DSC). Differential scanning calorimetry or DSC is a thermoanalytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference is measured as a function of temperature. Generally, the temperature program for a DSC analysis is designed so that the sample holder temperature increases linearly as a function of time. The reference sample should have a well-defined heat capacity over the range of temperatures to be scanned. All measurements that have been carried out were made under flowing nitrogen with a Mettler FP F90 controller connected to a FP85 Heat Flux cell. The equipment was calibrated for temperature and calorimetric sensitivities of the cell with indium to ensure precise measurement of crystallinity. Experiments were carried out under nitrogen flow (of 50ml/min) to avoid thermal degradation during measurements and also to displace atmospheric oxygen to prevent undesired oxidation of the sample.

A heating rate of 13°C/min was used within the range 40°C to 210°C for all three types of polymers chosen and the thermogram recorded. This heating thermogram characterises the material in the form that existed at the end of UV exposure. The crystallisation endotherms obtained in the heating runs were used to estimate the crystallinity. The peak areas were obtained between chosen limits for each sample. The temperature limits chosen are presented in Table 2. Heat of fusion is an important parameter for crystallinity measurements. The polyethylene crystal phase was taken to be 292.5kJ/kg while for PPCO was taken to be 267kJ/kg [5].

Figure 3: Degraded bar is clamped

Figure 4: Water spray is applied to bar

Table 2: Temperature limit

No.	Type of Polymer	Temperature Range (° C)
1	High density polyethylene (HDPE)	70 to 160
2	Lower density polyethylene (LDPE)	65 to 140
3	Polypropylene co-polymer (PPCO)	90 to 200

3.0 RESULTS

3.1 General Observation

The thermogram with different depths from an unexposed sample is given as a reference in Figure 5. The dashed line represents 0 to 0.1mm, dotted line represents 0.1 to 0.2mm and solid line represents sample from 0.2 to 0.3 mm.

The crystallinity values were found to be slightly higher towards the centre and the highest crystallinity was recorded from 0.2 to 0.3mm depth. This observation applied for all samples at all conditions whether they were exposed or unexposed to UV radiation.

The thermogram shown in the figure is likely to be seen in all three samples discussed here. The highest crystal melting point in the thermogram for the sample obtained from the exposed surface (0 to 0.1mm) is likely to be displaced significantly towards lower temperature.

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Table 3: Results

Samples/ UV Exposure	Average Crystallinity (%) before water spray	Average Crystallinity (%) after water spray	Crystallinity difference (%)	Average of weight removal (%) after water spray
HDPE				
2 Weeks	67.800	65.000	-2.80	0.600
4 Weeks	70.500	65.800	-4.70	0.110
8 Weeks	72.830	63.000	-9.83	0.010
LDPE				
2 Weeks	39.500	41.000	+1.5	0.020
4 Weeks	39.500	41.500	+2.0	0.260
8 Weeks	41.400	43.800	+2.4	0.060
PPCO				
2 Weeks	41.500	43.370	+1.87	0.083
4 Weeks	40.830	45.300	+4.47	0.013
8 Weeks	43.300	44.830	+1.53	0.019

Crystallinity values and weight removal after water sprays applied

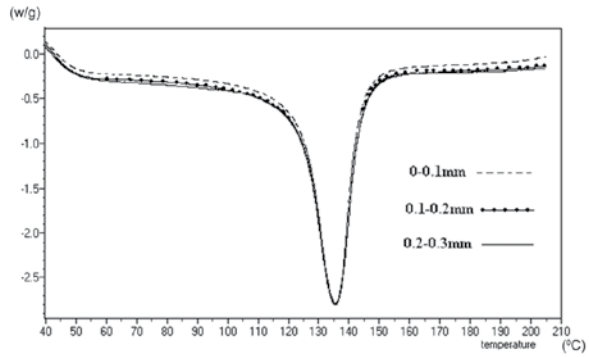

Figure 5: DSC thermogram obtained from different depths within a HDPE (unexposed) sample

4.0 CONCLUSION

All samples that have been sprayed with high pressure of water undergo slight mass loss due to the high pressure applied even though the amount removed differs. For HDPE samples, the highest degraded polymer removed is 0.6% which occurred at bars after two weeks of UV exposure. For 4 and 8 weeks exposure, the percentage of mass reduced is 0.11% and 0.01% respectively. In terms of the crystallinity values, the percentage decreased significantly after the water spray was applied. In contrast with LDPE and PPCO, the crystallinity values recorded were slightly higher after water spray and this is due to the fact that new layer appeared as a result of degraded parts that have been efficiently removed. Both LDPE and PPCO samples have shown the same pattern of results where crystallinity increased as well as consistency in degraded parts removed. In summary, high pressure of water for cleaning degraded parts is proven to be workable however the correlation between crystallinity and percentage of weight removal may need further investigation especially test on other samples.

5.0 ACKNOWLEDGEMENT

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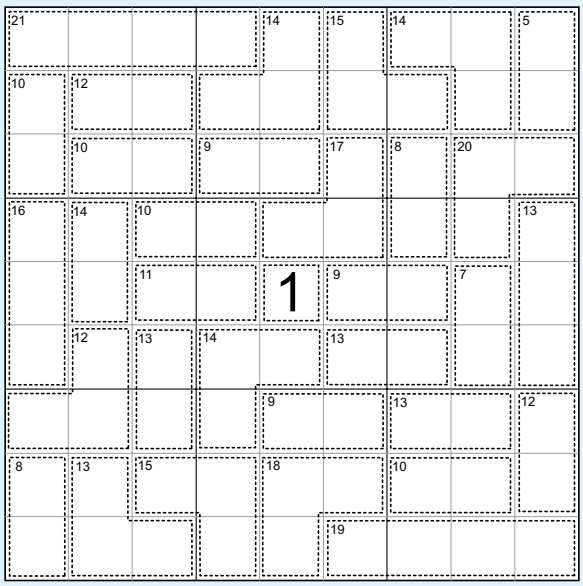

1SUDOKU Centerpiece "1"

by Mr. Lim Teck Guan

Fill in the remaining 80 squares with single digits 1-9 such that there is no repeat of the digit in every Row, Column and Block. The number at the top left hand corner of the dotted cage indicates the total for the digits that the cage encompasses.

For tips on solving, visit www.1sudoku.com.my

(*Solution is on page 34 of this issue.*)