Warpage Optimisation on Front Panel Housing Moulded From Recycled Acrylonitrile Butadiene Styrene (ABS)

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3D	Three Dimensions
ABS	Acrylonitrile Butadiene Styrene
Adj R^2	The power of two Adjusted Regression
AMI	Autodesk Moldflow Insight
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
BPNN	Back Propagation Neural Network
CAE	Computer Aided Engineering
CCD	Central Composites Design
CMM	Coordinate Measuring Machine
DOE	Design of Experiment
DVD – ROM	Digital Versatile Disc – Read Only Memory
FE	Finite Element
FFD	Full Factorial Design
GA	Genetic Algorithm
GRA	Grey Relational Analysis
HDPE	High Density Polyethylene
HDT	Heat Distortion Temperature
HIPP	High Impact Polypropylene
LDPE	Low Density Polyethylene
MFI	Melt Flow Index
MIMO	Multiple Input Multiple Output
MOPSO	Multi Objective Particle Swarm Optimisation
MPI	Moldflow Plastic Insight
OA	Orthogonal Array
PA 6	Polyamide-6
PB	Polybutadiene
PBT	Polybutylene Terephthalate
PC	Polycarbonate
PCA	Principal Component Analysis
PET	Polyethylene Terephthalate
PP	Polypropylene
Pred R	The power of two of Predicted Regression

PSO	Particle Swarm Optimisation
PSONN	Neural Network based on Particle Swarm Optimisation
p-value	Probability value
PVC	Polyvinyl Chloride
RSM	Response Surface Methodology
SM	Shot Material
S/N	Signal/noise
VSP	Vicat Softening Point
V/P	Velocity/pressure

LIST OF SYMBOLS

V_i^k	Velocity of particle i at iteration k
V_i^{k+1}	Modified velocity particle
S_i^k	Current position vector of particle i at generation k
S_i^{k+1}	Modified position vector
$pbest_i$	Best position found by particle i
$gbest$	Best position found by particle group
ω	Inertia weight
c_1 and c_2	Cognitive and social coefficients.
r_1 and r_2	Random parameters, to ensure good coverage of the design space and avoid entrapment in local optima.
SM	Ram position / shot material (mm)
$V_{\text{moulded part}}$	Moulded part volume based on 3D (mm3)
$V_{\text{feed system}}$	Feed system volume based on 3D (mm3)
d_r	Reciprocating screw diameter in this study = Ø 28 mm
ρABS_{m-s}	Percentage different between melt and solid density (%)
ρ_s	Solid density (g/cm2)
ρ_m	Melt density (g/cm2)
v	Ram speed – feed system / moulded part (mm/s)
Q	Volume flowrate – based on fill analysis log (mm^3/s)

Pengoptimuman Ledingan Pada Panel Perumah Hadapan Diacuankan Daripada *Acrylonitrile Butadiene Styrene* (ABS) Kitar Semula

ABSTRAK

Proses pengacuan suntikan amat dikenali dalam industri pengacuan plastik. Pembangunan proses ini telah menyebabkan peningkatan dalam penggunaan bahan plastik yang digunakan untuk membentuk produk plastik. Dua jenis sisa dihasilkan semasa pemprosesan, iaitu sisa pasca industri dan sisa pasca pengguna. Penggunaan sisa pasca industri sebagai bahan kitar semula, dicampur dengan bahan asal biasanya mempunyai kelebihan yang jelas di mana ia bersih dan komposisi polimer diketahui. Kualiti produk yang dihasilkan dengan mencampur bahan asal dan bahan kitar semula akan berbeza daripada produk yang dihasilkan menggunakan bahan asal sahaja. Ledingan adalah salah satu kecacatan yang biasanya berlaku pada komponen yang dibentuk dan memberi kesan terhadap dimensi komponen dan proses pemasangan. Penggunaan nisbah campuran yang bersesuaian antara bahan asal dan bahan kitar semula dilaporkan sebagai cara yang berkesan untuk meningkatkan kualiti komponen dibentuk berbanding menggunakan 100% bahan kitar semula. Selain daripada jenis bahan yang digunakan, penetapan parameter pemprosesan mesin juga mempengaruhi kualiti komponen yang dibentuk. Walau bagaimanapun, kebanyakan penyelidik terdahulu hanya memberi tumpuan kepada kesan nisbah campuran (bahan asal dan kitar semula) ke atas sifat-sifat mekanikal komponen yang dibentuk. Terdapat kajian terhad mengenai kesan nisbah campuran antara bahan asal dan kitar semula pada kualiti (ledingan) dengan parameter pemprosesan yang optimum. Dalam kajian ini, bahan *Acrylonitrile Butadiene Styrene* (ABS) yang banyak digunakan dalam industri pengacuanan digunakan untuk membentuk panel perumah hadapan dengan menggunakan acuan sedia ada. Penilaian terhadap prestasi dari segi kualiti (ledingan) pada komponen yang diacuankan menggunakan R0 (100% bahan asal), R30 (70% bahan asal: 30% bahan dikitar semula), R40 (60% bahan asal: 40% bahan dikitar semula) dan R50 (50% bahan asal: 50% bahan dikitar semula) dijalankan secara kajian-kajian simulasi dan kerja-kerja eksperimen. Seterusnya, kaedah pengoptimuman telah digunakan untuk mendapatkan parameter–parameter pemprosesan yang optimum untuk mengacuan komponen-komponen plastik dengan menggunakan campuran bahan asal dan bahan kitar semula. Kaedah Gerak Balas Permukaan (RSM) dan Pengoptimuman Partikel Berkumpulan (PSO) telah digunakan sebagai kaedah-kaedah pengoptimuman di dalam kajian ini. Keputusan dalam kajian-kajian simulasi dan kerja eksperimen, R0 menunjukkan bahawa tidak ada ledingan pada panel perumah hadapan dalam arah x. Oleh itu, kajian ini hanya tertumpu pada ledingan dalam arah y, sementara ledingan dalam arah x diabaikan. Nilai optimum ledingan dalam arah y untuk R0 menggunakan RSM dan PSO adalah masing-masing 0.245 mm dan 0.242 mm, yang talah ditambah baik sebayak 5.38% dan 6.92% berbanding hasil yang disyorkan dari kajian simulasi, 0.26 mm. Sementara itu, hasil ledingan dalam arah y pada panel perumah hadapan yang diacuan menggunakan R30 adalah kira-kira 7.35% (RSM) dan 8.25% (PSO) lebih tinggi daripada R0. Di samping itu, R30 adalah nisbah campuran terbaik berbanding R40 dan R50. Nilai ledingan yang dioptimumkan untuk R40 adalah 22.44% (RSM) dan 23.98% (PSO) lebih tinggi daripada R0. Manakala, nilai ledingan yang dioptimumkan untuk R50 adalah 32.65% (RSM) dan 33.42% (PSO) lebih tinggi daripada R0. Dari Analisis Perbezaan (ANOVA), hasil menunjukkan bahawa suhu lebur adalah parameter pemprosesan yang paling signifikan yang mempengaruhi ledingan dalam arah y untuk bahan campuran R0, R30, R40 dan R50. Penemuan menunjukkan bahawa, kualiti (ledingan) komponen-komponen diacuan yang dihasilkan dengan menggunakan gabungan campuran bahan dara dan bahan kitar semula boleh ditambahbaik, dengan itu menawarkan lebih banyak keuntungan kepada industri pengacuanan.

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ABSTRACT

Injection moulding process is well known in plastic moulding industries. The development of this process had caused an increase in the plastic materials used to mould plastic product. Two types of waste were generated during processing, which are postindustrial waste and postconsumer waste. The use of postindustrial waste as the recycled material, mixed with virgin material typically has distinct advantages where it is clean and the composition of polymer is known. The quality of products produced by mixing virgin and recycled materials will be different from the product produced using virgin material only. Warpage is one of the defects that normally occur on moulded parts as affect the dimensions of parts and assembly process. The use of appropriate blends ratio between virgin and recycled materials was reported as the effective way to improve the quality of moulded parts rather than using 100% recycled material. Other than the type of material used, setting of machine, processing parameters also influence the effect of the quality of moulded parts. However, most of the previous researchers only focused on the impact of blend ratio (virgin and recycled material) on the mechanical properties of the moulded parts produced. There have been limited studies on the effect of blend ratio between virgin and recycled material on the quality (warpage) with optimal processing parameters. In this study, the existing design of front panel housing was used. Acrylonitrile Butadiene Styrene (ABS) materials widely used in the moulding industry were used to form front panel housing using existing mould. Evaluation on the performance in terms of quality (warpage) on the moulded part using R0 (100% virgin), R30 (70% virgin: 30% recycled), R40 (60% virgin: 40% recycled) and R50 (50% virgin: 50% recycled) were conducted by simulation studies and experimental works. Next, optimisation methods were used in order to obtain the optimal setting of processing parameters to mould the plastic parts using the mixture blends of material. Response Surface Methodology (RSM) and Particle Swarm Optimisation (PSO) methods have been used as the optimisation methods. Results in simulation studies and experimental works of R0 indicate that there is no warpage on the front panel housing in x direction. Thus, this study only focuses on the warpage in y direction, while the warpage in x direction is neglected. The optimised value of warpage in y direction for R0 using RSM and PSO are 0.245 mm and 0.242 mm, respectively, which improved 5.38% and 6.92% as compared to the recommended result from simulation studies, 0.26 mm. Meanwhile, the result of warpage in y direction on the front panel housing moulded by R30 is approximately 7.35% (RSM) and 8.25% (PSO) higher than R0. In addition, R30 is the best blend ratio compared to R40 and R50. The value of optimised warpage for R40 are 22.44% (RSM) and 23.98% (PSO) higher than R0. While the value of optimised warpage for R50 are 32.65% (RSM) and 33.42% (PSO) higher than R0. From the Analysis of Variance (ANOVA), the results show that melt temperature is the most significant processing parameter influencing the warpage in y direction for R0, R30, R40 and R50 mixture blends material. The findings indicate that, the quality (warpage) of the moulded parts produced using mixture blends of virgin and recycle material can be improved, thus offering more profit to the moulding industries.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

Plastic injection moulding is one of the most important processes to produce plastic products in the industry (Chen et al., 2012). Plastics have great advantages in terms of weight, durability and lower cost as compared to other types of materials (Hopewell et al., 2009). The rapid increase in the use of plastic products has led to an increase in the number of plastics ending up in the waste streams. This alarming situation requires more attention to be given in the effort to encourage the 3R; Recycle, Reuse and Reduce (Hamad et al. 2013). For economic and environmental reasons, recycling operations on the product produced are becoming increasingly necessary, particularly for a large part where the quantity of scrap materials is very high. (Javierre et al., 2007).

Warpage is a one of the main defects in injection moulding process, especially thin-walled plastic products (Ozcelik & Sonat, 2009). Choosing the right plastic material and the appropriate processing parameters are the best ways to minimise warpage defects. On the other hand, reducing part thickness will also reduce part strength. By selecting suitable materials for durability, this problem can be solved. However, some materials may be suitable in terms of strength but not in terms of appearance and vice versa (Ozcelik & Sonat, 2009). Therefore, processing parameters, raw material, mould design and injection moulding machine must be well controlled in order to obtain high quality of the moulded part produced (Chen et al., 2009).

1.2 Background of Study

Plastic industry is one of the fastest growing industries in the world (Alias et al., 2016). The quantities of plastic products used is continuously increasing, annually. In many industries, virgin and polymer recycled mixtures are very common practices, where plastic scraps are crushed and reintroduced into the processing apparatus together with virgin material (Scaffaro et al., 2012). Thus, it is crucial to consider plastic recycling in the effort to reduce plastic waste. However, due to some reactions, the performance or quality of products made from recycled polymer will be different from those made from virgin polymer (Chen et al., 2011). Mixing virgin material with recycled material is an alternative way to maintain the properties of the product (Chen et al., 2011). Many studies had been conducted on the impacts of percentage of recycled material, focusing on strength and mechanical properties of the part produced during injection moulding process (Meran et al., 2008; Scaffaro et al., 2012; Kuram & Ozcelik, 2015).

Material selection, part and mould design as well as processing parameters in the injection moulding process influence the quality of the plastic product. An inaccurate combination can lead to numerous production issues besides reducing the competitive price advantage and also reducing the company's profitability (Chang & Faison, 2001; Fei et al., 2013). Acrylonitrile Butadiene Styrene (ABS) is a common material used in moulding components such as electronic housings, cars and motorcycles. Due to its extensive application, there is a huge demand to reproduce moulded parts using recycled ABS polymers (Chen et al., 2011; Ford & Fisher, 2019; Hamarat et al., 2018).

The quality of the product is the concern of both the manufacturers and customers. Hence, high quality of the product and the great rate of production are the vital key in determining the success of the industry (Fei et al., 2013). Thus, the identification of the root cause of the defects directly contributes to the elimination of part defects as well as the improvement of the quality of the moulded parts. Many researchers found that injection moulding processing parameters have an important impact on the quality of plastic parts such as shrinkage and warpage (Chiang & Chang, 2007; Yin et al., 2011; Chen & Kurniawan, 2014). Other than that, other processing parameters that influence the quality of the plastic parts are namely packaging pressure, melting temperature and mould temperature (Bushko and Stokes, 1996; Jansen et al., 1998; Huang & Tai, 2001).

In fact, it is noted that product defects, with process instability and so forth, are due to a combination of inappropriate processing parameters. To solve this problem, many researchers conducted simulation studies of injection moulding using computer-aided engineering (CAE) simulation software such as Autodesk Moldflow Insight (AMI), C-MOLD and Moldex3D and continued experimental design for optimisation processing parameters using optimisation methods such as Taguchi, Response Surface Methodology (RSM) and Genetic Algorithm (Chen et al., 2015, 2016; Nasir et al., 2016).

In recent years, the performance of recycled ABS in injection moulding process has triggered many researchers to investigate the effects of recycling process on physical and mechanical properties of r-ABS and virgin ABS when mixed according to the loading ratio (Chen et al., 2011; Scaffaro et al., 2012; Alias et al., 2016). Performing the injection moulding process is quite challenging as the processing parameters involved during the manufacturing process need to be controlled efficiently in order to obtain a high quality product.

1.3 Problems Statement

The demand of plastic products is continuously increasing with the increase of the population worldwide. Consequently, the amount of plastic waste also increases, which may cause harm to the environment. There is a very high amount of wasted polymer material (post-industrial) produced in the injection moulding process consisting of scraps from the moulded part produced throughout the process, due to quality problems and also the feeding system (Javierre et al., 2007). In order to overcome this issue, the recycling process should be implemented for both economic and environmental reasons. Many researchers had focused on the effect of virgin-recycled blends material and number of reprocessing cycles on mechanical properties of part produced in addressing this particular issue (Meran et al., 2008; Mehat & Kamaruddin, 2011a; Bhattacharya & Bepari, 2014; Marulanda et al., 2014; Abdullaha et al., 2016; Maria et al., 2016). Although several studies had been conducted on the effect of processing parameters on the plastic part produced by virgin-recycled blends material (Gu et al., 2014; Mehat & Kamaruddin, 2011b), the effect of processing parameters and virgin-recycled blends on the quality of part (warpage) is still less to be found in publication.

The moulded plastic parts may not be functional or may be visually unacceptable if warpage occurred on the plastic parts (Taghizadeh et al., 2013). It will affect the assembly process of the plastic part. The formation of warpage in plastic moulded part is influenced by the processing parameter in the process of injection moulding (Ozcelik &

Sonat, 2009; Mehat et al. , 2013; Taghizadeh et al., 2013; Sun et al., 2013; Nasir et al., 2016). Thus, in the plastic injection moulding industry, the formation of warpage will affect the quality, productivity and manufacturing costs (Chen et al., 2009; Xu et al., 2012; Sun et al., 2013; Wang et al., 2014). Traditionally, trial and error approach is often used in plastic injection moulding process to obtain an optimal combination of processing parameter. The artificial intelligent methods in simulation studies and experimental works are used to overcome this issue, consequently reducing both the time consumed and cost, at the same time producing the best quality product. Most studies based on method of optimisation were performed by optimising processing parameters to minimise the warpage of the part produced using only virgin materials (Chiang et al., 2011; Ozcelik & Sonat, 2009; Sanap et al., 2016; Taghizadeh et al., 2013). However, most researchers concentrated only on the mechanical properties of plastic parts rather than minimising warpage to optimize processing parameters for virgin recycled blends.

One of the most successful engineering thermoplastics is ABS (Scaffaro et al., 2012). ABS is widely used in the automotive, electronics and other commodities industries (Scaffaro et al., 2012). The demand of products made from ABS is increasing rapidly. Therefore, it is very important to focus on recycling and reusing ABS polymer. The effect of virgin-recycled ABS blends on reprocessing cycles and mechanical properties have been extensively studied (Scaffaro et al., 2012; Kuram & Ozcelik, 2015; Maria et al., 2016). Nevertheless, limited studies have been conducted on the effect of virgin-recycled ABS blends on warpage that affects product quality. In addition, most of the previous researches just conducted real experimental works without the aid of simulation software and artificial intelligence optimisation method (Hamarat et al., 2018; Kuram, Ozcelik, & Yilmaz, 2015; Scaffaro et al., 2012).