THE EFFECT OF RECYCLED – HIGH DENSITY POLYETHYLENE (HDPE) MIXING RATIO ON THE TENSILE STRENGTH OF HIGH DENSITY POLYETHYLENE (HDPE) POLYMER

SITI AMNI HUSNA BINTI ROSLAN

Thesis submitted fulfillment of the requirements

for the award of the degree of

Bachelor of Engineering in Manufacturing

Faculty of Manufacturing Engineering

UNIVERSITI MALAYSIA PAHANG

JUNE 2013

ABSTRACT

High Density Polyethylene (HDPE) polymer is widely being used nowadays. The advantages possessed by this polymer make it more preferable than metals. Lightweight, ease of manufacture, stronger and tough are HDPE specialties that make it as the top choice by manufacturers. However, the main disadvantages about this material is that their decaying consumes much time and this effects the environment as this material will dispose as wastes if they could not longer being used. Also, cause loss to certain companies. Therefore, ways to overcome this problem must be found, which is by recycling process. In recycling HDPE polymer, there is one method that mostly been used which is by mixing the recycled HDPE with pure HDPE with certain percentage of both materials.

In this project, the pure HDPE were mixed with recycled HDPE according to determined percentages. The samples produced then will undergo tensile test in order to determine the percentage which posses the optimum tensile strength. In the end of experiment, it showed that the mixture with 90% of pure HDPE with 10% recycled HDPE is the best percentage compared to others. This experiment was conducted by following ASTM D638.

ABSTRAK

Polimer Polietilena berketumpatan tinggi (HDPE) telah digunakan secara meluas pada hari ini. Kelebihan yang ada pada bahan ini menjadikan mereka menjadi pilihan berbanding keluli. Ringan, mudah di bentuk serta memiliki kekuatan dan ketahanan merupakan kelebihan yang ada pada bahan ini dan merupakan pilihan utama pembekal. Walaubagaimanapun, bahan ini mengambil masa untuk dihapuskan dan memberi kesan kepada alam sekitar. Juga menyebabkan kerugian kepada syarikat pembekal. Oleh itu, kaedah dan cara perlu untuk mengatasi masalah ini perlu di kaji, iaitu dengan mengitar semula bahan ini. Dalam proses mengitar semula polimer HDPE, satu kaedah yang kerap di aplikasikan iaitu mencampurkan HDPE yang telah diproses dengan HDPE yang asli mengikut peratusan tertentu dari kedua-dua bahan tersebut.

Dalam kajian ini, bahan HDPE yang asli telah dicampurkan dengan bahan HDPE yang telah di hancurkan untuk menjadikannya sebagai bahan yang telah dikitar mengikut peratusan yang telah ditetapkan. Sampel yang terhasil akan dilakukan ujian tegangan ke atas mereka bagi menentukan peratusan yang memiliki kekuatan tentangan yang terbaik. Di akhir ujian ini, keputusan menunjukkan peratusan yang mengandungi 90% bahan HDPE yang asli dengan 10% bahan HDPE yang dikitar semula memiliki kekuatan tentangan terbaik berbandingn dengan peratusan yang lain.

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HDPE	High Density Polyethylene
ASTM	American Society for Testing & Materials
MPa	Mega (1×10^6) Pascal
°C	Degree Celcius
N	Newton
kN	kilo (1×10^3) Newton
m	meter

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Polymers, or also known as plastics, are a major class of materials and possess a very wide range of mechanical, physical, chemical, and optical properties. Unlike metals, polymers generally are characterized by a lower density, strength, elastic modulus, thermal and electrical conductivity, and cost. Also, by a higher strength-to-weight ratio, higher resistance to corrosion, higher thermal expansion, wider choice of colors and transparencies; and by a greater ease of manufacture into complex shapes. Hence, plastics are been used mostly in agriculture, appliances, clothing, construction and numerous other fields which required their existence.

The most common polymer that has been used for industrial and commercial products nowadays is High-Density Polyethylene (HDPE). HDPE is one of basic types under Polyethylene (PE) polymer. It is a thermoplastic polymer; means that it can be melted to a liquid and remolded it to a solid state. It is tough, relatively inexpensive and has excellent process ability. It is used in numerous applications ranging from plastic grocery bags to heavy duty plastics containers. Moreover, HDPE also widely been used in construction industry for producing pipes and as insulator in electrical appliances.

Due to the advantages of HDPE plastics, during the last decade their use has increased greatly, both in areas of applications and in actual quantities employed. However, improper and uncontrolled plastics production and consumption causes wastes, which eventually causes loss to certain companies and also lead to pollution to

environment. In addition, because HDPE plastics are composed of organic compounds, their main disadvantage is that their decay process takes a very long time. As it is impossible to avoid plastic consumption, which parallel with the development of new technology, realistic solution have to be searched for the problems arising from the growing use of plastics, especially HDPE plastics. That is, recycling methods and ways of evaluating these recycled materials must be found.

For this purpose, a study on determining the effect of recycled HDPE mixing ratio on the tensile strength of HDPE polymer is carried out in order to reduce the HDPE wastes problem. Besides that, this research will present which the mixing ratio of recycled and pure HDPE that are likely improving in tensile strength, by comparing to the tensile strength of pure HDPE and eventually will be selected as the optimum percentage of mixing ratio at the end of the experiment.

1.2 PROBLEM STATEMENT

The worldwide production of plastics is approximately 100 million tonnes per annum [1], resulting in a significant proportion in municipal solid waste (MSW). Municipal solid waste is all types of solid waste generated by households and commercial establishments, and collected usually by local government bodies. According to a statistics, waste plastics account for 11.8% of the 246 million tonnes of MSW generated in Unites States for year 2005 [2]. Attempts have been made to recycle the post-consumer plastics in order to reduce the environmental impact and consumption of HDPE virgin plastics. However, the mechanical properties of recycled HDPE still not widely explored in open literature as there are not much input on the properties. Thus, study on the mechanical properties of the HDPE recycled product, especially tensile strength is necessary.

It is known that the mechanical properties of original materials are different from those of the corresponding recycled materials. However, it is possible to find an optimum point which can be determined by experimentation. Hence, the purpose of this project is to study the effect of recycled HDPE mixed with original HDPE materials in

various proportions on their new tensile strengths. The mixture with the highest tensile strength will be considered as the best percentage.

1.3 PROJECT OBJECTIVES

There are two objectives that need to be achieved from this project, which are:

i. To design dog-bone shape mould by using AutoCAD software and produce the real mould for this research purpose.

ii. To study the effect of mixing of recycled HDPE and pure HDPE according to determined percentage.

iii. To determine the best percentage of mixed pure and recycled HDPE materials by selecting the mixture with the highest tensile strength.

1.4 SCOPES OF THE PROJECT

The scope of this project is to design a mould that have a dog-bone shape, which is the form of testing specimen following ASTM D 638 [3] by using AutoCAD software and then produced the real mould by machining operations for research purpose. Next, using the virgin high density polyethylene (HDPE), and mixed with recycled HDPE according to the determined percentage from each of them. After that, tensile tests were done to examine the tensile strength of these mixtures. The tensile test results of each proportion were tabulated. The mixture with the highest tensile strength was selected as the best percentage. The location of this research was conducted laboratory of Faculty of Manufacturing Engineering and Faculty of Mechanical Engineering.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A literature review is a discussion of the published information in a particular subject area. While it can be a summary of sources on a certain subject, more often it takes a critical, evaluation approach, showing the relationships between the various writings and how they relate to our work. A good literature review will look at the research that has been done and synthesize those elements that are similar to the theme of work chosen. In simpler words, reading a literature review can often give readers a solid overview of the research on a topic.

2.2 POLYETHYLENE (PE)

Polyethylene (PE) is the most popular plastic in the world. It has a very simple structure, the simplest of all commercial polymers. Polymers are substances whose molecules have high molar masses and are composed of a large number repeating units. There are both naturally occurring and synthetic polymers. Among naturally occurring polymers are proteins, starches, cellulose and latex. The materials commonly called plastics are all synthetic polymers.

Polyethylene (PE) resins are a general class of thermoplastics, means that it has the property of softening or fusing when heated and of hardening and becoming rigid again when cooled without undergoing any appreciable chemical change. Polyethylene is produced from ethylene gas. Ethylene gas is derived from the cracking of natural gas

feedstock or petroleum by products. Under broad ranges of pressures, temperatures and catalysts (depending on PE type), ethylene generally polymerizes to form very long polymer chains. By utilizing techniques such as using different reactor technologies, operating multiple reactor configurations, or polymerizing other gases such as vinyl acetate or other olefins (butene, hexene, octene) in conjunction with ethylene to form copolymers, different types of PE resins can be produced. The ability to produce so many variations of a basic material permits the manufacturer to tailor PE resins for diverse applications, such as packaging films, rigid food containers, milk and water bottles, large toys, etc.

When comparing the polymerization processes among the PE family of resins, they vary significantly, which result in the wide range of physical properties associated with PE. However, in all cases, the resultant PE products are pelletized on compounding extruders where additives such as antioxidants, processing aids, etc. are incorporated. Figure 2.1 presents the polymerization of ethylene to produce polyethylene.

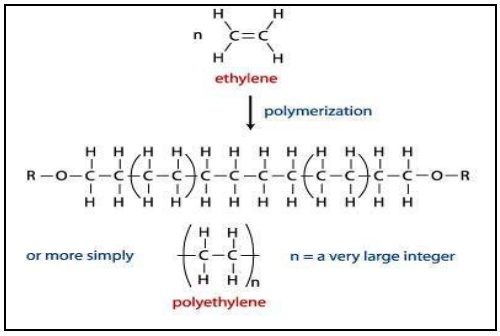


Figure 2.1: The polymerization of ethylene to produce polyethylene [4].

Polyethylene is classified into several different categories based mostly on its density and branching (See Figure 2.2). Their mechanical properties depend significantly on variables such as the extent and type of branching, the crystal structure and the molecular weight. With regard to sold volumes, the most important polyethylene grades are high density polyethylene (HDPE), linear-low density polyethylene (LLDPE) and low density polyethylene (LDPE).

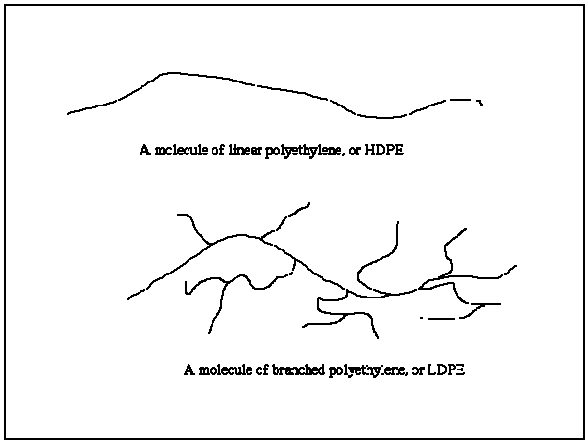
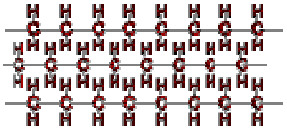


Figure 2.2: The diagram of polymer chain branching of HDPE and LDPE [5].

2.2.1 High-Density Polyethylene (HDPE)

High density polyethylene (HDPE) is a plastic polymer with flexible properties which make it ideal for a wide range of applications. It can be polymerized by using slurry, solution, or gas phase reactor technologies. HDPE manufacturing processes also use transition metal catalysts to make linear polymer chains with less branching, meaning it is light with a high tensile strength. The structure of HDPE is more closely packed compared to other types of polyethylene. The branching can be controlled and reduced by using specific catalysts during the production process. Butene, hexene and octene are typical HDPE comonomers. Polymerizing ethylene without any comonomer produces HDPE homopolymer. The resulting products exhibit the highest density and crystallinity in the PE family. Some of general properties of HDPE can be seen in Table 2.1.

Table 2.1: The general properties of HDPE [6].

Property	High Density Polyethylene (HDPE)
Melting Point	~135^{o}C
Crystallinity	Highly crystalline (>90% crystalline). Contains less than 1 side chain per 200 carbon atoms in the main chain leading to long linear chains that result in regular packing and high crystallinity.
Flexibility	More rigid than LDPE due to higher crystallinity.
Strength	Strong as a result of regular packing of polymer chains.
Heat Resistance	Useful above 100^{o}C
Transparency	Less transparent than LDPE because it is more crystalline.
Density	0.95-0.97 g/cm^{3} higher density than LDPE
Chemical Properties	Chemically inert.
Schematic diagram	
Uses	Freezer bags, water pipes, wire and cable insulation, extrusion coating.

HDPE has high modulus, yield and tensile properties relative to LLDPE and MDPE. Also, it has a higher specific density than LDPE. However, because it has higher crystallinity, HDPE cannot match the clarity of LDPE or LLDPE film. HDPE is widely used in extruded pipe for potable water and gas distribution. Another important application is in blow moulded packaging for household and industrial chemicals (HIC), such as bottles for bleach, shampoo, detergent, and many more applications.

HDPE possess some special characteristics that make it main choice by many industries. HDPE has good chemical resistance and high rigidity which make it a good

choice for trays and tanks. The high toughness and flexibility of HDPE make it suitable in piping application. In addition, HDPE also has good impact resistance, light weight, very low moisture absorption, and high tensile strength which make it a good candidate of material to be used in heavy industries such as construction and automotive industries.

2.2.2 Tensile Strength of HDPE

One of important mechanical properties when describing a polymer is tensile strength. Tensile strength refers to how much pressure a piece of material can withstand before breaking or ripping into two parts. The tensile strength of HDPE is commonly between 3,000 and 3,500 pounds per square inch (psi), which is about 20 to 24 Mpa in SI unit [7]. This also allows it to deal with the transportation of high pressure substances and be easily manufactured into shapes without risk of damaging the materials structure. Table 2.2 shows the range of mechanical properties of HDPE.

Table 2.2: The mechanical properties of HDPE [8].

Quantity	Value	Unit
Young's modulus	600 - 1400	MPa
Shear modulus	700 - 800	MPa
Tensile strength	20 - 32	MPa
Elongation	180 - 1000	%
Fatigue	18 - 20	MPa
Bending strength	20 - 45	MPa

2.3 RECYCLING PROCESS OF PLASTICS/POLYMER

Waste production has been increasing worldwide, owing to changes in economic activity, demography, technological innovation and production and consumption patterns. Due to their ubiquity and specific properties, plastics waste, namely from used packaging, has suffered most of the criticisms addressed to this environmental problem. Recent European legislation has stressed the need to solve it on the basis of a hierarchy of solutions [9]. Material recycling ranks high on that hierarchy. Since then, many countries encourage the recycling or reusing of plastics waste. Hence, many recycling or reusing approaches have been developed [10-12]. In particular, primary recycling seems to be an obvious answer to environmental concerns.

Primary recycling of thermoplastics is done in industry using standard processing operations, and homogeneous, non-contaminated scrap to fabricate parts with properties similar to those of the products from which it is obtained [13]. The scrap is usually continuously introduced in the feed and replaces the equivalent amount of virgin polymer. Consequently, this process, often called reprocessing, is not only environmentally desirable, but also economically advantageous.

According to a research done by some authors [14], they concluded that the amount of annual plastic consumption duplicates every four years based on their observations on plastics consumption between the years 1990 and 2005. The manufacturing of various plastics throughout the world can be described in the following percentages: 31% polyethylene (PE), 17% polyvinyl chloride (PVC), 15% thermosets, 14% polypropylene (PP), and 9% polystyrene (PS). Also, 14% of other kinds of plastics aside the plastics that already mentioned here [15].

2.3.1 Recycling Process of HDPE

HDPE, or type 2 plastics, are recyclable plastics. These plastics make up the heavier containers that many of our everyday goods are stored in. A person can look at the bottom of a type 2 plastic and see the number 2 surrounded by a triangle of arrows

and the abbreviation HDPE underneath it. The types of containers that are embossed with this code are milk containers, laundry detergent bottles, Tupperware, bleach bottles, shampoo bottles and motor oil bottles. (See Table 2.3).

Table 2.3: The recyclable plastics and descriptions [16].

Mark	Type	Recyclable	Abbreviation	Description
	**Type 1**	Yes	**PET**	**Polyethylene Terephthalate**
	**Type 2**	Yes	**HDPE**	**High-Density Polyethylene** Milk, detergent & oil bottles, toys, containers used outside, parts and plastic bags.
	**Type 3**	Yes, but not commonly	**V/PVC**	**Vinyl/Polyvinyl Chloride (PVC)** Food wrap, vegetable oil bottles, blister packages or automotive parts.
	**Type 4**	Yes	**LDPE**	**Low-Density Polyethylene** Many plastic bags. Shrink wrap, garment bags or containers and parts.
	**Type 5**	Yes	**PP**	**Polypropylene** Refrigerated containers, some bags, most bottle tops, some carpets, some food wrap.
	**Type 6**	Yes, but not commonly	**PS**	**Polystyrene** Throwaway utensils, meat packing, protective packing.
	**Type 7**	Some	------	**OTHER** Usually layered or mixed plastic.

Polyethylene polymer reprocessing has been often studied. This was to be expected as polyethylene is the most consumed general purpose polymer, prevalent in the packaging sector and is easy to reprocess. Often these studies covered different grades of polyethylene in general, and aimed at predicting the minimum amount of the virgin polymer that must be added to the feed in order to prevent significant loss of properties.

The recycling of high density polyethylene (HDPE) has already been study by some authors [17-20] and in general, provided that suitable reprocessing conditions are adopted, the properties of the recycled material are near to those of virgin HDPE. Recycled HDPE creates no harmful emissions during its production or during its use by the consumer [21]. Some authors, like La Mantia et al. [22], carried out a study on the influence of the number recycling steps on the structure and also the mechanical and rheological properties of HDPE. In the end of their study, they concluded that low residence time in the extruder leads to almost unaltered properties.

Other authors, like Cruz and Zanin [23] have studied the need of re-stabilization during HDPE reprocessing and Fernandez et al. [24] studied the blends of HDPE, focusing on rheological process. Sanches-Soto et al. [25] studied on mechanical properties of HDPE and the rest did studies on recycled HDPE as matrix composites and have demonstrated excellent results [26-27].

2.4 CONCLUSION

Consequently, recycling and using recycled materials is great importance to the economies and development of countries. Recycling can be performed with many different technologies. The critical point in recycling plastic materials is using a method which least effects the chemical structure of the plastic. Since last decades' efforts, many recycling or reusing approaches have been developed. In all the recycling methods, the mechanical recycling including blending technologies is a straightforward and relatively simple way of recycling.

CHAPTER 3

METHODOLOGY

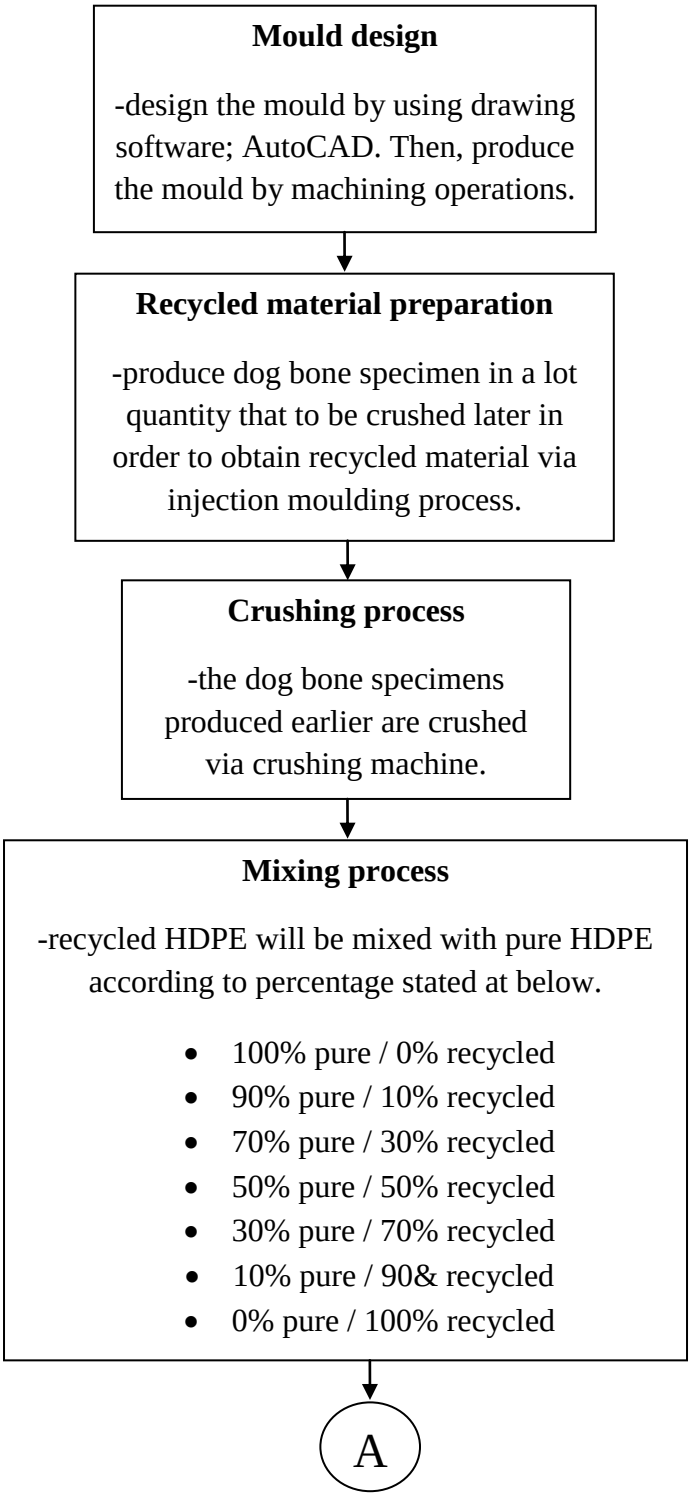
3.1 INTRODUCTION

Methodology is an important element where it specifically describes the method to achieve the objectives of this research. Methodology is used in order to make sure the progress of the project will follow the flow from the beginning until the end of the project.

In this project, there are four major stages that have been involved. They were:

i. Mould design
ii. Material preparation
iii. Material processing
iv. Samples testing

The flow of process for this project is illustrated in a methodology flow chart (See Figure 3.1). Flowchart is a visual representation of the sequence of the project. The flowchart shown will give the whole picture of this project from the initial step until the final step.


Mould design
-design the mould by using drawing software; AutoCAD. Then, produce the mould by machining operations.
Recycled material preparation
-produce dog bone specimen in a lot quantity that to be crushed later in order to obtain recycled material via injection moulding process.
Crushing process
-the dog bone specimens produced earlier are crushed via crushing machine.
Mixing process
-recycled HDPE will be mixed with pure HDPE according to percentage stated at below.
100% pure / 0% recycled
90% pure / 10% recycled
70% pure / 30% recycled
50% pure / 50% recycled
30% pure / 70% recycled
10% pure / 90& recycled
0% pure / 100% recycled
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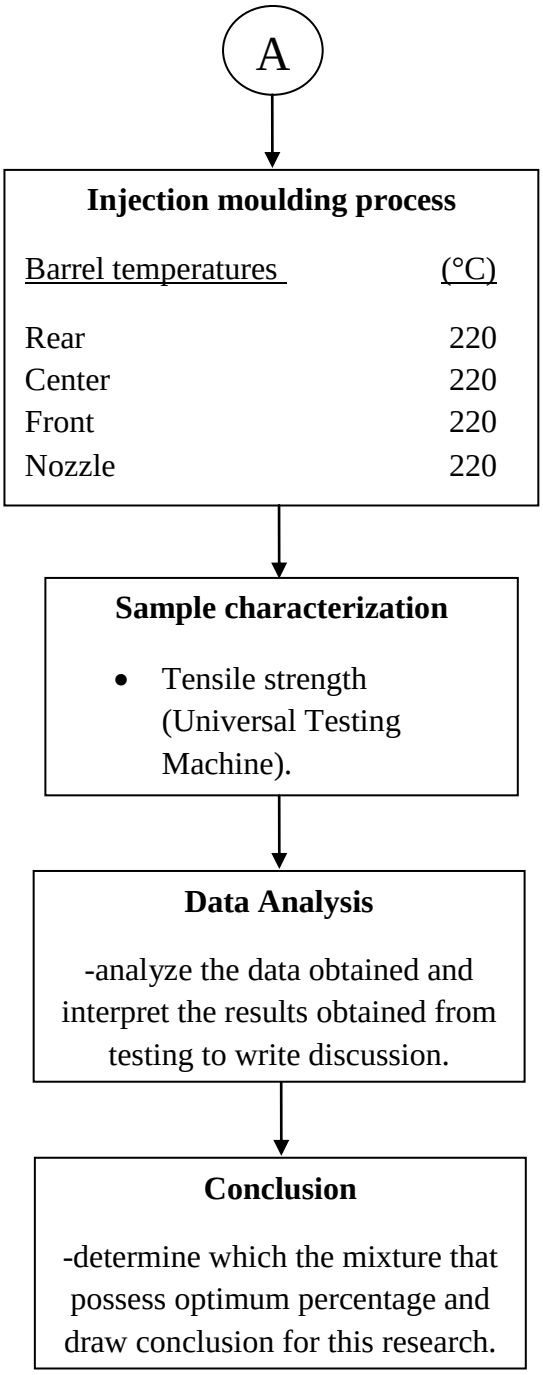

Figure 3.1: Flowchart that illustrate on experimental methodology.

3.2. MOULD DESIGN

The mould was first designed in 2D drawing by using AutoCAD software. (See the Appendix C). After confirming the design and the dimensions, the mould then was machined through few machining operations, such as roughing, drilling, reaming, die sinking and other operations needed. Next, the mould plates were assembled manually and put in the injection moulding machine to inject dog bone specimen that will be crushed later with crushing machine in order to obtain recycled material.

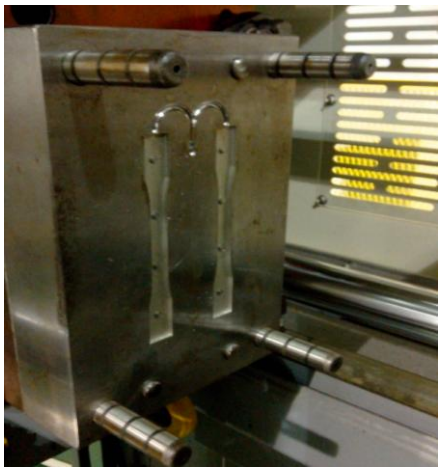

Figure 3.2: The mould plate machined by machining operations after designing via AutoCAD drawing software.

3.3 MATERIAL PREPARATION

3.3.1 Raw Material (pure HDPE)

The material selected for this project was high density polyethylene (HDPE). High Density Polyethylene (HDPE) material was supplied by Titan Chemicals Company which is operating in Johor.

Figure 3.3: The virgin HDPE material supplied by Titan Chemicals Company.

3.3.2 Recycled HDPE

Recycled HDPE materials were obtained from the crushing of HDPE products (dog-bone shape product) produced through injection moulding process before the actual experiment was carried out. The HDPE products were crushed with crusher machine in order to get the materials in smaller particles form. After that, the recycled materials of HDPE were divided into certain percentages that had been determined for experimentation purpose.

Figure 3.4: HDPE material that already been crushed through crushing machine and will be used as the recycled HDPE for this research.