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JUDUL: ANALYSIS AND PREDICTION OF MICRO INJECTION MOLDING PART USING COMPUTER SIMULATION SOFTWARE

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ANALYSIS AND PREDICTION OF MICRO INJECTION MOLDING PART USING MOLDFLOW SIMULATION SOFTWARE

MOHAMMAD FARHAN BIN OTHMAN

A report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Manufacturing Engineering

Faculty of Manufacturing Engineering
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JUNE 2012

SUPERVISOR DECLARATION

I hereby declare that I had read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the purpose of the granting of Bachelor of Manufacturing Engineering.

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Date	: 07 JUNE 2012

STUDENT DECLARATION

I declare that this thesis entitled "Analysis and prediction of Micro Injection Molding part using Moldflow Simulation Software" is the result of my own research except as cited in the references. This thesis has not been accepted for any degree and is not concurrently submitted in candidature of any degree.

Signature : ....

Name : MOHAMMAD FARHAN BIN OTHMAN

Date : 07 JUNE 2012

DEDICATION

To beloved Mother and Father

ACKNOWLEDGEMENT

Firstly, I would like to express my grateful to ALLAH S.W.T as for HIS blessing, I have accomplished my project.

I would like to give my greatest appreciation to my Project Supervisor, **Mr. Mohd Zairulnizam Bin Mohd Zawawi** for guiding and assist us during the **Final Year Project** from the beginning stage until the end of producing this Final Year Project entitled **Analysis and Prediction of Micro Injection Molding Part using Moldflow Simulation Software.**

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ABSTRACT

The demands of micro injection molding parts has been increase tremendously that promote the potential of its huge markets in this new millennium. The complexity of producing micro injection molding parts is much higher compare to typical injection molding process. Normally, micro injection molding parts was produce by using specially built micro injection molding machine or modified conventional injection molding machine that suit the process of producing micro parts. However, micro injection molding parts can also be ejected in conventional injection molding process. The problem is the amount of plastic material wasted from the feed system design is always more than 90%. This is due because the size of conventional injection molding process biggest than micro injection molding process. But nowadays, that problem can be predicted earlier by using Moldflow simulation software analysis. Moldflow simulation software can be used to determine the best feed system design, predict possible molding defects and suggest optimum injection molding parameters. This project was conducted analyze and predict of micro injection molding part using Moldflow simulation software. The analysis is made for three different size of runner that is 4mm, 5mm and 6mm. For the melt temperature material at 230°C and mould at both sides is 50°C. The Moldflow results are barely different. From the result, we can determine the best of runner before fabrication process take place. This analysis may reduce miscellaneous cost. The comparison need to be undertaken. The analysis can tell the best fill time, injection pressure, shot weight, air traps, weld line, time to freeze, temperature at flow front, and etc. The analysis will determine that weather Moldflow is suitable for micro plastics or not.

ABSTRAK

Permintaan dalam menghasilkan produk mikro acuan suntikan semakin meningkat tinggi yang mempromosikan potensi yang besar di alaf millennium yang baru. Kerumitan menghasilkan bahagian acuan suntikan mikro adalah lebih tinggi berbanding dengan proses pengacuan suntikan biasa. Biasanya, bagi produk mikro acuan suntikan adalah menghasilkan dengan menggunakan mesin acuan suntikan yang khusus atau mesin acuan suntikan konvensional yang telah di ubahsuai yang sesuai untuk menghasilkan produk mikro. Namun, bagi produk mikro acuan suntikan juga dapat dikeluarkan dalam proses injection molding konvensional biasa. Masalahnya adalah jumlah bahan yang dihasilkan oleh 'feed system' selalu lebih dari 90% adalah bahan terbuang. Hal ini disebabkan kerana ukuran acuan suntikan proses konvensional adalah lebih besar dari proses acuan suntikan mikro. Namun saat ini, masalah ini dapat diramalkan dengan menggunakan perisian simulasi Moldflow. Perisian simulasi 'Moldflow' dapat digunakan untuk menentukan 'feed system' yang terbaik, meramal kecacatan acuan suntikan dan mencadangkan parameter acuan suntikan yang optimal. Projek ini dilakukan untuk menganalisa dan meramalkan produk acuan suntikan mikro menggunakan perisian simulasi 'Moldflow'. Analisis ini dilakukan kepada tiga saiz ukuran 'runner' yang berbeza iaitu 4mm, 5mm dan 6mm. Untuk suhu bahan plastik pada 230 ° C dan di kedua sisi acuan suntikan adalah 50 ° C. Hasil dari perisian simulasi 'Moldflow' tidak banyak beza. Dari hasilnya, kita dapat menentukan yang parameter yang terbaik ketika dilakukan pada proses yang sebenar. Analisis ini dapat mengurangkan banyak kos. Perbandingan perlu dilakukan. Analisis ini dapat memberitahu masa pengisian yang terbaik, tekanan suntikan, berat suntikan, perangkap udara, garis pertemuan, masa untuk membekukan, suhu di bagian depan aliran, dan lain-lain Analisis ini akan menentukan bahawa perisian simulasi 'Moldflow' adalah sesuai untuk plastik mikro atau tidak.

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CHAPTER 1

INTRODUCTION

1.1 Background to the Study

Injection molding is a widespread mass production that also used to produce large number of micro components at low cost. Besides polymers, various engineering material are employed to manufacture micro part with complex geometries. Corresponding to different requirement and challenges concerning the production or the part design, micro components can be broadly categorized into the following:-

- The part has small dimensions and a low mass (less than 1 gram)
- The part is of conventional size, but it contains detail regions or features in the micrometer range
- The parts dimensions are basically irrelevant, but size deviations are limited to the micrometer range (less than 1mm).

For the production of micro parts, many established techniques were scale down, but new technologies were also developed. Micro injection molding is a key technology for the low cost production of polymer micro parts in large numbers. Figure 1.1 show example of micro injection molding part characteristic. The weight of a micro part is of the order of a few milligram and dimension in the millimeter to micron range by Pötsch G and Michaeli W [1].

Figure 1.1: Example product micro injection molding

Source: http://books.google.com.my/books/about/Injection_Molding

1.2 Problem Statement

In plastics injection there are a few problem may occurs that can affect the product. The problem like air traps, weld line, sink mark, shrinkage, and many more can occurs to the products if the mold not design correctly. The mold components are an expensive therefore the mold design should be precise and accurate in order to reduce cost. Previously, production engineers used trial-and-error method to determine optimum optical process parameter setting for micro plastic injection molding. However, this method is unsuitable in present micro plastics injection molding because the increasing complexity of product design and the requirement of multi-response quality characteristics. The problem can be solves by using Moldflow simulation software. It is one of tools can use to solve this problem.

Different size of runner gives different result of defects when making the analysis and therefore the analysis about the different size of runner by using Moldflow simulation software should be analyze. The problem occurs in order to compare with actual at injection process and then to understand the application of Moldflow simulation software to make the analysis.

So the project to analyze and predict the micro injection molding part using Moldflow simulation software and compare with the actual part in injection molding machine. The comparison of Moldflow simulation software with actual part micro injection molding which is the parameters involved the injection pressure, temperature, filling time, clamping force and etc. The research of project includes designing and fabricating the mold to get the actual part in injection molding.

1.3 Research Objective

I. To analyze the plastics flow characteristics of micro injection molding part by using Moldflow simulation software

II. To compare the prediction outcome from Moldflow simulation software with actual injection molding process in term of possible molding defects and molding processing condition.

1.4 Scope of Project

1. Analysis of plastics flow characteristics of multi cavities micro injection molding parts by using Moldflow simulation software.
2. Design a micro injection molding part for the analysis by using CATIA software.
3. Design the mold to produce the actual of micro injection molding part by using CATIA software
4. Fabricate the mold for micro injection molding part.
5. Perform the actual injection process and analyze the comparison

1.5 Significance of Research

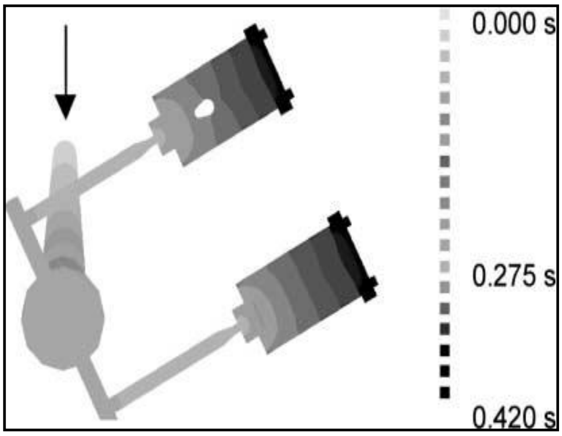
Micro-system technology and related products will be used more widely in the new millennium. There is significance of this study when the objective has been achieved which is the micro injection molding can use for new student as a references or review to improve, analysis or design and develop more the micro injection molding within the application required.

CHAPTER 2

LITERATURE REVIEW

2.1 Simulation of Micro Injection Molding

Simulation program applied in micro injection molding is to avoid the risks of costly re-engineering or simply mis-investments, the functions of the final products as well as the manufacturing steps are simulated extensively before starting real work. Useful assistance for the optimization of molding tools, mold inserts, micro component designs, and process parameters can be provided by software tools adapted from conventional injection molding in micro manufacturing technology [2]. At Forschungszentrum Karlsruhe, the software package ABAQUS is used for simulating the temperature distribution in the tools during the different steps of a complete molding cycle. For the filling process itself, the well-known MOLDFLOW software is applied [3]. In figure 2.1.1 shows for the left side, example of simulation of filling time for multi-fiber connector for micro injection molding simulation and the right side for heat dissipation in a micro molding part tool during the heating period.



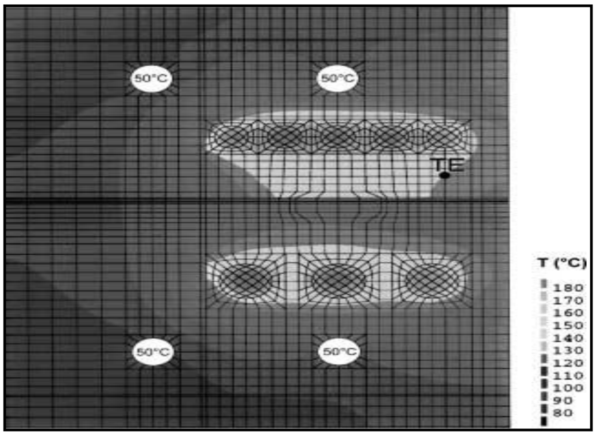


Figure 2.1 Example simulation of filling time and heat dissipation for micro injection molding simulation.
Source: Lei Xie1, Longjiang Shen2,3 and Bingyan Jiang3, Modelling and Simulation for Micro Injection Molding Process

2.2 Material Selection

Choosing the right material is one of the importance elements that should be considered in advance to determine the quality, process ability and overall cost for the product. For that reason, it has done some researches according to the product specification. There are some materials that are suitable for this product such as from table 2.2.1 in below. The table 2.2.1 show the common materials using to produce product of micro injection molding part. The polymers are among the materials used for micro injection molding is LCP, COC, PC, PS, PE, PMMA, PEEK, PSU, PAI, PEI, PBT, PA and POM. Good to very good reproduction of the microstructures on cavity surfaces can be achieved with LCP, COC, easy-flowing PC, PA, POM, PBT, PEI, PPE and PSU. High-temperature materials such as LCP, PEEK and PEI are suitable for subsequent soldering processes. Allowance must be made for the appropriate remolding conicity with PEEK, PEI, PAI, PC and PMMA, in particular. Low shrinkage values of between 0.1% and 0.8% are achieved with LCP, COC, PAI, PEI, PPE, PS, PC, PEEK, PMMA and PSU [4]. With the comparison of materials and provide at laboratory, the material suitable selection is Polyethylene (PE).

Table 2.1: Polymer materials often used in micro injection molding, maximum aspect ratios (AR), minimum structural thicknesses (smin), and typical applications.

Source: Piotter. V, Mueller. K, Plewa. K, Ruprecht. R, and Hausselt. J, June 2001

Polymer	**Abbr.**	**AR**	**^{s}min [lm]**	**Example of application**
Polymethyl methacrylate	PMMA	20	20	Optical fiber connector
Polycarbonate	PC	7	350	Cell container
Polyamide	PA	10	50	Micro gear wheels
Polyoxymethylene	POM	5	50	Filter with defined pore diameters
Polysulfone	PSU	5	270	Housings for Microfluidic devices
Polyetheretherketone	PEEK	5	270	Housings for micro pumps
Liquid crystal polymers	LCP	5	270	Microelectronic devices
Polyethylene	**PE**	**230***	**20**	**Components for micro actuators**
Conductively filled polyamide	PA 12-C	10	50	Housings for Electrostatic micro valves

*** flow length to wall thickness ratio**

2.2.1 Polyethylene (PE)

Polyethylene is a thermoplastic commodity heavily use in consumer products. Over 60 million tons of the materials are produced worldwide every year. Polyethylene is a polymer consisting of long chains of the monomer ethylene. The recommended scientific name 'polyethene' is systematically derived from the scientific name of the monomer. In certain circumstances it is useful to use a structure based nomenclature (Tony Whelan, 1994).

Polyethylene is classified into several different categories based mostly on its density and branching. Polyethylene suitable for produce micro injection molding parts because of the properties. The mechanical properties of PE depend significantly on variables such as the extent and type of branching, the crystal structure, and the molecular weight (Tony Whelan, 1994). Table 2.3 shows the material properties for polyethylene (PE).

Table 2.2: Polyethylene (PE) standard properties
Source: www.matraplast.com/twinwall/specs/pepp_properties

Property	**English units**	**SI units**
Melt Index	1.4 dg	
Density	0.898 gm/cm^3	
Tensile @ yield	27 MPa	3,880 psi
elongation @ yield	10%	10%
Flexural Modules	1,220 MPa	177,000 psi
Softening Pt. (vicat)	143 °C	290 °F
Melting Temperature	160 °C - 166 °C	320 °F - 330°F
Low Temperature Brittleness	-5 °C	23 °F
Hardness	90 Rockwell (R Scale)	

2.3 Design Consideration of Micro Injection Molding

Design consideration in the micro injection molding from selection of appropriate material. Design consideration important because to make the part in the best quality and meet the requirement of design. There are some new physical aspects associated with the scale-down of forming parts need to consider, which are:

- Sliding of polymer frozen layer due to high shear stress near mold wall
- High heat transfer rate of polymer melts in micro cavity resulting from micro mass/volume of materials
- Complex rheological behaviour of polymer melts flowing in micro geometry, especially in sub-micro/nano dimensional cavities
- Dominating of sources force related to surface effect and neglecting of sources force contributed by viscous and interior because of the micro scale [5]
- Selection size and shapes should be selected accordingly. Depending on the application, a high section modulus can be archived based on design principles common to I-beams and tubes. Larges, flat surfaces can be stiffened by such simple means as prescribing curvatures on parts.
- The designs on the part and the mold should be such that they will not present difficulties concerning proper shape generation, dimension control, and surface finish.
- Large variations in cross-sectional areas, section thicknesses, and abrupt changes in geometry should be avoided to achieve proper shape generation.
- Need for drafts to enable removal of the part from mold.
- Improper part design or assembly can lead to distortion (warping) and uneven shrinking.
- The properties of the final product depend on the original material and its processing history [6].

2.3.1 Design Considerations of Runner System.

Several issues should be taken into account when designing runner systems. These include:

i. Polymer material and Injection molding machine

Heat loss during the melt fill can prevent flow, so for high and low viscosity polymers an appropriate runner size is necessary. The heat loss in the material occurs firstly at the runner walls, where a vitrified layer of polymer acts as insulation for the higher melt temperature (T) at the core of the flow. The selected T must be maintained long enough for the cavity to be filled completely. The temperature in the core should be high enough to apply the holding pressure. During the holding pressure time (t), the material is packed out in the cavities long enough for it to solidify and counteracts any contraction during cooling.

For injection molding machine, the pressure, temperature the runner size, notably its cross section is less affected by wall temperature. However, there are two economic implications that are associated with large runners and speed capabilities together with its minimum and maximum shot weights should be considered. The ratio of runner to part weights is important because micro part volumes with large or small runner systems can be outside the machine shot weight range [7].

ii. Mold and Part design

This includes part size, number of cavities and the selected layout. The choice of the runner type must be based on the available tool space and include adequate distance between the part cavities. Available technologies/methods for machining the cavities can also influence the runner design, especially the runner size in order to minimize the tool manufacture cost. For parts design of the cooling time of the runner and the part depends on their dimensions. In particular, an increase in. The first is that the runner cooling time can exceed that of the parts, and thus lead to an increase of the cycle time. Secondly, as the runner is not part of the final product this represents an extra material cost. An optimum runner should provide flow control within a reduced working area, and ideally should be as small as possible with a cooling time [7].

2.4 Basic Terminology for Mold.

Figure 2.4.1 shows the injection molding parts from top plate to bottom plate for two plate mold. A mold is generally divided into two parts which is fixed half and moving half. The half that is attached to the stationery platen of the machine is termed the fixed half. The other half of the mold attached to the moving platen of the machine is known as a moving half. Generally, the core side is suitable in the moving half because easiness of providing and do an ejector system.

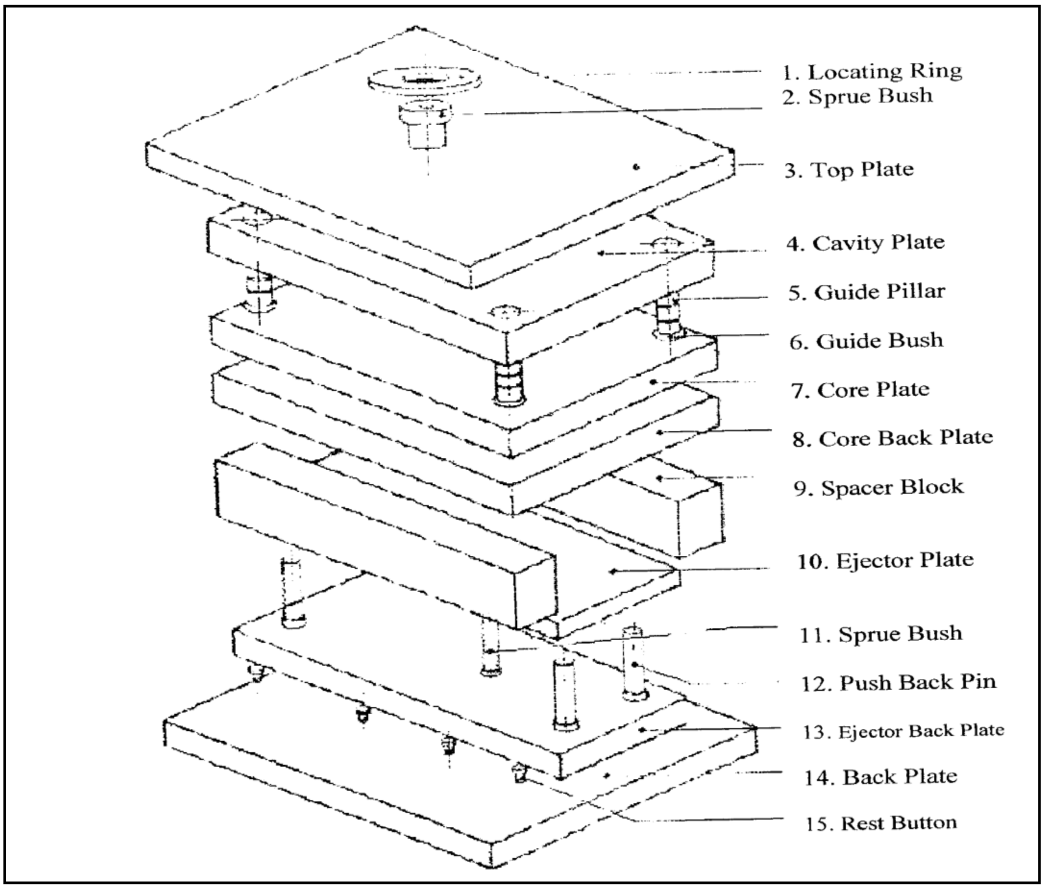


Figure 2.2: Injection molding parts

Source: Haris, H (Mei 2006)

2.4.1 Cavity and Core Plate

The basic mold consists of two plates. The plate in which the cavity is formed is known as cavity plate. Similarly the plate from which a core project is termed the core plate. When the mold is closed, the two plates come together forming a space between the cavity and core which is the impression.

2.4.2 Sprue Bush

During the injection molding process the plastic material is delivered to the nozzle of the machine of the machine as a melt. Sprue bush can define as the part of the mold in which the sprue is formed. Sprue bush connecting between the machine nozzle and the mold face. Sprue bush should be hardened to withstand the streses. The backward movement of the sprue bush is prevented by stepping the end fitting a located ring which serves a dual purpose of securing the sprue bush and mold location. The internal aperture of the sprue bush has included taper of 3° and 5° which facilities the removal of the sprue from the mold. The taper should be highly polished to avoid the part stuck in spure bush. There are two basic types of sprue bush which is sprue bush with a spherical front ended nozzle and sprue bush with perfectly flat rear surface and corresponding nozzle used. Figure 2.4.2 shows example of the sprue bush.

Figure 2.3: Example sprue bush

Source: http: www.helpinghand.co.in/sprue_bush_2.htm

2.4.3 Locating Ring

The nozzle and the sprue must be correctly aligned if the material has pass without hindrance into the mold. By including a located ring the mold can be aligned to the machine. The located ring is a flat circular member fitted on to the front face of the mold. Its purpose is it located injection machine platen. The located ring form a direct connection between the sprue bush and the hole in injection molding machine. Figure 2.4.2 shows the example of Reversible locating ring in dimensional to guide for references.

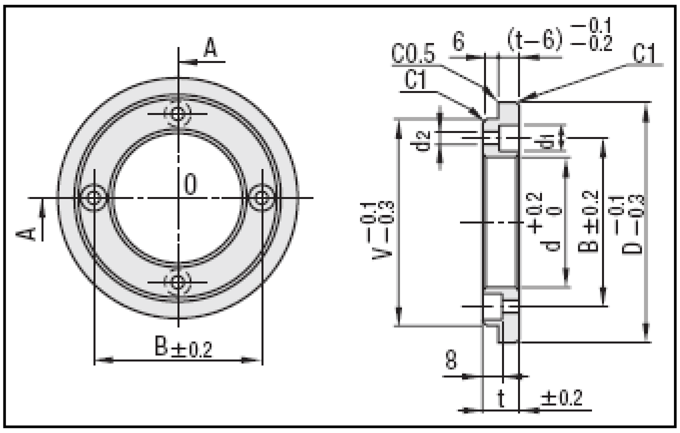


Figure 2.4: Example of locating ring

Source: us.misumi-ec.com/us/ItemDetail/10200080520

2.4.4 Runner and Gate System

The material can be directly injected into the impression through the sprue bush or multi impression molds it can be pass through a runner and gate system before entering the system. The runner is a channel machined into the mold plate to connect the sprue with the entrance to the impression. The gate is a channel connecting the runner with the impression. It has a small cross sectional are when compared with the rest of feed system. Figure 2.4.3 shows the example runner and gate system.

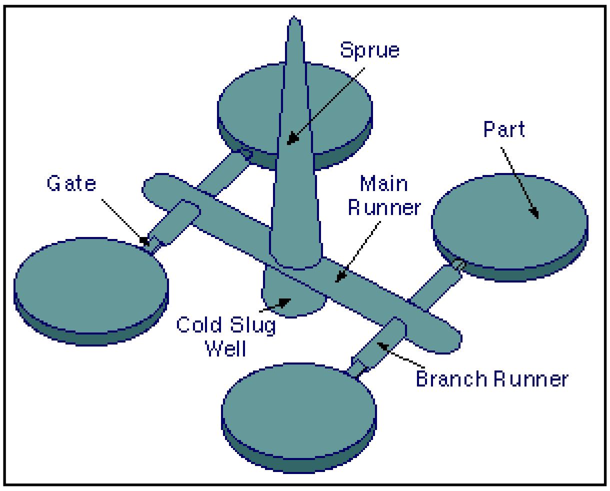


Figure 2.5: The molded system includes a delivery system and molded parts.

Source: Rees, H. and Catoen, B. (2006)

2.4.5 Guide Pillars and Bushes

To assembly the mold it is necessary to ensure that the cavity and core plate are keep in alignment. Guide pillars and bushes provide to align this mold. The guide pillar has diameter smaller than fitting diameter. A guide bush is incorporated in the mold to provide a suitable wear, resisting working surface for the guide pillar and to permit replacement in the event of wear or damage. Figure 2.4.4 shows actual and drawing for guide pillars and bushes.

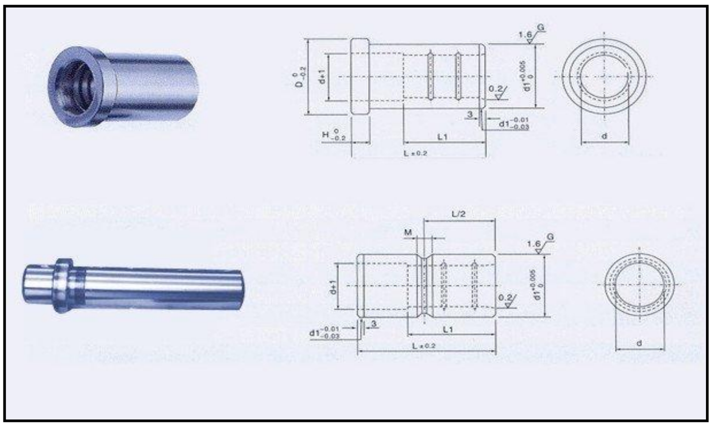


Figure 2.6: Specification of guide pillars and bushes

Source: www.alibaba.com/product-free/250392570/GuidePillarGuideBushes.html

2.4.6 Ejector system and ejector plate

Ejector is that part of the system which applies the ejector force to the molding. There are different types of ejectors use for example ejector pin, ejector plate and sleeve ejectors. The types of ejector are selected depending on the mold impression. Ejector plate is used for serving the purpose of transmitting the ejector force from the actuating system on the injection machine to ejector element. Figure 2.4.5 shows the location of ejector plate and the type of ejector system use is common system which is by using ejector pin.

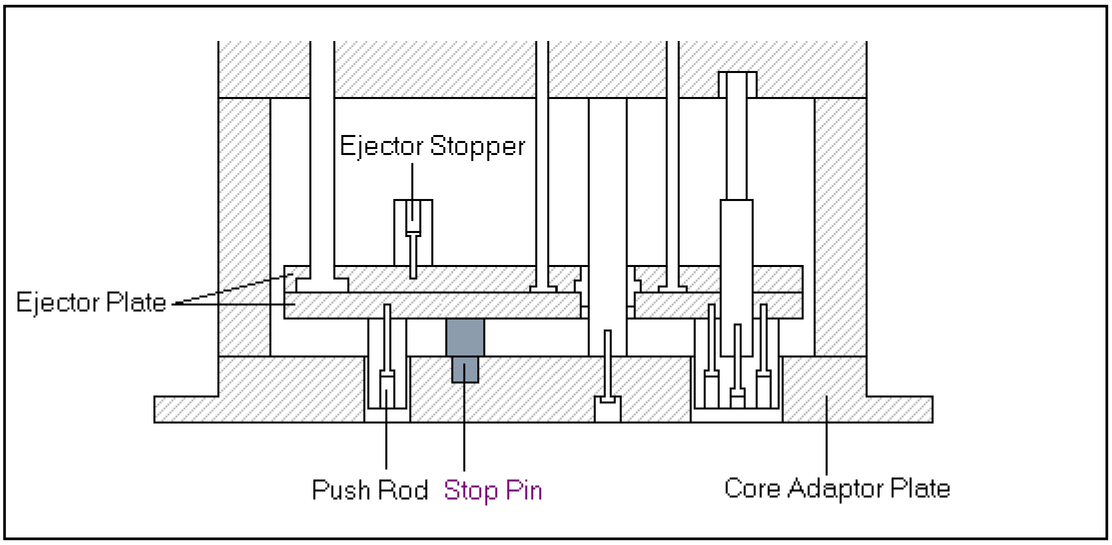


Figure 2.7: location of ejector plate and type of ejector system

Source: http://www.powerfive.com.cn/en/about/news_view.asp?id=51

2.5 MoldFlow

Moldflow offers a range of products and services in the plastics injection molding industry. "Moldflow has the most experience, technical depth, strong support organization, and widest range of applications" (La Salle). Moldflow software has been developed by moldflow International Pvt. Ltd., Australia. It helps in finite elemental analysis used in the design of plastics product, mold design and production of plastics components. Following are the modules of MOLDFLOW software. The flow analysis is used to determine parameters and filling pattern for micro injection molding part. It analysis polymer flow within the mold, optimizes mold cavities layout, balances runners and obtains mold processing conditions for filling and parameters mold such as clamping force, injection pressure and etc.

Cooling analysis it analyze the effect of cooling on flow, of optimizes cooling line geometry and processing conditions. Process Optimization Analysis it gives optimized processing parameters for a component considering injection molding conditions. Warpage analysis simulates the effect of molding of product geometry, isolates the dominant cause of warpage so that the correct remedy can be applied.

Shrinkage analysis give dimensions of mold cavities, using shrinkage determined from specific grade material shrinkage data and flow analysis results. Stress analysis is nonlinear structural analysis program that determines component thickness to meet performance requirements. It evaluates product strength and stiffness.

2.6 Moldflow Plastics Insight (MPI)

Moldflow Plastics insight products are a complete suite of advanced plastics process simulation tools for predicting and eliminating potential manufacturing problems and optimizing part design, mold design, and the injection molding process. MPI products simulate the broadest range of manufacturing process and support all design geometry types associated with plastics molding. With MPI, one can simulate the filling, packing and cooling stages of the thermoplastics injection molding process and also predict post-molding phenomena such as part warpage. MPI users can also simulate other complex molding process such as gas-assisted injection molding, co-injection molding, injection-compression molding, microcellular molding, reactive molding and microchip encapsulation.

MPI software also allows us to do some troubleshooting very easily. Some of the materials we use are very expensive. Therefore, less time on the production floor working through the problem saver labor and material costs. Using MPI software, we have been able to run simulations, locate and eliminate unsightly nit lines. It also can be employed in both tooling design and simulation of molding. MPI used to simulate mold design before the tool is actually built. The simulations help users determine different gate designs and location of injection, placement of cooling lines, melt overflows.

The MPI suite of software is the world's leading product for the in-depth simulations to validate part and mold design. This software allows you to analyze CAD solid models of thin-walled part directly, resulting in a significant decrease in model preparation time. The time-saving allow you to analyze more design iteration as well as perform more in-depth analysis. The user friendly environments in MPI employ visualization and project management tools that allow you to undertake extensive design analysis and optimization. After you analysis are complete, you can produce detailed, web ready design reports quickly and easily.

Proven solutions for all Type of Application. Moldflow's analysis products can simulate plastics flow and packing, mold cooling, and part shrinkage and warpage for thermoplastic injection molding, gas-assisted injection molding, co-injection molding and injection-compression molding process. Additional modules simulate reactive molding process including thermoset and rubber injection molding, reaction injection molding (RIM), structural reaction injection molding (SRIM), resin transfer molding and etc.

2.7 Micro molding with conventional injection molding machine

Fabrication of micro molded part comes to be a challenge when conventional injection molding machines (see Figure 2) are used for the replication very small part. If such machines are adapted to the direct production of micro product, i.e. parts with a part weight down to a milligram (mg), they produce precise but big sprues to achieve the minimum necessary shot weight to perform properly the process. Very often over 90% of the polymer is wasted and this waste can be an important cost factor (considering e.g. plastic material for medical applications, it is not unusual tohave costs up to €70 for 1 kg of special material, e.g. PEEK). Moreover, the big sprue increases cooling time and, along with that, cycle time [8].

In conventional injection molding, an injection cycle is composed of the main phases described in the following:

1. Plastification – During the plasticization phase, the screw is rotating to build up the melt polymer necessary for the injection phase. The pressure pushes the screw backwards. When sufficient polymer has built up (i.e. shot volume is plastificated) rotation stops.

2. Injection, filling and packing phase - When the mold is closed, the screw is pushed (injection). The melt polymer fills the sprue, the runners and the mold cavity (filling). The screw begins rotating again to build up more polymers (packing).

3. Cooling and ejection - After polymer is solidified (cooling), the mold opens and ejector pins remove the molded part (ejection) [9]

A problem which occurs with the small shot weight typical of micro parts is related to the size of pellets used in standard injection molding. Conventional injection molding machines utilizes screws with diameters down to 14 mm. Thus the depth of the screw channels should have at least the dimensions of a single grain. Hence, when the screw moves just 1 mm, about 185 mg of plastic are injected. Even one single pellet of poly (methyl methacrylate) (PMMA) weights 24 mg. This exceeds the part weight of e.g. gears for watch industry of 0.8 mg. Again, to produce such gears relatively huge runner systems are used to compensate for this issue. It is clear these data represent a limit for a correct processing of injection molded micro part: the minimum shot weight for a stable production lies in the range of some tenth of grams. When producing parts at the lower limit of the machine capacity problems dwelling time of the material will appear with risk of polymer degradation.

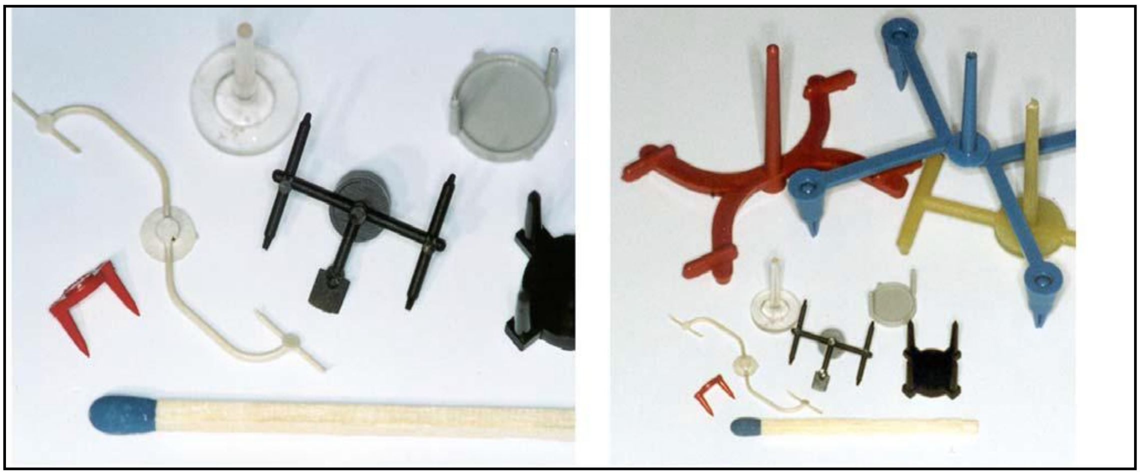


Figure 2.8: Comparison of runner systems to mold micro part with conventional injection molding machines (right) and with micro injection molding machine (left) Source: Thesis_GuidoTosello_2008.

CHAPTER 3

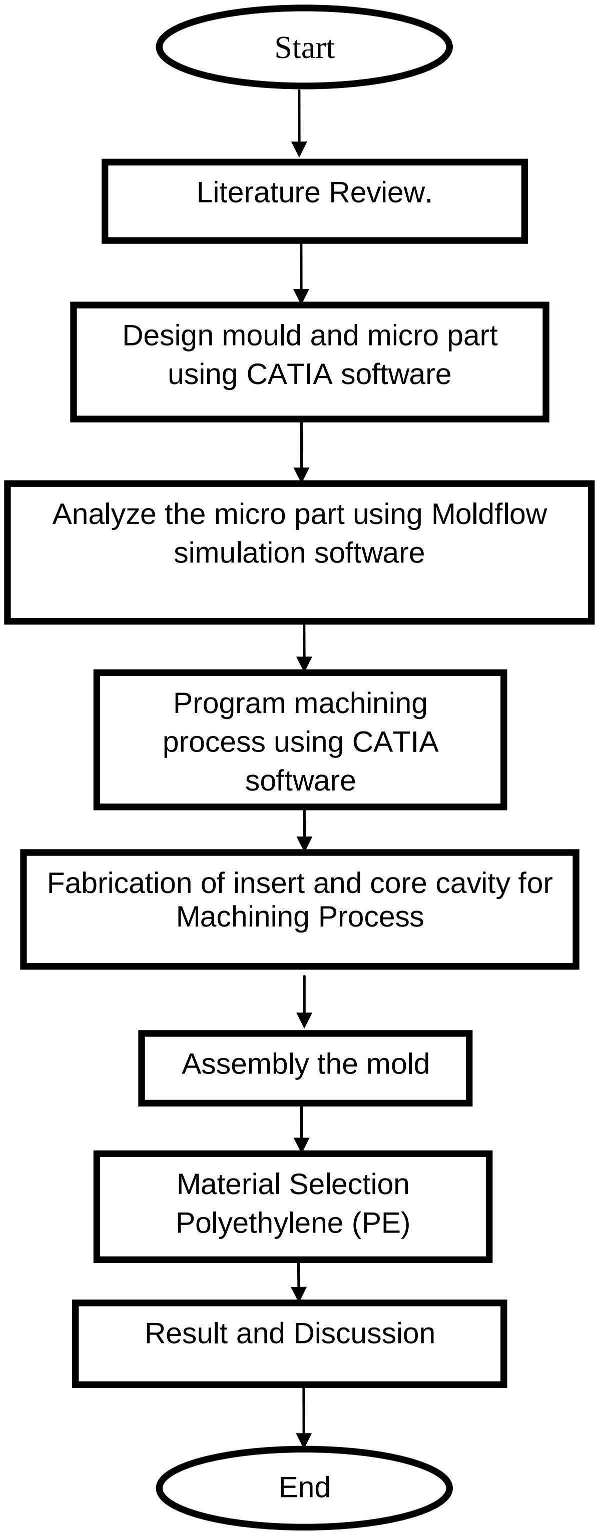
METHODOLOGY

3.1 Introduction

In this section, it will comprise all the methods and processes that will use in order to achieve our objectives which is analyze and prediction of micro injection molding part using computer simulation software. We have started this project with finding all the materials that related with the project title for research and study such as journals, articles and books. After the research and study have been made, it followed with project planning. In this process, we have made a prediction and determine for the next process that needs to take in order to smooth the project progress.

In this project, analysis by using Moldflow software, MPI 5.0, is the main step in getting the result. Through the analysis, comparison of the result will be done. It is important that the analysis that have going through follow the objective and also project scope. The results also have to achieve the project objective. Some analysis sequences have been decided to run through the Moldflow software. We will stress more on how the product or machine is being fabricated, start from the design process until we get the actual micro injection molding part from injection process. Through this chapter also, the full explanation of all processes and tools that involve in fabricate the micro injection mold and part will also include.

3.2 Flow chart

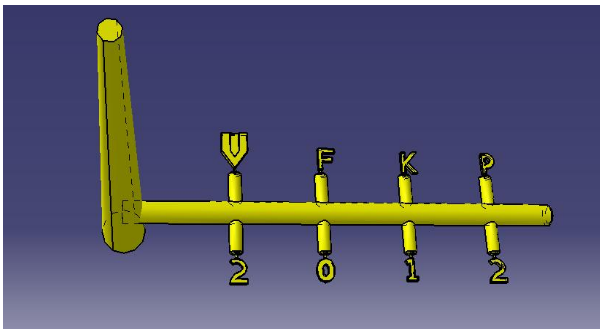


3.3 Process Design Mold and Part of Micro Injection Molding.

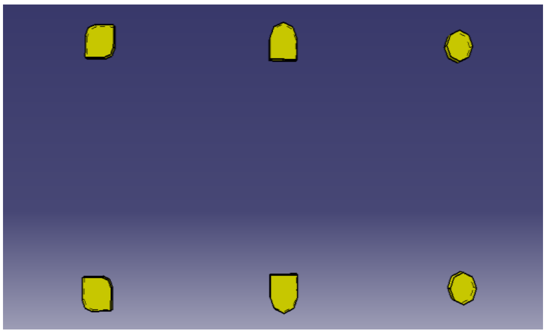
In this section, we will compile all the data and information that related with design of micro injection molding part. The first step is to figure the size of the micro injection molding part. There are few things important considerations was define in order to specify the size of the part which are size of part in cavity side and at the core side. The part must be meeting the consideration of requirement.

After that, define the standard parts for the micro injection molding is taking place. In this process, we will consider all parts that required executing the mold and part. After all the information, data and rough design have been made, we will start design the mold and part by using the CATIA software. Figure 3.1 shows the first design and final design for this project. First design cannot develop at laboratory because not enough tools can produce this part. The solution come out with final design which is the simple product and still in range of micro injection molding part. Figure 3.2 show the mold design for produce the micro injection mold.

3.3.1 Design of Part



a) First design of micro part



b) Final design of micro part

Figure 3.1: Micro injection molding part using CATIA software
(a) Four cavities in one cavity insert (b) Three cavities in one cavity insert

3.3.2 Design of mold micro part injection molding

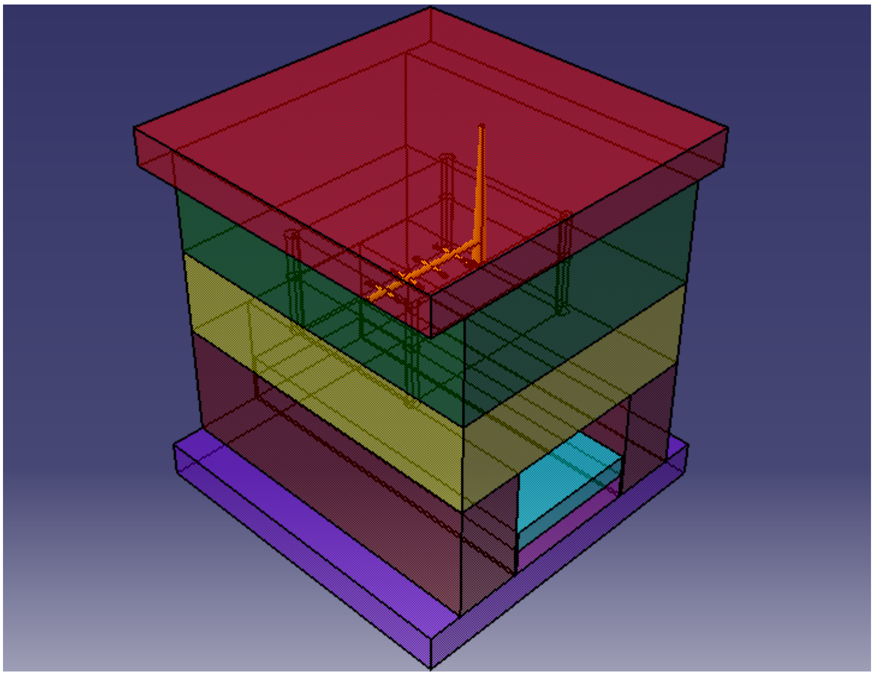


Figure 3.2: Mold base for micro part injection molding.

3.4 MoldFlow Analysis

The most important method to ensure that the product and the mold can be manufactured is mold analysis. This is the first step before we design the mold. The advantages of this mold flow analysis are we can determined the manufacturability of the product in the early design stages and also it can avoid any potential problems which can lead to production delays and can cost overruns.

From the mold analysis, we can also get complete result about our feed system. The parameter includes gate, runner, sprue, and metering. The example of the problem can occur in Moldflow software is:

3.4.1 Air Trap

Is the air that caught inside the impression by converging polymer melt fronts. It is because the air failed to escape from the mold vents or mold inserts which also act as a vent. To eliminate air trap, we modify the filling pattern by reducing injection speed, enlarging the air venting and placing a proper venting in the cavity

3.4.2 Weld line

Occur if two emerging melt fronts flow parallel to each other and create a bond between them. Weld and meld lines can be caused by holes or inserts in the part, multiple gates or variable wall thickness where hesitation or race tracking occurs.

3.4.3 Sink Marks

Appear as depressions on the surface of a molded part. These depressions are typically very small; however they are often quite visible, because they reflect light in different directions to the part. The visibility of sink marks is a function of the color of the part as well as its surface texture so depth is only one criterion. Although Sink Marks do not affect part strength or function, they are perceived to be severe quality defects.

3.5 Analysis Sequences

In this project, there are three type of analysis that has been chosen. Firstly is size diameter of runner system analysis. In this analysis, the diameter change in order to get effect of each micro part and get a micro part full fill when doing injection molding. The size diameter of runner system that has been chosen is 4mm, 5mm, and 6mm.

Then, the analysis will be the size diameter of runner system analysis. Through this analysis, the size diameter of runner system will be change. The purpose is to study the effect on the fill time, injection pressure, and also defects since the different size diameter of runner system. The third analysis is injection pressure and temperature at flow front analysis. The value of injection pressure and temperature change in order to investigate the effect on filling time and also the defects.

The melt temperature will be the final analysis by Moldflow Plastics Insight 5.0 in this project. The value of the melt temperature change in order to differentiate the effect on filling time, freezing time, defects, also the injection pressure and clamping force that recommended by the software.

3.6 Step for Analysis Moldflow Plastics Insight 5.0

1) A plan
2) Enter a cad model
3) Mesh Generation Model
4) Inspection of the model grid defects
5) Select Process
6) Material selection
7) Setting gate location
8) Analysis Model
9) Show results

3.7 Quality of Fabrication Machining Process (Milling Machine)

The quality of the mold component should be maintained during fabrication process to achieve good quality product. Below are the guides to be followed to ensure the qualities of components are well maintained.

3.7.1 Step for Milling Process

1. Remove burrs from the work piece
2. Checking dimension of the work piece
3. Make sure machine table and vice are clean before starting machining
4. Align vice using Dial Indicator
5. Clamp the vice securely
6. Mount work piece securely
7. Make sure tools and cutters to be used are correct and suitable
8. Use correct speed and feed during machining
9. If possible complete all machining process without removing the work piece from the vice to avoid errors.

3.7.2 Before and during Machining

- Make sure the type of material and size according to design and specification.
- The vise/material to be machined must be aligning before any machining process start.
- Standby all tools needed for the machining process for easier job and reduce the waste time.
- Machine the material according to detail drawing and follow the right method (process plan) to decrease mistaken.

3.7.3 After machining

- Clean up the material to ensure no burr in every part after cut.
- Check the material dimension according to detail drawing. Make sure the measurement of each plate is within the tolerance. Measuring equipment that we used such as *Dial Caliper, Dial Indicator and Micrometer.*
- Make chamfer to all sharp edges.
- Make sure all the part after machine is in good condition to avoid from problem during assembly process.

3.8 Quality of Assembly

The assembly process comes after all the above process completed. In this stage, all parts are assembled. The machined parts and standard parts are being assembled together in order to ensure that it is match and function. As assembly is the last process after machining, the quality needs to be control:

- Make sure every part have been grind parallels to get smooth and to maintain the thickness.
- Make sure the plates free from burrs and dust.
- The standard parts are ready to be fastened.
- Be careful when assemble to avoid any problem or mistake.
- When assemble is done, check again and again to make sure it really in good condition before injection mold process

3.9 Injection Molding Process (Injection Molding Machine PNX60)

PNX hydraulic injection molding has acquired a reputation of high performance, safety, and sturdiness. The hydraulic injection molding machine excels in controllability, responsiveness, stability, and energy saving due to X pump system by servomotor, whereby the stable and precise molding is enable. This closed loop set by the digit makes short-term and long term reproducible, molding, and possible. This machine is designed to bear long and severe operation, undergoes severe inspection, and then is delivered to you. Figure 3.3 show the example of conventional injection molding machine that have in laboratory.

Figure 3.3: Injection Molding Machine PNX60
Source: http://www.en-plasinc.com/Nissei_s/3.htm

For this operation, the part should be ejected and can compare with actual operation between simulation computer software (moldflow). Some procedure should be follow to operating this machine, which is:

i. Operating machine (clothing, cooling water circulation, operation power, and heater power)
ii. Starting and stopping motor
iii. Operation during mold clamping and mold opening
iv. Operation of ejector
v. Operation of injection unit movement
vi. Operation of screw (injection, screw and metering)
vii. Automatic Operation
viii. Mold Completion (stop the machine)
ix. Mounting mold
x. Removing mold

CHAPTER 4

RESULT AND DISCUSSION

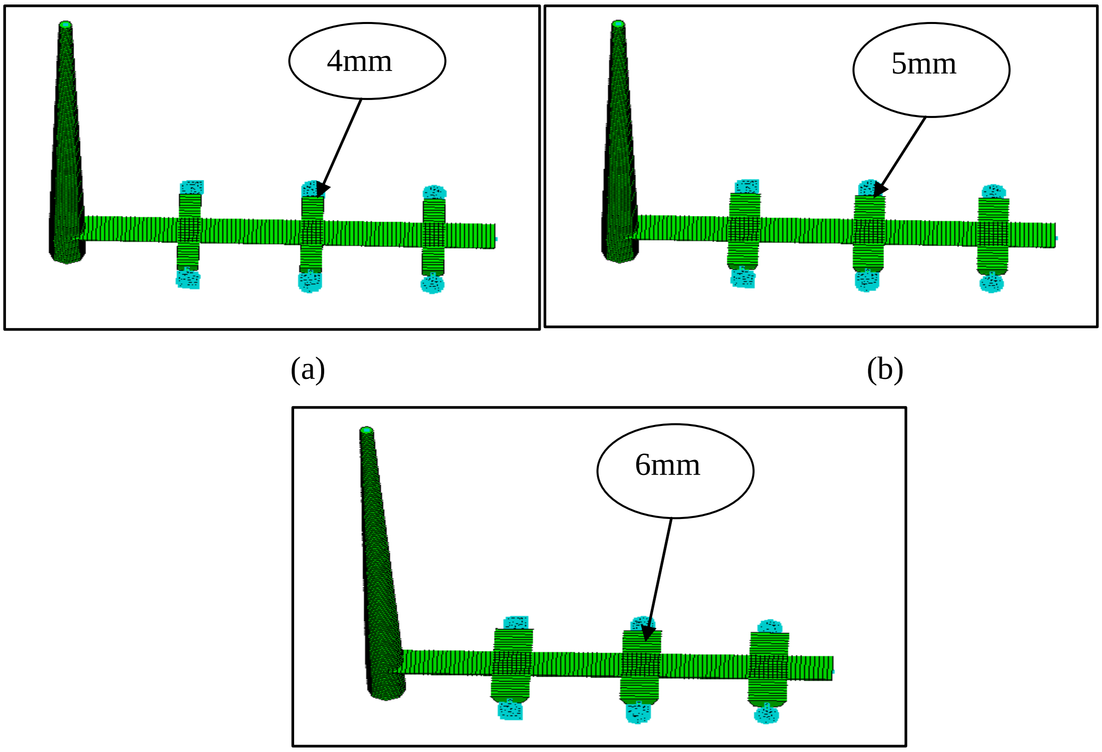
4.1 Introduction

In this chapter, the analysis of micro injection molding part by using Moldflow simulation software can bring many advantages to the engineers in order to cut time consumption in setting the parameter on injection molding machine process instead of by using trial and error method. This software will generate the optimum parameter for injection process by analysis the model or product and setup of criterion onto thus the result will be used in preparing the injection molding process. MPI is one of tools can use in doing the analysis of micro injection molding process. This tools capable of analysis up to thirty important parameters involves in the injection process where some of those cannot determined by human capabilities. The parameter is setup as default setting as 230°C for injection temperature and 50°C for mold temperature and injection time is set as automatic.

The results that have been taken from Moldflow analysis had been compared and predicted with actual injection molding process. The comparison based on the diameter of runner used. That has analyzed the differences between the fill times, injection pressure time to freeze, temperature at flow front and also defects include air traps and weld lines. The trend of result had been investigated. Most of results and discussion are based on the figure and data that have been collect from Moldflow Plastics Insight 5.0.

4.2 Diameter of Runner Analysis

The analysis takes from different diameter of runner in micro injection molding part which is 4mm, 5mm, and 6mm as shows at figure 4.1. The result generated by software is compiled as the report. The analysis included fill time, injection pressure, time to freeze, temperature at flow front, weld line and also air traps.

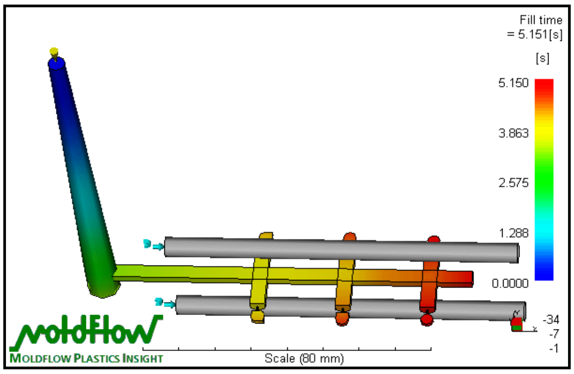


(a) (b) (c)

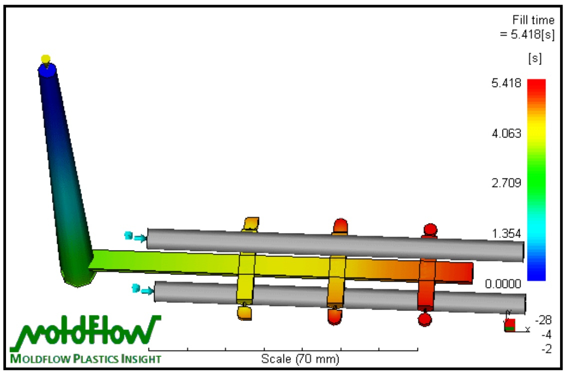
Figure 4.1: Size diameter of runner (a) 4mm (b) 5mm and (c) 6mm

4.3 Fill time

From Figure 4.2, the different runner diameter gives difference results of filling time as we analyze in the Moldflow Software even though the size of gate are same at diameter 1mm. Fill Time for runner that have diameter of 4mm, 5mm and 6mm are 5.151s, 5.418s, and 5.778s. The results shows us that the larger the diameter of runner the higher the fill time required as the area of filling surface is larger. The blue colour represents the fastest area filled with melted resin, while the slowest area filled represented by red colour.



(a)



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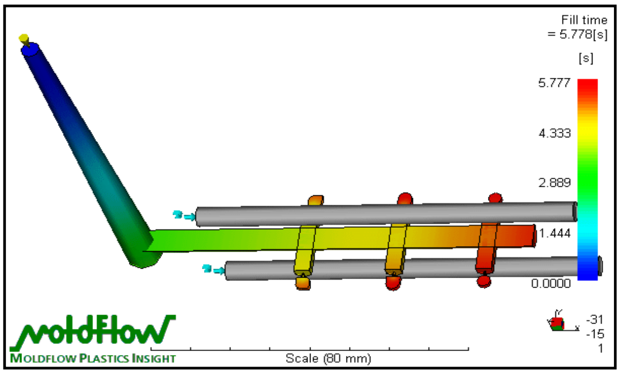


(c)

Figure 4.2: Fill Time of different size of runner (a) 4mm (b) 5mm and (c) 6mm

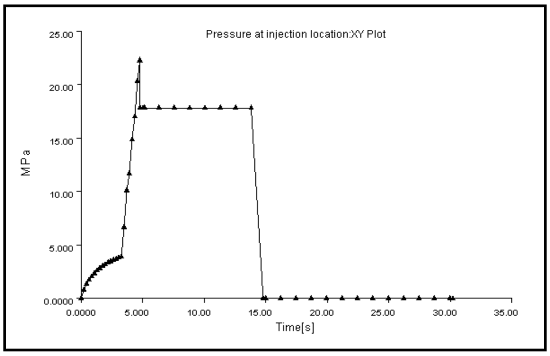
Table 4.1: The Filling analysis result

Size runner	Size gate	Fill time
4mm	1mm	5.151s
5mm	1mm	5.418s
6mm	1mm	5.778s

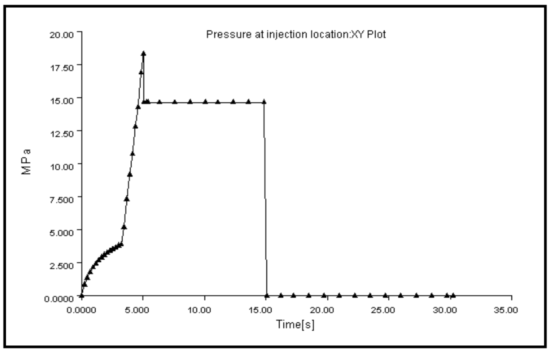
For the conclusion that does the filling analysis, smallest diameter of runner which is 4mm and total weight is 3.4002g gives advantages for filling time analysis. The filling time take to full fill this product is 5.151s. This is caused by the small size of runner diameter that took place, grounds the time taken for the resin to take place. As such, the quality of the resin reduced and also the cycle time of product will be decrease. Reduces of the resin and cycle time can increase the mass product. So that, both deduction can reduce the cost of product produced.

4.4 Injection Pressure

From Figure 4.3, the different runner diameter gives difference results of injection pressure. The injection pressure result uses a range of colours to indicate the region of lowest pressure (colored blue) through to the region of highest pressure (colored red). The colours at each place on the model represents the pressure at that place on the model, at the moment the part is filled completely. This is a 'snapshot' result, that is, it shows the pressure through the whole part at the end of fill. The analysis results required high pressure for smaller diameter of runner as the site needed for the resin to enter the impression is less. This are the maximum injection pressure needed for different runner diameter of 4mm at 4.780s 22.2601MPa, 5mm at 5.048s is 18.2866MPa and 6mm at 5.366s 15.1974MPa. By reducing the runner diameter from 6mm to 4mm, the simulation software result show an increase amount at injection pressure which is $\frac{15.1974}{22.2601} \times 100\% = 68.27\%$



(a)



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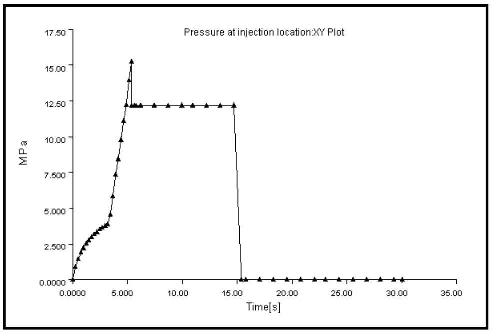


(c)

Figure 4.3: Injection Pressure of different size of runner (a) 4mm (b) 5mm and (c) 6mm

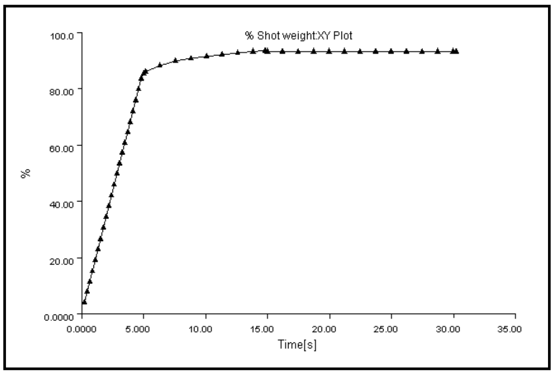
Table 4.2: The injection pressure analysis result

Size runner	Size gate	Maximum Injection Pressure	Time of max during injection
4mm	1mm	22.2601MPa	4.780s
5mm	1mm	18.2866MPa	5.048s
6mm	1mm	15.1974MPa	5.366s

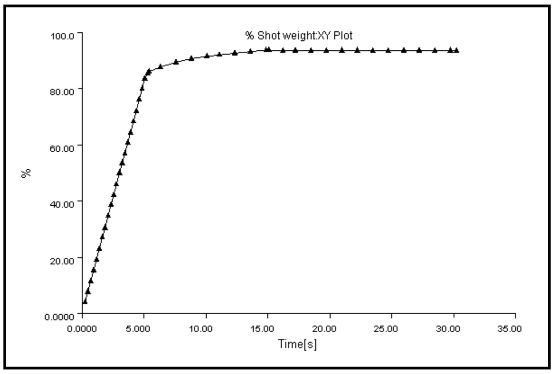
For the conclusion, the highest injection pressure is chosen which size diameter is 4mm at maximum pressure 22.2601Mpa. This is because, the high injection pressure can make sure that the resins are filled entirely in the impression through the feed system machined. Insufficient of injection pressure can cause the part to defect such as short shot and air trap can be happen.

4.5 Shot weight

From Figure 4.4, the different runner diameter gives difference results of shot weight depend on % between time. The % Shot weight result shows the total shot weight, as a percentage of the total part weight, at various time-steps during the filling analysis. It is because the total part weight changes with time, the % Shot weight result measures the total part weight, as a percentage of the total part weight, at various time-steps during the filling analysis. The total part weight is determined from the room-temperature density and the total volume defined in the finite-element mesh. From this information, you can decide if removing the holding pressure will influence the shot weight. The percentage runner weight is also displayed with reference to the total part weight. The economics of the runner design can be assessed by considering its percentage weight in the total shot. The total of weight can refer at table 4.3.



(a)



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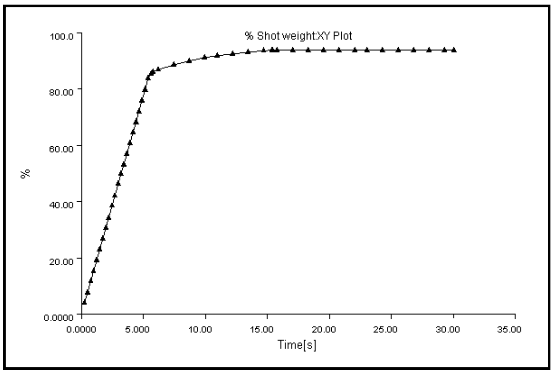


\

(c)

Figure 4.4: Shot weight of different size of runner (a) 4mm (b) 5mm and (c) 6mm

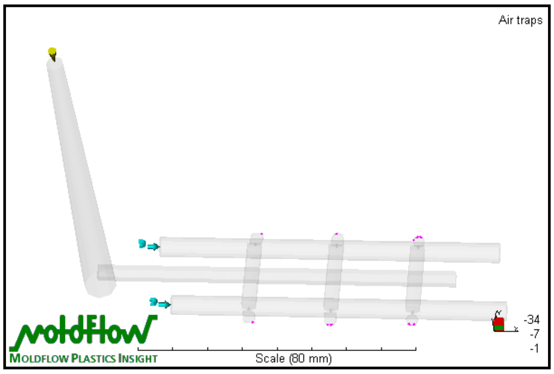
Table 4.3: The shot weight analysis result

Size runner	Size gate	Total weight maximum	Time at maximum weight	Total weight of part	Runner/gate/sprue weight	Total weight
4mm	1mm	3.6932 g	14.792s	0.0630 g	3.3372 g	3.4002 g
5mm	1mm	3.9113 g	15.061s	0.0626 g	3.5294 g	3.5920 g
6mm	1mm	4.1557 g	15.379s	0.0626 g	3.7508 g	3.8134 g

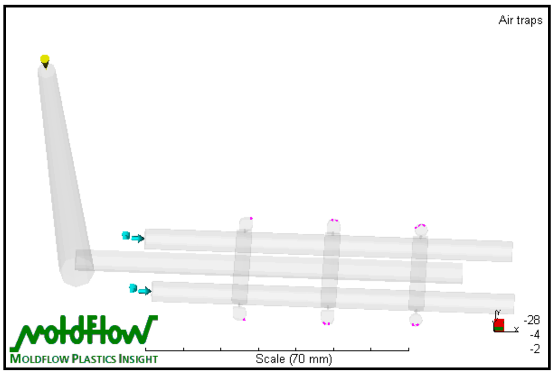
For this result, it can decide the best of shot weight depend on the maximum total of weight at time. The light weight and shorter cycle time is the best choice for the part weight per short. Size 4mm for runner is selected because the result of analysis more suitable refer to others diameter.

4.6 Air Traps

The Air Trap result shows the regions where the melt stops at a convergence of at least 2 flow fronts or at the last point of fill, where a bubble of air becomes trapped. The regions highlighted in the result are positions of possible air traps. Figure 4.5 shows the possible air trap location for the part. Less injection pressure can results in increasing of air trap position.



(a)



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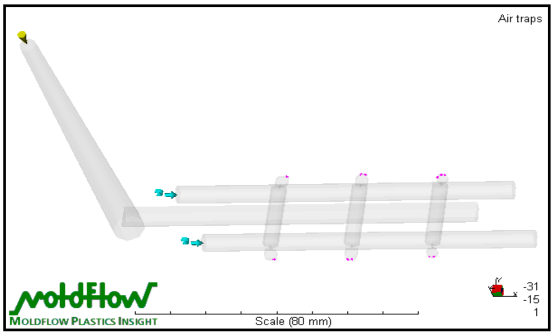


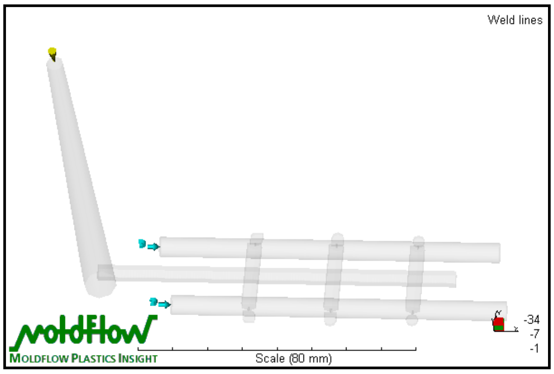
(c)

Figure 4.5: Air Trap of different size of runner (a) 4mm (b) 5mm and (c) 6mm

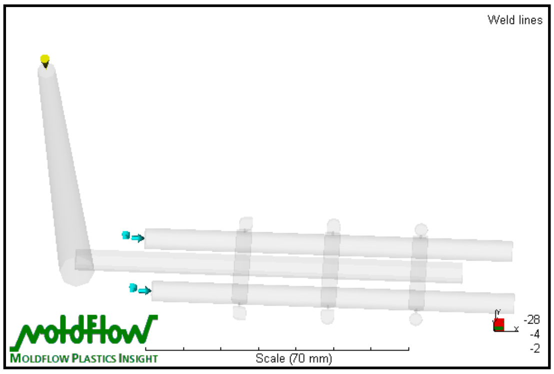
By the comparison of these three sizes of diameter, there's no different for the air traps. So select the best diameter from others characteristics.

4.7 Weld Line

This result indicates the presence and location of weld and meld lines in the filled part model. These are places where two flow fronts have converged. The presence of weld and meld lines may indicate a weakness or blemish. When a weld line forms, the thin frozen layers at the front of each flow path meet, melt, and then freeze again with the rest of the plastic. The orientation of the plastic at the weld is therefore perpendicular to the flow path. Figure 4.6 shows the result of weld line for three different size of runner.



(a)



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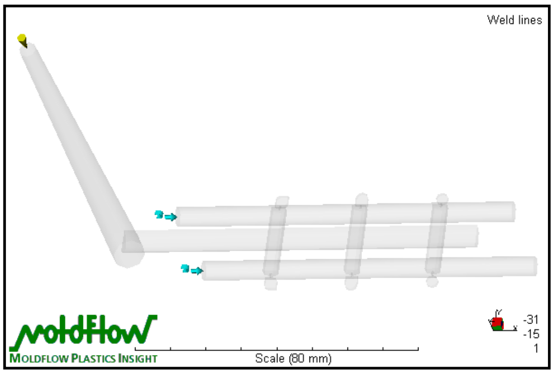


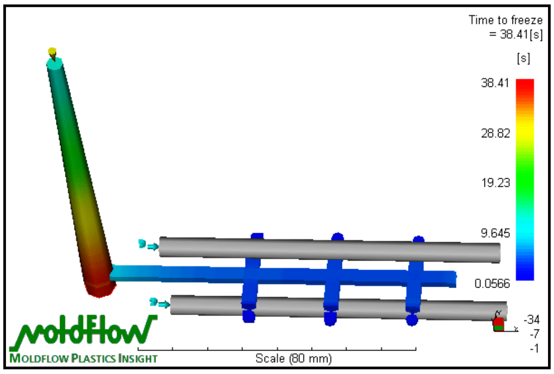
(c)

Figure 4.6: Weld Line of different size of runner (a) 4mm (b) 5mm and (c) 6mm

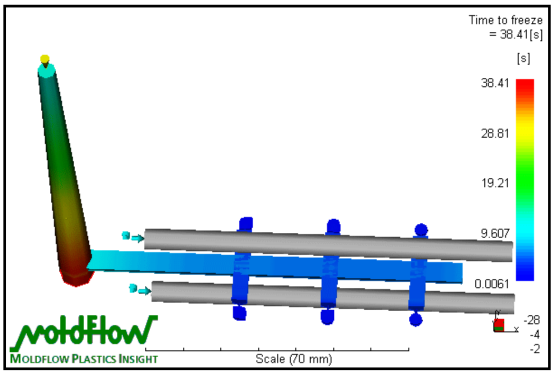
From this analysis, the weld line cannot be seen as the micro injection mold produced very small parts that involved parts that have measurement in millimetre or even micron. Therefore, size of the feed systems does not entirely affect the part.

4.8 Time to freeze

Figure 4.7 shows the Freeze Time result. Plots the deviation of the time it takes the polymer to freeze in any region of the part from the average time to freeze for the entire part. Areas that are plotted as positive values (red) take longer to freeze than the average time to freeze, and areas that are plotted as negative values (blue) freeze more quickly.



(a)



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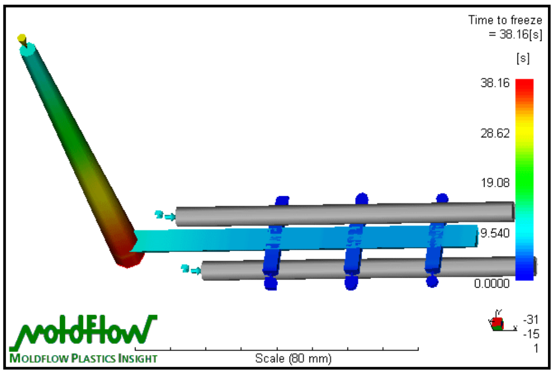


(c)

Figure 4.7: Time to freeze for different size of runner (a) 4mm (b) 5mm and (c) 6mm

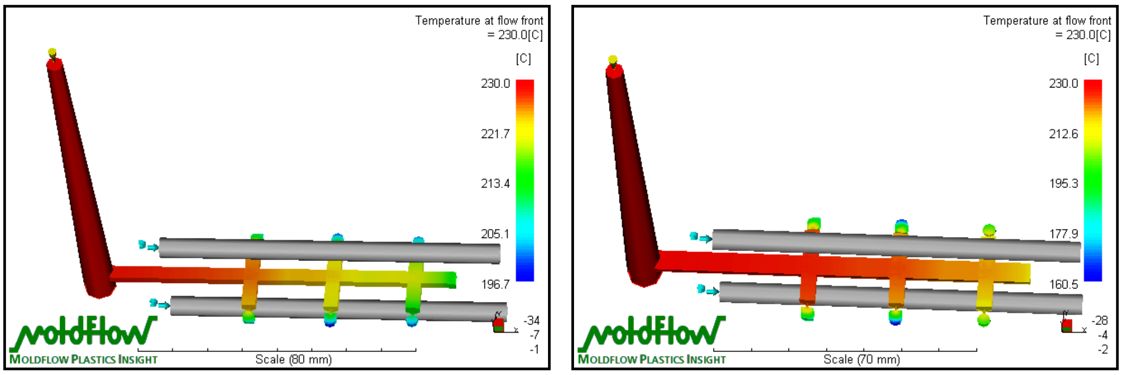
Table 4.4: Time to Freeze analysis result

Size runner	Size gate	Time to freeze
4mm	1mm	38.41s
5mm	1mm	38.41s
6mm	1mm	38.16s

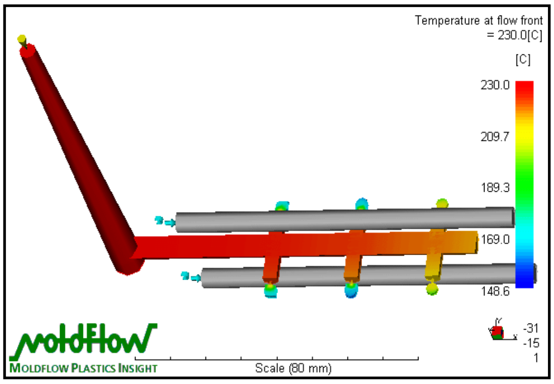
For this analysis, there are not so much dissimilar between the times to freeze because the total areas of the part are so much alike. However, the least time to freeze are the finest as its can control the cycle time of every shot.

4.9 Temperature at flow front

Figure 4.8 shows the temperature at flow front. The temperature for analysis using at melt temperature at 230^{o}C. The flow front temperature result uses a range of colors to indicate the region of lowest temperature (colored blue) through to the region of highest temperature (colored red). The colors represent the material temperature at each point as that point was filled. The result shows the changes in the temperature of the flow front during filling.



(a) **(b)**



(c)

Figure 4.8: Temperature at flow front of different size of runner (a) 4mm (b) 5mm and (c) 6mm

Table 4.5: Temperature at flow front analysis result

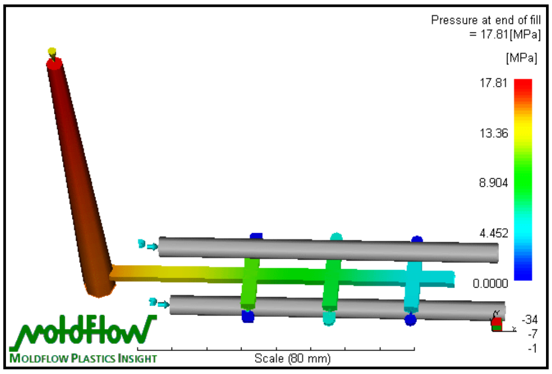
Diameter runner	Size gate	Melt temperature	Low temperature	Different of temperature decrease
4mm	1mm	230°C	196.7°C	33.3°C
5mm	1mm	230°C	160.5°C	69.5°C
6mm	1mm	230°C	148.6°C	81.4°C

For the conclusion, temperature at flow front analysis important because it simplify the resin to flow into the impression while the resin is still hot. Less temperature drop is preferable to ensure the polymer melt is still hot enough to full fill the cavity insert. This is because solidification of material cannot take place if the resin are still in a liquid condition. So that, the diameter of runner selected is 4mm because the comparison between diameter 5mm, and 6mm shows that the temperature at flow front is high compared to diameter 4mm.

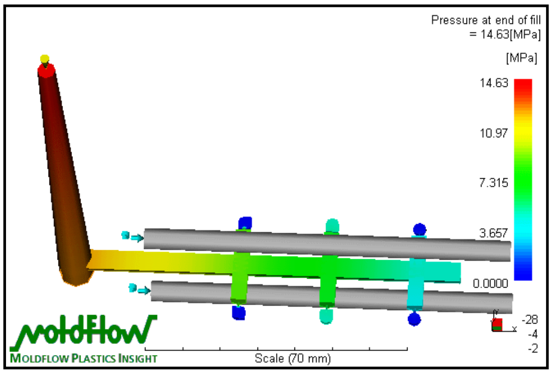
4.10 Pressure at End of Fill

The pressure at end of fill result, which is produced by a Fill analysis, shows the pressure distribution in the cavity at the instant when the cavity is completely filled with polymer. At the beginning of filling, the pressure is zero, or 1 atmosphere in the absolute pressure scale, throughout the mold. The pressure at a specific location starts to increase only after the melt front reaches that location. The pressure continues to increase as the melt front moves past, due to the increasing flow length between this specific location and the melt front.

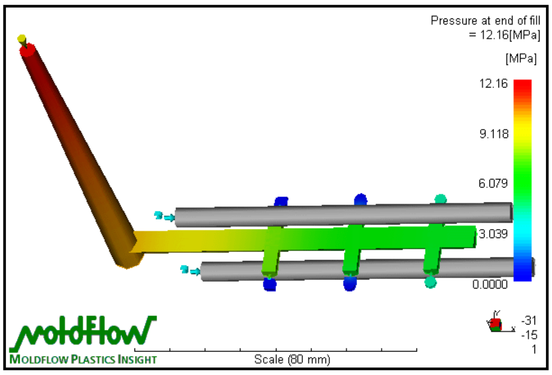
Figure 4.9 shows the result of pressure at end of fill. The magnitude of the pressure depends on the resistance of the polymer in the mold. This is because polymer with high viscosity requires more pressure to fill the cavity. Restricted areas in the mold, such as thin sections, small runners, and long flow lengths, also require a larger pressure gradient, and, therefore, a higher pressure to fill which is at 4mm diameter of runner. If the pressure drop is greater than 80 percent of the injection pressure, there may be filling problems, particularly short shots.



(a)



(b)



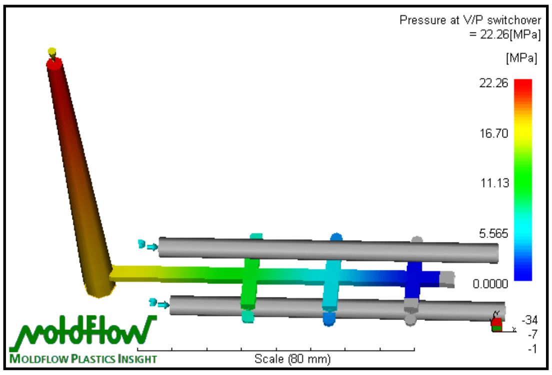
(c)

Figure 4.9: Pressure at end of fill at different diameter of runner

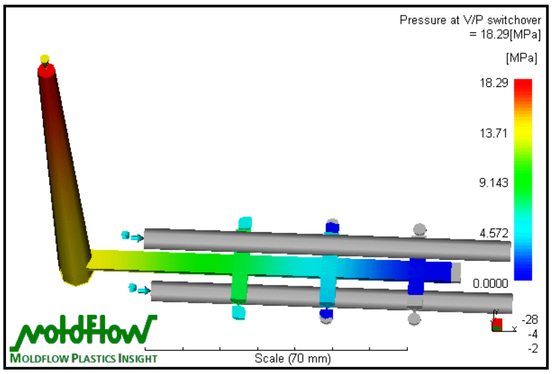
(a) 4mm (b) 5mm and (c) 6mm

4.11 Pressure at V/P switch over

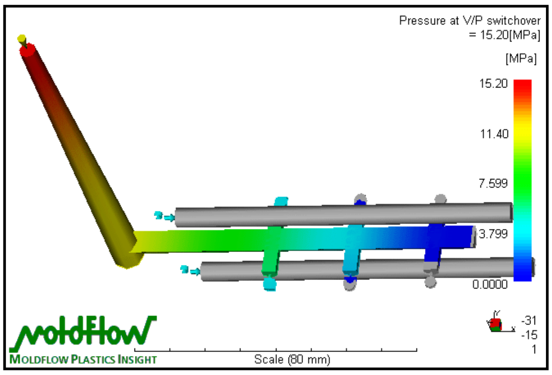
The Pressure at V/P switchover result is generated from a Fill analysis, and shows the pressure distribution through the flow path inside the mold at the switchover point from velocity to pressure control. Pressure should be zero at the extremities of each flow path at the end of filling. Use this result with the Pressure drop result to locate areas where the actual injection pressure may be too high. Figure 4.10 shows the result of pressure at V/P switch over at different diameter of runner. Diameter 4mm present the higher pressure because the projected area of is small. So the material at the end of part not full fill because has high pressure and the part full fill with holding pressure. Thus, the higher pressure is selected as the best pressure because the pressure can make sure the part can full fill.



(a)



(b)



(c)

Figure 4.10: Pressure at V/P switch over with different diameter of runner (a) 4mm (b) 5mm and (c) 6mm

4.12 Selected the Best Diameter of Runner

By using simulation software, the result shows the best diameter of runner can use for this analysis is 4mm. It is because, the properties and characteristics of 4mm diameter shows the good result. The result of simulation can see at table 4.6 which is the parameter of fill time, injection pressure, total of weight and volume, melt temperature, drop temperature at flow front, and V/P switch over.

Table 4.6: Moldflow simulation software analysis result

Parameter	4mm	5mm	6mm
Fill time, s	5.151	5.418	5.778
Injection pressure	22.2601Mpa	18.2866Mpa	15.1974Mpa
Total weight, g	3.4002	3.5920	3.8134
Total volume cm^3	4.1293	4.3670	4.6367
Melt temperature	230^oC	230^oC	230^oC
Temperature at flow front drop	33.3°C	69.5°C	81.4°C
V/p switch over	22.26Mpa	18.29Mpa	15.20Mpa

From the result of analysis, the data can compare with actual at injection molding process. The result are selected to compare is diameter 4mm. The result shows at table 4.7 for comparison with actual process in injection molding machine.

Table 4.7: Analysis result for Simulation software

Parameter	Average diameter of runner 4mm
Fill time, s	5.151
Maximum Injection pressure	22.2601Mpa
Total weight, g	3.4002
Total volume cm^3	4.1293
Melt temperature	$230^{o}C$
Temperature at flow front drop	33.3°C
V/p switch over	22.26Mpa

4.13 Trial & Testing

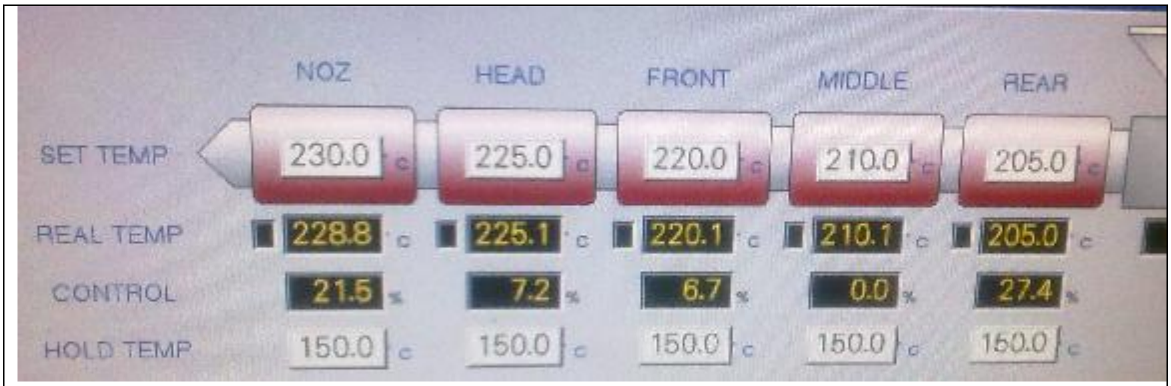
The assembly process comes after all of the process is completed. In this stage, all parts are assembled. The machine part and the standard part are assemble together in order to ensure that the mold is functioning. Then, after all the components of the mold including the insert and standard part being assembled together, it is ready for trial on injection molding machine.

When inject the product at the injection machine, the machine parameter also needs to change according to plastic material to be used. Different material need to different setting of parameter. Product is then need to be studied in order to detect any error. Then, we need to troubleshoot the problem occurred. Table 4.8 shows the result of actual injection process at machine.

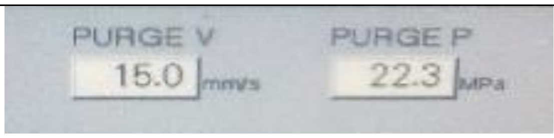
Table 4.8: Actual injection analysis result

Parameter	Average Value
Maximum injection pressure (Mpa)	22.3
Total volume (cm^3)	41.75
Melt temperature	230^oC
Cycle time (s)	35
Fill time (s)	5.34
Maximum clamping force (kN)	300

Table 4.9: The figure of parameter at injection molding machine

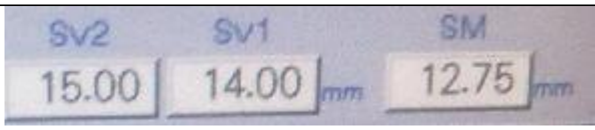


Melt temperature, 230^oC



Maximum injection pressure, 22.3Mpa

Cycle time, 35 s



Total volume, 15+14+12.75= 41.75mm^3

4.14 Comparison from Moldflow between Actual Injection molding Process

As the objective of this project is comparing the parameters after finished product have been produce. For the parameter category it include the Maximum injection pressure, Total volume, Melt temperature, Cycle time, fill time, and clam force.

The parameters to inject the micro part for both analyses are compared in this section. The results are picked when the product is fully filled into finished product. The data for both analyses will be compared by the table 4.10.

Table 4.10: Comparison at both of analysis

Parameter	Actual injection	Simulation software	Differences
Maximum Injection pressure	22.30Mpa	22.26Mpa	+0.04
Total volume (mm^3)	41.75	41.29	+0.46
Melt temperature	230^{o}C	230^{o}C	0^{o}C
Cycle time (s)	35	35	0
Fill time (s)	5.34	5.151	+0.189
Clamping force (60 tonne)	30.58 tonne	7.0002 tonne	+23.58

As the analysis use the exact value of the parameter from the simulation software the core will be over pack and have the ejector mark. It is because some error during machining process come out because lack of skill during machining process. It is known that there are some errors for the results of simulation software as there are present of different value of results. The value of clamping force generated by simulation software is slightly lowest than the actual injection at 30.58 tonne since the machine is only capable provide 60 tonne maximum of clamping force. The defect can happen if the value of clamping force is not enough in clamping moveable and fixed plate together thus some of molten plastics injected through the gap of less clamping force.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objective of this study to analyze and predict the micro injection molding part by using Moldflow simulation software and compare the outcome of Moldflow simulation software with actual injection molding process. For this study, various size of diameter runner analyze by using Moldflow simulation software, MPI 5.0. Other than that, the analysis also include the effect of injection pressure and melt temperature on the fill time, clamping force, time to freeze, air traps, weld line, temperature at flow front and pressure at end of fill and V/P switch over.

The analysis and prediction of micro injection molding part needs us to figure out what are the main components and characteristics that own by the injection molding. In order to design the micro injection molding part and mold, we need to study the parameters that affect the size of the injection molding by using the Moldflow Simulation Software. Besides that, we also need to define the best mold and part design that will meet the criteria of micro injection molding without lost its main function and mechanism of injection molding.

By using Moldflow simulation software, it recommends the finest and optimum parameter for the part product. In this study, the parts that have been analyzed are almost the same with the produced part. The parameter that can be obtained are the melt temperature (230^{o}C), mold temperature (60^{o}C), injection pressure at 22.2601MPa, and other more.

The preparation for both analyses is done by doing the literature study based on micro injection molding part book and articles from previous research. The previous research which including the use of Moldflow simulation software and mico plastics injection molding part indicates that there are very rare of 100% same of result for software analysis and actual injection obtained. However the results are not totally wrong but it can be the guidelines or benchmark for the actual injection setup than start from scratch which consumed a lot of time.

The simulation software analysis results are acceptable since there are absent of errors during the analysis and the offset of the value for the parameter between simulation software and actual injection are at minimal. The parameters that need to be setup onto the software such as dimensional of model micro parts, dimension and layouts of sprue and runner, melting temperature and mold temperature should be setup as accurate as possible to get the most accurate result from the software. Thus the values should be manipulated with detail observation.

Actual injection of micro parts processing the result generated by the simulation software produces flashing and ejector mark defects as it lack during the machining process. Thus the value from the software acts as the guideline to get the finished product. Several fine products injected to get the average result.

As for the conclusion, it is provided that during the analysis both result are not same and if the result from the actual injection taken as benchmark then it can be concluded that the result from Moldflow simulation software are not accurate 100 percent. Even though, at range 90 to 91 percent accurate for the result of simulation software can be used as benchmark or guideline during setup the parameter onto the plastics injection molding machine rather than using trial and error method which consume a lot of times and saving the materials used.

5.2 Recommendation

To produce micro injection product, the part should be at micro injection molding machine. This is because, the standard injection molds have a larger area at core and cavity. This cause the material needed for every short a waste especially at the feed system. In addition, micro mold design for micro part increase the design flow quality to be more balanced.

On top of that, analysis for micro injection moulding part become more precise, material can reduced and actual data parameter are easy to predicted effected to decrease time in troubleshooting machine parameter while part are ejected.

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APPENDICES A

Result summary for runner diameter 4mm

```
-----------------------------------------------------------------------------------------------
            Flow
-----------------------------------------------------------------------------------------------
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Flow Analysis


Version: mpi500  (Build 04453)

Analysis running on host: user-PC
       Operating System: Windows
         Processor type: AuthenticAMD x86 Family 20 Model 1 Stepping 0 ~1596 MHz
    Number of Processors: 2
   Total Physical Memory: 1770  MBytes

Date : MAY23-12
Time : 00:31:13
  File name : new_pro_study_(copy)(flow_cool_warp)_(copy)~3

  No mesh for the cores was found.
  Core shift analysis switched OFF


Summary of analysis inputs :

-----------------------------------------------------------------------------------------------------------

Solver parameters :

   No. of laminae across thickness                   =          12
   Intermediate output options for filling phase
     No. of results at constant intervals            =          20
     No. of profiled results at constant intervals    =           0
   Intermediate output options for packing phase
     No. of results at constant intervals            =          20
     No. of profiled results at constant intervals    =           0
   Melt temperature convergence tolerance             =      0.2000 C
   Mold-melt heat transfer coefficient               =  2.5000E+04 W/m^2-C
   Maximum no. of melt temperature iterations         =         100

------------------------------------------------------------------------------------------------------------
Material data :

   Polymer   : PE-58 : Occidental Chem
   ---------
   PVT Model:    2-domain modified Tait
              coefficients: b5 =    414.5000 K
                            b6 =  1.5430E-07 K/Pa
                            Liquid phase        Solid phase
```

```
-----------------------------------------------------------------------
b1m =      0.0013  b1s =      0.0011 m^3/kg
b2m =  1.0260E-06  b2s =  2.0770E-07 m^3/kg-K
b3m =  9.2630E+07  b3s =  3.3240E+08 Pa
b4m =      0.0049  b4s =  2.4600E-06 1/K
                   b7 =      0.0002 m^3/kg
                   b8 =      0.0516 1/K
                   b9 =  1.0230E-08 1/Pa

Specific heat (Cp)                    =   3000.0000 J/kg-C

Thermal conductivity                  =      0.2700 W/m-C

Viscosity model:              Cross-WLF
           coefficients: n    =      0.3151
                    TAUS =  2.2000E+04 Pa
                    D1   =  7.4800E+20 Pa-s
                    D2   =    153.1500 K
                    D3   =      0.0000 K/Pa
                    A1   =     46.1730
                    A2T  =     51.6000 K

Transition temperature                =    112.0000 C

Mechanical properties data:               E1  =    911.0000 MPa
                    E2  =    911.0000 MPa
                    v12 =      0.4260
                    v23 =      0.4260
                    G12 =    319.0000 MPa

Transversely isotropic coefficent of
  thermal expansion (CTE) data:        Alpha1  =      0.0002 1/C
                    Alpha2  =      0.0002 1/C

Residual stress model without CRIMS

-------------------------------------------------------------------------------------------------

Process settings :

Machine parameters :
------------------
Maximum machine clamp force                  = 7.0002E+03 tonne
Maximum injection pressure                   = 1.8000E+02 MPa
Maximum machine injection rate               = 5.0000E+03 cm^3/s
Machine hydraulic response time              = 1.0000E-02 s

Process parameters :
-----------------------------------------------------------------------------------------------
Fill time                             =      4.3552 s
Injection time has been determined by automatic calculation.
Stroke volume determination                  = Automatic
Cycle time                            =     35.0000 s

Velocity/pressure switch-over by             = Automatic
Packing/holding time                  =     10.0000 s
Ram speed profile (rel):
  % shot volume        % ram speed
  ---------------------------------------------------------------------------------------------
```

100.0000 100.0000
0.0000 100.0000
Pack/hold pressure profile (rel):
duration % filling pressure

duration	% filling pressure
0.0000 s	80.0000
10.0000 s	80.0000
15.6448 s	0.0000

Ambient temperature = 25.0000 C
Melt temperature = 230.0000 C
Ideal cavity-side mold temperature = 50.0000 C
Ideal core-side mold temperature = 50.0000 C

NOTE: Using mold wall temperature data from cooling analysis

Model details :

Mesh Type = Fusion

Match ratio = 99.9 %
Total number of nodes = 780
Total number of injection location nodes = 1
The injection location node labels are:
649
Total number of elements = 1156
Number of part elements = 810
Number of sprue/runner/gate elements = 346
Number of channel elements = 0
Number of connector elements = 0
Average aspect ratio of triangle elements = 1.6947
Maximum aspect ratio of triangle elements = 4.5270
Minimum aspect ratio of triangle elements = 1.1623
Total volume = 4.1293 cm^3
Volume filled initially = 0.0000 cm^3
Volume to be filled = 4.1293 cm^3
Sprue/runner/gate volume to be filled = 4.0812 cm^3
Total projected area = 5.1514 cm^2

Filling phase results summary :

Maximum injection pressure (at 4.780 s) = 22.2601 MPa

End of filling phase results summary :

Time at the end of filling = 5.1514 s
Total weight = 3.4002 g
Maximum Clamp force - during filling = 0.4355 tonne
Recommended ram speed profile (rel):

% stroke	% speed
0.0000	29.7509
10.0000	41.4704
20.0000	54.9595
30.0000	66.8971
40.0000	77.8787
50.0000	88.1094
60.0000	100.0000

70.0000	61.5054
80.0000	43.9678
98.2665	43.9678
100.0000	14.6179

Melt front is entirely in the cavity at % fill = 98.2665 %

Filling phase results summary for the part :

Bulk temperature - maximum (at 4.139 s) = 209.9000 C
Bulk temperature - 95th percentile (at 4.139 s) = 202.7110 C
Bulk temperature - 5th percentile (at 5.150 s) = 68.1470 C
Bulk temperature - minimum (at 5.150 s) = 62.9150 C

Wall shear stress - maximum (at 5.151 s) = 0.1755 MPa
Wall shear stress - 95th percentile (at 5.151 s) = 0.1172 MPa

Shear rate - maximum (at 5.151 s) = 527.2520 1/s
Shear rate - 95th percentile (at 5.151 s) = 177.8620 1/s

End of filling phase results summary for the part :

Total part weight = 0.0630 g

Bulk temperature - maximum = 195.2490 C
Bulk temperature - 95th percentile = 187.1680 C
Bulk temperature - 5th percentile = 68.2140 C
Bulk temperature - minimum = 62.9150 C
Bulk temperature - average = 127.5130 C
Bulk temperature - RMS deviation = 43.4615 C

Wall shear stress - maximum = 0.1755 MPa
Wall shear stress - 95th percentile = 0.1172 MPa
Wall shear stress - average = 0.0348 MPa
Wall shear stress - RMS deviation = 0.0422 MPa

Frozen layer fraction - maximum = 1.0000
Frozen layer fraction - 95th percentile = 1.0000
Frozen layer fraction - 5th percentile = 0.1366
Frozen layer fraction - minimum = 0.0500
Frozen layer fraction - average = 0.6105
Frozen layer fraction - RMS deviation = 0.3275

Shear rate - maximum = 527.2520 1/s
Shear rate - 95th percentile = 177.8620 1/s
Shear rate - average = 34.0501 1/s
Shear rate - RMS deviation = 75.2610 1/s

Filling phase results summary for the runner system :

Bulk temperature - maximum (at 0.229 s) = 229.6970 C
Bulk temperature - 95th percentile (at 0.229 s) = 229.6970 C
Bulk temperature - 5th percentile (at 5.151 s) = 188.1450 C
Bulk temperature - minimum (at 5.150 s) = 128.6230 C

Wall shear stress - maximum (at 5.151 s) = 0.3294 MPa
Wall shear stress - 95th percentile (at 4.780 s) = 0.1331 MPa

Shear rate - maximum (at 5.019 s) = 5770.1699 1/s
Shear rate - 95th percentile (at 4.366 s) = 301.5720 1/s

End of filling phase results summary for the runner system :

Total sprue/runner/gate weight = 3.3372 g
Bulk temperature - maximum = 229.0050 C
Bulk temperature - 95th percentile = 223.0820 C
Bulk temperature - 5th percentile = 188.1450 C
Bulk temperature - minimum = 128.7130 C
Bulk temperature - average = 210.6330 C
Bulk temperature - RMS deviation = 11.4583 C

Wall shear stress - maximum = 0.3294 MPa
Wall shear stress - 95th percentile = 0.0788 MPa
Wall shear stress - average = 0.0302 MPa
Wall shear stress - RMS deviation = 0.0214 MPa

Frozen layer fraction - maximum = 0.7765
Frozen layer fraction - 95th percentile = 0.4184
Frozen layer fraction - 5th percentile = 0.1333
Frozen layer fraction - minimum = 0.0625
Frozen layer fraction - average = 0.2587
Frozen layer fraction - RMS deviation = 0.0825

Shear rate - maximum = 5348.9800 1/s
Shear rate - 95th percentile = 58.9033 1/s
Shear rate - average = 15.1508 1/s
Shear rate - RMS deviation = 56.8404 1/s

Packing phase results summary :

Peak pressure - minimum (at 0.000 s) = 0.0000 MPa
Clamp force - maximum (at 6.311 s) = 0.5084 tonne
Total weight - maximum (at 14.792 s) = 3.6932 g

End of packing phase results summary :

Time at the end of packing = 30.1892 s
Total weight = 3.6806 g

Packing phase results summary for the part :

Bulk temperature - maximum (at 5.152 s) = 194.8510 C
Bulk temperature - 95th percentile (at 5.152 s) = 187.4550 C
Bulk temperature - 5th percentile (at 30.189 s) = 32.6730 C
Bulk temperature - minimum (at 30.189 s) = 30.7250 C

Wall shear stress - maximum (at 5.152 s) = 0.1553 MPa
Wall shear stress - 95th percentile (at 5.152 s) = 0.0914 MPa

Volumetric shrinkage - maximum (at 5.152 s) = 19.4982 %
Volumetric shrinkage - 95th %ile (at 5.152 s) = 17.1230 %
Volumetric shrinkage - 5th %ile (at 6.311 s) = 1.4669 %
Volumetric shrinkage - minimum (at 6.311 s) = 0.9129 %

Total part weight - maximum (at 6.311 s) = 0.0663 g

End of packing phase results summary for the part :

Total part weight = 0.0663 g

Bulk temperature - maximum	=	36.1310 C
Bulk temperature - 95th percentile	=	35.8440 C
Bulk temperature - 5th percentile	=	32.6730 C
Bulk temperature - minimum	=	30.7250 C
Bulk temperature - average	=	34.1350 C
Bulk temperature - RMS deviation	=	1.1461 C
Frozen layer fraction - maximum	=	1.0000
Frozen layer fraction - 95th percentile	=	1.0000
Frozen layer fraction - 5th percentile	=	1.0000
Frozen layer fraction - minimum	=	1.0000
Frozen layer fraction - average	=	1.0000
Frozen layer fraction - RMS deviation	=	0.0000
Volumetric shrinkage - maximum	=	5.6038 %
Volumetric shrinkage - 95th percentile	=	5.1483 %
Volumetric shrinkage - 5th percentile	=	1.4669 %
Volumetric shrinkage - minimum	=	0.9129 %
Volumetric shrinkage - average	=	3.1209 %
Volumetric shrinkage - RMS deviation	=	1.1367 %
Sink index - maximum	=	0.0000 %
Sink index - 95th percentile	=	0.0000 %
Sink index - minimum	=	0.0000 %
Sink index - RMS deviation	=	0.0000 %

Packing phase results summary for the runner system :

Bulk temperature - maximum	(at 5.152 s)	=	229.0040 C
Bulk temperature - 95th percentile	(at 5.152 s)	=	223.0800 C
Bulk temperature - 5th percentile	(at 30.189 s)	=	34.8360 C
Bulk temperature - minimum	(at 30.189 s)	=	31.3640 C
Wall shear stress - maximum	(at 5.152 s)	=	0.2986 MPa
Wall shear stress - 95th percentile	(at 14.792 s)	=	0.1360 MPa
Volumetric shrinkage - maximum	(at 5.152 s)	=	19.4901 %
Volumetric shrinkage - 95th %ile	(at 5.152 s)	=	16.8483 %
Volumetric shrinkage - 5th %ile	(at 16.189 s)	=	2.0951 %
Volumetric shrinkage - minimum	(at 7.561 s)	=	0.5577 %
Sprue/runner/gate weight - max.	(at 14.792 s)	=	3.6268 g

End of packing phase results summary for the runner system :

Total sprue/runner/gate weight	=	3.6143 g
Bulk temperature - maximum	=	133.3900 C
Bulk temperature - 95th percentile	=	131.4500 C
Bulk temperature - 5th percentile	=	34.8360 C
Bulk temperature - minimum	=	31.3640 C
Bulk temperature - average	=	83.4360 C
Bulk temperature - RMS deviation	=	33.9752 C
Frozen layer fraction - maximum	=	1.0000
Frozen layer fraction - 95th percentile	=	1.0000
Frozen layer fraction - 5th percentile	=	0.6514
Frozen layer fraction - minimum	=	0.6399
Frozen layer fraction - average	=	0.9207
Frozen layer fraction - RMS deviation	=	0.1209

Volumetric shrinkage - maximum	=	12.1931 %
Volumetric shrinkage - 95th percentile	=	11.9136 %
Volumetric shrinkage - 5th percentile	=	2.0951 %
Volumetric shrinkage - minimum	=	0.5577 %
Volumetric shrinkage - average	=	7.2415 %
Volumetric shrinkage - RMS deviation	=	3.4755 %

Sink index - maximum	=	1.4384 %
Sink index - 95th percentile	=	1.2267 %
Sink index - minimum	=	0.3932 %
Sink index - RMS deviation	=	0.4217 %

Execution time

Analysis commenced at	Wed May 23 00:31:13 2012
Analysis completed at	Wed May 23 00:32:32 2012
CPU time used	59.58 s

APPENDICES B

Result summary for runner diameter 5mm

Flow

Flow Analysis

Version: mpi500 (Build 04453)

Analysis running on host: user-PC
Operating System: Windows
Processor type: AuthenticAMD x86 Family 20 Model 1 Stepping 0 ~1596 MHz
Number of Processors: 2
Total Physical Memory: 1770 MBytes

Date : MAY23-12
Time : 00:38:48
File name : new_pro_study_(copy)(flow_cool_warp)_(copy)~3

No mesh for the cores was found.
Core shift analysis switched OFF

Summary of analysis inputs :

Solver parameters :

No. of laminae across thickness = 12
Intermediate output options for filling phase
No. of results at constant intervals = 20
No. of profiled results at constant intervals = 0
Intermediate output options for packing phase
No. of results at constant intervals = 20
No. of profiled results at constant intervals = 0
Melt temperature convergence tolerance = 0.2000 C
Mold-melt heat transfer coefficient = 2.5000E+04 W/m^2-C
Maximum no. of melt temperature iterations = 100

Material data :

Polymer : PE-58 : Occidental Chem

PVT Model: 2-domain modified Tait
coefficients: b5 = 414.5000 K
b6 = 1.5430E-07 K/Pa
Liquid phase Solid phase
----
b1m = 0.0013 b1s = 0.0011 m^3/kg

b2m = 1.0260E-06 b2s = 2.0770E-07 m^3/kg-K
b3m = 9.2630E+07 b3s = 3.3240E+08 Pa
b4m = 0.0049 b4s = 2.4600E-06 1/K
b7 = 0.0002 m^3/kg
b8 = 0.0516 1/K
b9 = 1.0230E-08 1/Pa

Specific heat (Cp) = 3000.0000 J/kg-C

Thermal conductivity = 0.2700 W/m-C

Viscosity model: Cross-WLF
coefficients: n = 0.3151
TAUS = 2.2000E+04 Pa
D1 = 7.4800E+20 Pa-s
D2 = 153.1500 K
D3 = 0.0000 K/Pa
A1 = 46.1730
A2T = 51.6000 K

Transition temperature = 112.0000 C

Mechanical properties data: E1 = 911.0000 MPa
E2 = 911.0000 MPa
v12 = 0.4260
v23 = 0.4260
G12 = 319.0000 MPa

Transversely isotropic coefficent of
thermal expansion (CTE) data: Alpha1 = 0.0002 1/C
Alpha2 = 0.0002 1/C

Residual stress model without CRIMS

Process settings :

Machine parameters :

Maximum machine clamp force = 7.0002E+03 tonne
Maximum injection pressure = 1.8000E+02 MPa
Maximum machine injection rate = 5.0000E+03 cm^3/s
Machine hydraulic response time = 1.0000E-02 s

Process parameters :

Fill time = 4.6031 s
Injection time has been determined by automatic calculation.
Stroke volume determination = Automatic
Cycle time = 35.0000 s

Velocity/pressure switch-over by = Automatic
Packing/holding time = 10.0000 s
Ram speed profile (rel):

% shot volume	% ram speed
100.0000	100.0000
0.0000	100.0000

Pack/hold pressure profile (rel):

duration	% filling pressure
0.0000 s	80.0000
10.0000 s	80.0000
15.3969 s	0.0000

Ambient temperature = 25.0000 C
Melt temperature = 230.0000 C
Ideal cavity-side mold temperature = 50.0000 C
Ideal core-side mold temperature = 50.0000 C

NOTE: Using mold wall temperature data from cooling analysis

Model details :

Mesh Type = Fusion

Match ratio = 99.9 %
Total number of nodes = 780
Total number of injection location nodes = 1
The injection location node labels are:
649
Total number of elements = 1156
Number of part elements = 810
Number of sprue/runner/gate elements = 346
Number of channel elements = 0
Number of connector elements = 0
Average aspect ratio of triangle elements = 1.6947
Maximum aspect ratio of triangle elements = 4.5270
Minimum aspect ratio of triangle elements = 1.1623
Total volume = 4.3670 cm^3
Volume filled initially = 0.0000 cm^3
Volume to be filled = 4.3670 cm^3
Sprue/runner/gate volume to be filled = 4.3189 cm^3
Total projected area = 5.5827 cm^2

Filling phase results summary :

Maximum injection pressure (at 5.048 s) = 18.2866 MPa

End of filling phase results summary :

Time at the end of filling = 5.4190 s
Total weight = 3.5920 g
Maximum Clamp force - during filling = 0.4089 tonne
Recommended ram speed profile (rel):

% stroke	% speed
0.0000	27.0670
10.0000	38.1181
20.0000	50.8831
30.0000	62.2264
40.0000	72.5755
50.0000	82.2080
60.0000	100.0000
70.0000	29.4902
80.0000	50.2306

98.3603 50.2306
100.0000 16.9124
Melt front is entirely in the cavity at % fill = 98.3603 %

Filling phase results summary for the part :

Bulk temperature - maximum (at 5.295 s) = 202.4970 C
Bulk temperature - 95th percentile (at 5.295 s) = 196.1080 C
Bulk temperature - 5th percentile (at 5.419 s) = 68.8620 C
Bulk temperature - minimum (at 5.417 s) = 61.6370 C

Wall shear stress - maximum (at 5.419 s) = 0.1729 MPa
Wall shear stress - 95th percentile (at 5.295 s) = 0.1249 MPa

Shear rate - maximum (at 5.419 s) = 488.5380 1/s
Shear rate - 95th percentile (at 5.419 s) = 163.3350 1/s

End of filling phase results summary for the part :

Total part weight = 0.0626 g

Bulk temperature - maximum = 192.8640 C
Bulk temperature - 95th percentile = 185.3770 C
Bulk temperature - 5th percentile = 68.8620 C
Bulk temperature - minimum = 61.6370 C
Bulk temperature - average = 130.9430 C
Bulk temperature - RMS deviation = 43.4971 C

Wall shear stress - maximum = 0.1729 MPa
Wall shear stress - 95th percentile = 0.1159 MPa
Wall shear stress - average = 0.0331 MPa
Wall shear stress - RMS deviation = 0.0418 MPa

Frozen layer fraction - maximum = 1.0000
Frozen layer fraction - 95th percentile = 1.0000
Frozen layer fraction - 5th percentile = 0.1491
Frozen layer fraction - minimum = 0.0544
Frozen layer fraction - average = 0.5832
Frozen layer fraction - RMS deviation = 0.3304

Shear rate - maximum = 488.5380 1/s
Shear rate - 95th percentile = 163.3350 1/s
Shear rate - average = 30.7937 1/s
Shear rate - RMS deviation = 68.7052 1/s

Filling phase results summary for the runner system :

Bulk temperature - maximum (at 0.242 s) = 229.6920 C
Bulk temperature - 95th percentile (at 0.242 s) = 229.6920 C
Bulk temperature - 5th percentile (at 5.419 s) = 188.3730 C
Bulk temperature - minimum (at 5.417 s) = 126.4060 C

Wall shear stress - maximum (at 5.419 s) = 0.3202 MPa
Wall shear stress - 95th percentile (at 5.048 s) = 0.1179 MPa

Shear rate - maximum (at 5.419 s) = 4862.5801 1/s
Shear rate - 95th percentile (at 5.048 s) = 205.7060 1/s

End of filling phase results summary for the runner system :

Total sprue/runner/gate weight = 3.5294 g
Bulk temperature - maximum = 228.9890 C
Bulk temperature - 95th percentile = 222.8350 C
Bulk temperature - 5th percentile = 188.3730 C
Bulk temperature - minimum = 126.5240 C
Bulk temperature - average = 210.2020 C
Bulk temperature - RMS deviation = 11.6060 C

Wall shear stress - maximum = 0.3202 MPa
Wall shear stress - 95th percentile = 0.0661 MPa
Wall shear stress - average = 0.0293 MPa
Wall shear stress - RMS deviation = 0.0186 MPa

Frozen layer fraction - maximum = 0.7964
Frozen layer fraction - 95th percentile = 0.4092
Frozen layer fraction - 5th percentile = 0.1440
Frozen layer fraction - minimum = 0.0624
Frozen layer fraction - average = 0.2660
Frozen layer fraction - RMS deviation = 0.0812

Shear rate - maximum = 4862.5801 1/s
Shear rate - 95th percentile = 38.9454 1/s
Shear rate - average = 12.8400 1/s
Shear rate - RMS deviation = 49.5085 1/s

Packing phase results summary :

Peak pressure - minimum (at 0.000 s) = 0.0000 MPa
Clamp force - maximum (at 6.328 s) = 0.5009 tonne
Total weight - maximum (at 15.061 s) = 3.9113 g

End of packing phase results summary :

Time at the end of packing = 30.2078 s
Total weight = 3.9030 g

Packing phase results summary for the part :

Bulk temperature - maximum (at 5.419 s) = 192.4420 C
Bulk temperature - 95th percentile (at 5.419 s) = 185.7650 C
Bulk temperature - 5th percentile (at 30.208 s) = 33.1720 C
Bulk temperature - minimum (at 30.208 s) = 31.2150 C

Wall shear stress - maximum (at 5.419 s) = 0.1532 MPa
Wall shear stress - 95th percentile (at 5.419 s) = 0.0906 MPa

Volumetric shrinkage - maximum (at 5.419 s) = 19.3040 %
Volumetric shrinkage - 95th %ile (at 5.419 s) = 16.7816 %
Volumetric shrinkage - 5th %ile (at 6.328 s) = 1.4963 %
Volumetric shrinkage - minimum (at 6.328 s) = 1.0179 %

Total part weight - maximum (at 6.328 s) = 0.0664 g

End of packing phase results summary for the part :

Total part weight = 0.0664 g

Bulk temperature - maximum = 36.7370 C

Bulk temperature - 95th percentile = 36.3940 C
Bulk temperature - 5th percentile = 33.1720 C
Bulk temperature - minimum = 31.2150 C
Bulk temperature - average = 34.6770 C
Bulk temperature - RMS deviation = 1.1749 C

Frozen layer fraction - maximum = 1.0000
Frozen layer fraction - 95th percentile = 1.0000
Frozen layer fraction - 5th percentile = 1.0000
Frozen layer fraction - minimum = 1.0000
Frozen layer fraction - average = 1.0000
Frozen layer fraction - RMS deviation = 0.0000

Volumetric shrinkage - maximum = 5.3630 %
Volumetric shrinkage - 95th percentile = 4.8498 %
Volumetric shrinkage - 5th percentile = 1.4963 %
Volumetric shrinkage - minimum = 1.0179 %
Volumetric shrinkage - average = 3.0618 %
Volumetric shrinkage - RMS deviation = 1.0135 %

Sink index - maximum = 0.0000 %
Sink index - 95th percentile = 0.0000 %
Sink index - minimum = 0.0000 %
Sink index - RMS deviation = 0.0000 %

Packing phase results summary for the runner system :

Bulk temperature - maximum (at 5.419 s) = 228.9880 C
Bulk temperature - 95th percentile (at 5.419 s) = 222.8340 C
Bulk temperature - 5th percentile (at 30.208 s) = 36.0540 C
Bulk temperature - minimum (at 30.208 s) = 31.4600 C

Wall shear stress - maximum (at 5.419 s) = 0.2922 MPa
Wall shear stress - 95th percentile (at 15.061 s) = 0.1053 MPa

Volumetric shrinkage - maximum (at 5.419 s) = 19.7776 %
Volumetric shrinkage - 95th %ile (at 5.419 s) = 16.8802 %
Volumetric shrinkage - 5th %ile (at 14.828 s) = 2.1633 %
Volumetric shrinkage - minimum (at 7.578 s) = 0.5847 %
Sprue/runner/gate weight - max. (at 15.061 s) = 3.8449 g

End of packing phase results summary for the runner system :

Total sprue/runner/gate weight = 3.8366 g
Bulk temperature - maximum = 133.4420 C
Bulk temperature - 95th percentile = 127.6240 C
Bulk temperature - 5th percentile = 36.0540 C
Bulk temperature - minimum = 31.4600 C
Bulk temperature - average = 82.3230 C
Bulk temperature - RMS deviation = 34.1578 C

Frozen layer fraction - maximum = 1.0000
Frozen layer fraction - 95th percentile = 1.0000
Frozen layer fraction - 5th percentile = 0.6936
Frozen layer fraction - minimum = 0.6356
Frozen layer fraction - average = 0.9217
Frozen layer fraction - RMS deviation = 0.1214

Volumetric shrinkage - maximum = 12.1306 %

Volumetric shrinkage - 95th percentile = 11.1482 %
Volumetric shrinkage - 5th percentile = 2.1680 %
Volumetric shrinkage - minimum = 0.5847 %
Volumetric shrinkage - average = 6.9989 %
Volumetric shrinkage - RMS deviation = 3.5263 %

Sink index - maximum = 1.3977 %
Sink index - 95th percentile = 0.9696 %
Sink index - minimum = 0.3651 %
Sink index - RMS deviation = 0.4097 %

Execution time
Analysis commenced at Wed May 23 00:38:47 2012
Analysis completed at Wed May 23 00:39:51 2012
CPU time used 57.47 s

APPENDICES C

Result summary for runner diameter 6mm

Flow

Flow Analysis

Version: mpi500 (Build 04453)

Analysis running on host: user-PC
Operating System: Windows
Processor type: AuthenticAMD x86 Family 20 Model 1 Stepping 0 ~1596 MHz
Number of Processors: 2
Total Physical Memory: 1770 MBytes

Date : MAY23-12
Time : 00:45:36
File name : new_pro_study_(copy)(flow_cool_warp)_(copy)~3

** WARNING 98013 ** The cycle time listed in the Cool to Flow solver
interface file (*.c2p) will be used instead of the value
that was specified in the Process Settings Wizard.

No mesh for the cores was found.
Core shift analysis switched OFF

Summary of analysis inputs :

Solver parameters :

No. of laminae across thickness = 12
Intermediate output options for filling phase
No. of results at constant intervals = 20
No. of profiled results at constant intervals = 0
Intermediate output options for packing phase
No. of results at constant intervals = 20
No. of profiled results at constant intervals = 0
Melt temperature convergence tolerance = 0.2000 C
Mold-melt heat transfer coefficient = 2.5000E+04 W/m^2-C
Maximum no. of melt temperature iterations = 100

Material data :

Polymer : PE-58 : Occidental Chem

PVT Model: 2-domain modified Tait
coefficients: b5 = 414.5000 K
b6 = 1.5430E-07 K/Pa

```
              Liquid phase        Solid phase
              -----------------------------------------------------------------
              b1m =      0.0013  b1s =      0.0011 m^3/kg
              b2m =  1.0260E-06  b2s =  2.0770E-07 m^3/kg-K
              b3m =  9.2630E+07  b3s =  3.3240E+08 Pa
              b4m =      0.0049  b4s =  2.4600E-06 1/K
                                 b7 =      0.0002 m^3/kg
                                 b8 =      0.0516 1/K
                                 b9 =  1.0230E-08 1/Pa

  Specific heat (Cp)                 =   3000.0000 J/kg-C

  Thermal conductivity               =      0.2700 W/m-C

  Viscosity model:             Cross-WLF
                     coefficients: n    =      0.3151
                               TAUS =  2.2000E+04 Pa
                               D1   =  7.4800E+20 Pa-s
                               D2   =    153.1500 K
                               D3   =      0.0000 K/Pa
                               A1   =     46.1730
                               A2T  =     51.6000 K

  Transition temperature             =    112.0000 C

  Mechanical properties data:                  E1  =    911.0000 MPa
                               E2  =    911.0000 MPa
                               v12 =      0.4260
                               v23 =      0.4260
                               G12 =    319.0000 MPa

  Transversely isotropic coefficent of
   thermal expansion (CTE) data:           Alpha1  =      0.0002 1/C
                               Alpha2  =      0.0002 1/C

  Residual stress model without CRIMS

--------------------------------------------------------------------------------

Process settings :

  Machine parameters :
  ------------------
  Maximum machine clamp force                  = 7.0002E+03 tonne
  Maximum injection pressure                   = 1.8000E+02 MPa
  Maximum machine injection rate               = 5.0000E+03 cm^3/s
  Machine hydraulic response time              = 1.0000E-02 s

  Process parameters :
  ------------------
  Fill time                          =      4.8844 s
  Injection time has been determined by automatic calculation.
  Stroke volume determination                  = Automatic
  Cycle time                         =     35.0000 s

  Velocity/pressure switch-over by             = Automatic
  Packing/holding time               =     10.0000 s
  Ram speed profile (rel):
   % shot volume        % ram speed
```

```
    ----------------------------------------------------------------
       100.0000          100.0000
         0.0000          100.0000
  Pack/hold pressure profile (rel):
       duration  % filling pressure
    --------------------------------------------------------------
         0.0000 s         80.0000
        10.0000 s         80.0000
        15.1156 s          0.0000
  Ambient temperature                           =     25.0000 C
  Melt temperature                              =    230.0000 C
  Ideal cavity-side mold temperature            =     50.0000 C
  Ideal core-side mold temperature              =     50.0000 C

  NOTE: Using mold wall temperature data from cooling analysis

------------------------------------------------------------------------------------------

Model details :

  Mesh Type                                = Fusion

  Match ratio                              = 99.9 %
  Total number of nodes                         =        780
  Total number of injection location nodes      =          1
    The injection location node labels are:
                                              649
  Total number of elements                      =       1156
    Number of part elements                     =        810
    Number of sprue/runner/gate elements        =        346
    Number of channel elements                  =          0
    Number of connector elements                =          0
  Average aspect ratio of triangle elements     =     1.6947
  Maximum aspect ratio of triangle elements     =     4.5270
  Minimum aspect ratio of triangle elements     =     1.1623
  Total volume                                  =     4.6367 cm^3
    Volume filled initially                     =     0.0000 cm^3
    Volume to be filled                         =     4.6367 cm^3
     Sprue/runner/gate volume to be filled      =     4.5887 cm^3
  Total projected area                          =     6.0123 cm^2

Filling phase results summary :

  Maximum injection pressure        (at   5.366 s) =     15.1974 MPa

End of filling phase results summary :

  Time at the end of filling                    =     5.7789 s
  Total weight                                  =     3.8134 g
  Maximum Clamp force - during filling          =     0.4013 tonne
  Recommended ram speed profile (rel):
       % stroke          % speed
    ------------------------------------------------
         0.0000          30.7265
        10.0000          43.8484
        20.0000          58.8523
        30.0000          72.1555
        40.0000          84.2867
        50.0000          95.5695
```

60.0000	100.0000
70.0000	33.7695
80.0000	64.5151
98.4552	64.5151
100.0000	25.6880

Melt front is entirely in the cavity at % fill = 98.4552 %

Filling phase results summary for the part :

Bulk temperature - maximum (at 5.618 s) = 197.9830 C
Bulk temperature - 95th percentile (at 5.618 s) = 193.8970 C
Bulk temperature - 5th percentile (at 5.775 s) = 69.3730 C
Bulk temperature - minimum (at 5.775 s) = 60.1850 C

Wall shear stress - maximum (at 5.779 s) = 0.1884 MPa
Wall shear stress - 95th percentile (at 5.779 s) = 0.1392 MPa

Shear rate - maximum (at 5.779 s) = 356.1790 1/s
Shear rate - 95th percentile (at 5.779 s) = 114.4480 1/s

End of filling phase results summary for the part :

Total part weight = 0.0626 g

Bulk temperature - maximum = 179.6210 C
Bulk temperature - 95th percentile = 178.1860 C
Bulk temperature - 5th percentile = 69.3900 C
Bulk temperature - minimum = 60.1850 C
Bulk temperature - average = 132.1370 C
Bulk temperature - RMS deviation = 40.8486 C

Wall shear stress - maximum = 0.1884 MPa
Wall shear stress - 95th percentile = 0.1392 MPa
Wall shear stress - average = 0.0411 MPa
Wall shear stress - RMS deviation = 0.0515 MPa

Frozen layer fraction - maximum = 1.0000
Frozen layer fraction - 95th percentile = 1.0000
Frozen layer fraction - 5th percentile = 0.2211
Frozen layer fraction - minimum = 0.0920
Frozen layer fraction - average = 0.5789
Frozen layer fraction - RMS deviation = 0.3212

Shear rate - maximum = 356.1790 1/s
Shear rate - 95th percentile = 114.4480 1/s
Shear rate - average = 23.6901 1/s
Shear rate - RMS deviation = 46.1944 1/s

Filling phase results summary for the runner system :

Bulk temperature - maximum (at 0.255 s) = 229.6870 C
Bulk temperature - 95th percentile (at 0.255 s) = 229.6870 C
Bulk temperature - 5th percentile (at 5.774 s) = 189.2880 C
Bulk temperature - minimum (at 5.775 s) = 124.2630 C

Wall shear stress - maximum (at 5.779 s) = 0.3424 MPa
Wall shear stress - 95th percentile (at 5.366 s) = 0.1044 MPa

Shear rate - maximum (at 5.618 s) = 3625.9399 1/s

Shear rate - 95th percentile (at 0.255 s) = 143.8300 1/s

End of filling phase results summary for the runner system :

Total sprue/runner/gate weight = 3.7508 g
Bulk temperature - maximum = 228.9060 C
Bulk temperature - 95th percentile = 222.2160 C
Bulk temperature - 5th percentile = 189.6010 C
Bulk temperature - minimum = 124.4740 C
Bulk temperature - average = 209.4440 C
Bulk temperature - RMS deviation = 11.8200 C

Wall shear stress - maximum = 0.3424 MPa
Wall shear stress - 95th percentile = 0.0518 MPa
Wall shear stress - average = 0.0259 MPa
Wall shear stress - RMS deviation = 0.0145 MPa

Frozen layer fraction - maximum = 0.8164
Frozen layer fraction - 95th percentile = 0.4017
Frozen layer fraction - 5th percentile = 0.1566
Frozen layer fraction - minimum = 0.0631
Frozen layer fraction - average = 0.2741
Frozen layer fraction - RMS deviation = 0.0796

Shear rate - maximum = 3171.5901 1/s
Shear rate - 95th percentile = 22.2295 1/s
Shear rate - average = 9.1850 1/s
Shear rate - RMS deviation = 31.4498 1/s

Packing phase results summary :

Peak pressure - minimum (at 0.000 s) = 0.0000 MPa
Clamp force - maximum (at 6.188 s) = 0.4800 tonne
Total weight - maximum (at 15.379 s) = 4.1557 g

End of packing phase results summary :

Time at the end of packing = 30.0256 s
Total weight = 4.1529 g

Packing phase results summary for the part :

Bulk temperature - maximum (at 5.779 s) = 179.5570 C
Bulk temperature - 95th percentile (at 5.779 s) = 178.2430 C
Bulk temperature - 5th percentile (at 30.026 s) = 33.8980 C
Bulk temperature - minimum (at 30.026 s) = 31.9010 C

Wall shear stress - maximum (at 5.779 s) = 0.1753 MPa
Wall shear stress - 95th percentile (at 5.779 s) = 0.1172 MPa

Volumetric shrinkage - maximum (at 5.779 s) = 16.5475 %
Volumetric shrinkage - 95th %ile (at 5.779 s) = 14.5683 %
Volumetric shrinkage - 5th %ile (at 7.438 s) = 1.5664 %
Volumetric shrinkage - minimum (at 5.779 s) = 1.1000 %

Total part weight - maximum (at 7.438 s) = 0.0663 g

End of packing phase results summary for the part :

Total part weight = 0.0663 g

Bulk temperature - maximum = 37.5850 C
Bulk temperature - 95th percentile = 37.1870 C
Bulk temperature - 5th percentile = 33.8980 C
Bulk temperature - minimum = 31.9010 C
Bulk temperature - average = 35.4360 C
Bulk temperature - RMS deviation = 1.2173 C

Frozen layer fraction - maximum = 1.0000
Frozen layer fraction - 95th percentile = 1.0000
Frozen layer fraction - 5th percentile = 1.0000
Frozen layer fraction - minimum = 1.0000
Frozen layer fraction - average = 1.0000
Frozen layer fraction - RMS deviation = 0.0000

Volumetric shrinkage - maximum = 5.3360 %
Volumetric shrinkage - 95th percentile = 4.8060 %
Volumetric shrinkage - 5th percentile = 1.5664 %
Volumetric shrinkage - minimum = 1.1000 %
Volumetric shrinkage - average = 3.1860 %
Volumetric shrinkage - RMS deviation = 1.0072 %

Sink index - maximum = 0.0000 %
Sink index - 95th percentile = 0.0000 %
Sink index - minimum = 0.0000 %
Sink index - RMS deviation = 0.0000 %

Packing phase results summary for the runner system :

Bulk temperature - maximum (at 5.779 s) = 228.9050 C
Bulk temperature - 95th percentile (at 5.779 s) = 222.2140 C
Bulk temperature - 5th percentile (at 29.276 s) = 37.9910 C
Bulk temperature - minimum (at 30.026 s) = 32.2160 C

Wall shear stress - maximum (at 5.779 s) = 0.3273 MPa
Wall shear stress - 95th percentile (at 15.379 s) = 0.0565 MPa

Volumetric shrinkage - maximum (at 5.779 s) = 19.9803 %
Volumetric shrinkage - 95th %ile (at 5.779 s) = 16.7678 %
Volumetric shrinkage - 5th %ile (at 15.379 s) = 2.2706 %
Volumetric shrinkage - minimum (at 7.438 s) = 0.6133 %
Sprue/runner/gate weight - max. (at 15.379 s) = 4.0894 g

End of packing phase results summary for the runner system :

Total sprue/runner/gate weight = 4.0866 g
Bulk temperature - maximum = 134.1330 C
Bulk temperature - 95th percentile = 128.2160 C
Bulk temperature - 5th percentile = 38.0310 C
Bulk temperature - minimum = 32.2160 C
Bulk temperature - average = 81.8480 C
Bulk temperature - RMS deviation = 34.0299 C

Frozen layer fraction - maximum = 1.0000
Frozen layer fraction - 95th percentile = 1.0000
Frozen layer fraction - 5th percentile = 0.6847
Frozen layer fraction - minimum = 0.6277
Frozen layer fraction - average = 0.9200

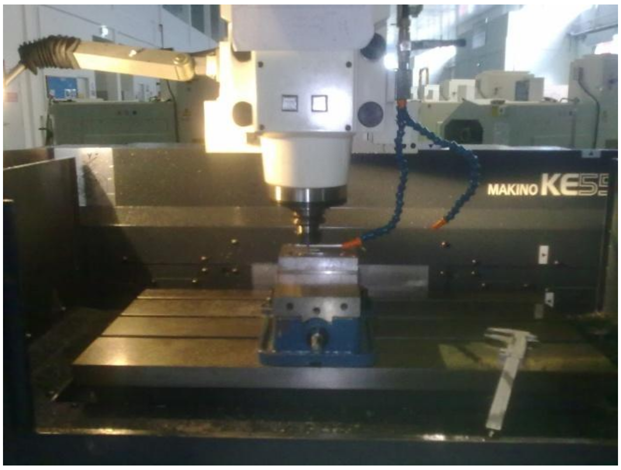
Frozen layer fraction - RMS deviation	=	0.1249
Volumetric shrinkage - maximum	=	12.0495 %
Volumetric shrinkage - 95th percentile	=	11.0765 %
Volumetric shrinkage - 5th percentile	=	2.2732 %
Volumetric shrinkage - minimum	=	0.6133 %
Volumetric shrinkage - average	=	6.7637 %
Volumetric shrinkage - RMS deviation	=	3.5428 %
Sink index - maximum	=	1.3513 %
Sink index - 95th percentile	=	0.9360 %
Sink index - minimum	=	0.3336 %
Sink index - RMS deviation	=	0.3944 %

Execution time

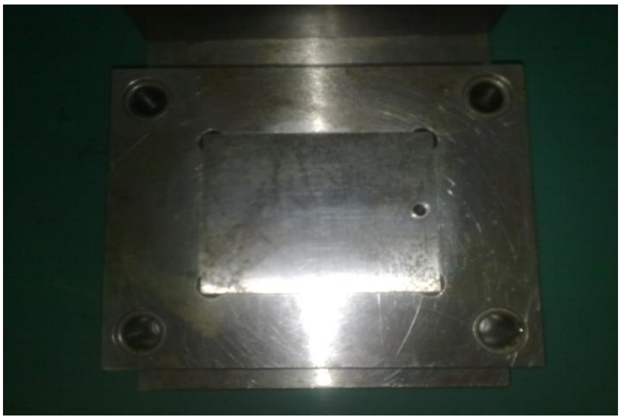
Analysis commenced at	Wed May 23 00:45:36 2012
Analysis completed at	Wed May 23 00:46:39 2012
CPU time used	53.35 s

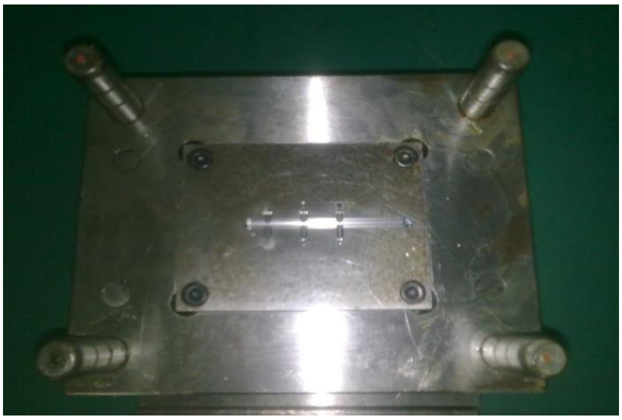
APPENDICES D

Fabrication of micro injection moulding part

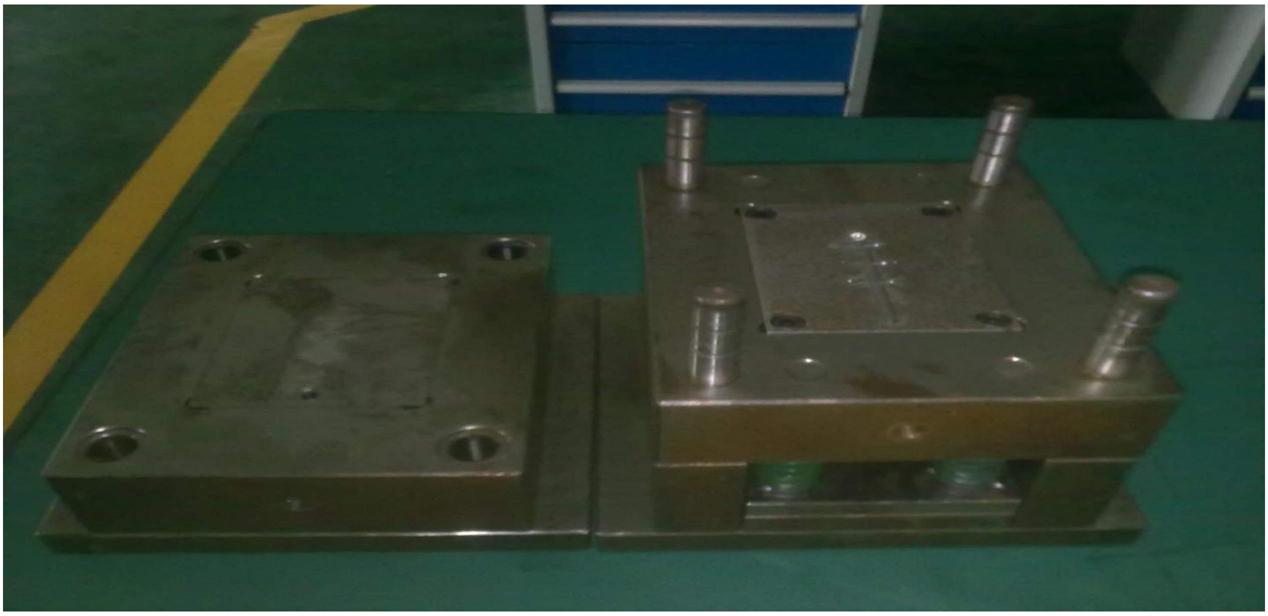


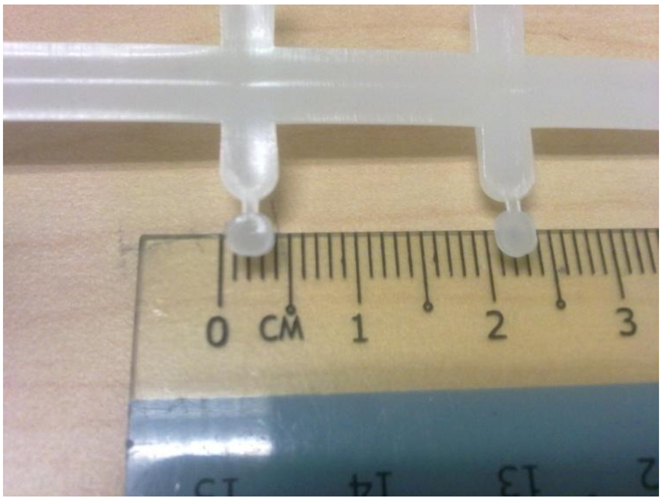
Machining process (insert core and cavity)





Cavity and Core plate





Example of micro injection moulding part