Study on Rheological and Dimensional Properties of Polypropylene on End-Of-Life Vehicles

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Abstract. As the global population increased, the production of vehicles also has increased. It is estimated that the population of vehicles in the world has exceeded 1.32 billion units at the end of 2016. The increased vehicle production brings a lot of negative impact to the environment such as noise pollution and the increase of end-of-life vehicles (ELVs). This study aims on the potential of recycled polypropylene that has been used in ELVs. The recycled materials are obtained from vehicles dismantling center at DRB-HICOM Environmental Services Sdn Bhd. The materials were then cleaned and crushed into the pellet before undergoing rheological test at the heat treatment laboratory, Faculty of Mechanical Engineering in Utim Shah Alam. The purpose of rheological test is to study the melt flow behavior of recycled polypropylene in order to obtain the optimum temperature to be applied in plastic injection molding process. The graph of shear viscosity vs. shear rate represents the behavior of both materials at 190°C, 200°C and 210°C. Then materials are produced as a new product. The process of plastic injection molding is carried out at Sheikh Brothers Industries Sdn Bhd in Pelabuhan Klang.

1. Introduction

Vehicle production has seen drastically increased for the past 20 years. This scenario is heavily influenced by the increase in world population and transport needs in human life. The goal of mass production is low-cost manufacturing [1]. In Malaysia, as the population is increasing (equivalent to 0.42% of total world population), the demand for the vehicles is also increased [4]. The sudden increase in vehicles production contributes to the increase of end-of-life vehicles (ELVs). Motor vehicles have been around for little more than one hundred years, however, due to the mass production of cars, it is estimated that around 1.6 - 2 million end-of-life vehicles (ELVs) are arising in the UK each year [3]. Not only aggravate the scenery, but also ELVs complicate the process of conserving the environment.

The recycled polypropylene is collected and segregated from ELVs and undergo rheological test. The purpose of the test is to examine the liquid recycling polypropylene behaviour at optimum temperatures so that the materials will yield the best results in the plastic injection molding process. Then, the process is analysed. Wavelike flow marks are a kind of surface defect that can arise during the filling stage of the injection molding process [8]. Cavity pressure control during filling, packing, and cooling phases is imperative for maintaining product quality in injection molding process [7]. The recycled materials then produced as new product and all dimensions of the product is recorded and compared with the actual design. Overall, this study provides information on the proper way to recycle ELVs and the potential of materials used in ELVs.
2. Methodology

**Figure 1.** Research methodologies (CDIO)

CONCEIVE

- Identification of problems, objectives of the project and scope of the project
- Study on the literature review related to law, management process and statistic of End-of-Life vehicles (ELVs) and the application of recycle materials from the ELVs. Study on the demands of plastic material around the world.

DESIGN

- Preparation of material:
  1) Selection of ELVs dismantling center.
  2) Classification of materials used in ELVs based on location installed.
  3) Selected part made from polypropylene is then cleaned from dirt.
  4) The selected part is crushed into pellet.
- Preparation for testing the recycled material:
  1) Rheological test:
     - The virgin and recycled specimen is prepared in the form of pellet.
  2) Plastic injection molding:
     - Selection of company that can provide the plastic injection molding service.
     - Obtaining the detail drawing for the product to be produced.
     - Obtaining the specification of dimension for the part to be produced.
     - Obtaining basic parameters data of the injection molding machine.

IMPLEMENT

- 1) Rheological test:
   - Based on information on the graph, the best melted polypropylene behavior is selected.
- 2) Plastic injection molding:
   - The defects of the recycle product is identified and compared with virgin product.
   - The dimension of the recycled product is compared with the actual design.
   - The optimum parameters of the injection molding machine are recorded.

OPERATE

- 1) Optimization on procedure for dismantling ELVs.
- 2) Conclusion of the study and recommendation on improvising the results.
3. Result and Discussion
All data for the rheological test is calculated automatically by the software. For the rheological test, software that has been used is Flowmaster. For the injection molding process, the results are obtained manually.

3.1 Rheological Test
The results for this test is based on temperature applied and types of materials. The result for Shear Viscosity (Pa.s) vs. Shear Rate (/s) is then plotted.

![Figure 2. Graph of shear viscosity (Pa.s) vs. shear rate (/s) at temperature of 190°C](image1)

![Figure 3. Graph of shear viscosity (Pa.s) vs. shear rate (/s) at temperature of 200°C](image2)

![Figure 4. Graph of shear viscosity (Pa.s) vs. shear rate (/s) at temperature of 210°C](image3)

3.2 Discussion
Both results are showing the degradation of recycled polypropylene. For viscosity test, the results presented as graph of shear viscosity vs. shear rate. For plastic injection molding, the results are taken from the different of dimension compared to actual design. The defects of product were also studied.
For rheological test, the temperatures applied are 190°C, 200°C and 210°C. Theoretically, viscosity of a fluid depends on the temperature. For liquid, as the temperature is high, the viscosity is low. Fluid flow can be divided into two, Newtonian fluid and non-Newtonian fluid. Newtonian fluid is the fluid that satisfies the Newton’s Law of Viscosity. For polypropylene, fluids are shear thinning when the viscosity is decreased and the shear rate is increased. This behaviour is known as pseudo-plastic.

For the first graph (Figure 3.1.2), the test was carried out using temperature of 190°C. Shear viscosity of recycled polypropylene is lower than shear viscosity of virgin polypropylene for the first 1000 shear rate. Then, the graph of recycled polypropylene remains almost the same as the graph of virgin polypropylene. For the second graph (Figure 3.1.3), the test was carried out using temperature of 200°C. Shear viscosity of recycled polypropylene is higher than shear viscosity of virgin polypropylene for the first 1000 shear rate. Then, at range 1000 to 2000 of shear rate, the shear viscosity of recycled polypropylene is lower than shear viscosity of virgin polypropylene. The graph of recycled polypropylene remains almost the same as the graph of virgin polypropylene. The last graph (Figure 3.1.4) obtained from test at 210°C. Shear viscosity of recycled polypropylene is lower than shear viscosity of virgin polypropylene for the first 2000 shear rate. Then, the graph of recycled polypropylene remains almost the same as the graph of virgin polypropylene.

The injection molding process is carried out by using recycled polypropylene at three different nozzle temperatures, 190°C, 200°C and 230°C. Major flow marks appear when applying nozzle temperature of 230°C. This is due to the viscosity of the melted polypropylene is too low. Thus, the most suitable temperature to be applied in the injection molding process is 190°C.

Then, the best product is selected and the dimension is recorded. Based on the results on the details drawing, from 45 points of dimension that have been checked, there is one dimension that is not satisfying the standard dimension. The dimension is out of ranged allowed because the part is warped due to several reasons such as pressure in the cavity, fill rate and cooling rate. Warping is caused by too much stress acting on the product. The reason of the stress acting on the product is uneven pressure in the mold and temperature of mold is too low. To improve this defect, the parameter of the machine needs to be changed.

4. Conclusion and Recommendation

The study has successfully satisfy the objectives which are to identify materials used in ELVs, to compare rheological behaviour of recycled polypropylene from ELVs with virgin polypropylene and to produce product by using recycled polypropylene from ELVs.

Rheological test indicates that at temperature of 190°C, the behaviour of melted recycled polypropylene is nearly the same as compared to virgin polypropylene. As the temperature is increased, the shear viscosity of the recycled polypropylene dropped as compared to virgin polypropylene due to several factors such as location of polypropylene parts that have been installed and life cycle of the polypropylene. To increase the properties of the recycled materials, some improvement can be made. For example, additive such as talc will increase the strength of the material. The product that has been produced by using three different temperatures have shown that the recycled polypropylene is best operates at 190°C. This proves that the result in rheological test is applicable in real manufacturing process. In order to make the recycling process of ELVs more effective, proper standard operating procedures (SOPs) need to be followed. For example, at the dismantling center, the parts need to be sorted according to type of materials. For plastic, the parts need to be isolated by type of plastic. With this procedure, process of recycling recycled material will be more effective.

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