DESIGN AND ANALYSIS OF FOOD CONTAINER IN PLASTIC INJECTION MOLDING PROCESS

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons).

The members of the supervisory committee are as follow:

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ABSTRAK

Proses pengacuan suntikan plastik adalah salah satu daripada proses pembuatan yang banyak digunakan untuk menghasilkan produk plastik dengan produktiviti yang tinggi. Selain itu, industri perkilangan pembungkusan makanan mengalami percubaan dan kesilapan untuk mendapatkan tetapan parameter optimum untuk meminimumkan isu kualiti dan percubaan dan kesilapan ini memakan masa dan mahal. Tujuan projek ini adalah untuk meningkatkan mutu bekas mentega dengan meminimumkan pengecutan volumetrik, anggaran tanda tenggelam dan warpage dari bekas mentega. Projek ini adalah untuk menangani penggunaan Moldflow yang mengintegrasikan dengan teknik statistik untuk meminimumkan pengecutan volumetrik, taksiran tanda tenggelam dan warpage dari bekas mentega yang bergantung pada parameter proses pengacuan suntikan plastik. Untuk tujuan ini, bentuk segi empat tepat bekas mentega direka dengan menggunakan SolidWorks. Molflow digunakan untuk mensimulasikan pengisian plastik acuan tunggal acuan bekas mentega berdasarkan jadual array ortogonal Taguchi's L_{18}. Di samping itu, analisis varians (ANOVA) digunakan untuk menyiasat kesan ketara parameter proses pada kualiti bekas mentega. Sementara itu, Minitab digunakan untuk mengoptimumkan tindak balas pengecutan volumetrik, anggaran tanda tenggelam dan warpage dengan memilih parameter proses yang paling sesuai untuk memaksimumkan nilai keinginan. Selain itu, bekas mentega mempunyai ketebalan seragam yang 1.2 mm dan faktor keselamatannya adalah 3.383 dan tindak balas pengecutan volumetrik, anggaran tenggelam dan warpage telah dioptimumkan masing-masing 0.956 %, 1.252 % dan 0.097 %. Yang terakhir tetapi tidak terkecuali, suhu lebur dan suhu acuan didapati adalah parameter proses yang paling penting untuk proses pengacuan suntikan plastik bekas mentega dan nilai pengecutan volumetrik yang diperoleh dari simulasi disahkan dengan nilai pengecutan volumetrik yang dikira.

ABSTRACT

The plastic injection molding process is one of the widely used of the manufacturing process to manufacture the plastic product with high productivity. Moreover, the food packaging manufacturing industry undergoes the trials and errors to obtain the optimal setting of the process parameters in order to minimize the quality issues and these trials and errors are time consuming and costly. The aim of this project is to improve the quality of the butter tub by minimizing the volumetric shrinkage, sink mark estimate and warpage on the butter tub. This project is to deal with the application of Moldflow integrating with the statistical technique to minimize the volumetric shrinkage, sink mark estimate and warpage of the butter tub which depends on the process parameters of the plastic injection molding. For this purpose, the rectangular shape of butter tub is designed by utilizing the SolidWorks. The Molflow is used to simulate the plastic filling of the single cavity mold of butter tub based on the Taguchi's L_{18} orthogonal array table. In addition, the analysis of variance (ANOVA) is applied to investigate significant impact of the process parameters on the quality of the butter tub. In meantime, the Minitab is used to optimize the response of the volumetric shrinkage, sink mark estimate and warpage by selecting the most appropriate process parameters that maximizing the desirability value. Furthermore, the butter tub has a uniform thickness which was 1.2 mm and its factor of safety was 3.383 and the volumetric shrinkage response, sink mark estimate response and warpage response have optimized by 0.956 %, 1.252 % and 0.097 % respectively. The last but not least, the melt temperature and mold temperature are found to be the most significant process parameters for the plastic injection molding process of butter tub and the volumetric shrinkage value obtained from the simulation is verified by the calculated volumetric shrinkage value.

DEDICATION

Only

my appreciated father, Liew Kim Hoi

my beloved mother, Ho Ah Yin

my adored sister, Liew Yoong En

for giving me the moral support, cooperation, money, encouragement and understandings

Thank You So Much

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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
BHN	-	Brinell Hardness
DOE	-	Design of Experiment
EPR	-	Ethylene-Propylene Copolymer Rubber
IML	-	In Mold Labelling
PPV46	-	Polyvinyl Alcohol Blending with 60% Starch
PPV55	-	Polyvinyl Alcohol Blending with 50% Starch
CAE	-	Computer Aided Engineering
hPP	-	Propylene Homopolymer
CTE	-	Coefficient of Thermal Expansions
PVT	-	Pressure, Volume and Time
DOF	-	Degree of Freedom

LIST OF SYMBOLS

cm^3	-	Volume
mm	-	Millimeter
℃	-	Degrees Celsius
%	-	Percentage
f	-	Degree of freedom
f_T	-	Total degree of freedom
N	-	Newton
S	-	Sum of squares
S_T	-	Total sum of squares
S_e	-	Sum of error
V	-	Variance
F	-	F-ratio
°	-	Angle Degree
wt%	-	Weight Percentage
S/N ratio	-	r
kV	-	Kilo Volt
MPa	-	Mega Pascal
g	-	Gram
s	-	Second
$g/_{cm^3}$	-	Density
$1/_C$	-	Alpha
R^2	-	Coefficient of Multiple Determination
°F	-	Degrees Fahrenheit
cm^3/g	-	Specific Volume
mm^2	-	Surface Area
kg	-	Kilogram

MJ	-	Mega Joule

CHAPTER 1
INTRODUCTION

Plastic injection molding is one of the widely used of the manufacturing process to manufacture the plastic product with a high productivity (Satoshi et al., 2018). The plastic injection molding is used to produce the plastic products in many fields such as the electronic apparatus, automotive and food packaging. The process cycle of the injection molding process can be divided into four different steps which are the clamping, injection, cooling and ejection. The injection molding process produces the plastic part by injecting the plastic material into the mold, then the plastic material is fed into heated barrel and becomes the molten plastic is then fill into the mold cavity with a high pressure and high speed. The desired shape of the molten plastic can be formed by the mold upon solidification. Moreover, the manufacturing process parameters affect the quality of the plastic product during the production and the most significant quality problem is the warpage (Ozcelik and Erzurumlu, 2005). Moreover, Behrooz et al. (2010) found that the major defects in the manufactured plastic product are the warpage and shrinkage. The dimensional and the physical characteristic of the product is affected by the mold temperature, injection speed, packing pressure and inhomogeneous cooling under packing process (Joon Kim et al., 2013).

1.1 Background of Study

The plastic injection molding is one of the main manufacturing processing technology of the polymer. The plastic injection molding is commonly used due to its high productivity, short cycle time and economic to produce the complex product in a high volume. However, the process parameters of the plastic injection molding such as the mold temperature, melt

temperature and the injection pressure has an effect on the quality of the plastic product. Besides that, the requirements for design the proper mold for the new product plays an important role in attaining a high quality product with a good exterior look and a good mechanical properties. The plastic injection molding required adequate knowledge about the mold design, the polymer types and the requirements of the process parameters for producing a low cost product.

In fact, most of the manufacturing industry prefer to undergo the trials and errors at the commencement of manufacturing a new product in order to decrease the defects such as the warpage, volumetric shrinkage, sink mark and short shot by optimizing the process parameters of the plastic injection molding. Nevertheless, normally the final cost of the product might increase due to these trials and errors and also cause the reducing of the profit earned from the product. Besides that, these trials and errors are time consuming and causes the reducing of the productivity of the product, hence the manufacturing industry is not able to compete the advantage in the market with their competitor and also loss the competiveness in the long run business. Nowadays, the prediction and the resolution of the plastic injection molding problem can be done before starting the manufacturing. Moreover, the appropriate mold design and the optimum process parameters can be determined with the aid of the plastic injection molding simulation such as the Autodesk Moldflow.

1.2 Problem Statement

The food packaging manufacturing industry obtains the optimal setting of the process parameters in order to minimize the quality issue such as volumetric shrinkage, sink mark estimate and warpage by undergoing the trials and errors and these trials and errors are time consuming. This may lead the food packaging manufacturing industry loss their competitiveness in the market by undergoing these trials and errors to obtain the optimal process parameters in order to reduce the quality problem of the plastic injected food packaging. In addition, many injection plastic product manufacturers prefer to undergo the trials and errors to optimize processing conditions with lower warpage, shrinkage and weld line (Erfan et al., 2016). Furthermore, the quality issue of the food packaging is due to the process parameters of the

plastic filling in the plastic injection molding process and the process parameters that might give an effect to the plastic filling behavior in the plastic injection molding process such as the filling (packing) pressure, injection pressure, melt temperature, mold temperature and coolant temperature.

In addition, the plastic filling stage is the most important stage because many defects may occur such as the volumetric shrinkage, warpage, sink mark and short shot. The most representative defect in the plastic injection molding is the warpage, for the dimensional accuracy of the plastic product, the warpage should be minimized (Satoshi et al., 2016). Moreover, with the aids of the injection molding simulation such as Autodesk Moldflow, the injection molding problems can be predicted and resolved before the starting of the manufacturing (Erfan et al., 2016). This project is to do the simulation for the plastic filling in the plastic injection molding process by utilizing the Autodesk Moldflow and to investigate which process parameters of the plastic injection molding will give the most effect on the quality of the food packaging. Moreover, the quality of the food packaging can be improved by selecting the appropriate combination of process parameters that give the maximum desirability value by using the Minitab. The high quality of product, the process parameters such as the melt temperature, packing pressure and the cooling time should be optimized (Satoshi et al., 2016).

Moreover, the process parameters such as the melt temperature, mold temperature and injection pressure affect the quality of the food packaging and many of the food packaging manufacturing industries use trials and errors to obtain the optimum process parameters in order to minimize those quality problems. In addition, the optimum processing parameters can be determined by the Autodesk Moldflow and the Autodesk Moldflow can simulate the plastic flow pattern, warpage, shrinkage and fill time with low error (Erfan et al., 2016).

1.3 Objectives

The aim of this project is to improve the quality of the butter tub by minimizing the volumetric shrinkage, sink mark estimate and warpage on the butter tub. The objectives are as the following:

1.) To design the plastic butter tub in rectangular shape.

2.) To investigate the significant effect of the process parameters on the quality of the butter tub.

3.) To optimize the process parameters of the plastic injection molding.

1.4 Scope of Study

This project only covered the design of the rectangular butter tub by using the SolidWorks software. After finished designing the butter tub, then the butter tub model is imported into the Autodesk Moldflow simulation software. Next, the Moldflow simulation is conducted for the complete butter tub with single cavity mold based on the Taguchi's L_{18} orthogonal array table. The simulation software used in this project is the Autodesk Moldflow software. Moreover, the analysis of variance (ANOVA) is used to analyze which process parameters give the most effect on the quality of the butter tub. The analysis of variance (ANOVA) only analyze these process parameters such as the melt temperature, mold temperature and injection pressure in this study. In addition, the optimization for the response of volumetric shrinkage, sink mark estimate and warpage are carried out by utilizing the Minitab with the appropriate selection of the combination of the process parameters which give the maximum desirability value.

Furthermore, the limitation of this project were the real prototype of the butter tub and the real mold of the plastic injection molding are not be manufactured. Since there was no real

mold is manufactured due to the high cost in fabricating the mold and therefore no experiment is carried out in this project.

1.5 Significant of Study

This project is emphasis the design stage of tub in the rectangular shape which was suitable for the storage of butter. Normally in the market, the butter is wrapped with the aluminium foil and seldom filled inside the container and most of the design of the container which can be found in the market was in a rounded or in a semi-rounded shape. From the observation, there was a very few rectangular shape of the butter tub is available in the market and this project is to design a rectangular shape of the butter tub. Furthermore, at the beginning of the manufacturing of a new product, the food packaging manufacturing industry prefer to undergo the trials and errors in determining the optimum processing parameters of the plastic injection molding. These trials and errors are time consuming and it could increase the final cost of the new product, thus the food packaging manufacturing industry will lost their competiveness in the long run business and would not be able to compete the advantages in the market.

In addition, this project is also emphasis on the investigation of the significant impact of the process parameters on the quality of the butter tub and the optimization of the processing parameters of the plastic injection molding. Furthermore, the plastic injection molding simulation such as the Autodesk Moldflow is used to simulate the plastic filling process of the butter tub in the plastic injection molding. Moreover, the analysis of variance (ANOVA) is applied to investigate the significant impact of the process parameters on the quality of the butter tub by utilizing the Minitab.

The optimization for the response of volumetric shrinkage, sink mark estimate and warpage of the butter tub are carried out by selecting the appropriate combination of the process parameters which give the maximum desirability value with the use of Minitab. Moreover, the Autodesk Moldflow simulation allows to set up the expected process parameters, material of the

part and to visualize the defects on the part in order to optimize and minimize the defects on the plastic food packaging before to start up the mass production and thus the final cost and the time consuming can be reduced significantly. The last but not least, there were some potential benefits that can be gained by the food packaging manufacturing industry after the completion of this project.

1.6 Organization of the Report

This project focuses on the design stage of a rectangular shape of the tub which is suit for the storage of butter and the simulation of the plastic filling process of the butter tub in the plastic injection molding by utilizing the Autodesk Moldflow simulation software.

In Chapter 1 introduction discussed the background of study on the plastic injection molding process and the simulation of the plastic filling in the plastic injection molding. The quality problems of the plastic food packaging product which is produced by the injection molding machine such as the volumetric shrinkage, warpage, sink mark estimate and short shot and these quality issues is currently facing by the food packaging manufacturing industry. Next is followed by the objectives that needs to be achieved throughout this project. This project comprises three objectives that needs to be achieved are to design the plastic butter tub in rectangular shape, to investigate the significant effect of the process parameters on the quality of the butter tub and to optimize the process parameters in the plastic injection molding. Then is followed by the scope of study which narrow down the area of the study and the limitations of the study is listed. Finally is the significant of study in which the potential benefits will be gained by the food packaging manufacturing industry after the completion of this study.

Moreover, in the Chapter 2 literature review covered all the basic theory which regarding to the topic of the study and to review the previous studies from journals, books, articles and internet which is regarding to the topic of design and analysis of food container in plastic injection molding process. First, the five principles which are the golden rule for the part design and the mold design comprises the gate design and the runner system design is covered in this

chapter. Then is followed by the simulation of the plastic filling process in the plastic injection molding by using the Autodesk Moldflow simulation software is described. The Moldflow simulation is carried out based on the L_{18} orthogonal array table which is one of the Taguchi technique is covered in the literature review. Next is followed by the analysis of variance (ANOVA) is used to investigate the important effect of the process parameters on the quality of the food packaging and the material of polypropylene random copolymer and the polypropylene impact copolymer which are the most suitable material for the food packaging are covered in the Chapter 2. The last but not least, the in mold labelling and the in mold labelling molding are also covered in the literature review.

Furthermore, in the Chapter 3 methodology described the butter tub drawing that has drawn by using the SolidWorks software. The thickness analysis and the factor of safety for the butter tub are conducted by utilizing SolidWorks. Next, the butter tub model is imported into the Autodesk Moldflow to conduct the simulation of the plastic filling in plastic injection molding process. Furthermore, the Moldflow simulation is carried out based on the Taguchi's L_{18} orthogonal array table which consist of three process parameters such as the melt temperature, mold temperature and the injection pressure and each process parameter with three levels. Moreover, the analysis of variance (ANOVA) is conducted to investigate the significant impact of the process parameter on the quality of the butter tub by utilizing the Minitab. The optimization for the response of volumetric shrinkage, sink mark estimate and warpage of the butter tub are carried out by using the Minitab. The last but not least, the equation of the volumetric shrinkage is used to do the calculation manually in order to compare the calculated volumetric shrinkage value with the volumetric shrinkage value that obtained from the Autodesk Moldflow simulation.

In Chapter 4 results and discussions exhibited that the butter tub model has a uniform thickness which was 1.2 mm. This butter tub with a thickness of 1.2 mm is safe to be used and it could not be broken easily is justified by its factor of safety which was 3.383. Furthermore, the diameter of the gate, runner and sprue are calculated and the single cavity mold is modeled for the butter tub model. The Moldflow simulation is carried out by selecting the dual domain analysis, since the wall thickness of the butter tub is very thin and the results of the 18 runs of