Libyan Journal of Science & Technology 7:1 (2018) 54–57

Faculty of Science - University of Benghazi
Libyan Journal of Science & Technology
(Formerly known as Journal of Science & It's Applications)
journal home page: www.sc.uob.edu.ly/pages/page/77

# Evaluation of multiple plastic recycling in Benghazi-Libya

**Salah A. Elsheikhi, Hamzah A. Mohamed, Khaled A. Eldressi**

*Department of Industrial and Manufacturing Systems, Faculty of Engineering, University of Benghazi, Libya*

ARTICLE INFO

*Article history:*
Received 22 January 2018
Revised 31 March 2018
Accepted 08 April 2018
Available online 21 April 2018

***Keywords:***
Injection moulding, High-density polyethylene, regrind, and reprocessing.

* Corresponding author:
*E-mail address*: salah.elsheikhi@uob.edu.ly
S. A. Elsheikhi

ABSTRACT

This study is aimed at evaluating how feasible is the production of moulded products based on multiple recycled materials in order to manufacture new products without compromising the product quality. The effect of the reprocessing on the properties (mass, shrinkage, density, and colour) was examined. It has been reported that no significant change in these properties occurred.



## 1. Introduction

Around 85% of the consumed plastics worldwide are thermoplastics (Elsheikhi and Benyounis, 2016). Therefore, more and more of the plastic-based materials are being reprocessed. In this context, there have been several factors that contributed to developing plastic recycling programs. These factors include rising raw material costs, increased consumer requirements, and raised environmental awareness (La Mantia, 2002).

Many different technologies can be used to reprocess polymer. One of these techniques is the injection moulding techniques, which is widely used for recycling several types of polymers (Elsheikhi and Benyounis, 2016). This technique is used to reprocess the selected product in this paper.

Several studies have explored the recycling of the polymer using injection moulding. Part of them used post-consumer materials or material reclaimed from scrap yards (Elsheikhi *et al*., 2014), while the others used the virgin material (Lewis and Buser, 1997), and mixed materials (Elsheikhi, 2015).

The recycling of polymer using injection moulding has many economical and environmental benefits (La Mantia, 2002). Indeed, this process can be easily achieved and does not involve several operations including sorting, filtering, and cleaning that are usually required with rubbish yards based materials. On the other side, it is imperative not to compromise on the quality of the new products (i.e., the characteristics of the recycled material remain the same as the raw material). To this end; the sprues, runners, and unused parts be sure that reused again in this work.

Depending on customer requirements, the regrinded material is mixed with the raw material in ratios from 0-50% or more (Elsheikhi and Benyounis, 2016). The effect of processing low-density polyethylene "LDPE" on tensile properties by adding 25% of recycled to the raw material with differential melt histories within the same batch have been examined by Lewis and Buser (1997).

Lewis and Buser (1997) have also shown that the addition of LDPE with 25% of regrind to the process does not have effects on its ability nor on its tensile properties. Producing parts with regrind, without being concerned with its effects on the tensile properties allows manufacturers to reduce the cost. In another study based on high-density polyethylene "HDPE" with different regrind ratios of 0%, 50%, and 100%, it was found that no change in the melt temperatures between the raw material to 100% regrind (Dave *et al*., 1997; Elsheikhi and Eljaarani, 2017). In such scenario, It can be seen that for the three considered regrind ratios of 0%, 50%, and 100% regrind, the modulus of elasticity is the same.

Reprocessing of recycled materials or reclaimed from the post-consumer waste material is commonly used in industry; however, maintaining the product quality is a significant challenge to the recycling operations. Thus, the effect of reprocessing on the physical and mechanical properties of a range of polymers was the focus of most of the published studies that dealt with the reprocessing and recycling of such materials. The studies investigated the possibility of recycling and using recycled refuse LDPE, HDPE and polypropylene "PP" (Elsheikhi *et al*., 2014). As a result and taking the tensile strength of the process part as a reference, these three materials are among the most successfully recycled materials.

Some investigators have focused on the recycling operations in Benghazi and Misurata cities (Elsheikhi, 2015; Elsheikhi and Eljaarani, 2017). As a result, the authors have proved the relative consistency of the mould-ability of HDPE material through successive reprocessing plans using 0, 20, 50, 80, and 100 % regrind.

With the huge amount of daily-consumed plastic materials (bags, bottles, etc.) in the city of Benghazi-Libya, the recycling operation is considerably needed in this city. In this context, this study is aimed manufacture a product using 100% multiple recycling of moulded products of regrind material while ensuring an acceptable level of product quality.

In order to achieve the above objective, an examination of the type and behavior of the used materials, study of the parameters related to the process, and understand both the preprocessing and the regrind effects are conducted. More specifically, an examination of the effect of the reprocessing operations on some key properties is explored.

## 2. Limitations

### *2.1. Material Type*

Most of the recycling processes have been implemented on post-consumer materials, landfill materials mixed materials, or materials reclaimed from yards. These kinds of materials were chosen in this study as they are easy to identify with no sorting or filtrations are needed. Moreover, these kinds of materials were not subjected to harsh conditions such as degradations, ultraviolet, and corrosion.

*2.2. The Conditions of Injection Moulding*

In order to avoid any eventual reduction in the mechanical properties, the molecular weight, and other key properties, it is necessary to start by examining the optimal process settings including the time, pressure, velocity, and temperature. The machine that was used in this work was provided by a private company to predetermined operating conditions. Therefore, the machine parameters could not be controlled.

*2.3. Related Properties*

In the process of the recycling operations, there exist a number of key product quality indicators and physical characteristics that are expected to be modified through the thermal history. In order to understand the theory behind what is happening during these modifications, an association between the mechanical properties, molecular weight, thermal stability, and several related properties should be established. Due to the lack of availability of sophisticated equipment and machines at the university's labs, only the product mass, shrinkage, colour, and solid density were chosen in this study.

## 3. Procedure

*3.1. Preparation: Material and Sample*

HDPE represents a commonly used material is widely used – in Benghazi city – in order to deliver daily-consumed products such as the food keepers (containers). The raw material used was High-density polyethylene (HDPE); grade F00952 supplied by SABIC Inc.

The injection moulding machine that was used in this work was NG90 model of the VESUVIO100-tonne clamp force, which was offered by Alddabie Plastic Factory, Benghazi. As shown in Fig. 1, the product, which was used in this work, is a container (food keeper without cover). These products were granulated and reprocessed for twelve times, until the end of the time set on the machine to finish this work.



**Fig. 1.** Used product

*3.2. Process Conditions*

The screw rotational speed is set up to 550 rpm, and the injection pressure was 4 bars. The barrel temperatures for the front, middle, and rear zones are set to 230°C, 220°C and 200°C, respectively. In addition, using a water circulation controller, the mould temperature has been set to 14°C.

*3.3. Plans for the Recycling Operation*

In this work, the recycling operation has been achieved in twelve plans. In order to make sure to use 100% regrind, the scenario for these plans has been developed as explained in Fig. 2. For further details, these plans are explained as shown in Table 1.

## 4. Part Quality

*4.1. Product Mass*

Mass is commonly used as the main quality indicator of the part. The alterations of the product mass are linked to the changes in dimensions. In this context, the stability of the part dimension can be the result of the stability of the product mass. The product mass is obtained by measuring the test stability in the product mass (including the runner and sprue) for each plan and then the average mass is obtained.

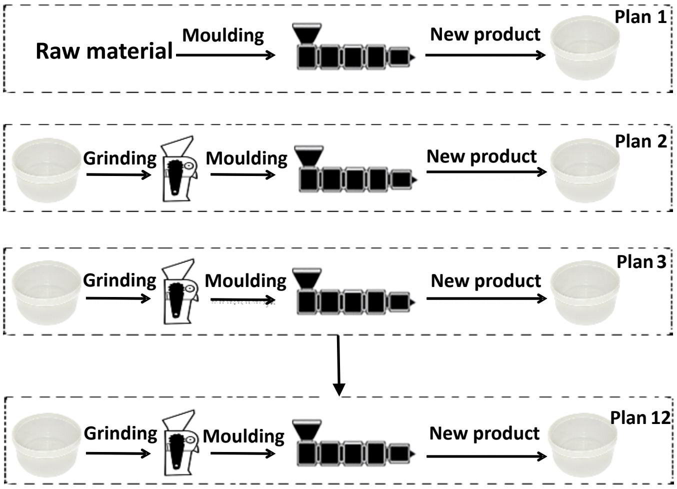


**Fig. 2.** The scenario of the recycling process

**Table 1**

The sequence of the recycling plans

| Plan No. | Amount of material used (gram) | No. of Products | Number of cycles that making the machine be stable |
|---|---|---|---|
| 1 | 12500 | 338 | 7 |
| 2 | 12240 | 308 | 13 |
| 3 | 10995 | 297 | 7 |
| 4 | 10380 | 271 | 12 |
| 5 | 9695 | 253 | 6 |
| 6 | 9150 | 233 | 15 |
| 7 | 8180 | 214 | 5 |
| 8 | 7745 | 193 | 12 |
| 9 | 6750 | 190 | 2 |
| 10 | 6335 | 171 | 2 |
| 11 | 5950 | 152 | 7 |
| 12 | 5205 | 140 | 2 |

*4.2. Shrinkage*

The behavior of shrinkage plays an essential role in determining the final dimensions of the part. This behavior takes place because of the molten material's thermal contraction in the process cooling and the relaxation of stretched polymer chains (Gowariker *et al.*, 1986). Several factors affect the shrinking phenomenon. These factors include material properties, process parameters at filling, packing and cooling phases, and cooling system design (Mamat *et al.*,1994).

The shrinkage was determined in several positions on the product and five samples have been collected for each plan. In order to calculate the shrinkage as a percentage of the cavity dimension, the following equation is used (Elsheikhi *et al.*, 2010):

$$R= (1-M/M_0)*100, \qquad (1)$$

where $R$ defines the shrinkage, $M_0$ represents the mould cavity dimension, and M is the actual dimension measured on the product. The mould cavity shape and the selected measurement positions were presented in Fig. 3.

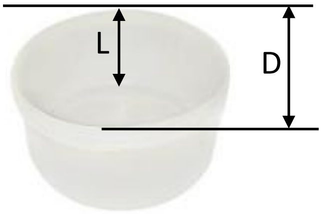


**Fig. 3.** Positions of the shrinkage

### 4.3. Product Colour

Depending on the end use of the product, the aesthetics of the polymeric material is considered as a quality feature. The change in the colour may indicate the possible material degradation. It is also possible that an associated change occurs in the mechanical performance and the material processability (Elsheikhi, 2015). Using a Canon model EOS 7D digital camera, the photos have been captured without flash. All the taken samples are included within the same frame for direct comparison under the same light conditions (from the plan I to plan XII with dimensions of 24mm * 34 mm) in order to avoid the need to build light reflections but allows for a reasonable colour change comparison. Adobe Photoshop CS 2 version 9 is used to analyze the yellow colour of the chosen photos. In order to evaluate the percentage of yellowing, the image mode CYMK (C: cyan, Y: yellow, M: magenta and K: black) and yellow channel were selected.

## 5. Density

Density represents an important physical property which is related to crystallinity. Also, HDPE is a semi-crystalline material consisting of amorphous and crystalline regions. The density of the bulk material is a function of the relative volume fractions of the amorphous (low density) and crystalline (high density) phases. On the other hand, it could be useful to examine and compare the densities of moulded products of all the plans. To perform this test, the volume and mass measurement (mass in grams and volume in $cm^3$) should be determined by cutting off five samples so that they have the same position and dimensions (width, length, and thickness) and then measured using a digital calliper. These samples were weighed using a digital weighing scale.

## 6. Results and Discussion

### 6.1. Product Mass

In this work, the average of the mass slightly increases over the twelve plans by 2%, while the product mass is stable at any given plan; as seen in Fig. 4. This increase can be justified by the reduction in viscosity since pressure gradients through the melt during the phase of extraditing are likely to be decreased, allowing more material to be compressed into the cavity. This change of mass may be linked to a reduction in viscosity, because of the possible effects of recycling. The error bars representing the standard deviation are consistent as shown in Fig. 4.

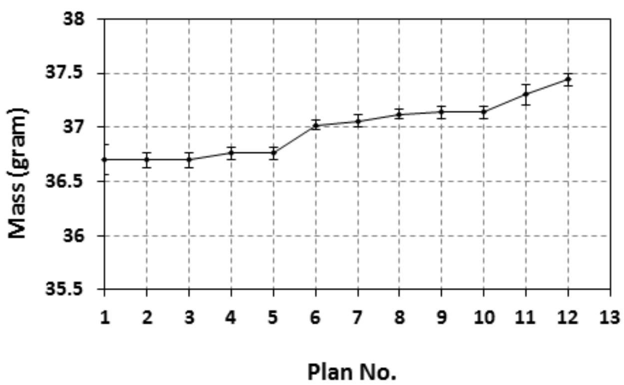


**Fig. 4.** Mass over twelve plans

### 6.2. Shrinkage

The shrinkage in diameter increases across the flow path as shown in Fig. 5. In the same way, as can be confirmed in Fig. 6, the shrinkage through height increases along the flow path, which is along the flow direction. Increasing shrinkage may be linked to the augmenting levels of crystallinity (Fischer, 2003; Lozano-González *et al.*, 2000; Pontes *et al.*, 2002).

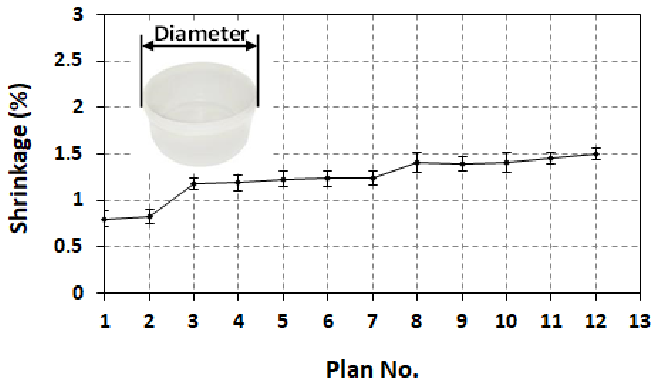


**Fig. 5.** Measurements of shrinkage at diameter position

The shrinkage at height position has an increase from 1.6% to 2.4%, from plan 1 to plan 12; approximately a 50% higher. The maximum shrinkage at diameter position (across flow direction) is noted to be at plan 12 (1.5%). The relative consistency for error bars can be noted in Figures 5 and 6.

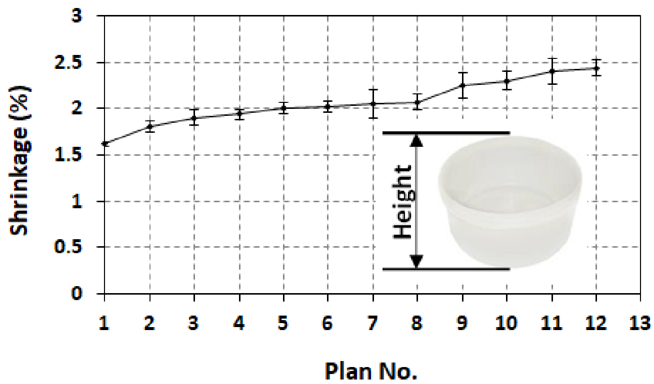


**Fig. 6.** Measurements of shrinkage at a height position

Based on ASTM D955, the shrinkage range of HDPE material related to the process is between 1.5 to 3%. Based on the results observed in this study, it can be stated that the moulded parts produced from the reprocessing plans show good dimensional stability.

### 6.3. Colour

The colour change has been assessed by the percentage of yellow within the colour spectrum. The colour analysis indicated that the yellowness had no remarkable change from the plan 1 to plan 5 as shown in Fig. 7. The appeared to change in yellowness is observed from plan 6 to 12 (47% from the plan 1 to plan 12). Commercially, the requirements/specifications of the customers and the type of applications used are the ones that determine the acceptability or rejection of the change in product colour. However, this problem can be fixed, if no severe or sharp reduction in other important properties, by adding artificial colours.

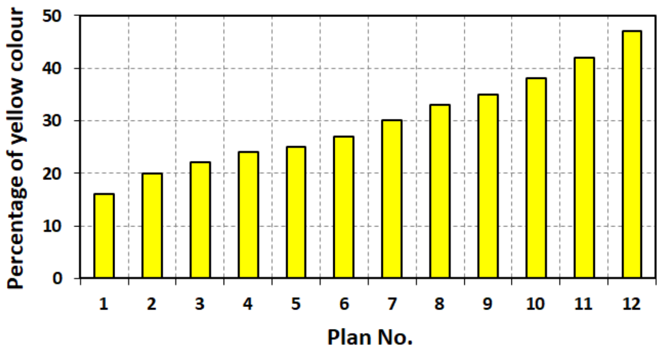


**Fig.7.** Percentage of yellowing for all plans

*6.4. Density*

HDPE as a semi-crystalline material is consisting of amorphous and crystalline regions (Gowariker *et al.*, 1986). The density of the bulk material depends on the relative volume fractions of the amorphous (low density) and crystalline (high density) phases. As depicted in Fig. 8, an increase of around 8 % in the density of the plans from the first plan 1 to the last plan 12 is noted. It could also be noticed from Fig. 8 that the error bars are consistent.

Elsheikhi (2011) clarified the behavior of density by increasing of crystallinity due to the crystals which grown-up using free molecule segments. This phenomenon might be explicated by greater mobility of the polymeric chains due to lower molecular weight as a result of the degradation.

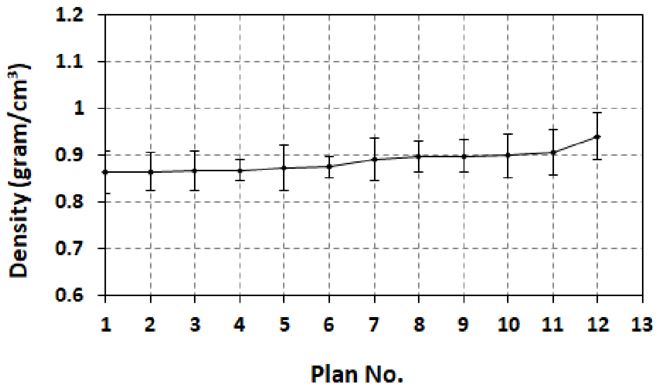


**Fig.8**. Density over twelve plans

**7. Conclusion**

The following points can be concluded:

1. No significant change in the consistency of the HDPE mould material was observed by using multi-stage recycling with 100% regrind. A slight change in the key physical properties such as mass, colour, shrinkage, and density was realized by using multi-stage recycling with 100% regrind. This would permit many plastic manufacturers to produce products with acceptable quality levels.
2. In terms of the impact of the multi-stage recycling on the product property, the following results have been found:
   - The product mass was not significantly influenced by the regrind ratios.
   - Similarly, a slight change in the colour of the final product was detected. This would increase the attractiveness of this kind of materials to the customers.
   - Shrinkage: The moulded parts produced from the reprocessing plans; using the ASTM D955 machine; showed good stability for the dimensions.
   - No significant change in the solid density of the final product was observed using the regrind ratios.

**Acknowledgment**

The authors would like to sincerely thank the engineers: Mustafa Elbarasi, Ahmed Elniehom, Nasr Idres and Nabil Elmesmari for achieving the experimental work. The great thanks extend to the management of the Alddabie plastic factory to offer the required machine, material, and accessories needed to finish this study.

**References**

Dave, P., Brown, K., MacIver, W., Chundury, D., Draucker, C., Lightener, L. (1997) 'Injection molding applications of polyolefin-based filled and reinforced products by the use of designed of experiment technique', The Annual Technical Conference, Society of Plastics Engineers Incorporated, 1, page 514.

Elsheikhi, S. A., Mulvaney-Johnson, L., Campean, I. F., Gough, T., Coates, P. D. (2010) 'Reprocessing of polypropylene material through injection moulding: investigation of part quality, physical properties, processing properties and mechanical properties', 26th Annual meeting of the polymer processing society, PPs 26, paper # R01-472.

Elsheikhi, S. A. (2011) A holistic approach to injection moulding optimisation for product quality and cost through the characterization of reprocessed polymeric materials and process monitoring. Doctoral dissertation, University of Bradford, UK.

Elsheikhi, S.A., Mulvaney–Johnson, L., Campean, I.F. (2014) Statistical evaluation of the reprocessing conditions through injection moulding using response surface methodology. International Conference on Biobased Materials and Composites, ICBMC14, paper # 148.

Elsheikhi, S. A. (2015) 'Reprocessing of post-consumer material through blow moulding In Benghazi/Libya', *Journal of Engineering and Information Technology*, 2, pp. 6-10.

Elsheikhi, S. A., Benyounis, K. Y. (2016) Review of Recent Developments in injection moulding process for polymeric materials. Reference module in materials science and materials engineering, Elsevier. https://doi.org/10.1016/B978-0-12-803581-8.04022-4

Elsheikhi, S. A., Eljaarani, M. A. (2017) 'Material reprocessing through blow moulding in Misurata–Libya', *International Journal of Engineering and Information Technology*, 3, pp. 141-146.

Fischer, J. (2003) Handbook of molded part shrinkage and warpage. William Andrew.

Gowariker, V. R., Viswanathan, N. V., Sreedhar, J. (1986) Polymer Science, John Wiley and Sons. Indianapolis.

La Mantia, F. (2002) Handbook of plastics recycling, iSmithers Repra Publishing.

Lewis, C. L., Buser, M. A. (1997) Effect of reprocessing pre-consumer polyethylene in an injection molding environment, 55th *Annual technical conference, ANTEC*, page 3162, part # 3.

Lozano-González, M., Rodriguez-Hernandez, M., Villalpando - Olmos, J. (2000) 'Physical–mechanical properties and morphological study on nylon-6 recycling by injection molding', *Journal of applied polymer science*, 76, pp. 851-858.

Mamat, A., Trochu, F., and Sanschagrin, B. (1994) Shrinkage analysis of injection molded polypropylene parts, ANTEC Conference Proceedings, 11, pp. 513-517.