OPTIMIZING OF INJECTION MOULDING PROCESS PARAMETERS FOR RECYCLED PLASTIC MATERIAL USING TAGUCHI METHOD

NIK MIZAMZUL BINTI MEHAT

UNIVERSITI SAINS MALAYSIA
2010

OPTIMIZING OF INJECTION MOULDING PROCESS PARAMETERS FOR RECYCLED PLASTIC MATERIAL USING TAGUCHI METHOD

by

NIK MIZAMZUL BINTI MEHAT

Thesis submitted in fulfilment of the requirements for the degree of Master of Science

Mac 2010

ACKNOWLEDGEMENT

BISMILLAHIRRAHMANIRRAHIM

In the name of Allah, the most graceful and the most merciful. Alhamdullilah after almost two and half years, I managed to complete this thesis. The research work presented in this thesis has been carried out at the School of Mechanical Engineering, Universiti Sains Malaysia (USM). Many people have supported this research and it is a pleasure to acknowledge all these peoples.

First of all, I would like to express my deepest appreciation and special thanks to my supervisor, Dr. Shahrul Kamaruddin for his excellent supervision, motivation and encouragement, thoughtful ideas, continuous guidance and support during this research.

I would like also to express my gratitude to the manufacturing laboratory technician, Mr. Abdul Hamid Fahmi and applied mechanic technician, Mr Fakruruzi Fadzil from the School of Mechanical Engineering and Mr Mohd Rokman Mat Nasir from the School of Material and Mineral Resources Engineering, Universiti Sains Malaysia (USM) for their generous technical assistance, support and friendship throughout this research.

A special thank you is offered to my colleagues at Kolej Kemahiran Tinggi MARA Balik Pulau, Pulau Pinang especially all my friends in Mould department, Mrs Zariwani Zakaria, Mrs Nazimah Che Aziz and Ms Sofiah Iskandar for their help in some technical issues and in the correction of my thesis. Also sincere thanks to my postgraduate sisters at School of Mechanical Engineering, Ms Izatul Hamimi, Ms Hasnida, Ms Ding Siew Hong, Ms Normariah and my friend Ms Yushazaziah, who assisted me in my efforts towards completing this research. Their kindness, continuous support and encouragement are always in my heart.

Finally, heartfelt thanks my family for the continuous blessing and 'doa', understanding, support and encouragement they have given to me during my research. Thanks to Allah for blessing me with the wonderful gift of life.

TABLE OF CONTENTS

APPENDIXES

PUBLICATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	Percent
°C	Degree Celsius
C.F	Correction factor
f	Degree of freedom
F	Variance ratio
MSD	Mean squared deviation from the target value of the quality characteristic
n	Total number of experiment
P	Percentage contribution
S	Factor sum of squares
s	Second
S_T	Total sum of squares
T	Total mean signal to noise ratio
V	Variance
Y_{opt}	Estimated value of the quality characteristics selected at optimum condition

LIST OF ABBREVIATION

ABS	Acrylonitrile-butadiene-styrene
ANOVA	Analysis of variance
APME	Association of Plastic Manufacturers in Europe
CFA	Chemical foaming agent
CRTM	Compression resin transfer moulding
DOE	Design of experiment
DOF	Degrees of freedom
EFB	Empty fruit bunches
EPDM	Ethylene-propylene
GAIM	Gas assisted injection moulding
GPS	General purpose polystyrene
HDPE	High density polyethylene
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
MAPP	Maleic anhydride grafted polypropylene
MFI	Melt flow index
MPa	Mega Pascal
MPI	Moldflow Plastic Insight
OA	Orthogonal array
PA66	Polyamide (Nylon) 66
PBT	Polybutylene terephthalate
PC	Polycarbonate
PET	Polyethylene terephthalate

POM	Polyoxymethylene
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
rHDPE	Recycled high density polyethylene
rONP	Recycled old news paper
RTM	Compression resin transfer moulding
S/N	Signal to noise
STL	Stereo-lithography
UHMWPE	Ultra-high molecular weight polyethylene
WGRT	Waste ground rubber tire
WPC	Wood plastic composite
WSD	Wood saw dust

LIST OF APPENDIXES

LIST OF PUBLICATIONS

1. Mehat,N.M. and Kamaruddin,S. **Warpage Minimization in Injection Thermoplastic Parts Using Taguchi Method and Moldflow Plastic Insight (MPI)**. Proceeding of 8th Mechanical Research Engineering Colloquium, 27-28 August 2008, Penang, Malaysia.

2. Mehat,N.M. and Kamaruddin,S. **Prediction and Optimization of Shrinkage in Plastic Molded Parts Due to Volumetric Shrinkage by Taguchi Method and Moldflow Plastic Insight**. Proceeding of 2nd International Conference On Science and Technology, 12-13 December 2008, Penang, Malaysia.

3. Mehat,N.M. and Kamaruddin,S. **Making the Perfect Plastic Molded Parts: The Integration Between Taguchi Optimization Method and Moldflow Plastic Insight (MPI).** Proceeding of International Conference On Advances In Mechanical Engineering, 24-25 June 2009, Penang, Malaysia.

4. Mehat,N.M. and Kamaruddin,S. **Application Of Taguchi Method On The Optimal Processing Parameters for Recycled Polypropylene Products.** Proceeding of 9th Mechanical Engineering Research Colloquium, 30 September- 2 October 2009, Penang, Malaysia.

5. Mehat,N.M. and Kamaruddin,S. **Optimization of Mechanical Properties of Recycled Polypropylene Products Using Taguchi Method.** Proceeding of Malaysia Polymer International Conference, 21-22 October 2009, Putrajaya, Malaysia.

PENGOPTIMUMAN PARAMETER PROSES SUNTIKAN ACUAN BAGI PLASTIK KITAR SEMULA MENGGUNAKAN KAEDAH TAGUCHI

ABSTRAK

Pengeluaran produk plastik dalam skala yang besar di era ini, menyebabkan pelbagai alternatif dirangka untuk mengitar semula mahupun memanfaatkan bahan-bahan tersebut memandangkan produk plastik tidak terurai secara semulajadi. Suntikan acuan merupakan salah satu teknik pemprosesan plastik yang meluas dan banyak digunakan bagi menghasilkan produk plastik. Teknik ini juga membolehkan plastik kitar semula digunakan bagi menggantikan penggunaan bahan plastik mentah. Namun, produk plastik yang dihasilkan menggunakan bahan plastik kitar semula mempunyai beberapa kelemahan terutamanya dari aspek kekuatan mekanikal. Ini mengekang penggunaan bahan plastik kitar semula sebagai bahan utama dalam pengeluaran produk plastik di pasaran. Salah satu penyumbang kepada permasalahan ini adalah variasi di dalam parameter pemprosesan. Oleh itu, pengawalan ke atas parameter pemprosesan yang mempengaruhi proses pengeluaran plastik produk yang efektif amatlah diperlukan dengan menggunakan kaedah pengoptimuman yang sesuai. Oleh kerana itu, tujuan utama penyelidikkan ini dilaksanakan adalah untuk mengkaji impak parameter-parameter suntikan acuan terhadap kekuatan mekanikal bagi produk plastik kitar semula yang dihasilkan dalam pelbagai komposisi.

Bagi mencapai objektif tersebut, Moldflow Plastic Insight (MPI) merupakan medium penting bagi menjalankan proses simulasi pada peringkat awal dengan menyepadukan L_{18} tatasusunan ortogon Taguchi sebagai rekabentuk eksperimen. Parameter-parameter proses yang memberi impak kepada kekuatan mekanikal bagi

produk plastik yang dihasilkan ditentukan di peringkat simulasi ini. Berdasarkan keputusan yang diperolehi menerusi eksperimen simulasi, produk plastik kemudiannya akan dihasilkan dalam eksperimen utama dengan kaedah suntikan acuan. Di dalam penyelidikkan ini, eksperimen utama dikendalikan pada dua fasa. Pada fasa pertama, produk plastik dihasilkan menerusi suntikan acuan menggunakan campuran PP mentah dan PP kitar semula di dalam pelbagai komposisi dengan mengadaptasikan L_9 tatasusunan ortogon Taguchi sebagai rekabentuk eksperimen. Kekuatan mekanikal bagi produk plastik yang dihasilkan diukur berdasarkan modulus dan kekuatan lenturan dan mampatan produk tersebut. Tidak hanya menfokuskan kepada kriteria kualiti tunggal, penyelidikkan ini juga mengetengahkan penggabungan dua kriteria kualiti untuk dikaji serentak. Pendekatan ini memberi dimensi baru ke arah penghasilan produk plastik yang lebih berkualiti. Manakala fasa kedua eksperimen utama akan memfokuskan kesan penambahan HDPE yang dikitar semula terhadap campuran PP kitar semula dan PP mentah tersebut. Perkaitan kesan penambahan ini terhadap kepelbagaian nilai indeks aliran leburan (MFI) serta kekuatan mekanikal produk yang dihasilkan seterusnya dikaji.

Daripada analisis dan keputusan yang diperolehi daripada eksperimen-eksperimen yang telah dijalankan, parameter pemposesan yang dikenalpasti memberi kesan yang sangat dominan ke atas sifat-sifat mekanikal produk yang dihasilkan sama ada daripada eksperimen simulasi atau eksperimen utama adalah suhu lebur, masa padatan dan masa suntikan. Manakala dari perspektif kitar semula, kehadiran PP dan HDPE yang dikitar semula ini memberi impak ke atas perubahan sifat-sifat mekanikal bahan mentah. Namun, pendekatan menggunakan kaedah penggabungan dua kriteria kualiti untuk dikaji serentak ternyata memberi kesan peningkatan kepada modulus dan kekuatan lenturan dan mampatan produk tersebut terutamannya produk yang dihasilkan menggunakan 100% PP kitar semula. Menerusi proses pengoptimuman menggunakan kaedah Taguchi, produk yang dihasilkan dengan menggunakan plastik yang dikitar semula mempamirkan sifat-sifat mekanikal yang menunjukkan plastik kitar semula ini berpotensi menggantikan bahan mentah utama. Dengan itu, permintaan yang tinggi ke atas sumber semulajadi serta penggunaan tenaga yang tinggi dapat dikurangkan. Malah permasalahan yang timbul akibat pembuangan sisa plastik yang memberi kesan yang negatif terhadap alam sekitar juga dapat diatasi.

OPTIMIZING OF INJECTION MOULDING PROCESS PARAMETERS FOR RECYCLED PLASTIC MATERIAL USING TAGUCHI METHOD

ABSTRACT

A large amount of plastic parts presently produced, makes it imperative to search for alternative for recycling or making use of these materials, since they are not biodegradable. Injection moulding, one of the most prevalent plastics processing techniques facilitates these recycled materials to be substituted for virgin material in producing plastic parts. However, the deterioration in mechanical properties of the part made of recycled plastic is the major drawback that limits the usage of recycled plastic. One of the foremost causes is variation in processing parameters. It is of critical importance to effectively control all the influencing processing parameters during the manufacturing process by an appropriate optimization method. Therefore, the main goal of conducting this research is to primarily investigate the effects of injection moulding parameters on the mechanical properties of plastic part made of recycled plastics in various of compositions.

In order to achieve the goal, the preliminary experiment is conducted by using Moldflow Plastic Insight (MPI) integrated with L_{18} Taguchi orthogonal array (OA). The significant processing parameters obtained from the preliminary experiment are then used to conduct the principal experiment. In this research, the principal experiment is conducted in two phases. In the first phase of principal experiment, the parts made of virgin and recycled PP in various compositions are produced using injection moulding by adopting L_9 Taguchi OA. The mechanical properties of the part are measured in terms of modulus and strength of flexural and compressive respectively. Instead of focusing only on single quality characteristics, this research also proposed the combination of quality characteristics to be studied

by combining the modulus and strength of flexural as well as modulus and strength of compressive. The optimal processing parameters and the significance of each processing parameters on the mechanical properties of the part produced are determined in this phase. For the second phase of principal experiment, the impact of recycled HDPE addition in various composition on the mixtures of recycled and virgin PP has been explored by correlated the various values of melt flow index (MFI) and mechanical properties exhibited by the part produced.

From the experimental analysis and results, it is shown that the most significant processing parameters affecting the mechanical properties of the part produced either in simulation or principal experiment is melt temperature, packing time and injection time. In the recycling point of view, the addition of recycled PP and HDPE in the compositions yet has changed the mechanical properties of the virgin material. However, the approach of combination of quality characteristics have improved the modulus and strength of flexural and compressive particularly for the part made of 100% recycled PP. From the Taguchi optimization processes, the mechanical performances exhibited by the part made of recycled plastic addition have shown that these recycled materials are potentially substituted for virgin material. Therefore, the demand of natural resources and energy consumption due to virgin material production can be reduced and environmental problems due to plastics disposal can be diminished as well.

CHAPTER 1

INTRODUCTION

1.0 Overview

This chapter is divided into six sections. The first section gives an overview of the research background followed by product quality optimization in second section. The next following section discusses on the research problem statement. The fourth section deals with the research aim and objectives, and research scope in fifth section. Lastly, the final section is highlighting on the thesis outline.

1.1 Research background

The development of plastics and their associated processing techniques has been a phenomenal episode in the history of materials science. Due to the wide spectrum of properties available, plastics have become one of the most sought after materials in the world today. The ubiquitous presence of plastics can be found in many applications, range from sophisticated parts, such as prosthetic hip and knee joints, to disposable food utensils and from household storage containers to auto parts and accessories to casual furniture, plastic has provided an affordable yet sturdy material for many of the items people use every day. One of the reasons for the great popularity of plastics in wide variety of industrial applications is the tremendous range of properties exhibited by plastic and their ease of processing. Furthermore, it is low cost, strong but lightweight, resistant to chemicals, sunlight, and bacteria, and are thermally and electrically insulating. By these advantages, plastics had become an extreme versatile material in replacing the primary materials used for consumer parts such as woods and metals.

Plastic materials can be produced by several of processing techniques. One of the most widely plastic processing techniques employed in producing plastic products is plastic injection moulding. Another plastic processing techniques including gas assisted injection moulding (GAIM), rotational moulding, transfer moulding, compression resin transfer moulding (RTM), compression resin transfer moulding (CRTM) and etc. With these various processing techniques, adding to the versatility and adaptability of plastics to meet a given application have been the basis of the considerable growth in their consumptions, which is expected to continue to increase. The study carried out by Meran et al (2008) clearly shown the rapid increasing in the consumption of plastics. The quantity of plastics, excluding rubber and fibre, produced in the world in 1930's was 100,000 tons. This amount reached 25 million tons in 1970's. Along with new development in technology, the production of the plastics reached 90 million tons in 1990's. In the year 2005, this number exceeded 500 million tons. The statistics are very clear to demonstrate that millions tons of plastic are produced and consumed in the world every year.

Unfortunately the increasing of plastics consumption significantly contributes to the large volume of plastic disposal. The majority of these plastics waste end up in landfills. Since these plastic materials are non-degradable, the decomposition process will take a long time to break down, possibly up to hundreds of years. This will result in serious pollution problems. In addition, the plastics production requires significant quantities of resources, primarily fossil fuels, both as a raw material and energy for the manufacturing of the plastic itself. It is estimated that 4% of the world's annual oil production is used as a feedstock for plastics production and an additional 3-4% during manufacturing process.

According to these facts, the recycling of the plastic material and the usability of the recycled materials are gaining significance. Recycling of plastic is very important as the scrap or plastics waste can be recovered and processed into useful parts. Making use of waste plastics is an important element in the economy of all countries. The recycling is one of the most effective methods for diminishing the negative effects of waste plastics on environment. As the plastic material is made from oil which will cause the depletion of this limited resource, with the recycling of plastic the oil can be saved and can be consumed for extended period of time.

1.2 Part quality optimization

Either the manufacturing of plastic part using the virgin material or recycled material, the most vital aspect that should be considered is the plastic part quality itself. There are many factors affect the plastic parts quality produced by means of injection moulding. Factors such as materials selection, part and mould design and processing parameters are example of factors that might have the influence on the appearance of the plastic parts or relating with mechanical properties (Min, 2003).Without the right combination of material, part and mould design and processing parameters, a multitude of manufacturing defects can occur, thus incurring in high cost. In fact, the most innovative part and mould design with a very resourceful material alone cannot comprise for fiscal plastic part manufacturing if inappropriate processing parameters selection are practiced.

Generally, plastic injection moulding (PIM) process is quite complex involving many variables of processing parameters that can be categorized into pressure, temperature, time and distance. Each of these processing parameters is dependent on the other and by changing one of it, one or all of the parameters will be affected. Any incoherent processing parameters during the manufacturing process either can lead to significant improvement of the injection-moulded plastic parts or degradation of accuracy, shape of the final parts, surface finish, and other part characteristics especially relating with mechanical properties.

The advanced development of computer technology including various simulation packages such as injection moulding flow analysis simulations have assisted the designers/engineers to predict and overcome the problems in selecting the appropriate processing parameters. Thus, relying on experiences, intuition, or trial and error in obtaining information regarding to the processing parameters can be avoided (Huang and Lin, 2008; Cardozo, 2008). In addition, the existence of simulation packages can support manufacturer to predict and overcome the problems in selecting the optimum processing conditions. The implementing these software packages in the earliest stage of manufacturing a plastic injection moulded parts not only reducing the time consuming and cost of manufacturing but also provides designers/engineers with visual and numerical feedback of the part behaviours.

1.3 Problem statement

Injection moulding, one of the most prevalent plastics processing techniques facilitates the recycled plastics to be substituted for virgin material in producing plastic parts. However, the deterioration in mechanical properties of the part made of recycled plastic is the major drawback that limits the usage of recycled plastic. The recycled plastics have not yet proved themselves to be a continuous and reliable source of raw materials by means of mechanical properties. This is due to the presence of impurities in the recycled material that remained from crushing and reheating process (Cruz and Zanin, 2004). Even though it is impossible to produce plastic parts that made of recycled plastic that have similar mechanical properties as virgin form, but it is possible to find the optimum point of mechanical properties of these recycled material by controlling all the significant processing parameters during the manufacturing process.

As stated in the previous section, the processing parameters do play a crucial role in producing a good quality of plastic parts especially in relating with mechanical properties. It is of critical importance to effectively control all the influencing processing parameters during the manufacturing process by an appropriate optimization method. The issues of optimizing the processing parameters have become significant among the manufacturers and researchers, particularly when it involves the recycled material. But the question is how the processing parameters can be optimized and which appropriate methods can be adopted as well. In the actual operations, normally the processing parameters are often selected from references or handbooks, and then adjusted subsequently by a trial and error approach. This is a common practice that has been adopted in industry for economic reasons; mainly the results are quite satisfactory. Even though this approach has it merits, it consumes and wastes lots of materials. Besides it is a costly and time consuming, as well as highly dependent on the experience and intuition of the moulding operators.

One of the solutions is adopting the simulation packages in early manufacturing stage. But utilizing these simulations technology enhancement single-handedly, the optimization of processing parameters still has to adopt trial and error procedure. In fact, in order to determine the optimal processing parameters in producing a good quality of plastic part, the simulation model must be simulated so many time if the experiment single-handedly done. As a result, the experimental procedures are cumbersome and chaotic.

Therefore, as an initial effort towards filling this void and address the stated problems, in the present work, the Taguchi method will be integrated in conducting all the experiments either in simulation or principal experiments to determine the best range of designs for quality and performances. The emphasis will be given on the impact of processing parameters on the mechanical properties of the part produced particularly when it involves recycled plastics. The feasibility of the substitution of recycled plastic for virgin plastic based on mechanical properties point of view will also be investigated.

1.4 Research aim and objectives

The emphasis of this research is to study the influence of injection moulding process parameters on quality of plastic parts that made of virgin and recycled material based on mechanical properties point of views. The Taguchi method, the technique that have been utilized widely in engineering analysis to optimize the performance characteristic within the combination of design parameters will be adopted to layout all the experiments.

The objectives of the research are as follows:

1. To analyze and select the effective injection moulding process parameters on mechanical properties of plastic part using simulation package in preliminary experiment integrated with Taguchi optimization method

2. To investigate the impact of injection moulding process parameters on mechanical properties of the part made of virgin and recycled plastic in various compositions using Taguchi optimization method.
3. To study the effects of adding the recycled plastics on the mechanical properties of the part produced associated with melt flow index (MFI).

1.5 Research Scope

With all the processing techniques used to produce plastic part, injection moulding is given significant attention in this study. The plastic part that has been investigated in this study namely ‘toolbox tray’ will be injected by the injection moulding machine. Even though there are several factors affected the final quality of the plastic part, such as mould and part design as well as processing parameters, this study emphasize only on optimizing processing parameters that affected the mechanical properties of the part. The effects of part and mould design will not taken into consideration in carrying out this study as the part and mould design are already established.

There are two main types of plastics including thermoplastic and thermosets. Thermosets will not be dealt with in this research. Among the different types of thermoplastics, this research will be limited to polypropylene (PP) and high density polyethylene (HDPE). According to the survey conducted in the plastic manufacturing companies in Malaysia, Wahab et al (2007) reported that the consumption rate for PP and PE is the highest among the resin types. The rapid consumption of the resins in producing plastic parts will result in high volume of plastic disposal in the landfills. This obviously will have a negative impact to the environment since the plastic wastes are not biodegradable. Therefore, this study will focus on feasibility of the substitution of recycled plastic particularly recycled PP and HDPE for virgin plastic based on mechanical properties point view. The mechanical properties of the virgin/recycled plastic parts is evaluated due to modulus and strength of flexural and compression respectively.

Another aspect that highlighted in this study is the importance of implementing the Taguchi method as the design of experiment to optimize the processing parameters, enhancing the part quality and reducing the cost as well. This method will be adopted in simulation and principal experiment as well.

1.6 Thesis Outlines

The overview of this thesis is as follows; Chapter 2 provides a literature review of the related subjects. For example, this section emphasize in the studies carried out by other researchers relating with the advancement of simulation software and the implementing of Taguchi method in producing good quality of plastic product and the scenario of utilizing the recycled plastic material as raw material in producing parts. The design of experiment used in this research will be discussed in Chapter 3. The aspect of materials and testing specimen preparation, the procedure of adopting Taguchi method in simulation and principal experiment, the testing procedure and others will be discussed in this chapter. Details can be viewed in Chapter 3. The following Chapter 4 will discuss the results obtained from the simulation and principal experiment. Finally, Chapter 5 addresses the conclusion and recommendations for the future research.

CHAPTER 2

LITERATURE RIVIEW

2.0 Introduction

This chapter will be commenced with plastic overview in the early discussion. This section discusses on plastic classification including thermoplastic and thermoset. It will followed by the discussion on plastic recycling highlighting in mechanical recycling approach as well as the limitations usage and enhancement of recycled plastics. General overview of plastic processing techniques will be further discussed and injection moulding will be the main focus in this discussion. Under the factors that affecting the quality of injection moulded part, the elaboration on the effect of processing parameters, part and mould design, and materials selection on the quality of the final parts will be included. In order to optimize all the factors affected the final quality of the part produced, the subsequent section will expand in details two approaches adopted in this research which are simulation and Taguchi method approach. In the Taguchi method approach section, overview of this method will be given. A review on previous works relating with these approaches will be the next focus. Findings from the literature review will then be discussed at the end of this chapter.

2.1 Plastic overview

Most plastics are made by using the hydrocarbons from natural resources such as oil and natural gas and also other chemicals. In technical terms, plastics are produced by chemical bonding of monomers into polymers. The size and structure of the polymer molecule determines the properties of the plastic material allowing huge variety and versatility (Potsch, 2008).

Based on the type of chemical reaction (polymerization) that link the molecules together, plastics are classified as either thermoplastics or thermosets. Thermoplastics are linear or branched polymeric materials that soften when heated and resolidified when cooled. Thermoplastics are available in a variety of types and grades having properties that range from rigid to elastomeric. It can be described as amorphous, semi-crystalline or liquid crystalline. In theory, the processing of thermoplastics involve only physical changes (e.g. phase changes), therefore the materials should be readily recycled. Thermoplastics are recyclable; however, it is very likely that at least some small degree of chemical change (e.g. oxidation, thermal degradation) will take place during the processing.

The other category of plastic is thermosets, often is processed in a similar manner to thermoplastics where this material is soften when heated and resolidified when cooled. However, once formed and cooled it cannot be reprocessed. Unlike thermoplastics, thermosets are not directly recyclable. Therefore, they cannot be recycled in the same way as thermoplastics. This is because they are chemically cross linked by a process termed ‘curing’. The result is highly dense molecular network making the material stiff and brittle. Thermosets are often used where their strength and durability can be utilized. Common thermoset are epoxy, melamine-formaldehyde resin, phenolics, polyurethane (PU) and unsaturated polyester.

With the great characteristics exhibited by these thermoplastic and thermoset, plastics have become one of the most important and versatile materials nowadays. According to Spokas (2008), plastics consumption began several decades ago. It would be hard to imagine a modern society today without plastics. Plastics have found a myriad of uses in fields as diverse as household appliances, packaging, construction, medicine, electronics, and automotive and aerospace component. The reason for its success in replacing traditional materials such as metals, woods and glass in such a diverse range of applications is the tremendous range of properties exhibited by plastics and their ease of processing. Furthermore, it is low cost, strong but lightweight, resistant to chemicals, sunlight, water and bacteria, and a good thermally and electrically insulator (Ozcelik and Sonat, 2009).

These intrinsic properties have been the basis of the considerable growth in plastic consumptions, which is expected to continue to increase. To get an idea of the plastic consumption, Achilias et al (2007) have stated that the annual total consumption of plastic for Western European in 2003 was 48.8 million tonnes corresponding to 98 kg per capita. Compared to a decade before, in 1993, the plastic consumption was only 64 kg per capita. The plastic consumption in Malaysia on the other hand, Wahab et al (2007) reported that the industrial sector that consumes the most plastic materials is the electrical and electronics sector. From the survey that has been conducted in plastic manufacturing companies, the consumption rate for poly-olefins (PP and PE) is the highest among the resin types. The continued increase in the use of plastics has led to an increasing amount of plastic ending up in the waste stream.

To show the extend of waste being created from plastic, Burgiel et al (1994) have stated that, a city in an emergent country with a population of three million inhabitants produces around 400 tonne of plastic waste per day . The increasing amount of plastic waste generated mostly contributed from used packaging. According to Selke (2002), the total amount of plastics in the United States municipal solid waste stream is around 10%; from this amount 44% is from containers and packaging. In Europe between 1997 and 2002, the growth in packaging waste generation was increased by 10% to arrive at an average of 172 kg/capita in 2002 (European Environmental Agency, 2005). On the other hand, a total of 19.2 million tons of plastic wastes were generated in 2001 in the United States, over 40% weigth of which was polyethylene (US Environmental Protection Agency, 2002).

The increasing of these plastics waste will result in serious pollution problems. This is due to some of the plastics are non degradable, the decomposition process will take a long time to break down, possibly up to hundreds of years. One possible solution for reducing the impact is through recycling especially the thermoplastics. As mentioned earlier, these materials can be reprocessed and hence recycled by re-melting them.

2.2 Plastic recycling

Plastic recycling is the process of reprocessing used scraps and waste plastics into new plastic material/part. Generally, the plastics waste can be categorized into two types; post-consumer waste and production scrap or also known as post-industrial scrap. Post-consumer recycling is associated with the collection and reuse of discarded plastic items from home use, including end-of-life electronics (such as personal computers, copier, ink and toner cartridges), phones, plastic food and beverage containers, carpeting, home appliances, toys and also automotive parts. These types of plastic waste are more difficult to recycle because of the different plastic types mixed in and might comprise unique blends and fillers. On the other hand, the post-industrial recycling process refers to polymer scrap from a polymer processing facility, which is sent to a recycling facility where the material is sorted and processed by grinding. These types of plastic waste can include runners and sprues from injection moulding, trim, product overruns, and quality rejects. Another example for this post-industrial plastic scrap in extrusion processes, whereby this process generate scrap in the form of fibre, sheet, film and process scraps including blocks of extrudate at the beginning and end of a run. Post industrial scrap may be homogenous and relatively clean, but not clearly identified by polymer type.

According to Scott (2000), plastic waste management can be done by three different approaches including the mechanical recycling, energy recovery and biological recycling. Among the three approaches of plastic recycling, the mechanical recycling is the most popular recycling technique (Poulakis and Papaspyrides, 1997; Fortelny et al, 2004) and will be the main focus in this research. This mechanical recycling is a technique which is similar to procedures used to recover materials suitable for second use. As noted by Brandrup et al (1996) , to be economical, a mechanical recycling procedure must be designed in such manner that the amount of energy needed to produce the virgin material and the energy to dispose of the material must be equal to the energy in order to recover the post-consumer materials as well as the energy during the reprocessing itself. Generally, there are two types of mechanical recycling as tabulated in Table 2.1.

Table 2.1 Type of mechanical recycling

Types of mechanical recycling	
Primary Recycling	'In-house' reprocessing of production waste
Secondary Recycling	Mechanical recycling of single or mixed plastic materials from external sources

(Source : Goodship, 2007)

In the plastics industry it has long been a common practice to reprocess waste plastic arising from day to day production. This in-house recycling, known as primary recycling, makes economic sense as it reduces both production waste and raw material. For example, in injection moulding, by regrinding the start-up waste and production waste such as rejects parts, can be fed directly back into the machine. In Malaysia for example, the consumption of recycled materials is high among the local manufacturing companies. Approximately 80% of the companies practice the plastic recycling which about 20% of these companies conducted in-house recycling due to cost savings (Wahab et al, 2007).

On the other hand, for the post-consumer waste the situation is slightly different and greater effort may be required on the part of the re-processor to separate the waste, which known as secondary recycling. For the secondary recycling, the process begins with sorting the plastic waste according to polymer type and/or colour. This sorting process can be done automatically by various techniques including X-ray, fluorescence, infra red and near infra red spectroscopy, electrostatics and floatation (Zhang and Forssberg, 1997; Kang and Schoenung, 2005). Once the plastic waste has been sorted it is either melted directly or moulded into a new shape (melt – processed), or melted after being shredded into flakes and then processed into granules called recyclate.

If these recyclates produced by the mechanical recycling has the same functional properties as the comparable virgin material, this recovered recyclate can replace the virgin material as raw material in producing new plastic parts. Under these circumstances, mechanical recycling is the most energy efficient of the various recycling option as this approach requires the least amount of energy and also has the lowest emissions of pollutants. All these great advantages offered by mechanical recycling can be referred to Dodbiba et al (2008).

Although the recycling approaches for plastics waste has been progressively improved but the fraction of plastics that end up in a landfill is still increasing

(European Environmental Agency, 2005). The municipalities are becoming concerned about the 25% increase in plastic waste generation per year while the landfill area is only increasing at a 7.5% annual rate. Of the plastics waste, high density polyethylene (HDPE) and polypropylene (PP) contribute the largest volume followed by polyethylene terephthalate (PET), polystyrene (PS) and low density polyethylene (LDPE) in the landfill (Ashori and Nourbakhsh, 2009). As stated by Scott (2000), by the year 2015 there will be no disposal options for plastic waste. In fact only a small percentage of plastics are recycled by re-melting and shaping into new parts according to the Association of Plastic Manufacturers in Europe (APME). This is due to the economic and logistic reasons, the limitation usage as well as the lack of knowledge about the quality and durability of these recycled plastics.

2.2.1 The limitations usage of recycled plastics

Even though the practice of using recycled plastics reduced the consumption of virgin materials, it is still have the limitations in usage. The vital constraint on the use of recycled plastics is concern with the decreasing performance of the physical and mechanical properties of the parts produced. As been stated by Scott (2000), compared to glass and metal, which can be recycled into part with properties essentially similar to those of the primary materials, each time plastics are reprocessed, it lose some of the physical and mechanical properties because of peroxidation. This deterioration of the physical properties and mechanical performance of recycled plastics is due to the irreversible chemical changes that occur in the plastic structure during its processing and lifetime (Kartalis et al, 2000, Bonelli et al, 2001)

The other significant aspect that limits the usage of recycled plastic is related to the contamination of the material itself. The contamination is due to the repeated processing of the material at high temperature. The contaminations include barrel residue of other thermoplastic, dirt particles, grease etc. This has resulted in the thermal and mechanical degradation and the subsequent loss of properties of the material (Pawlak et al, 2000).

Thermal degradation is another factor that limits the recycled plastic usage. This factor is important for recycled plastics as it go through a successive cycles of high and low temperature (Navarro et al, 2003). Thermal degradation generally involves changes to the molecular weight of the plastic which will have an effect on melt flow index (MFI) as can be viewed in Phuong et al (2008). Thermal degradation also will have an effect on the typical property changes. The typical property changes including reduced ductility and embrittlement, chalking, colour change, cracking, and decreasing in thermal stability.

Apart from thermal and mechanical degradation occurrence of repeating processing at high temperature, blending the recycled plastic material with virgin material in producing a good quality part is not a straightforward procedure. This is due to the thermodynamic immiscibility of most plastics (Utracki, 1990; Zenkiewicz and Kurcok, 2008). For example, even though PE and LDPE have been grouped under the generic term “commodity polyolefins”, both plastics and other polyolefins are somewhat immiscible. The adhesion between the individual molecules of these polymer blends is too low that has limited the application of the blending for producing parts. In fact, in many cases, insufficient mechanical strength of the recycled material is an unfavourable resulting from the thermodynamics immiscibility phenomenon (Albano et al, 2000).

On the other hand, parts made from recycled plastics are often cheap, having a moderate quality and simple in design. It is because the degradation of thermal properties in recycled plastics has affected the surface appearance and the aesthetic characteristic of the part. Thus many designers are hesitating of using the recycled plastic as the part produced might not be accepted by the market (Avila and Duarte, 2003; Sanchez- Soto et al, 2008). With all the limitations of the usages of recycled plastic discussed, many studies have been carried out in order to overcome those impediments. Most of the works are trying in findings ways substituting of recycled plastics with virgin materials in producing new plastic parts. The works are discussed as follows.

2.2.2 Enhancing the recycled plastics

As been discussed in the previous section, even though the recycled plastics have major limitations, it has the significant possibilities to be the substitute of the virgin plastics in producing new plastic parts. In order to impart certain specific properties and improve the limitations, the recycled plastics are generally compounded with small amounts of some chemical substances called additives. Such work can be found in Tzankova Dintcheva et al (1997), Aurrekoetxea et al (2001) and Kukaleva et al (2003). These additives modify and improve certain characteristics such as stiffness. On the other hand, the used of additives also improve the impact strength of the blending. This can be viewed in Czvikovszky (2003) and Zenkiewicz and Dzwonkowski (2007). Beside these characteristics, col**o**ur, weather ability, flammability, resistance for electrical applications, and ease of subsequent processing also can be improved by compounding the recycle plastic with additive. The additives include processing fillers or reinforcement, plasticizers, stabilizers, antioxidants, colorants/pigments, flame retardants, internal or external lubricants, other polymer or any number of other organic/inorganic additives used alone or in combination. However, their introduction normally leads to an increase in the cost of the material (Boldizar et al, 2000; Miller et al, 2001; Ramirez-Vargas and Sandoval-Arellano, 2006)

Since this research is focusing on polypropylene (PP) and high density polyethylene (HDPE) a reviewed of the works done in relation to improving and upgrading these recycled plastics will be further explored.

- **Polypropylene (PP)**

The use and demand of polypropylene (PP) in the plastic industry is increasing at a very fast pace. According to Mleziva and Snuparex (2002), PP global production reaches about 30 million tons yearly and the expected annual growth is 7%. The value is increasing year by year. In 2000, PP represented 23% of the thermoplastic consumed in Western Europe. Its sales in tonnage is the third most important amongst plastics in the world (Zebarjad et al, 2006). This polymer is a thermoplastic and can be heated and melt within minutes and moulded into a variety of shapes and sizes with great ease. Indeed PP can be produced from low-cost petrochemical raw material, making it an inexpensive thermoplastic, relative to others. This material is widely used because of the versatility in its usage, easy processing and their excellent properties; light but strong and durable, good electrical insulation properties, doesn’t absorb water and is highly resistant to aggressive chemicals (Valenza and La Mantia, 1987; Schwarz, 1995). The material is also resistant to oxidation or environmental degradation and has its application in a variety of corrosive environments.

In the recycle point of view, since PP only can be disposed of properly by incineration (Beck, 2002), various works has been carried out in order to improve the drawbacks of this recycled PP. For example, Rust et al (2006) investigated the use of recycled PP in lead acid batteries and its influence on the physical and flow properties of the material, especially with regards to the heat sealing ability of different grades of PP. Further, the influence of multiple recycling and the use of suitable stabilizers in PP were investigated. From the melt flow index (MFI) and rheological studies of this recycled PP that contained a stabilizer have showed a significant improvement in terms of maintaining long term polymer stability, in particular of the longer chain molecules within the polymer matrix. The study also showed a slight decrease in the tensile strength of a battery case containing a mixture of virgin and recycled PP with varying amounts of recycled material. However, it was found that small additions of recycled material with virgin PP initially increased the impact strength of the material, but tended to decrease as the amount of recycled material was increased.

As stated in the early discussion, filler is one of the promising additives used in producing high performance of recycled part. These materials are generally wood flour, silica flour, various minerals, powdered mica, and short fibres of cellulose, glass and asbestos. Depending on their type, fillers improve the strength, hardness, toughness, abrasion resistance, and stiffness of recycled plastic. These properties are maximized at various percentages of different types of polymer/filler combination. The effectiveness of filler depends on the nature of the bond between the filler material and the recycled plastic chains. There were studies of utilizing natural fibres as composite filler to improve the drawbacks of recycled PP such as kenaf, wood fibre, empty fruit bunches (EFB) and coir. These natural fibres have shown good performance as composite filler (Khalil, 2001). Another work by Khalil (2006) studied on the impact of five different wood saw dust (WSD) filler loading (0, 10, 20, 30, 40 and 50%) with three WSD filler sizes (100,212 and 300 µm) on the mechanical and water absorption of recycled PP and WSD compounding. The results show that composites with smaller filler size (100 µm) displayed higher tensile and impact properties compared to the larger ones. Increased filler loading, from 10 to 50% of WSD in recycled PP, displayed decreased tensile strength and impact properties, but increased flexural strength and modulus. Another work using similar filler can be viewed in Khoo et al (2008).

On the other hand, Phuong et al (2008) used the maleic anhydride grafted polypropylene (MAPP) as a compatibilizer to improve the properties of recycled PP/organoclay nanocomposite. This compatibilizer produces a better adhesion between the solid phase and the polymer matrix. In addition, both the impact and tensile strength increase with an increase in the compatibilizer content. At 20 wt% of the compatibilizers, the impact and tensile strength increase by 36% and 40% respectively. Using a similar MAPP, Adhikary et al (2009) studied the effect of this compatibilizer of accelerated weathering under combinative UV light and water spray conditions on the structure and properties of the recycled PP-wood flour composite. They summarized that MAPP addition to the composite did not influence the water absorption after UV light exposure. However, with the accelerated weathering exposure, the addition reduces the degradation of flexural strength and Young's Modulus by about 50% and 27% respectively. On the other hand, the MAPP addition also exhibited less of a colour change as compared to non-coupled composite.

The introduction of an elastomeric additive according to Navarro et al (2003) can improve the toughness, without compromising the processability and recycling capabilities of polypropylene. However the thermal properties of these blends should be assessed in order to limit degradation during recycling. In their research, the authors studied the thermal degradation of recycled PP and the influence of the concentration of elastomers additives in the thermal stability of the final part. The additives used for the PP compounds are an ethylene/α-octene copolymer (Affinity) and ethylene-polypropylene (EPDM)/PP blend (Santoprene). They concluded that the stability of recycled PP is not significantly altered by the addition of small amount of additives. Therefore, as the thermal properties of the blends used in their study do not significantly change, the improvement in mechanical and impact properties as well as the increase in value of a solid urban waste make the blending economically feasible.

Apart of that, the oxidative degradation of PP also can be reduced by blending with antioxidants (Tochacek, 2004; Setnescu et al, 2004). The essential requirements for antioxidants are good solubility, mobility, low volatility and stabilizing efficiency. However, the antioxidants exert their stabilizing effect even in landfills after expiry of the service life. This is not desired since it decelerates the decomposition of the plastic waste. This advantage may be eliminated by using natural antioxidants, which could affect the degradation of polypropylene matrix, e.g. lignins. Lignins are natural phenolics polymer occurring in higher plants, mainly in wood. Realizing this fact, Gregorova et al (2005) examined the influence of lignin concentration on its antioxidant activity and heat resistance in isotactic PP and recycled PP as well. Both types of PP are filled with 2-10 wt% of lignin. The antioxidative effect of the lignin sample used was determined by non-isothermal DSC measurements and compared with the synthetic antioxidant Irganox 1010 in both types of PP. The results showed that the antioxidant effect is increased with lignin concentration up to 5 wt%. Moreover, the positive effect of commercial antioxidant Irganox 101 was also enhanced by the addition of lignin. The mixture of lignin and Irganox exhibits the highest antioxidant efficiency in both types of polypropylene. The addition of lignin has not only a positive influence on the oxidative stability of PP blends but also increases their rigidity.

- **High-density polyethylene (HDPE)**

High-density polyethylene (HDPE) is one of the most widely used polymers, having a broad amount of applications such as bottles, containers and consumer goods. Thus, this thermoplastic material contributed the largest volume of plastic waste in landfill. Post-consumer HDPE from bottles is an interesting source of recycled material because, on one hand, it cannot be used again in alimentary applications and, on the other hand, its high melting viscosity makes direct transformation via injection moulding very difficult. Recycled HDPE (rHDPE) can be used in ample potential of applications, such as boxes or pallets, whenever the thermal, mechanical and impact properties of the recycled polymer are close to the ones of the virgin material. This is one of the goals for the general use of recycled polymers (Aurrekoetxea et al, 2003). Previous studies showed that the properties of the rHDPE obtained from the post-consumer milk bottles were not largely different from those of virgin resin and thus it could be used for various applications (Pattanakul, 1991). Also the recycled plastics are cheaper than in the virgin form, for example, rHDPE pellets and flakes are 31–34% less expensive than the virgin HDPE (Powell, 1999). Thus, increased usage of recycled plastics offers the prospect of lessening waste disposals and reducing the product costs.

There are tremendous studies regarding to the rHDPE. For example, Ambrose et al (2002) performed the mechanical recycling of 100% post-consumer rHDPE, as can be found in milk bottles. The recycle plastic was segregated into two types of plastic: natural HDPE and pigmented HDPE. The result of tensile stress at yield was found to be 30.2 MPa, with an elongation at yield of 15.6% for the injection moulded sample. Both the natural and pigmented recycled blow moulded samples showed higher tensile stress at yield and elongation at yield respectively. They also compared the results with an engineering specification for a windscreen wash bottle by Ford and found out that both results exceeded the specification (22 MPa and 5.6% respectively). This specification is for a high-quality engineering piece of automotive equipment. Thus, the findings from their study proved that high-quality products can be manufactured from 100% post-consumer recycled plastic material. The materials specifications of these recycled plastics are equivalent or better than those listed for virgin polymer resins.

Other related work by Yam et al (1990) and Selke and Wichman (2004), they studied the performance of post consumer rHDPE and wood fibre composites. From the results of tensile strength and tensile modulus of the composites, it can be seen that the performance of composites made from rHDPE was at least as good as that of composites made from virgin HDPE. From the study also revealed that incorporation of wood fibres tended to decrease elongation at break and impact strength of composites made with virgin milk bottle resin. However, the impact strength and elongation for composites made with mixed post-consumer HDPE bottles were improved. Interestingly, the incorporation of up to 40% wood fibre increased the impact strength of these materials, and this impact strength exceeded that of comparable composite from virgin HDPE. They concluded that, this phenomenon might be related to incompatibility between various HDPE resins, resulting in very poor impact strength for the mixed HDPE without wood fibre. Another studies carried out investigating the impact of rHDPE on performance of wood-plastic composites (WPCs) also can be observed in Jayaraman and Bhattacharaya (2004) and Chen et al (2006).

Concentrating on the rHDPE and wood fibre composites, Adhikary et al (2008) investigated the stability, mechanical properties and the microstructure of the composite by adding MAPP. The addition of 3-5 wt% of this MAPP in the composite formulation significantly improved both the stability and mechanical properties. Microstructure analysis of the fractured surfaces of MAPP modified composites confirmed improved interfacial bonding. On the other hand, the dimensional stability and strength properties of the composites can be improved by increasing the polymer content or by adding a coupling agent. The results of the present work clearly showed that rHDPE and wood sawdust can be successfully used to produce stable and strong WPCs. They also found out that the composites treated with coupling agents will be most useful as building materials due to their improved stability and mechanical properties.

On the other hand, Ashori and Nourbakhsh (2009) found out that the mechanical properties of the composites made from post-consumer rHDPE are similar to or, in some cases, better than the composites made from recycled PP. However, by adding the MAPP and lower fibre content, the composite showed better mechanical properties than all of the non-coupled ones. Even though the water absorption and thickness swelling increase with the fibre content, however, by adding the coupling agent reduces these properties significantly. The results also showed that the composites of 55 wt% of rHDPE with the 2–4 wt% MAPP can achieve adequate stability. From the findings, they concluded that recycled old news paper (rONP) and rHDPE can be successfully used to produce stable and strong