rHDPE/rPP HYBRID BLENDS FROM INJECTION MOLDING SCRAP: CHARACTERIZATION FOR CONVENTIONAL MILLING WORKPIECE APPLICATION

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MASTER OF MANUFACTURING ENGINEERING (QUALITY SYSTEM ENGINEERING)

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ABSTRACT

Various ratio combinations for two difference polymeric phases could enhance the resulted properties of newly developed miscible blends. The blend could possess higher strength characteristic that would beneficial for various engineering applications. In this study, scrapped from injection molding IM) operation is recycled for polymeric blend development. Recycling of polymeric waste helps to conserve the natural resources and environment by reducing the utilization of hydrocarbon. Up to now, specific research focusing on the blend made from recycled high density polyethylene (rHDPE) and recycled polypropylene (rPP) due to IM waste are really scarce. Hence, this research has been conducted to develop and formulate the optimum rHDPE/rPP blends for conventional milling operation. This to replace the utilization of an expensive Delrin or steel machining block for teaching and learning purposes in IKTBN Pagoh and IKTBN Sepang, Malaysia. At first, the prime investigation is to evaluate the performance of rHDPE/rPP blends and their correlation between miscibility effects with the resulted mechanical properties of hybrids at various blends ratio. The rHDPE/rPP blends are produced by crushing both rHDPE and rPP materials, followed by secondary mixing via an extrusion process, as to ensure well-mixing of rHDPE/rPP hybrid at their respective formulation ratio. Different ratio of rHDPE/rPP (0/100 wt.%, 30/70 wt.%, 50/50 wt.%, 70/30 wt.%, 100/0 wt.%) are used to investigate the effects of materials phases towards the resulted mechanical, thermal and physical properties of rHDPE/rPP blends. Later, the fracture surface morphology of the selected rHDPE/rPP m blend samples are analysed through Scanning Electron Microscopy (SEM) observation. In addition, the melting temperatures (Tm) of rHDPE/rPP samples are measured by Differential Scanning Calorimeter (DSC) technique for miscibility evaluation through thermal route. At the end of this study, rHDPE/rPP blend with higher strength and thermal performances is proposed for substituting the Delrin material for machining application. It was found that the 70/30 wt.% of rHDPE/rPP was significantly possessed outstanding mechanical and physical characteristic in terms of their tensile, elongation at break and the hardness behaviour, as well as better thermal properties improvement. The 70/30 of rHDPE/rPP blend has yielded an extraordinary improvement at about 59.8% in their tensile strength, 473% of elongation at break and 2.3% of the hardness improvements. It was also found that there are two T_m peaks appeared in the total heat flow curve for all formulated blends which indicates the immiscible nature of produced blends. The range of T_m was found gradually decreased when the portion of rHDPE phase is increased up to 100 wt.%. At the end, this research has significantly important to be carried out as to provide another alternative candidate for cost saving machining materials in teaching and learning purposes. This new candidates of rHDPE/rPP blend material produced from recycled IM by-product are also environmental friendly and will not cause pollution or any harm toward the environment.

ABSTRAK

Kombinasi pelbagai nisbah bagi dua polimer yang berbeza boleh meningkatkan sifat bahan tersebut. Gabungan polimer yang bagus, cenderung untuk mempunyai sifat kekuatan yang tinggi yang boleh digunakan dalam pelbagai aplikasi kejuruteraan. Dalam kajian ini, bahan buangan daripada operasi pengacuanan suntikan dikitar semula bagi menghasilkan bahan gabungan bagi dua polimer berbeza. Hasil buangan polimer yang dikitar semula dapat membantu mengekalkan sumber semulajadi dan dapat menjaga alam sekitar dengan mengurangkan penggunaan hidrokarbon. Sehingga sekarang, jarang ditemui penyelidikan spesifik yang menggabungkan polyethylene berketumapatan tinggi kitar semula (rHDPE) dan polypropylene kitar semula (rPP) daripada sisa buangan melalui pemprosesan pengacuanan suntikan (IM). Maka, kajian ini untuk membangunkan dan menghasilkan formulasi yang terbaik bagi bahan gabungan rHDPE dan rPP daripada proses IM untuk menghasilkan bahan kerja pemesinan bagi operasi kisar secara konvensional. Ini adalah bertujuan bagi menggantikan bahan kerja sedia ada iaitu Delrin atau keluli dalam proses pelajaran dan pembelajaran di IKTBN Pagoh dan IKTBN Sepang, Malaysia. Kajian awal adalah untuk menilai prestasi bagi kebolehan percampuran rHDPE/rPP dan sifat mekanikal bagi pelbagai nisbah gabungan rHDPE/rPP. Bahan campuran rHDPE/rPP dihasilkan dengan menggunakan kombinasi bagi formulasi dua bahan tersebut melalui proses penghancuran bahan dan kemudian diikuti dengan proses penarikan, untuk menghasilkan campuran yang sebati bagi dua polimer yang dihasilkan. Dalam kajian ini, kandungan rHDPE/rPP yang berbeza peratus berat (0/100, 30/70, 50/50, 70/30 dan 100/0) digunakan untuk menyiasat karakter, sifat mekanikal, sifat termal dan sifat fizikal bagi bahan campuran rHDPE/rPP yang telah dihasilkan. Kemudian morfologi permukaan patah bahan ujikaji rHDPE/rPP yang telah dipilih kemudiannya dianalisa dengan menggunakan mikroskop elektron imbasan (SEM). Takat cair bagi rHDPE dan rPP diukur dengan menggunakan teknik kalorimeter imbasan perbezaan (DSC) untuk melihat percampuran kedua-dua bahan melalui haba. Penghujung kajian ini, kekuatan dan kekerasan yang paling tinggi dan prestasi termal yang bagus bagi campuran formulasi rHDPE/rPP dicadangkan kerana ia bersesuaian dengan perbandingan sifat bagi bahan Delrin. Komposisi peratus berat bagi 70/30 bahan rHDPE/rPP telah berjaya meningkatkan ciri-ciri mekanikal dan fizikal iaitu kekuatan terikan, pemanjangan pada kadar patah dan sifat kekerasan yang tinggi bagi bahan tersebut, selari dengan peningkatan sifat haba yang baik. Keputusan kekuatan terikan menunjukkan peningkatan sebanyak 59.8%, 473% peningkatan pada nilai pemanjangan pada kadar patah, dan 2.3% peningkatan pada kekerasan bahan peratus berat 70/30 bagi rHDPE/rPP. Melalui keputusan yang diperoleh, semua sampel menunjukkan dua puncak bagi takat lebur dan semua formulasi adalah tidak bercampur antara satu sama lain. Perbezaan dua puncak didapati menurun dengan peningkatan rHDPE sehingga nilai peratus berat sebanyak 100. Penyelidikan ini sangat penting untuk dijalankan bagi meyediakan bahan alternatif dapat mengurangkan kos untuk tujuan pengajaran dan pembelajaran. Bahan alternatif yang baru dihasilkan daripada barangan buangan proses IM kitar semula juga dapat menjaga alam sekitar daripada tercemar dan mengurangkan pencemaran atau kerosakan kepada alam sekitar.

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LIST OF ABBREVIATIONS

PET	-	Polyethylene Terephthalate
LDPE	-	Low Density Polyethylene
PVC	-	Poly-vynil Chloride
HDPE	-	High Density Polyethylene
VLDPE	-	Very Low Density Polyethylene
PP	-	Polypropylene
PS	-	Polystyrene
IKTBN	-	National Youth and High Skill Institute
KBS	-	Ministry of Youth and Sport
IM	-	Injection Molding
rHDPE	-	Recycled High Density Polyethylene
rPP	-	Recycled Polypropylene
POM	-	Polyoxylmethylene
ASTM	-	American Society for Testing and Materials
DSC	-	Differential Scanning Calorimetry
SEM	-	Scanning Electron Microscopy
ISO	-	International Organization for Standardization
UTM	-	UltimateTensile Strength
PSW	-	Plastic Solid Waste

CHAPTER 1

INTRODUCTION

1.1 Background

Abundant of plastic waste is one of the global environmental issue and becoming tough challenge for most of the developing country (Gu and Ozbakkaloglu 2016, Iwata 2015, Singh et al. 2016). The amount of plastic wastes disposal are getting increasing due to increase of development and industrial activities, population growth, socio-economic and urban lifestyle. Less awareness in our society pertaining to the issue that contributes to the plastic waste disposal problem is getting alarming and troublesome. It was estimated about ten thousand tonnage per day of plastic wastes are being generated or simply disposed especially in the developed country. In India itself, the total post- consumer plastic generated, which constitutes of two major category of polymers which are thermoplastic had contributed into 80% of total wastes while the other balance is generated by the thermoset based wastes. The thermoplastics materials are the recyclable types of plastics which including the polyethylene terephthalate (PET), low density polyethylene (LDPE), poly-vynil chloride (PVC), high density polyethylene (HDPE), very low density polyethylene (VLDPE), polypropylene (PP), polystyrene (PS) and etc. However, thermoset resins which containing alkyd, epoxy, ester, melamine formaldehyde, phenolic formaldehyde, silicon, urea formaldehyde, polyurethane, metalized and multilayer plastics are not recyclable like thermoplastic polymers does (Achilias et al. 2007).

Some arguments about the environmental impact on plastics goes outwardly based on facts and logic and based on values and emotion. Aside from their technical prowess, plastic industry people are proud of the capabilities of their products and of the unique qualities of plastic materials as compared than other engineering materials (Tolinski, 2012). On the extreme other side, the environmental activist are particularly sensitive to the waste resources and their impact damaged towards the ecological and earth system that are mainly effecting the future generation (Verdolotti et al. 2014).

Waste management is becoming crucial issue in industrialize and developing country. The waste management without proper mechanism will surely affecting not only the environment but to the society and economy of the country (Al-Salem et al. 2009, Salih et al. 2013). In the perspective of this study, the recycling of recyclable plastic waste materials which generated from an injection molding process has been the main interest of this study.

Recycling the polymer is a noble approach to reduce the environmental pollution issues that causes by the polymeric waste generation from everyday utilization of polymer materials such as house hold, parts and construction (Bernardo, et al. 2016). The recycling effort of polymeric waste could help to conserve the natural resources as the main back-bone materials for polymers are the hydrocarbon from oil and natural gaseous.

This research is conducted in collaboration with National Youth and High Skill Institute (IKTBN) Sepang and Pagoh under the Ministry of Youth and Sports (KBS), whereas previous practice, the scrap from an injection molding (IM) process for teaching and learning purpose had just been disposed without any further utilization. At the same time, in teaching and learning activities, the management had problems of shortage supply in allocating the expensive raw materials (metal and

Delrin) costs for conventional machining purposes. By using the generated waste from the IM process, it was hope that the combination of these two recycled materials of HDPE (denoted as rHDPE) and recycled PP (denoted as rPP) as hybrid blends, could be able to replace the utilization of metal and Delrin for machining block the teaching and learning activities in order to reduce the overall cost of teaching materials. This project had spurred an initiative of developing the idea to convert waste into something that was benefited for educational purposes, especially in the machining practical work that utilizing a conventional milling operation which requires vast investment for machining block as a workpiece materials.

1.2 Problem Statement

There are many researchers has been performed pertaining to the recycling polymer based materials. However there are too scarce or no specific focused research that specifically combined the rHDPE and rPP from IM processing waste or scrapped materials. Therefore this research has mainly focused to develop and formulate the best composition of rHDPE and rPP hybrid materials blends from the IM process to produce the machining block for conventional milling operation in replacing the utilization of existing expensive Delrin or steels machining block. By combining both rHDPE and rPP together as rHDPE/rPP blends, the properties and performance could be significantly explored and optimized.

According to Najafi et al. (2005), the combination of various ratio between two difference polymer phases could enhance the resulted properties of new polymeric blend. Blend of PP and PE have becoming a great interest to the global researchers because of the need to improve the processing and properties of PP as an engineering plastic due to its limitation of being relatively low impact strength

especially at lower temperature and poor environmental stress cracking resistance (Salih et al. 2013). However, there are limited number of researches that have been developed by using rHDPE and rPP from the IM scrapped materials. Most of the researchers has studied the properties of blends between virgin HDPE, LDPE, VLDPE and PP or combination between the rPE and rPP from consumer parts products.

In Polymer Laboratory at National Youth and High Skill Institute (IKTBN) in Sepang and Pagoh, the students have to mastery in their mold making and process operation by using an IM processes. Thermoplastic materials are the most commonly used materials to manufacture IM based products. The problems had been noticed when there are abundant of thermoplastic scraps and rejected parts have been generated due to high volume of IM process utilization. Usually the wastes are being scrapped then simply disposed without further action of recycling it as showed in Figure 1.1. This scenario basically could harm the environment and absolutely could generating wastes at the alarming rate. Hence the noble aims of this study are to recycle the wastes generated from the IM process into parts that can be further used for another special function related with teaching and learning activities. Through this effort, it could possibly help IKTBN Sepang and Pagoh to optimize their investment for teaching and learning activities.

Figure 1.1: Waste Materials from Injection Molding Processes

The optimum composition of rHDPE/rPP can be determined through the combination of various ratios of rHDPE/rPP scraps and the performance testing of polyacetal or also known as Delrin that will be utilized for comparison study. In our normal practice for machining activities during the teaching and learning session, Delrin was utilized as machining block to train our students to mastery their conventional milling skills operation. Delrin as shown in Figure 1.2 is from the family of polyoxylmethylene (POM) polymer (Kapakjian and Schnid, 2001). The utilization of Delrin as machining block had resolved the common issue of expensive utilization for aluminium and mild steel machining block. Utilization of Delrin had enable the management of IKTBN to reduce the purchasing cost related to the teaching materials, and at the same time assisting the students to avoid fear of failure due to machining trial and error in their project delivery. This cheaper alternative also provides safety to our students since this materials provide less chipping compared than steel or aluminium based machining blocks. However dealing with Delrin, had created another

problems as this option is not fully environmental savvy as virgin POM that being used to produce the machining block has also not economically feasible at the long run. It is considered still expensive relatively among other types of polymer and at the same time the contaminated parts from scrap or rejected machine parts cannot be reused for another machining cycle. Due to this problem, the innovative solution to utilize scrapped materials of HDPE and PP from the IM process has been actualized in this research to test its suitability and feasibility as another option for machining block to substitute the utilization of Delrin material.

Polymers blending strategy is currently viewed as an outstanding alternatives for the advancement of new advanced polymeric materials (Shaban, 2014). Materials with enhanced resulted properties could be obtained by mixing up at least two different polymers which possessing distinctive atomic attributes. It is understandable that the morphologies of somewhat miscible polymer blends are relying on their macromolecular composition, morphological structure and their specific processing conditions (Shanks et al. 2000).

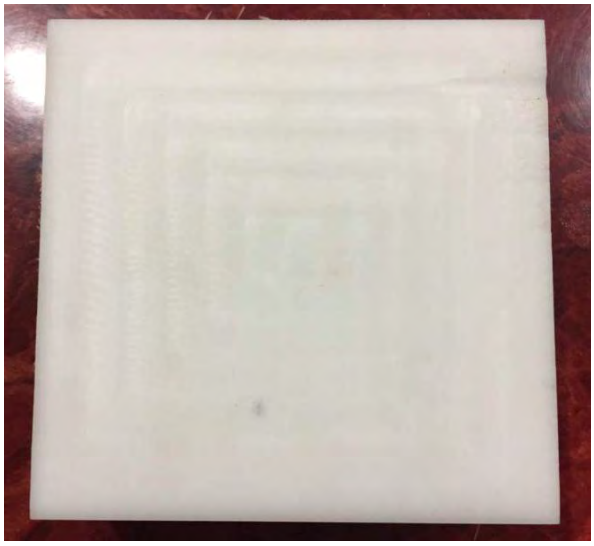

Figure 1.2: Delrin Material As Machining Block

Polyblends could be obtained by liquefying or mixing the dissolvable of at least two different types of polymer phases. The mechanical or physical properties of polyblends are strongly depended to their phase morphologies, activity amongst continuous and dispersed phase, and the part proportions (Ronkay, 2013). In processing condition, the phase morphology of the blends are depended to their processing steps that taken place including extrusion, injection molding, and the manufacturing conditions or processing parameters such as temperature and applied shear force (Lin et al. 2015).

In conclusion, by considering all these matters, the motivation of conducting this research is clearly justified and essential to be further explored. Moreover, there is no previous similar studies have been conducted in the existing literature, specifically about the utilization of rHDPE and rPP from the IM waste materials to be used specifically as machining block for conventional milling operation.

1.3 Statement of Purposes

The purpose of this research is to investigate and to observe the performance of rHDPE and rPP blends formulated from IM scrapped materials and the correlation between the miscibility and resulted mechanical properties of rHDPE/rPP blends at various blends ratio. In addition, the best selected ratio of rHDPE/rPP blend is based on their mechanical, physical and thermal performances that will be further investigated as machining block for their machining properties capability in comparison with conventional Delrin machining block.

1.4 Objectives

The main objectives of this study are to explore the optimum composition of HDPE/PP blends formulation generated from rHDPE and rPP waste from the IM process. The contribution towards the performance testing will be investigated further through conventional milling process for machining operation. Towards achieving these main objectives, these studies are sets out the specific objectives as follows:

i. To prepare the rHDPE/rPP blends from the IM processing scrapped, at various different formulation blend ratio.

ii. To characterize the physical, mechanical and thermal properties of rHDPE/rPP blends for optimum miscibility and resulted engineering attributes characteristics.

iii. To evaluate the performance of selected rHDPE/rPP blend for machining block application in comparison with Delrin material by using a conventional milling operation.

1.5 Scope of Study

The basic scope of this research is to formulate the best HDPE/PP blend composition ratio between the rHDPE and rPP from the IM processing scrapped. There are five different blends formulations to be experimented with the aim to evaluate the best performances of rHDPE/rPP blended recycled materials at various composition ratios. The miscibility, hardness, water absorption, tensile strength, flexural strength, fracture morphology and their performance study were investigated further. Later, the selected optimum rHDPE/rPP blend will be used and applied as machining block for comparison with commercially available Delrin materials, in terms of machinability properties.

In order to actualize the objectives of this research study, to be successful and reasonably implemented, the following scope of studies has been considered and decided further.

a) Materials: Two types of most commonly used recycled plastics of rHDPE and rPP that are existingly available in the polymer laboratory at IKTBN Sepang will be utilized for rHDPE/rPP blends development. Both of these materials will be formulated and further tested to be decided for the best rHDPE/rPP blend formulation materials for comparison study between the Delrin as machining block materials.

b) Preparation of specimens: The plastic scrap materials from injection molding process will be separately crushed by using the industrial grinder machine. Subsequently, it will be divided into five (5) different blend formulations. Later the hot press machinery will be utilized to convert it into rectangular shape samples with specific dimension in accordance to their standard testing dimension. The following are the control samples and blends formulation recipes that has been utilized in this research study:

   i) 100% rHDPE;

   ii) 100% rPP;

   iii) 30% rHDPE and 70% rPP;

   iv) 50% rHDPE and 50% rPP; and

   v) 70% rHDPE and 30% rPP

The samples were then pressed into sheets of 2.0 mm nominal thickness and 25x25 cm^2 nominal dimensions using a laboratory hydraulic hot press at 190^0C for rHDPE, rPP and their related rHDPE/rPP blends formulations respectively. Specimens for mechanical testing were cut out into their specific dimension, in accordance to their ASTM standard.

c) Testing techniques;

i) Differential Scanning Calorimetry (DSC) is a thermal analysis technique that is used to measure changes in heat flow associated with material phase transitions. The DSC technique can be used to make a qualitative statement about whether or not polymer blend systems are miscible or immiscible, provided that the inherent homopolymer transition temperatures of the blend components are sufficiently well separated.

ii) Mechanical tensile properties testing is the tensile testing that is used to measure the force required to break a plastic sample specimen and the extent to which the specimen stretches or elongates to that breaking point. Tensile tests for plastics provide the information on ultimate tensile strength, Young modulus, flexural strength and elongation at break. Macroscopic analysis is performed by visual inspection of the fractured surfaces by using a Scanning Electron Microscopy (SEM). About 5.00 mm sections of all the fractured fragments were subjected to SEM observation for microscopic analysis to verify the fracture morphological behavior.