Faculty of Manufacturing Engineering

MECHANICAL PROPERTIES OF RECYCLED POLYPROPYLENE (rPP) PROCESSED BY INJECTION MOLDING METHOD

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DECLARATION

I declare that this thesis entitle "mechanical properties of recycled polypropylene (rPP) processed by injection molding method" my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of Master of Manufacturing Engineering (Industrial Engineering)

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DEDICATION

This thesis is dedicated to my beloved wife Marlina Bt Abdul Rahman , my son Faris Izzudin and daughter Nur Izzaraa. They have been a source of motivation and strength during moments of despair. Their support has been shown in incredible ways recently.

ABSTRACT

The injection moulding process is one of the most important processes in the plastic processing industry. The process mostly used thermoplastic materials that are recyclable, non-biodegradable and the decomposition process consume a significant length of time. This results the serious pollution problem, therefore studies on the recycling of thermoplastic and the usability of the recycled materials have gained significance. The objective of this research is to investigate the effect of melting temperature, packing pressure, and cooling times on tensile strength elastic modulus and Izod impact test properties of recycle PP (rPP). Samples consist of 100% virgin polypropylene (vPP) and 100% recycled polypropylenes (rPP) which are processed by using Nissei (110kn) Injection Molding Machine. Cavity of the mold is a dumbbell shape which is referring to ASTM D638 and ASTM D256. This research used three controllable parameters are melting temperature, packing pressure, and cooling times. While the other parameters remained constant. Taguchi's L9 orthogonal array design was employed in design of experiment and each one at three levels, tested to determine the optimal combination effect of factors and levels in the injection moulding process. In analyse the results, Taguchi method introduced the use of the signal to-noise (S/N) ratio to determine the quality of the characteristics applied. Mechanical properties such as maximum tensile strength, elastic modulus and Izod impact strength of the specimens were measured and analysed. The results are expected to compare the mechanical properties of vPP and rPP. The experimental analysis revealed that the melt temperature has high influence of mechanical properties of rPP due to high P-value in ANOVA result for maximum tensile strength, Izod impact strength and elastic modulus. The study emphasis that the improvement of mechanical properties of recycle polymers were able to achieved by optimizing the correlated processing parameters during injection molding process without any influences of additives.

ABSTRAK

Proses acuan suntikan adalah peroses paling penting dalam pemprosesan dalam industry plastic. Proses selalunya menggunakan bahan termoplastik yang boleh diguna semula, tidak boleh terurai secara semulajadi dan proses penguraian mengambil masa yang panjang.Keadaan ini menyebabkan pencemaran yang serius dan oleh itu,kajian mengenai kitar semula bahan termoplastik dan kebolehguaan bahan tersebut mempunyai impak yang tinggi. Objektif kajian ini adalah untuk mengkaji kesan pembolehubah masa suntikan, tekanan mampatan dan masa mampatan terhadap kekuatan regangan dan ujian 'Charpy impact' terhadap sifat bahan kitar semula polipropeline (rPP). Sample yang diperbuat daripada dua komposisi ,100% PP asli (vPP) dan 100% kitar semula polipropeline (rPP) dihasilkan melalui mesin acuan suntikan Nissei (110kn) . Mold ini menggunakan kaviti berbentuk 'dumbbel' mengukut spesifikasi ASTM D638. Kajian ini menggunakan tiga parameter yang boleh dilaraskan (suhu lebur , tekanan mampatan, masa penyejukan) sementara parameter yang lain kekal malar. Rekbentuk 'Taguchi's L9 orthogonal array' digunakan untuk rancangan ekperimen pada setiap tiga peringkat dan di uji untuk mengenalpasti kombinasi yang optimum oleh faktor dan peringkat dalam proses acuan suntikan.Dalam menganalisa keputusan ,Taguchi memperkenalkan keguaan kadar signal to-noise (S/N) untuk menentukan kualiti pada characteristics yang dikenakan. Sifat mekanikal seperti kekuatan terikan, kekuatan tegasan dan kekerasan pada sample diukur dan dianalisa. Hasil analisa kajian membuktikan bahawa suhu lebur mempunyai pengaruh yang kuat terhadap sifat mekanikal rPP disebabkan oleh nilai P yang tinggi didalam ANOVA untuk kekuatan terikan maksima, 'Izod impact strength' dan modulus kekenyalan. Kajian menekankan bahawa penambahbaikan terhadap sifat mekanikal rPP dapat dicapai dengan mengoptimakan paremeter pemprosesan yang berkaitan semasa process acuan suntikan tanpa pengaruh dari bahan penambah.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Today, large generation and occupancy of plastics in landfill are gaining interest of many people. These plastic materials are non-biodegradable and their decomposition processes consume significant length of time. The recycling was a preferable choice since other possible choices to handle waste such as incineration and pyrolysis required much more processing cost and set up. Not only that, both incineration and pyrolysis will emit significant amount of greenhouse gases to the environment during the process. Thus, this will lead to more negative consequences towards environment.

Recycling the thermoplastic can be classified as a promising sector. Recycling or making products from mixed plastics waste is a business which has more economical on raw material cost. This is mainly due to huge amount of mixed plastics waste generated on daily basis due to the fact that they are being used in a great volume . Cemal Meran et al. (2007) state, from the costs associated with recycled PP plastics in Europe the cost of recycled plastic is consider low if compared with the cost of first production plastic. To the degree that these costs allow a profit margin, recycling can be considered. Achilias et al. (2007) stated that the annual total plastic consumption of Western Europe in 2003 was 48.8 million tons, corresponding to 98 kg per capita. In comparison, in 1993, the plastic consumption was only 64 kg per capita. Unfortunately, the increase in plastic consumption significantly contributes to the large volume of disposed plastic. According to statistics

from the Association of Plastics Manufactures in Europe, in 2010, polypropylene represented 19% of thermoplastic consumption in Europe. In terms of market share, this is the largest of the "big five" plastic types (polypropylene, polyethylene, polyvinyl chloride, polystyrene, polyethylene terephthalate) in Europe and global production reaches about 30 million tons yearly and a 7% annual growth is expected.

However, recycling causes some downturn in which there is some decrement in the properties of recycled materials. Compared to virgin materials, the deterioration of recycled plastic in quality and durability, physical and mechanical properties, surface appearance, and thermal properties have limited its use in the market. Recycled plastics are generally compounded with small amounts of chemical substances, called additives to impart certain properties and lessen the usage limitations. Therefore, more research had been done in order to cope with the situation. Nik Mizamzul et.al (2010) used Taguchi method to optimize the mechanical properties of recycle plastic product via optimal injection processing parameter. This work actually focuses on the feasibility of substitution of recycled plastic for virgin plastic using injection molding process with four varied parameter include melt temperature, packing pressure, injection time and packing time, while other remaining parameters are being constant.

In contrast, Babur Ozcelik et.al (2011) also used Taguchi method to optimize of injection parameters for mechanical properties of specimens with weld line of PP, discuss about virgin ABS sample and did optimization by using the same method used by Nik Mizamzul et.al (2010). The research focussed on virgin material produced by injection moulding process. Not only that, Taguchi method had also been used in the study on optimization on property enhancement of PP/organoclay by Hunter et.al (2007). This is due to the fact that this study involved a lot of factors that were affecting the performance

of the composite which includes amount of interlayer spacing, grades of types of PP and type of organoclay that been used. From that, another tool of DOE, that was Pareto analysis of variance (ANOVA), also been used in order to identify the factors for enhancing the optimum factors for enhancing mechanical properties of the plastics.

1.2 Problem statement

Up until today, plastics wastes are generated in big volume since they are used in all applications. To overcome this, recycling is the best option. Unfortunately, the concept of recycling still cannot be fully adapted by people due to decrement in the properties of those recycled materials. However, a lot of that has been done in order to improve their properties. This can be done by manipulating several factors such as operating conditions, ratio of recycled to virgin materials, additive and number of recycling process done on the for products before turning them into a new products . Although there have improvement in mechanical properties but the cost of materials have increased due to introduction of additive (Ramirez 2006).

However, limited study has done on 100 % rPP. In this research, the aims is to improve the mechanical properties of recycled plastic by controlling the process parameters of injection molding instead of coupling the products with additives .Those mechanical properties are investigated by conducting tensile and Izod impact test.

1.3 Objectives of the Research Work

The objectives of this study are:

- To characterize mechanical properties of virgin PP

- To investigate the effect of melting temperature, packing pressure, and cooling times on tensile strength , elastic modulus and Izod impact strength properties of recycle PP by Injection Molding method

- To optimize the tensile strength , elastic modulus and Izod impact strength properties of recycle PP using Taguchi method

1.4 Scope of study

Scope of study is represent by a K-Chart and can be referred to Appendix L

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of the Virgin Polypropylene

Polypropylene (PP) was originated from the thermoplastic family which synonyms with multifunction role in automotive industry, packaging and containers medical device and textile which relatively gave huge impact in terms market and production. Mier and Calafut (1998) stated that PP was commonly applied in the industry to produce modern bumpers which have been major utilized in the automotive companies such as Ford, Peugeot, Opel and BMW. Pritchard (2005) stated that global consumption of PP was USD 34 million on 2002 based on Philip Townsend Association's polypropylene annual report while Hosetti (2006) explain that the consumption of PP was 11.4% higher compared to LDPE consumption with only 7.9% .

Rust et al. (2005) emphasis the important of Polypropylene (PP) as one of the most widely used plastics and very versatile in its use and application in the polymer industry. Schwarz (2005) explain regarding on how polypropylene (PP) was developed in the early 1950's using Ziegler type catalysts and has since gained enormous attention where no other polymer encompasses its versatility in physical properties, regarding its ease of manufacturing and its use in many applications.

2.2 Overview of the Recycled Polypropylene

According to Brandrup (1996) the past 20 years in plastic industry have seen the amount of rPP have been used in Western Europe approximately 180000 tonnes which consisted of both processing scrap and PP product waste. Presently, in Australia, Harper (2002) showed the increment in overall recycling rate of polypropylene in 2003 with 9.9% compared to 8.0% in 2001. Both of these statistics proved a significant development in PP recycling along with higher acceptance in the market of rPP products where resin producers started to combine recycled resin with virgin resin to meet customers' needs.

The Battery Council International reports (2003) a recycling rate on 2003 of more than 97 percent's for lead acid batteries. Polypropylene makes up about 7 percent's of the battery, by weight, and is recovered along with the lead. The primary market for the recovered PP is new battery cases. A typical battery contains 60 to 80 percent rPP. The recycled rate for the cases can be assumed similar to that for batteries "The American plastic council reported (2003) a 3.4 percent recycling rate for PP bottles in 2003, down from 3.9 percent in 2002 while the 2001 rate was 3.8 percent.

Cemal Meran et al. (2007) study of the possibility of recycling and utilizing recycled polyethylene and polypropylene conclude that the usability of recycle polypropylene is 100%. The experiments demonstrated that the material which can be most successfully recycled is polypropylene. The sample of 100% rPP only drop 15% of their tensile strength compare to 100% vPP and did not faces any moldability problem during injection molding process . The important result from Cemal Meran et al. (2007) research is that the recycling of polypropylene did not show any problem during pressing and that the recycling reached a level of 100%. The usability of 100% recycled polypropylene which are used most widely in the world offer a great significance for the plastics industry.

2.2.1 Polypropylene Recycling

High awareness of the environment and sustainable issues of raw material have been a driving force for rapid recycling activities. In polymer recycling, Pilato (2010) have stated that there are three recycling systems synonyms with plastics which are mechanical, feedstock, and energy recovery. Thermoplastics materials such as PP were suitable for this processing due to its ability to be melt and moulded upon heating repetitively. Within the thermoplastics molecular chain there were no strong secondary bonding like hydrogen bonding or crosslinking for example polypropylene was a linear structure where the molecules were held together by Van Der Waals bonding.

Therefore, once the material introduced to heat, the weak bonding was easily ruptured due to high frequency of molecular vibration and increment of kinetic energy. As a result, the molecular were freely mobile to be reshaped and moulded. Due to the behaviour, rPP was often introduced to extrusion and injection moulding processing in order to develop new product.

Previously PP recycling was commonly done via direct recycling where the materials were introduce to sorting and shredding process prior molten the materials. Plus, as explained by Zweifel et al. (2009) this process was widely utilized in both short term application product and long term application such in automotive and packaging industries. However, this scheme was not effective due to contamination, lower properties value, and inefficient sorting technique.

2.2.2 Mechanical Properties of Recycled Polypropylene

According to Brandrup (1996) there were several factors influencing the reduction properties of rPP such as repeated processing, exposed to high temperature, comprehensive outdoor and the material history itself. These factors led to changes in terms of both quality and processing condition. The rPP properties were able to tailor through molecular level or modification of processing techniques.

2.3 Effect of Injection Moulding Parameters on Polypropylene

Brostow (2000) clarified that reprocessing material as recycling effort definitely affected the end products' properties since rPP experienced both pronounced mechanical and thermal loading through shearing and melting mechanism during plasticizing. Presence of oxygen within the barrel resulted in oxygen penetration into the melt resin. Brostow further explained oxidation reaction which gave the chemical loading impact to rPP more definite compared to vPP. All those definite stresses build up in rPP increased the degradation effects. Along the reciprocating screw in the barrel, recycled PP flowed in shear flowed pattern where the molecules flowed over each other while flowed in extensional pattern as the molecules flowed towards the mould. The temperature , time, pressure are important in determined the mechanical behaviour of plastic materials as claimed by Lawrence (1994).

Mantia (2002) stated that rPP not only suffered from crystalline morphology degradation but also in rheological behaviour as reprocessing affected the viscosity of the recycled polypropylene. Crystallization of PP during processing was diverse compared to crystallize of the microstructures of polypropylene without any external forces.

2.3.1 Effect of Melting Temperature

Rosato et al. (2000) identified that melt temperature of PP correlated to the flow rate of the viscous element. The authors highlighted that the melt temperature determined the mechanical properties of PP as the increment of melt temperature definitely reduce the stiffness of the material where relatively seen decline trend of impact strength. Osswald and Ortis (2006) proposed that melt temperature of polypropylene during injection moulding should not beyond 270°C in order to avoid rapid degradation of the materials especially when using rPP which have been subjected to elevated temperature before. Lawrence (1994) emphasis there is strong dependence on temperature and time of the properties of polymers compared to those of others materials such as metals. This strong dependence of properties on temperature and on how fast the materials are deformed (time scale) is a result of the viscoelastic nature of polymers. Viscoelasticity implies behaviour similar to both viscous liquids in which the rate of deformation is proportional to the applied force.

Nagaoka et al. (2005) explain the melting temperature have greater influence on bending strength than on the tensile strength due to the greater rate of deterioration with increasing cylinder temperature. The mechanical properties of PP deteriorated as the melting temperature increased at different injection speeds. Nagaoka et al. (2005) figure out that the rise in cylinder temperature results in lower tensile strength. This trend continue to the two sample 100 % vPP and vary mixture between vPP and rPP but at different injection speeds .

2.3.2 Effect of Cooling Time

PP experienced solidification transformation from the molten resin into solid end PP product during cooling phase. Osswald et al. (2008) explain during cooling time, the heat