SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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MOLD FILLING SIMULATION FOR INJECTION MOLDING OF NATURAL RUBBER COMPOUND IN GLOVE FABRICATION

By

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled "**MOLD FILLING SIMULATION FOR INJECTION MOLDING OF NATURAL RUBBER COMPOUND IN GLOVE FABRICATION**". I also declared that it has not been previously submitted for the award or any degree or diploma or other similar tittle of this for any other examining body or university.

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LIST OF ABBREVIATIONS

NR	Natural rubber
Tg	Glass Temperature
Mw	Molecular Weight
FEM	Finite Element Method
CAD	Computer-aided design
3D	Three Dimensional

NOMENCLATURES

η_0	Zero Shear Viscosity
η	Viscosity
η_∞	Infinite Shear Viscosity
C	Mass Concentration Fraction
λ	Lambda
ρ	Density
γ	Apparent Viscosity
τ	Torque
λ_c	Time Constant
n	Power-Law Index
K	Thermal Conductivity
τ^*	Power Law Region

MOLD FILLING SIMULATION FOR INJECTION MOLDING OF NATURAL RUBBER COMPOUND IN GLOVE FABRICATION

ABSTRACT

Rubber injection molding is a process whereby a rubber mix is injected into a closed mold where the material is shaped to the desired geometry. The aim of the study was to observe and understand the behavior of the mold filling of natural rubber compound in injection molding. The numerical studies on mold filling of glove fabrication in injection molding were carried out. Injection moldings with natural rubber compounds having sections with thickness of 0.4, 0.5 and 0.6 mm have been prepared. CADMOULD software was used in the simulation with the Cross viscosity model. The effects of variation in process parameters such as temperature, location of gate, and viscosity on its mold filling were studied. A CADMOULD is employed to investigate appropriate rubber behavior during curing and viscosity model, respectively. Vulcanization at different quantities of gate have advantages in curing thin sections adjacent to thick ones because of their superior reversion resistance. Increase in temperature resulted in higher flow rate due to increase in viscosity. Cure time is highly dependent on injection temperature and the art of injection molding is to inject at the highest possible temperature consistent with freedom from scorch. The injection temperature of natural rubber depends on the injection molding machine variables such as barrel temperature. The simulation results are in good conformity and the strength of CADMOULD Rubber in handling mold filling in glove fabrication problems is proved to be excellent.

SIMULASI PENGISIAN SUNTIKAN UNTUK PENGACUAN SUNTIKAN SEBATIAN GETAH DALAM FABRIKASI SARUNG TANGAN

ABSTRAK

Pengacuan suntikan sebatian getah adalah satu proses di mana campuran getah telah disuntik ke dalam acuan tertutup dan bahan dikehendaki berbentuk geometri. Tujuan kajian ini adalah untuk memerhati dan mengenalpasti tingkah laku pengisian acuan bagi sebatian getah asli dalam pengacuan suntikan. Kajian berangka pada pengisian acuan fabrikasi sarung tangan dalam pengacuan suntikan telah dijalankan. Pengacuan suntikan dengan sebatian getah yang mempunyai bahagian yang berbeza ketebalan iaitu 0.4, 0.5 dan 0.6 mm telah disediakan. Perisian CADMOULD telah digunakan dalam simulasi ini dengan model kelikatan Cross. Kesan perubahan dalam proses parameter seperti suhu, lokasi saluran, dan kelikatan pada pengisian acuan telah dikaji. CADMOULD telah diguna untuk mengenalpasti tingkah laku kinetik dengan menggunakan setiap pengawetan dan model kelikatan. Vulkanisasi pada kuantiti yang berbeza saluran mempunyai kelebihan dalam mengenalpasti kenipisan dengan menggunakan sarung tangan tebal yang disebabkan rintangan. Peningkatan suhu akan menyebabkan kadar aliran yang lebih tinggi disebabkan oleh peningkatan dalam kelikatan. Masa kelikatan adalah bergantung kepada suhu suntikan dan pengacuan suntikan adalah untuk menyuntik pada suhu yang paling tinggi selaras dengan kebebasan yang menyebabkan ia lecuh. Suhu suntikan sebatian getah bergantung kepada suntikan pemboleh ubah mesin seperti suhu lilitan di mesin. Keputusan simulasi adalah memuaskan dan kekuatan CADMOULD getah dalam mengendalikan pengisian acuan dalam masalah sarung tangan fabrikasi dapat diselesaikan.

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter provides a review of the concept of plastic injection molding and rubber injection molding. Manufacturers are constantly coming up with ways to make the cost of production less and the performance and quantity of the product greater. Plastic molding is a process that many manufacturers use today to create plastic parts. It is much faster and cost efficient than other methods of manufacturing. Other than that, this chapter also includes the information of the rubber injection molding successfully. This is different from the plastic injection molding process where the materials are cooled under lower pressure.

1.2 Plastic Injection Molding Process

Injection moulding is a manufacturing process for producing parts by injecting material into a mold. Injection moulding can be performed with a host of materials mainly including metals glasses, elastomers, confections, and most generally thermoplastic and thermosetting polymers (Ramorino et al. 2010).

Juang et al. (2006) described that polymer injection molding is the most used technology of polymer processing currently. It allowed the manufacture of final products, which do not require any further operations. Injection molding lower the time required for curing, eliminates the need to perform the rubber prior to molding, reduces the amount of mold handling and scrap in comparison with compression molding.

Injection molding machines include of four key units which is injection, clamping, drive and control. Basically, in an injection molding process, the injection unit receives the raw material through the hopper, heats it up by heater bands, screw rotates until it melts, and injects the molten plastic into the mold, then the clamping unit holds the part under pressure until the provided plastic part cools down and solidifies.

Thus, an injection molding cycle can be described in eight steps which are the mold closing, clamping, injecting, holding, plastification, cooling, mold opening, and ejecting. Moreover, if the plastification of the polymer for the next cycle is completely finished but the part in the mold still requires more cooling time, there will be also an idle period in the injection molding cycle (Mianehrow & Abbasian 2017).

In previous injection molding research, many process parameters, such as the melting temperature, mold temperature, injection pressure, injection velocity, injection time, packing pressure, packing time, cooling temperature, and cooling time, were found to possibly influence the quality of injection-molded plastic products.

Plastic injection molding (PIM) has also some advantages such as short product cycles, high quality part surfaces, good mechanical properties, low cost, and light weight, so it is becoming increasingly more significant in today’s plastic production industries. PIM needs to be improved because of all reasons mentioned and the customer demands (Arpornwichanop et al. 2015).

Plastic injection molding process demands precise control of melt temperature, melt viscosity, injection speed, injection follow-up pressure, and switch over point from speed to pressure and cycle time.

Different polymers have different characteristics and different limitations in processing. Shear rate and shear stress influence melt temperature, viscosity, density and flow behavior of polymer.

The change in each parameter has its own influences on other parameters. Hence, process control becomes very complex. Moreover, new polymers and the demand for high quality electronics, consumer products, automobiles and airplanes have forced engineers and designers to improve mold tooling efficiency and the quality of final parts

For thermoplastics, the injection molding machine converts granular or pelleted raw plastic into final molded parts via a melt, inject, pack, and cool cycle. A typical injection molding machine consists of the following major components which is injection system, hydraulic system, mold system, clamping system and control system.

1.3 Rubber Injection Molding

Rubber is a polymer of isoprene that is formed with double bonds between each of the individual monomers. In simple terms, one of these bonds is flexible and can allow the polymer to take up many shapes and sizes, which is what basically gives rubber its property of elasticity.

Furthermore, that flexible bond is also what makes rubber in its natural form somewhat imperfect because if that bond were stronger, it would create a better material that could be more widely used.

There is a process that can strengthen that bond called rubber vulcanization. This process involves heating natural sheet rubber and rubber products with sulfur, and it is a widely-used method for the creation of commercial rubber parts.

Rubber injection molding is ideal for producing small and/or complicated parts that require precision and high productivity, or stock-fitting parts that fit inside other components. Rubber supplies and parts are now generally vulcanized, unless they are made out of tire crumb in which case they are molded (Choi & Im 2000).

Rubber injection molding is a process whereby a rubber mix is injected into a closed mold where the material is shaped to the desired geometry. The pressure traces at different locations in the mold during cavity filling are obtained at different inlet and mold temperatures.

Natural rubber (NR) is mostly used in various applications because of its unique properties such as high resilience, low heat build-up, outstanding tack and green strength. In most applications, carbon black (CB) and/or silica are usually added to NR to improve some properties such as crack growth, abrasion resistances and hardness (Junkong et al. 2015).

Furthermore, for a rubber injection-molding machine produce high quality products, accurate temperature control of the mold and screw speed during the production process is an essential factor (Fetecau et al. 2010).

When the cavity is filled, temperature gradients persist in the rubber, this results in temperature distributions within the bulk of the rubber. When the mold is set at a high temperature, the material continues heating because of convection and start to cure when a certain critical temperature is successfully achieved (Dang 2014).

In addition, molded natural rubber is best used in applications that require high flexibility, tensile strength and tear resistance. In addition, Natural Rubber is soft and has good flexing characteristics at low temperatures. It is wear resistant and non-toxic.

Moreover, since in the production cycle the most time consuming stage is the vulcanization of the component in a closed mold, the exact evaluation of the curing time in relation with the mold temperature is specifically useful for cost savings in the production process (Pei Chin et al. 2011).

The interest in kinetics of curing or vulcanization grew mostly as a result of the need to impart uniform cures in rubber profiles, attain equivalent cures, and to achieve adequate cures in thick rubber sections. Kinetic studies of crosslinking have also proved useful in characterizing various concomitant reactions that take place during fabrication (Fetecau et al. 2010).

1.4 Problem Statement

Vulcanization is the process whereby a viscous and tacky uncured rubber is converted into an elastic material through the incorporation of chemical crosslinks between the polymer chains. The degree of cure achieved depends on the formulation recipe and the time–temperature history endured by the material during the curing process while in the mold (Arrillaga et al. 2011).

Both compression and injection molding techniques for the fabrication of rubber products involve crosslinking or vulcanization which is invariably assisted by temperature and pressure. Vulcanization is a chemical process and therefore its simulation necessarily involves characterization of kinetic parameters (Juang et al. 2006).

Compound viscosity has a profound effect on processes in most rubber manufacturing system. This is certainly true for rubber injection molding where plasticized material must pass through narrow pathways, under pressure to reach the mould. The prevention of this scorching has become a serious problem in the rubber industry. Thus, it needs to stimulate to prevent the scorching of rubber by increasing the temperature of rubber.

When screw speed increases, rubber in the barrel of the injection machine becomes hotter and it is possible to obtain higher injection temperatures and shorter cure times. Cure time, assessed by the hardness of the top, center and bottom of the moulding, closely follows the injection temperature and illustrates that under the prevailing back pressure and barrel temperature conditions there is an optimum screw speed (Ismail 2002).

Injection temperature increases with elevation of barrel temperature. When there is no screw delay in operation, temperatures above optimum level causes premature vulcanization of rubber in the barrel (Juang et al. 2006).

1.5 Objectives

Objective in this research is determined the simulated injection molding of natural rubber compound in glove fabrication and observed mold filling using CADMOULD Rubber. Main objectives of this study are:

i. To study the scorch of rubber compounds at difference quantities of gate during injection molding process

ii. To determine the effect of rubber compounding on viscosity which influence the shear rate of natural rubber compound during injection molding

iii. To study the effect of temperature to simulate material flow behavior in the rubber injection molding process

1.6 Scope of the Study

Rubber injection molding is a process which a rubber mix is injected into a closed mold where the material is shaped to the preferred geometry. The possibility of using CADMOULD software to simulate the filling behaviour of a natural rubber compound during an injection moulding process was investigated. The investigation is to study the scorch in steady shear flow of natural rubber compound by rubber injection molding and the characteristics of shear rate.

For the simulation process, the determination of Natural Rubber input data involving the rheological and cure kinetics data of the designed rubber compound were conducted. Cross models was used to acquire the rheological parameters by curve fitting (Abdullah et al. 2009).

With mold filling the advancement of the Natural rubber inside the mold cavity can be studied. When analyzing an injection molded, mold filling in the glove is the first result generated by the CADMOULD software. During mold filling the velocity vectors, pressure and temperature are computed over time and form the basis for post-fill analyses. Mold filling is used to predict cycle times, to ensure complete filling of the mold (Zhuang et al. 2016).

The temperature of the glove surface can be simulated with CADMOULD. Modelling and meshing of three dimensional glove was performed by CADMOULD. This software was used because it is user-friendly and probably cheaper than most of the software used by previous researchers to study about mold filling simulation (Sardarian et al. 2016).

1.7 Thesis Outline

There are five chapters in this thesis provide information related to the research interest. Chapter 1 contains introduction of the project. It covers brief introduction about research background, problem statement, objectives and organization of the thesis.

Chapter 2 provides an overview survey of literature on the material, rubber compounding and effect of injection parameters, glove fabrication and glove fabrication simulation.

Chapter 3 outlines the general methodology adopted in the research project. Discussion on the research flow chart and methods, tests and step by step simulation procedure employed in the study are given in detail.

Chapter 4 presents and discusses the results and analysis their findings of the simulation works and provides the information on the usefulness of glove fabrication simulation in this study.

Chapter 5 highlights the conclusion and recommendations pertaining on the advantages and disadvantages of the glove fabrication and suggestion for future work and further development s as optimum process of this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The injection molding process is frequently applied for polymer engineering materials. Computer analysis of the filling, packing and cooling phases of injection molding process requires data on the physical properties of the polymer and the material from which the mold is constructed. Elastomers are usually thermosets that need vulcanization, but also include different types of thermoplastics. The Carreau and Cross models were used to acquire the rheological parameters by curve fitting. It must be related to fluid properties through non-Newtonian fluid theory.

2.2 Manufacturing of Injection Molding

Rusdi et al. (2016) discovered several processes involved in producing polymer products such as injection molding, blow molding, thermoforming, etc. The world-class and widely used process is an injection molding, due to reduce cost, versatility and capability. Injection molding machine consists of several parts, which are hopper, screw barrel and mold.

Injection Molding is a manufacturing process for producing parts in large volume. It is most typically used in mass production processes where the same part is being created thousands or even millions of times in succession.

The quality of injection molding parts depends on the material, part and mold designs, and the process parameters required to manufacture them. Warpage and shrinkage involve among the most highly the defects of thin-shell plastic parts in terms of the quality.

The reasons of warpage in injection molded parts are very complex and numerous. The main cause of warpage is commonly known as the variation in shrinkage towards injection process of thin shell plastic parts. Material properties, part design, and injection-molding process conditions are classified as the factors influencing the variations in the part shrinkage during injection molded thin-shell parts.

Part geometry and mechanical property of material also play a critical role in the warpage and the final warpage of part considerably bases on its mechanical stiffness, which is a function of the geometrical configuration and the material's mechanical properties.

If a part has higher mechanical stiffness, it is subjected to warp the low due to high variations in the shrinkage and the part with less mechanical stiffness will be more warp.

Injection molding is the most commonly used manufacturing process for the fabrication of plastic parts. A wide variety of products are manufactured using injection molding, which vary greatly in their size, complexity, and application.

The injection molding process requires the use of an injection molding machine, raw plastic material, and a mold. The plastic is melted in the injection molding machine and then injected into the mold, where it cools and solidifies into the final part. The steps in this process are described in greater detail in the next section (Zhuang et al. 2016).