THE MODELLING OF PROCESSING CONDITIONS FOR POLYPROPYLENE-NANOCLAY INTEGRAL HINGES AT HIGH HEAT EXPOSURE

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To my late father, mother, my wife, and my kids.

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ABSTRACT

This research is about generating models of injection moulding processing conditions, towards quality performance of polypropylene-nanoclay integral hinges, exposed to high heat temperature. The assessment of hinges' quality performance analyses was translated as the signal to noise ratio values for ultimate tensile strength, shrinkage and warpage. This research had adopted Taguchi Optimisation Method, to optimise the processing conditions, to generate the regression models and to construct master curves for quality performance prediction based on nanoclay content. According to the results, 18 regression models have been successfully generated. 3 types of master curves have been constructed based on the produced models with the specific nanoclay content. Additionally, the quality performance of the integral hinges was extended to high heat exposures, and the additional of nanoclay had produced a significant advancement in the injected mould samples. Validation test has been carried out towards the regression model with most of the models have produced good predictions of quality performances. The novelty of this research is the correlations between the optimum injection moulding processing conditions with the precise range of shrinkage, warpage and ultimate tensile strength. The correlations were simplified in the form of regression models and master curves. These models and master curves were recommended as references and a prediction method, specifically for polypropylene-nanoclay integral hinges manufacturing and design process. These findings will lead to wider and optimum applications of thin layer parts and components such as packaging products; as well as other manufacturing field such as artificial human parts development and building appliances.

ABSTRAK

Kajian ini adalah mengenai penjanaan model keadaan pemprosesan bagi proses acuan suntikan; terhadap prestasi kualiti engsel bersepadu polipropelina-tanah liat nano yang terdedah pada suhu tinggi.Penilaian analisis prestasi kualiti ini diterjemahkan melalui nilai-nilai nisbah isyarat terhadap hingar bagi kekuatan tegangan muktamad, pengecutan dan perlengkungan. Kajian ini telah mengguna pakai Kaedah Pengoptimuman Taguchi, untuk mengoptimumkan keadaan pemprosesan, untuk menjana model regresi dan untuk membangunkan keluk induk bagi prestasi kualiti berdasarkan kandungan tanah liat nano. Berdasarkan kepada keputusan yang diperolehi, 18 model regresi telah dijana. 3 jenis keluk induk telah dibangunkan berdasarkan model yang dihasilkan, mengikut kandungan tanah liat nano yang khusus. Sebagai tambahan, prestasi kualiti engsel bersepadu ini diperluaskan kepada pendedahan terhadap suhu yang tinggi, dengan penambahan tanah liat nano yang mampu menghasilkan kemajuan nilai terhadap sampel acuan suntikan. Ujian pengesahan telah dijalankan ke atas model regresi dan kebanyakan model menghasilkan ramalan prestasi kualiti yang baik. Keunikan penyelidikan ini adalah korelasi antara keadaan pemprosesan acuan suntikan yang optimum dengan julat nilai yang jitu bagi pengecutan, perlengkungan dan kekuatan tegangan muktamad. Kolerasi ini telah diterjemahkan dalam bentuk model regresi dan keluk induk, yang mana hasil dapatan ini sangat dicadangkan sebagai rujukan dan kaedah ramalan, khusus untuk proses pembuatan dan rekabentuk engsel bersepadu dari polipropelina-tanah liat nano. Penemuan ini akan membawa kepada aplikasi yang lebih luas dan optimum bagi pembuatan bahagian-bahagian dan komponen berlapisan nipis, seperti produk pembungkusan dan juga bidang pembuatan lain seperti pembangunan anggota tiruan manusia dan peralatan pembinaan.

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LIST OF SYMBOLS AND ABBREVIATIONS

^0C	-	Degree Celsius
2D WAXS	-	Two Dimension Wide Angle X-ray Scattering
ABS	-	Acrylonitrile–Butadiene-Styrene
AFM	-	Atomic Force Microscopy
ANN	-	Artificial Neural Network
ANOVA	-	Analysis of Variance
BP	-	Back Propagation
CAD	-	Computer Aided Design
CAE	-	Computer Aided Engineering
CBR	-	Case Based Reasoning
CEC	-	Cation Exchange Capacity
CNC	-	Computer Numerical Control
DMA	-	Dynamic Mechanical Analysis
DSC	-	Differential Scanning Calorimetry
EVA	-	Ethylene Vinyl Acetate
FEM	-	Finite Element Method
FKMP	-	Faculty of Mechanical and Manufacturing Engineering
FT	-	Filling Time
FTIR	-	Fourier Transfer Infra Red
G	-	Grams
G'	-	Storage Modulus
GA	-	Genetic Algorithm
H	-	Height
HDPE	-	High Density Polyethylene
HRS	-	Hot Runner System
HSC	-	High Strength Concrete
iPP	-	Isotactic Polypropylene

L	-	Length
L_{ave}	-	Average Length
L_c	-	Length of Actual Mould Cavity
LRM	-	Linear Regression Method.
MD	-	Machine Direction
min	-	Minute
mm	-	Millimetre
MPa	-	Mega Pascal
MSD	-	Mean Squared Deviation
MT	-	Melt Temperature
MWNT	-	Multi Walled Nano Tubes
ND	-	Normal Direction
o-MMT	-	Organo-Montmorillonite
OLS	-	Ordinary Least Squares
P-V-T	-	Pressure-Volume-Temperature
PC/ABS	-	Polycarbonate / Acrylonitrile–Butadiene-Styrene
PCA	-	Principal Component Analysis
PP	-	Packing Pressure
PP-EP	-	Polypropylene-Ethylene Propylene
PP-g-AA	-	Polypropylene-grafted-Acrylic Acid
PP-g-MA	-	Polypropylene –grafted- Maleic Anhydride
$Q1@60^0C$	-	Quality Performance for the first formulation for the exposure condition at 60^0C
$Q1@70^0C$	-	Quality Performance for the first formulation for the exposure condition at 70^0C
Q1@RT	-	Quality Performance for the first formulation for the exposure condition at Room Temperature
QP	-	Quality Performance
R-Sq	-	Correlation Coefficient
R-Sq (adj)	-	Correlation Coefficient (Adjusted)
S	-	Second
S	-	Shrinkage
S/N	-	Signal to Noise

S/N_{QP}	-	Signal to Noise for Quality Performance
S/N_{S}	-	Signal to Noise for Shrinkage
S/N_{UTS}	-	Signal to Noise for Ultimate Tensile Strength
S/N_{Z}	-	Signal to Noise for Warpage
SA	-	Simulated Annealing
SEM	-	Scanning Electron Microscopy
SIM	-	Sequential Injection Moulding
SIRIM	-	Standards and Industrial Research Institute of Malaysia
SS	-	Screw Speed
$T_{ambient}$	-	Ambient Temperature
T_{mould}	-	Mould Temperature
t_a	-	Average Thickness
TD	-	Transverse Direction
TEM	-	Transmission Electron Microscopy
TGA	-	Thermal Gravimetric Analysis
TS	-	Transmission Spectroscopy
UTM	-	Universal Testing Machine
WAXS	-	Wide Angle X-ray Scattering
wt.%	-	Weight Percentage
XRD	-	X-Ray Diffraction
Z	-	Warpage
α	-	Coefficient of Thermal Expansion

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CHAPTER 1

INTRODUCTION

In this chapter, discussion about research background, problem statements, objectives and scope of study in this research have been presented. The expected result, which is the novelty of this research also, was stated at the end of this chapter.

1. 1 Background study

This research is about modelling of injection moulding processing conditions toward the performance of functional polypropylene integral hinges samples with the additional of nanoclay Cloisite-20A, exposed to high heat temperature. The research started by performing injection moulding simulation and practical work; in order to verify and validate the developed mould for test the samples. The mould test sample was used to optimise the processing conditions towards shrinkage, warpage and ultimate tensile strength, with exposure to high heat environment. These properties analysis are very important in the manufacturing industry, because the characterisation of functional integral hinges was very useful in various thermoplastic component designs and manufacturing processes. The findings of this research, in the form of the regression model and developed the master curves, can lead to production of better quality, with longer life span of functional integral hinges. The model and curves were very useful as references, for further applications and improvement with wide potential in the manufacturing of plastic parts and components. Moreover, the additional value of this research was the usage of nanoclay Cloisite-20A as the nano size filler in the polymer nanocomposites system was rectified to withstand exposure to the high heat environment.

1. 2 Problem statement

The manufacturing of thin wall components with integral hinges is crucial for the several plastic industries due to the thinner components permit considerable improvement of environmental impact, beneficial effects on the reduction of fuel consumption and overall weight savings. Additionally, the decrease in thickness allows significant reduction in production costs because shorter cycle times and less material consumption. Particularly, thin wall plastic products relate to smaller and lighter parts; should be able to withstand the daily usage, and at the same time maintaining their aesthetic appearance. These features are critical in the realization of automotive interior components that must maintain high quality look and feel throughout the life cycle of the vehicle (Spina, 2004).

These intricate parts in the plastic industry, comes with toughest quality requirements, could be achieved through injection moulding technology (Nardin et al., 2002). Due to its ability to produce multifaceted shape plastic parts with good dimensional accuracy and very short cycle times, injection moulding has become one of the processes that is greatly preferred in manufacturing industry (Bozdana & Eyercioglu, 2002). These injected moulded parts, however, are very prone to defects. To avoid such quality control problems, it is desirable to successfully predict the optimum processing conditions, such as pressures, temperatures, and times (Hill, 1996). Any change in these variables can affect the process stability and the quality of the manufactured parts. Unfortunately, it has been found difficult to control and adjust simultaneously between the processing conditions and the properties of the product; and there is no single set of rules to designate which parameters to use in order to manufacture consistently a part with no defects (Dumitrescu et al., 2005). Furthermore, failures or damages of these parts become more frequent when it exposed to high temperature environment.

In order to solve the problems, optimising the processing conditions through several techniques becomes one of the promising solutions. The optimisation methods, such as Principal Component Analysis (Fung & Kang, 2005) ; Neuro Fuzzy Model (Antony & Anand, 2006) ; Gaussian Process Approach with Genetic Algorithm (Zhou

& Turng, 2007), Grey Relational Analysis (Khan et al., 2010) and Taguchi (Mehat & Kamaruddin, 2011) have been proven as a good solution in finding the suitable injection moulding processing condition.

Additionally, the utilisation of fillers in polymer composites also a possible solution, whereby the fillers such as nanoclay could improve the mechanical properties as well as the fire retardant behaviour. However, too many fillers with wrong processing condition might lead back to poor quality and component performance (Wang, 2012; Yuan et al., 2008).

Therefore, this research proposes to solve the problem of thermoplastic integral hinges parts design and processing conditions, by introducing a suitable model and master curves as the reference to predict the properties of polypropylene integral hinges with the additional of nanoclay Cloisite-20A. By transforming the pristine polypropylene into polymer nanocomposites, with the right clay content and processing conditions, the integral hinges were expected to sustain its function; even when it was exposed to the high heat environment.

1. 3 Objectives

The objectives of this research are:

a) To develop mould for producing the integral hinges test's sample.
b) To optimise the processing conditions by adopting the Taguchi Optimisation Method.
c) To generate regression model base on the optimised processing condition of polypropylene-nanoclay integral hinges with the responses of quality performance, exposed to 60^0C to 70^0C.
d) To construct master curves based on the regression model for quality performance versus clay content for integral hinges.

1. 4 Scope of study

The scopes of this study are as stated:

a) The raw material selected is polypropylene, a type of homopolymer, Titan Pro 6331, from Titan Petchem (M) Sdn. Bhd. The compatibilizer is a functionalized polypropylene-grafted-maleic anhydride (PP-g-MA), containing 1 wt. % of maleic anhydride (OREVAC C100).

b) The additional material to develop these polymer nanocomposites is nanoclay Cloisite-20A, varies from 0 wt. %, 1 wt. %, 2 wt. %, 3 wt. %, 4 wt. % and 5 wt. %, obtained from Southern Clay, Inc. US, courtesy from Wilbur-Ellis Company, Connell Bros. Company (Malaysia) Sdn. Bhd.

c) The performance of polypropylene integral hinges shall be translated through shrinkage, warpage and ultimate tensile strength. The test conducted for the manufactured samples shall adopt ISO standards.

d) The mould was made from AISI D2 cold work tool steel. Evaluation shall be made to choose the best mould design to define runner size and gate location.

e) The expected result shall focus more on generating the regression model that shall be fitted in the master curves, after getting the optimised processing condition by using the Taguchi Optimisation Method.

f) The chosen processing condition were screw speed, melt temperature, injection pressure and filling time.

1. 5 Expected result

In this research, a mould for preparing test samples specifically representing an integral hinge component was produced. These samples were made by using the mould that had been developed using simulation. The actual mould was fabricated and actual injection moulding was carried out to validate the simulation findings. The novelty of this research is the correlations between optimum injection moulding processing conditions and the quality performances of the products, exposed to the high heat environment, which were translated in the form of regression models. Master curves have been constructed for quality performance versus the nanoclay content, based on the regression models. The model and master curves can be used as references specifically for polypropylene-nanoclay integral hinges manufacturing and design process, with the extend condition in high heat environments. The additional of nanoclay shall be the additional advantage, whereby with the right nanoclay content, the quality performance of integral hinges was improved.

CHAPTER 2

LITERATURE REVIEW

2. 1 Introduction

This chapter is about the past works related to this project. It summarizes several previous researches which were related to this project. Previous research findings about the optimisation of injection moulding processing condition and research about polypropylene-nanoclay were included in this chapter. Research on the application of polypropylene, especially at high heat exposure was also been stated at the end of this chapter.

2.1.1 Injection moulding processing conditions

In general, injection moulding is a process that involves hot, injection moulded molten polymer which is heated with a highly plastic state; and then injected automatically by a screw with the support of hydraulics actuator, under high pressure into a mould cavity where it solidifies into cooled mould where the molten polymer will follow the final shape of the mould. The moulded part is then removed from the cavity. The advantage of this process is, that it may produce discrete components that are almost net shape and significant economies of mass production. The production cycle time is typically in the range of 10-30 seconds, for small components and longer time is not uncommon for large parts. Moreover, the mould may contain more than one cavity, therefore multiple mouldings are produced for each cycle and it also increases the cycle time as well. An injection moulding machine usually consists of an injection unit and clamping unit. A schematic diagram of injection moulding machine is shown in Figure 2.1 (Groover, 2007).

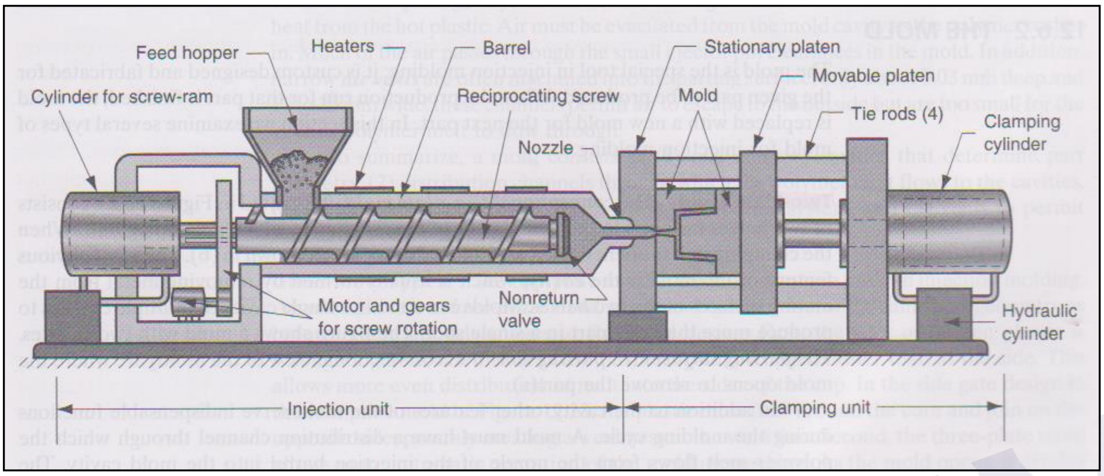

Figure 2.1: Single screw injection moulding (Groover, 2007).

Intricate and complex designs/dimensions are possible with injection moulding. In these cases, the challenge is to design and fabricate a mould that has the same geometry as the original component and which also easy for part removal. Part sizes can be in the range from about 50 grams up to about 25 kilograms, whereby the bigger parts represented by components such as refrigerator doors and automobile bumpers. The mould is the special tooling in injection moulding, because not only it determines the part shape and size, it also contributes a lot towards parts quality. For large, complex parts, the mould can be expensive, depending on the type of material and the machining time. For small parts, the mould can be built to contain multiple cavities, which is also making the mould expensive. Thus, injection moulding is economical and provide a good return of investment only for mass production (Groover, 2007).

2.1.2 Mould for injection moulding

Mould in injection moulding usually is in the form of cavity whereby the molten polymer shall be injected and solidified in this particular part. The surface of this tool will act as heat exchanger when the injected material solidifies with contact or for cooling the moulded component. The most common cold runner in plastic injection moulding tooling is a two-plate, cold runner mould at horizontal injection moulding. With thermoplastic materials, a cold runner mould refers to a mould in which the runner is cooled, solidified, and ejected with the moulded part during each moulding cycle. This tooling becomes common due to its simplicity, least expensive, easy to construct and the easiest to operate with less maintenance as compared with the hot runner mould. This type of mould consists of two halves; which is stationary and movable half; fastened to the two platens of the moulding machine's clamping unit. When the clamping unit opened, the two mould halves open. The function of movable half is to eject finish or desired part (Osswald et al., 2008).

Most of the mould consists of the cavity, sprue, runner, gates, injection system and cooling system. These elements are very important in ensuring the melt polymer distributed uniformly. The details about these elements are stated as below (Osswald et al., 2008).

a) Cavity - the feature which usually formed by removing metal from the mating surfaces of the two halves. Moulds can contain a single cavity or multiple cavities to produce more than one part in a single shot.
b) Sprue /distribution channels – This element leads the melt polymer from the nozzle into the mould. The sprue is in the form of carrot and act as an inlet channel to transfer molten material from the heating chamber into the runner system.
c) Runner - the function is to lead the melt polymer from the sprue to the multiple cavity moulds. Runner also acts as channels to connect the sprue bush to the cavity gates. There are two types of runner system-cold and hot. Cold runners are ejected with the part are trimmed after mould removal. The advantage of cold runner is lower mould cost. The hot runner keeps the polymer at or above its melt temperature. The material stays in the runner system after injection for the next injection.
d) Gates- Is a part that constricts the flow of plastic into the cavity. It prevents material from flowing out of the cavity when the injection pressure removed. There are one or more gates for each cavity in the mould.
e) Ejection system- A system required to eject the moulded part from the cavity at the end of the moulding cycle. Ejector pins built into the moving half of the mould usually accomplish this function. The cavity is divided between the two mould halves in such a way that the natural shrinkage of the moulding causes the part to stick to the moving halt When the mould opens, the ejector pins push the part out of the mould cavity.

f) Cooling system- This system consists of an external pump connected to passageways in the mould, through which water is circulated to remove heat from the hot plastic. Air must be evacuated from the mould cavity as the polymer rushes in. Much of the air passes through the small ejector pin clearances in the mould. In addition, narrow air vents are often machined into the parting surface; only about 0.03 mm deep and 12 to 25 mm wide, these channels permit air to escape to the outside but are too small for the viscous polymer melt to flow through.

Besides of these elements, there are other crucial factors that need to be considered specifically for thin-layered product. The factors are cycle time, gate locations and cavity condition. Cycle time is largely dependent on section thickness, machine conditions, heating capacity and injection capacity. The overall cycle time can vary from apply five seconds for thin articles to 60 seconds or more for thick articles. As for injection moulding hinges, it is important that the flow front cross the thin section at one instant. Gate location must provide balanced fill. The substantial pressure drop occurs when the flow front crosses the hinge, resulting in an increase of shrinkage rate. This may require adjustment of cavity dimensions to ensure proper fit of mating halves. The flow through the hinge will generate additional shear heating requiring additional local cooling. If the mating halves require two gates for filling and packing, they must be designed and developed to locate the weld line away from the hinges (Bauccio et al., 1994).

2.1.3 Simulation in injection moulding

With plastics gaining more and more ground in engineering applications, there was a critical demand on the quality of injected moulded parts. To satisfy these demands, software was manipulated to achieve the outstanding level of part design, mould design, machining of cavities, and part mouldings (Beaumont et al., 2002). Correct control of the processing condition usually plays major roles in achieving good quality, whereby this parameter settings are usually quantified either based on statistical experimental methods, computer aided simulations, or through operators’ experiences. Table 2.1 shows a review of several studies which have manipulated the effectiveness of numerical simulation.

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