STUDY ON MECHANICAL CHARACTERISTICS OF MIXED HETEROGENEOUS COASTAL PLASTIC WASTE

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ABSTRACT

Coastal plastic pollution is a common problem in many coastal regions in Malaysia. Arising from environmental concern and at the same time supporting waste to wealth program, the best way to overcome coastal plastic pollution is by recycling. However, due to photo degradation and nature of the surroundings, the characteristics of coastal plastic waste are differ from land plastic waste that drives for further research in determining the characteristics of coastal plastic waste and discovering its potential value. The objectives of this study are to improve the characteristics of mechanical properties of coastal plastic waste by heterogeneous recycling, to compare the mechanical properties of heterogeneous coastal plastic waste with the commercial plastic and to study the potential value of heterogeneous coastal plastic waste. Polypropylene (PP) and Polyethylene terephthalate (PET), two types of plastic waste which are highly abundant at the coastal region for its great consuming in food and beverages packaging and containers are used as sample. Samples are collected, cleaned and sorted manually according to the types and crushed into small flakes. PP and PET are mixed by volume composition of 0%, 3%, 5%, 7% and 10% of PET before undergo extrusion process. Under extrusion process, the plastic is extruded to strands and then pelletized to produce a single-polymer plastic. Then, plastic is moulded into testing specimen according to standard measurement, ASTM D638-05 and tested in term of its mechanical properties- tensile strength, elongation at break and elastic modulus- by using Universal Testing Machine. From analysis of obtained result, the mechanical properties of mixed heterogeneous coastal plastic waste are poor compared to homogeneous recycling except for elastic modulus. However, at 7% composition of recycle PET, it shows the optimum mixing ratio which gives better of mechanical properties. Homogeneous recycled plastic has the close and almost similar mechanical properties as the commercial plastic and have the potential to be utilized in some application as in producing household items. Varying the mechanical testing and blending polymers with plastic additives can be applied in further research for improvement of mechanical characteristics of recycled materials.

ABSTRAK

Pencemaran plastik di pesisiran pantai merupakan masalah biasa di kebanyakan kawasan-kawasan pantai di Malaysia. Timbul dari kesedaran terhadap penjagaan alam sekitar dan pada masa yang sama menyokong program '*Waste to Wealth'*, cara terbaik untuk mengatasi masalah pencemaran plastik di pantai adalah melalui amalan kitar semula. Walaubagaimanapun, disebabkan oleh kemerosotan akibat terdedah kepada cahaya matahari dan persekitaran, ciri-ciri sampah plastik pantai berbeza daripada sampah plastik biasa yang mendorong kepada penyelidikan lanjut dalam menentukan ciri-ciri sampah plastik pantai dan mengenalpasti potensi sampah tersebut sebagai produk alternatif. Objektif kajian ini adalah untuk meningkatkan ciri-ciri dan sifat-sifat mekanikal sampah plastik pantai melalui oleh kitar semulasecara mencampurkan jenis-jenis plastik, untuk membandingkan sifat-sifat mekanikal sampah plastik pantai yang berbeza dengan plastik komersial dan mengkaji potensi sampah tersebut sebagai produk alternatif. Polypropylene (PP) dan Polyethylene terephthalate (PET), dua jenis sampah plastik yang sangat banyak terdapat di kawasan pantai yang banyak digunakan dalam pembungkusan makanan dan minuman, digunakan sebagai sampel. Sampel dikumpulkan, dibersihkan dan diasingkan secara manual mengikut jenis sebelum dihancurkan menjadi kepingan kecil. PP dan PET dicampur dengan komposisi isipadu 0%, 3%, 5%, 7% dan 10% daripada PET sebelum menjalani proses penyemperitan. Melalui proses penyemperitan plastik di dalam bentuk lembar dan kemudian dipellet untuk menghasilkan polimer tunggal. Kemudian, plastik tersebut dibentuk menjadi spesimen mengikut standard pengukuran ASTM D638-05 dan diuji dari segi kekuatan mekanikal –kekuatan tegangan (*tensile strength*), pemanjangan (elongation) dan kekenyalan (*elastic modulus*) dengan menggunakan *Universal Testing Machine*. Berdasarkan analisis keputusan yang diperoleh, sifat-sifat mekanikal bagi sampah plastik pantai yang dikitar semula secara campuran lebih lemah berbanding kitar semula plastik tanpa campuran PET kecuali bagi kekenyalan. Walaubagaimanapun, pada komposisi 7% PET, ia menunjukkan nisbah optimum campuran PP dan PET yang menghasilkan produk dengan sifat-sifat mekanikal yang lebih baik. Plastik kitar semula tanpa campuran PET mempunyai sifat-sifat mekanikal yang rapat dan hampir serupa dengan plastik komersial dan mempunyai potensi untuk digunakan dalam aplikasi tertentu seperti penghasilan barang-barang isi rumah. Bagi kajian di masa hadapan untuk memperbaiki sifat-sifat mekanikal bahan yang dikitar semula, ujian mekanikal yang berbeza-beza perlu ditambah dan pengadunan polimer dengan bahan tambah plastik boleh diaplikasi.

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LIST OF SYMBOLS

%	Percentage
°C	Degree Celcius
J	Joule
mm	milli meter
MPa	Mega Pascal
rpm	Revolution per minute
R	Radius

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
EB	Elongation at Break
ISO	International Organization for Standardization
PE	Polyethylene
PET	Polyethylene terephathalate
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl chloride
SEM	Scanning Electron Microscope

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Synthetic polymers, especially plastics, have gained wide popularity over the years as choice material in numerous applications in daily life due to the characteristics and uniqueness of the plastic material. Plastic characteristics; low density, strong, user-friendly design and fabrication capabilities and low cost, are the factors to its growth. The world's annual consumption of plastic materials has increased from around 5 million tonnes in the 1950s to nearly 100 million tonnes nowadays. This rapid increase of plastic consumption and demand in the world today is the main factor of land and water pollution. However, as ocean covers 73% of the earth's surface, usually, pollution in land tends to end up in ocean (William, 1996; and Shahidul Islam, Tanaka, 2004). Because of most of plastics are non degradable and takes decades or even hundreds of years to degrade, it is the factor why plastic pollution become worldly problem.

Numerous researchers have documented the magnitude of marine debris and the threat towards marine life (Fowler, 1987; Ryan, 1987; Bjorndal *et al.,* 1994; and S.L. Moore *et al.,* 2001). Goldberg (1995) in a study about plastic debris in North-Western Mediterranean claimed that, plastic is most significant part of pollution contribution and constituted most of the debris, an average about 77% in North-Western Mediterranean. Another study conducted by Kusui and Noda (2003) stated that, plastic contribute 72.9% of total litter among 26 beaches in Japan. Malaysia is no exception having the same problem although there is no specific research and finding is documented yet regarding statistic of coastal plastic pollution in Malaysia. Nevertheless, mass media always reported on visitors' dissatisfaction about cleanliness level and plastic pollution in most coastal region throughout Malaysia. Other than that, Department of Environment under Ministry of Natural Resources and Environment had conducted numerous case studies and interviews involving visitors and residents.

1.2 PROBLEM STATEMENT

There are several methods in order to manage plastic waste. Subramanian (2000) listed five methods to manage plastic waste which are source reduction, reuse, recycling, land fill and waste-to-energy conversion. By reduction in plastic manufacturing, waste can also be reduced. Reuse and recycling are the ways to minimize plastic manufacturing. Arising from environmental concern, it is a necessity to reduce coastal plastic wastes by recycling those plastic wastes rather than dumping into landfill which can cause another major environmental problem because plastic takes hundred years to degrade, or incineration process that can affect health through toxic gas release. Moreover, to support Waste to Wealth program, plastic wastes become valuable in gaining high profits through recycling process and at the same time promote environment preservations.

There are many researches regarding plastic waste recycling are documented purposely to improve the characteristics of plastics waste so it can be reused in order to preserve environment and at the same time minimize the usage of natural resources. However, coastal plastic waste had different characteristics compared to typical land plastic waste that drives further research in determining the mechanical characteristics of heterogeneous coastal plastic waste.

1.3 RESEARCH OBJECTIVES

The objectives of this study are:

1. To improve the characteristics of mechanical properties of heterogeneous coastal plastic waste by mixed heterogeneous plastic recycling.
   Recycle of mixed heterogeneous coastal plastic waste is expected to result in better mechanical properties compared to homogeneous plastic recycling.

2. To compare the mechanical properties of improved heterogeneous coastal plastic waste with the commercial plastic.
Mechanical properties data of mixed heterogeneous recycled coastal plastic waste will be compared to the commercial plastic in order to determine the similarity and difference of their characteristics.

3. To study the potential value of mixed heterogeneous coastal plastic waste.
From known characteristics, the potential value of the plastic can be developed, whether it has the possibility to be manufactured in industry like commercial plastic and thus marketed.

1.4 SCOPE OF STUDY

This study will focus on the mechanical properties- tensile strength, elongation at break and modulus of elasticity- for the experiment to be conducted towards mixed heterogeneous coastal plastic waste. Plastic wastes are collected from coastal area in Kuantan, Pahang, and undergoes recycling process. Based on rough observation, plastic wastes in coastal region composed mainly of polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE) and polystyrene (PS) that come from multi purposes usage mostly in food and beverages packaging.

The types of plastic wastes used in this study are PP (Polypropylene) and PET (Polyethylene terephthalate) which been mixed to certain volume composition. As for comparison of mechanical properties of improved heterogeneous coastal plastic waste to the commercial plastics, data for commercial PP (Polypropylene) is used as PP is the main composition in recycling of mixed heterogeneous coastal plastic waste.

1.5 RATIONALE AND SIGNIFICANCE OF THE STUDY

The study of the effects of mechanical characteristic of heterogeneous coastal plastic waste can be an alternative to treat such wastes by recycling it and reproduce the plastics product that has potential to be marketed in order to fulfil consumer demands. The high demands of plastics are showed by high plastic consumer over past 50 years. This is due to the abundance and low cost of plastic materials compared to the other materials.

Increasing in cost of plastic production resulting from increasing price of petroleum for petroleum-based plastics also could be the significance for this study to be conducted. Plastic wastes as raw material for reproduction of new plastic materials able to reduce the plastic manufacturing cost as well as save the natural resources. From waste to wealth, recycling is a paradigm in gaining high profits from invaluable dump and waste.

By coastal plastic waste recycling, it can preserve the environment and surroundings from plastic pollution. Since most of the plastics are non degradable; it may takes decades or even hundreds of years to degrade. At the top of that, coastal plastics are taking away intoxicating view as well as harmful to marine life if it carried away into the ocean.

CHAPTER 2

LITERATURE REVIEW

2.1 COASTAL PLASTIC WASTE

According to Andrady (1990), the characteristics differ due to the nature of the surrounding. He expected several reasons that influence the rate of degradation of plastics at sea. Firstly, high humidity is known to accelerate the rates of degradation of several classes of plastics (Davis and Sims, 1983). This may be due to the "plasticizing" action of small quantities of sorbed water leading to increased accessibility of the matrix to atmospheric oxygen or by the leaching out of stabilizing additives from the formulation.

Secondly, plastics exposed to sunlight tends to outdoors undergo a process which results in the plastic material reaching significantly higher temperatures than the surrounding air or mentioned as "heat build-up". (Summers *et al*. 1983). The higher temperatures generally result in an acceleration of light-induced degradation and may even be high enough to induce significant thermo oxidative degradation which called as photodegradation.

Finally, all materials exposed to the sea invariably undergo fouling (Fischer *et al*. 1984). In the initial stages of fouling, a biofilm forms on the surface of plastic. Gradual enrichment of the biofilm leads to a rich algal growth within it. Consequently, the biofilm becomes opaque, and the light available to the plastic for photodegradation is restricted. Thus, the rate of photodegradation at sea might be determined in part by the rate of fouling.

2.2 HETEROGENEOUS PLASTIC WASTE RECYCLING

As documented by F.P La Mantia (1993), in the case of recycling of heterogeneous plastics, the situation is still more complicated than homogeneous recycling primarily due to the incompatibility and melting point difference between different types of polymer. High temperature for processing high melting point plastic will result in dramatic degradation in low melting point plastic. Incompatibility of polymer, on the other hand, will result in poor mechanical properties. The properties of the recycled materials are in general poor and cannot be predicted only on the basis of the properties of individual components.

Improvements of the mechanical properties can be achieved by adding compatibilizing agents. In the case of blends made with the same polymer which virgin and recycled plastics are blended together, the incompatible blends can result and only small amounts of recycled material can be used to avoid drastic decrease in the mechanical properties. One of the success methods for heterogeneous plastic recycling is by reactive blending where polymers are blended in extruder with presence of compatibilizing agent. However, in recycling industry, this technique is not economically feasible.

Through a study conducted by Sadat-Shojai and Bakhshandeh (2010), recycling of heterogeneous plastic waste gives a secondary material with poor physical and mechanical properties, because of the lacking in compatibility among the various components, especially polymers existed in the waste. Even at low contents of impurity, the incompatible polymer significantly worsens the mechanical properties.

Numerous researchers suggest an alternative approach in which the other polymers exiting in recycled PVC can be miscible using a compatibilizer. In such approach, the deficiencies in the properties of the resulting polymer mixture are significantly reduced and critical properties of the final blend are then improved. Compatibilizers are a family of additives which allow for bonding of two or more incompatible polymers when blended together. Compatibilizers can be separately incorporated into the blends or generated in situ during a reactive extrusion process. In the process, theoretically, compatibilizer migrates to the interface, acting as a bridge between the two incompatible phases, reducing the interfacial tension, improving adhesion and mechanical performance, and stabilizing the blend morphology.

In a research conducted by Lebovitz, Klementina and Torkelson (2003), polystyrene and polyethylene are mixed without presence of compatibilizing agent. The first technique is mixing the two polymers in twin-screw extruder by mean of melt-mixing process. The other method is pulverisation where the final products in powder form. Through the research, it is proven that pulverisation technique yield finer dispersion of mixed polymer compared to melt mixing process. Fine dispersion of mixed polymer is important in determining the homogeneity of mixed polymer which will affect the properties of the new polymer product.

In recycling of heterogeneous plastic wastes mainly composed by PE, PET and PVC with ratio as in **Table 2.1**, by blending with the recycled polyethylene conducted by La Mantia (1993), the data as tabulated in **Table 2.2** is gained. Thus the data is compared to the mechanical properties of recycled polyethylene. It can be analysed that recycling heterogeneous plastic waste will result in almost similar mechanical properties compared to homogeneous recycling except for elongation at break.

Table 2.1: Average Composition of Mixed Plastic Waste (MPW)

Types of Plastics	Percentage of Composition (%)
Polyethylene (PE)	33
Polyvinyl chloride (PVC)	39
Polyethylene therephthalate (PET)	28

Table 2.2: Mechanical Properties of RPE and RPW

Sample	Elastic Modulus (MPa)	Tensile Strength (MPa)	Elongation at Break (%)	Impact Strength (J/m)
Recycled polyethylene (RPE)	200	10	350	450
Mixed Plastic Waste (MPW)	600	6	<2	20

A.N.M Rose et al. (2008) stated that recycle PET fibre has influence in improving the tensile properties of the composite specimen. By mixing polypropylene matrix phase with varied composition of recycle PET fibre from 0% to 10% of volume composition, it is proved that 7% of compositions of recycle PET fibre gives an increment of 9.8% compared to genuine polypropylene. It is concluded that at small amount of volume composition, PET fibre can improve the mechanical properties of the composites.

In recycling heterogeneous coastal plastic waste, in order to prevent poor mechanical properties of new plastic product, it is whether utilize compatibilizing agent in mixed plastic recycling or undergoes pulverisation technique. The addition of this compatibilizer into blending of heterogeneous coastal plastic waste or pulverisation process introduced in recycling of mixed plastic waste is expected to improve the mechanical properties of recycled coastal plastic waste.

2.3 RECYCLING PROCESS

Plastic recycling is not a new thing nowadays. Until now, there are numerous process and methods developed as well as technology invented for recycling process. In Brazil, recycling coastal plastic waste process take the similar process as in land plastic waste recycling. It is reported that plastic recycling activity grown by an average of 15% per year in Brazil. Recycling activity in Brazil almost entirely mechanical recycling (Agnelli *et al.,* 1996).Generally, the first step in mechanical recycling involves size reduction of the plastic to a more suitable form which is in the form of pellets, powder or flakes. This is usually achieved by milling, grinding or shredding (Zia et al., 2007).

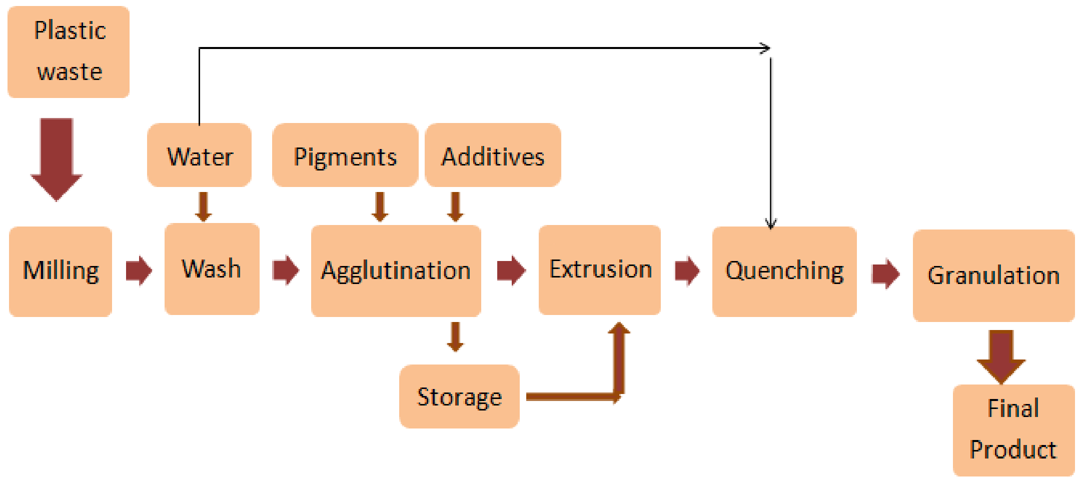

Figure 2.1: Mechanical Recycling Step as Described by Aznar *et al.*

Figure 2.1 shows the recycling route as described by Aznar *et al.* (2006), proposed by S.M. Al-Salem, P. Lettieri, and J. Baeyens (2009). The first step is cutting or shredding where large plastic parts are cut by shear or saw for further processing into chopped small flakes. Then, the shredded plastic undergoes contaminant separation to separate paper, dust and other forms of impurities from plastic usually in a cyclone. Next, different types of plastic flakes are separated in a floating tank according to their density.

Milling process take place where separate, single-polymer plastics are milled together. This step is usually taken as a first step with many recyclers around the world. The next step is washing and drying which refers to the pre-washing stage (beginning of the washing line). The actual plastic washing process occurs afterwards if further treatment is required. Both washing stages are executed with water. Chemical washing is also employed in certain cases (mainly for glue removal from plastic), where caustic soda and surfactants are used.

Next, the process proceed with the agglutination step where the product is gathered and collected either to be stored and sold later on after the addition of pigments and additives, or sent for further processing. Under extrusion process, the plastic is extruded to strands and then pelletized to produce a single-polymer plastic. Then, quenching step takes place involving cooling of the plastic by water. The plastic is then granulated and after that sold as a final product.

A.S.F. Santos *et al* (2005) proposed the typical mechanical plastic recycling in their research. Based on **Figure 2.2**, the mechanical recycling process involves identification, separation and classification of different types of plastics in first step, grinding (2); washing with or without addition of cleaning agents (3); drying (4); silos (5); agglutination (films and products with fine thickness) (6); extrusion (7) and granulation (8).

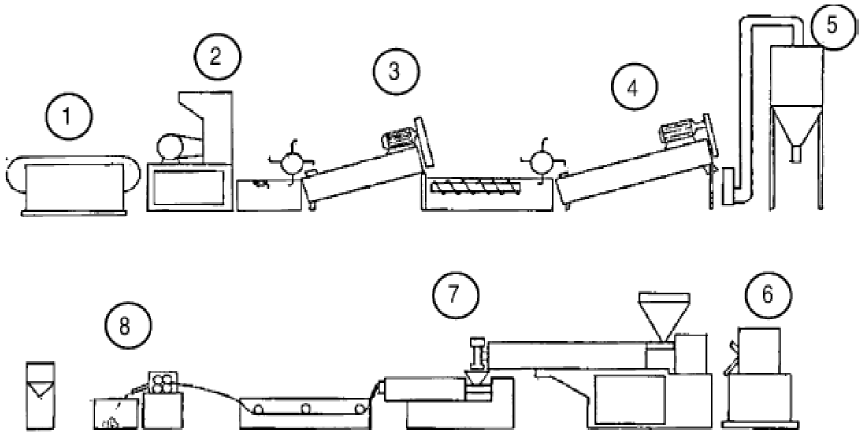

Figure 2.2: Mechanical Recycling Process Proposed by A.S.F. Santos *et al* (2005)

The process begins with collection the plastic waste, identification and separation according to the types of plastic. The large size plastic waste then is being grinded to produce small size plastic usually resulting in small flakes. The small flakes plastic waste is washed to remove dirt and then dried. The plastic then brought to the silos before undergoes agglutination process to ensure the homogeneity of the plastic. Under extrusion step, plastic is blended with or without addition of plastic additive and finally granulated for production of palletized plastic. This palletized plastic will be moulded into final desired product.

Practical Action, the Schumacher Centre for Technology and Development, United Kingdom proposed mechanical recycling for plastic recycling as in **Figure 2.3.** Plastic waste from various sources for example industrial, commercial, agricultural and municipal waste is collected and then washed to remove dirt. The plastic waste then sorted according to the types of plastic. Next, the large size plastic is being reduced to smaller size by means of process like cutting, shredding or agglomeration. Depending on technique, the plastic waste is in form of small flakes or powder.

The small size plastic is fed into the extruder, are heated to induce plastic behaviour and then forced through a die to form a 'spaghetti-like' plastic which then be cooled in a water bath. The plastic is then being pelletized to reduce the 'spaghetti' polymer form to pellets which can then be used for the manufacture of new products. For product manufacturing, there are several techniques can be applied according to desired shape of final product; extrusion, injection moulding, blow moulding and film blowing.

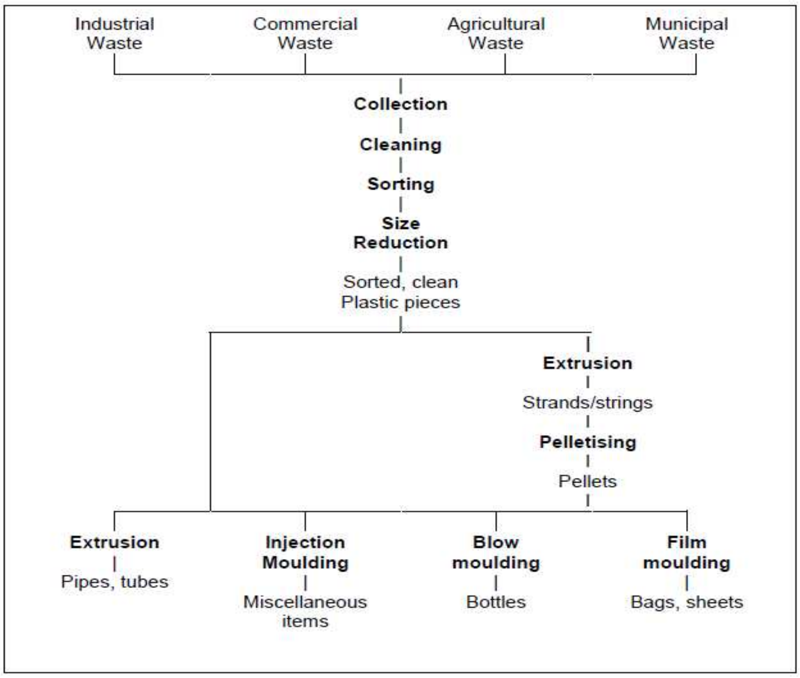

Figure 2.3: Mechanical Recycling Steps

Based on the method proposed in the study, the similar processes are applied as in recycling heterogeneous coastal plastic waste which involves the main steps; collecting of plastic waste, cleaning, identification of plastic type and sorting accordingly, shredding, extrusion, palletizing, moulding and testing the samples.

2.4 MECHANICAL TESTING

2.4.1 Tensile Strength

Tensile strength is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contract. According to Dilara and Briassoulis (1997), tensile testing is one of the most used methods in determining the strength of a material. It provides a measurement of the ability of a material to withstand forces that tend to pull it apart and to determine to what extent the material stretches before breaking.

In a tensile testing done by Abdulkadir Gu'llu', Ahmet O'zdemir and Emin O'zdemir (2006), the testing sample is produced following ISO 294 and ISO 527 specifications as in **Figure 2.2.** 5 mm/min speed of the Tensile Testing Machine is applied.

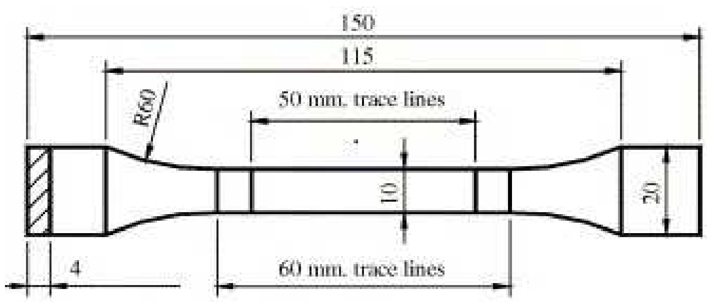

Figure 2.4: Mechanical Testing Specimen

2.4.2 Elastic Modulus

Elastic Modulus or Young's modulus is the ratio of stress to strain when deformation is totally elastic and also the measure of stiffness of a material. (Callister and Rethwisch; 2008). Elastic modulus is the ratio of stress, which has units of pressure, to strain, which is dimensionless; therefore, elastic modulus has units of pressure. According to Abdulkadir Gu'llu', Ahmet O'zdemir and Emin O'zdemir (2006), the specimen of elastic modulus is the same as in Tensile testing in **Figure 2.4.**

2.4.3 Elongation at Break

Ductility is another important mechanical property. It is a measure of the degree of plastic deformation that has been sustained at fracture. Ductility may be expressed as percent elongation. Percent elongation is elongation recorded at the moment of rupture of the specimen, often expressed as a percentage of the original length. It corresponds to the breaking or maximum load. (Callister and Rethwisch; 2008).

$$\%\mathrm{EB} = \frac{\text{fracture length} - \text{original gauge length}}{\text{original gauge length}} \times 100$$

Based on the study by Abdulkadir Gu'llu', Ahmet O'zdemir and Emin O'zdemir (2006), the specimen for elongation at break testing is the similar as in Tensile testing and Elastic Modulus testing which is in **Figure 2.4.**

CHAPTER 3

METHODOLOGY

3.1 RESEARCH FRAMEWORK

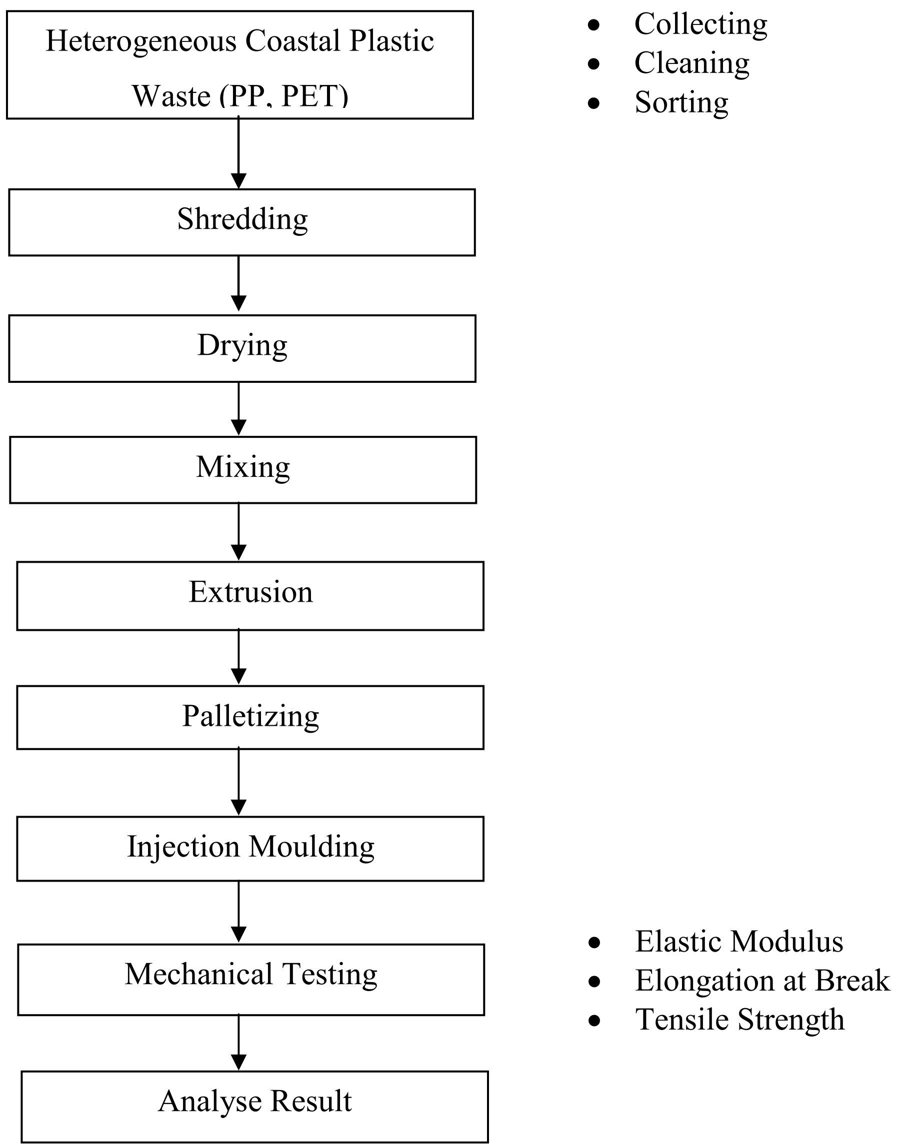

Figure 3.1: Process Flow of Plastic Recycling

3.2 PROCESS AND EQUIPMENT

Mechanical recycling of heterogeneous coastal plastic waste that applied in this study is adapted by mechanical recycling steps described by Aznar et al. (2006), proposed by S.M. Al-Salem, P. Lettieri, and J. Baeyens (2009).

3.2.1 Material Preparation

Heterogeneous coastal plastic waste is defined as plastic that exist at the coastal region; in sandy area including that floating in the sea. Sample are collected at Kuantan, Pahang coastal region and cleaned to remove dirt, residue and other contaminated material. Then, it was manually sorted according to the type of plastic. Identification of types of plastic is based on the recycling label on the plastic waste. Heterogeneous coastal plastic waste which types are Polypropylene (PP) and Polyethylene therephthalate (PET) used in the experiment with manipulated volume composition.

3.2.2 Shredding

The next step is cutting or shredding where large plastic parts are cut into small flakes. Polypropylene (PP) and Polyethylene therephthalate (PET) are crushed by using Plastic Crusher.

Figure 3.2: Plastic Flakes

Figure 3.3: Plastic Crusher

3.2.3 Drying

Small plastic flakes are dried to remove water and minimize the moisture in the oven before it has been mixed. The plastic flakes are left in the oven for five to six hours at the temperature of 50 °C.

Figure 3.4: Oven Used for Drying Purpose