Evaluation of Shrinkage and Weld Line Strength on Thick Flat Part in Injection Moulding Process

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LIST OF ABBREVIATIONS

3D	Three dimensions
ABS	Acrylonitrile Butadiene Styrene
Adj R^2	The power of two of Adjusted Regression
AMI	Autodesk Moldflow Insight
ANN	Artificial Neural Networks
ANOVA	Analysis of Variance
BP	Back Propagation
CAE	Computer Aided Engineering
CCD	Center Composite Design
CNFs	Carbon Nano Fibers
DMPGA	Distributed Multi-Population Genetic Algorithm
DOE	Design of Experiment
EPCS	Ejector Pins Compression System
FEM	Finite Element Method
FRPP	Fiber Reinforced Polypropylene
GA	Genetic Algorithm
GF	Glass fiber
HDPE	High-density Polyethylene
HIPS	High Impact Polystyrene
LCD	Liquid Crystal Display
LOF	Lack of Fit
OEA	Obstacle Edge Angle

PA 6	Polyamide – 6
PBT	Polybutylene Terephthalate
PMMA	Polymethylmethacrylate
POM	Polyoxymethylene
PP	Polypropylene
PPE	Polyphenylene
PPO	Polyphenylene Oxide
PPS	Polyphenylene Sulfide
Pred R^2	The power of two of Predicted Regression
PS	Polystyrene
PSO	Particle Swarm Optimization
p-value	Probability value
PVC	Polyvinyl Chloride
RHCM	Rapid Heat Cycle Moulding
RSM	Response Surface Methodology
SAO	Sequential Approximate Optimization
SEM	Scanning Electron Microscope
SM	Shot Material
SMA	Poly Styrene-co-Maleic Anhydride
TiO_2	Titanium dioxide
V/P	Velocity/pressure
VIAM	Vibration Assisted Injection Moulding

LIST OF SYMBOLS

S	shrinkage (%)
L_{cavity}	Length of the cavity (mm)
L_{part}	Length of the moulded part (mm)
σ_M	Tensile strength (N/m^2)
σ	Tensile stress (N/m^2)
F	Force (N)
A	Cross-sectional area (mm^2)
S_{Mp}	Shrinkage in parallel direction of the melt flow (%)
S_{Mn}	Shrinkage in normal direction of the melt flow (%)
l_c	Length across the centre of the cavity (mm)
l_1	Corresponding length of the test specimen (mm)
b_c	Width across the centre of the cavity (mm)
b_1	Width of the test specimen respectively (mm)
ΔP	pressure drop (Pa)
$\dot{V}$	Volumetric flow rate (m^3/s)
$t_{c,}$	Cooling time (s)
α	Thermal diffusivity of the material (m^2/s)
T_{eject}	Specified ejection temperature (°C)
$T_{coolant}$	Coolant temperature (°C)
T_{melt}	Melt temperature of material (°C)
$\dot{\gamma}$	shear rate (s^{-1})
t_s	gate freeze time (s)
$T_{no\ flow}$	Specified temperature material cannot be flow anymore (°C)

$Q_{molding}$	The total amount of heat needs to remove by the cooling system (J)
C_p	Specific heat of material (J/g.°C)
ρ	Density of material (kg/m^3)
$\dot{Q}_{cooling}$	Rate of heat transfer from the moulded part (J/s)
R_e	Reynolds number
$h_{conduction}$	Convection heat transfer coefficient (W/m^2.^{o}C)
$\emptyset$	Diameter (m)
V_{part}	Volume of the moulded part (m^3)
V_{gs}	Volume of the gating system (m^3)
A_{screw}	Cross sectional area of reciprocating screw (m^2)

Penilaian terhadap Pengecutan dan Kekuatan Garis Kimpal pada Bahagian Rata yang Tebal dalam Proses Pengacuan Suntikan

ABSTRAK

Sifat-sifat mekanikal seperti kekuatan bahagian yang dibentuk adalah sangat penting terutamanya bagi bahagian-bahagian yang memerlukan kekuatan yang secukupnya untuk kefungsian sesuatu produk. Salah satu daripada kebimbangan utama yang memberi kesan kepada sifat-sifat mekanikal adalah kecacatan garis kimpalan yang berlaku apabila dua atau lebih pintu digunakan semasa proses pengacuan suntikan. Di samping itu, dimensi bahagian juga penting bagi memastikan ketepatan produk. Oleh yang demikian, pengecutan pada bahagian-bahagian yang dibentuk juga perlu dikawal. Kebanyakan kajian sebelum ini memberi tumpuan kepada kekuatan garis kimpalan atau pengecutan bahagian dibentuk secara berasingan dan sukar untuk mencari kajian yang menggabungkan kedua-dua aspek ini. Oleh itu, kajian ini menilai kedua-dua pengecutan dan kekuatan garis kimpalan menggunakan ‘Design of Experiment (DOE)’ dan ‘Response Surface Methodology (RSM)’ dalam pengoptimuman pelbagai objektif menggunakan parameter-parameter pengacuan suntikan. Acuan telah berjaya direkabntuk dan lengkap dengan sistem laluan, sistem penyejukan, teras dan rongga bagi bahagian rata yang tebal berdasarkan piawaian ISO.Parameter-parameter pembolehubah yang digunakan dalam kajian ini adalah suhu masukan penyejuk, suhu leburan, tekanan pemampatan dan masa penyejukan. Proses simulasi telah dijalankan untuk menentukan parameter pengacuan suntikan yang disyorkan dan julat parameter-parameter pembolehubah. Julat boleh terima pembolehubah untuk suhu masukan penyejuk telah ditetapkan antara 50°C hingga 70°C, manakala suhu leburan adalah 250°C hingga 270°C. Julat bagi tekanan pemampatan terletak antara 50 MPa hingga 70 MPa dan masa penyejukan antara 8 s hingga 12 s. Kerja-kerja eksperimen telah dijalankan berdasarkan reka bentuk eksperimen di mana model regresi telah dihasilkan untuk meramalkan pengecutan dan kekuatan garis kimpalan. Tetapan parameter proses yang optimal telah dibentuk untuk mencapai pengecutan dan kekuatan garis kimpalan yang optimum pada bahagian yang dibentuk. Keputusan pengecutan dan kekuatan garis kimpalan menggunakan tetapan yang optimal selepas proses pengoptimuman dibandingkan dengan keputusan yang diperolehi menggunakan tetapan yang disyorkan. Hasilnya, pengecutan dalam arah normal dan selari dengan aliran leburan telah dikurangkan masing-masing sebanyak 5.97 % dan 4.91 % yang diramalkan oleh model yang dijana menggunakan RSM. Sebaliknya, kekuatan garis kimpalan telah meningkat sebanyak 3.76 % berbanding dengan kekuatan garis kimpalan yang diperolehi dari tetapan yang disyorkan. Di samping itu, pengecutan dalam arah yang selari dan normal kepada arah aliran leburan yang dioptimumkan menggunakan kaedah pelbagai objektif dapat dikurangkan masing-masing sebanyak 5.93 % dan 4.19 %, manakala kekuatan garis kimpalan dipertingkatkan sebanyak 3.76 %, dengan menggunakan gabungan parameter-parameter berikut, iaitu 69.93°C suhu masuk penyejuk, 270°C suhu leburan, 70 MPa tekanan mampatan dan 8 s masa penyejukan, dengan ralat model ramalan adalah dari 0.2 % kepada 14.5 % yang diperolehi dalam eksperimen pengesahan. Tekanan pemampatan didapati sebagai parameter paling penting yang memberi kesan kepada pengecutan dalam kedua-dua arah selari dan normal kepada aliran leburan. Sebaliknya, suhu masukan penyejuk adalah parameter paling penting yang mempengaruhi kekuatan garis kimpalan. Kesimpulannya, RSM dengan kaedah pengoptimuman pelbagai objektif telah meningkatkan kedua-dua respon (mengurangkan pengecutan dan meningkatkan kekuatan garis kimpalan) pada bahagian yang dibentuk.

Evaluation of Shrinkage and Weld Line Strength on Thick Flat Part in Injection Moulding Process

ABSTRACT

Mechanical properties such as strength of moulded part is critical predominantly for parts that require a sufficient strength for the functionality of the product. One of the main concerns that affects the mechanical properties is weld line defect which occurs when two or more gates are used during the injection moulding process. In addition, the dimensions of the part are also crucial in terms of precision of the product. Thus, the shrinkage of the moulded parts also needs to be controlled. Most of the previous studies focus on the weld line strength or the shrinkage of the moulded part separately and it is rare to find studies that incorporate both of these aspects. Therefore, the current study evaluates both shrinkage and strength of weld line using Design of Experiment (DOE) and Response Surface Methodology (RSM) in multi-objectives optimisation utilizing the injection moulding parameters. The mould was successfully designed and fabricated complete with gating system, cooling system, core and cavity of a thick flat part based on ISO standard. The variable parameters used in this study are coolant inlet temperature, melt temperature, packing pressure and cooling time. Simulation process was conducted to determine the recommended setting of injection moulding parameters and the range of the variable parameters. The acceptable range of coolant inlet temperature was set between 50°C and 70°C, while the melt temperature was between 250°C and 270°C. The range of packing pressure was set between 50 MPa to 70 MPa and cooling time between 8 s and 12 s. Experimental works were conducted according to the experimental design where regression models were established to predict the shrinkage and weld line strength. An optimal setting parameter of the process was established to achieve the optimum shrinkage and weld line strength of the moulded part. The results of shrinkage and weld line strength using an optimal setting after optimisation process were compared with the results obtained using the recommended setting. It was found that, the shrinkage in the normal and parallel directions to the melt flow were reduced by 5.97 % and 4.91 % by predicted model generated using RSM. On the other hand, the weld line strength was improved by 3.76 % as compared to the weld line strength obtained from the recommended setting. In addition, the shrinkage in parallel and normal directions to the melt flow using multi-objective optimisation reduced by 5.93 % and 4.19 %, respectively, while the weld line strength improved by 3.76 %, using a combination of parameters, of 69.93°C of coolant inlet temperature, 270°C of melt temperature, 70 MPa of packing pressure and 8 s of cooling time, with the predicted errors ranging from 0.2 % to 14.5 % during the validation experiments. The packing pressure was found to be the most significant parameter affecting the shrinkage in both parallel and normal directions to the melt flow. The coolant inlet temperature on the other hand was the most significant parameter affecting the weld line strength. As a conclusion, the RSM in multi-objectives optimisation method improves both responses (reduces the shrinkage and increases the weld line strength) on the thick flat moulded parts.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Plastic material is commonly used in variety of consumer products as well as industries. Nowadays, plastic has become popular for various types of industries such as food, agriculture, automotive and aerospace. In an automotive industry, most of the internal components are made of plastic, which makes plastic very tangible and widespread. The demand for the plastic product is very high in the market as a wide variety of shapes can be produced using the injection moulding process. However, some defects could occur during the process which affect the quality and cost of the products produced.

1.2 Background of study

The undesirable defects will affect the quality of the moulded parts. If the defects are reduced, then the quality can be improved. The common defects in the injection moulding process include sink mark, void, short shot, flash, flow marks, silver streaks, shrinkage, weld line and warpage (Fischer, 2003; Harper, 2006; Osswald & Hernández-Ortiz, 2006). These defects can be minimised or eliminated by a good combination of parameters setting during the injection moulding process (Kazmer, 2009; Shoemaker, 2006). Traditionally, the parameters setting was determined by trial and error method, however this approach does not produce the best quality of the moulded part produced (Kovács & Sikló, 2010). Therefore, parameter optimisation