OPTIMIZATION OF MOLDING PARAMETER EFFECT TO WARPAGE OF CAR BUMPER BASED ON PLASTIC FLOW SIMULATION SOFTWARE

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We certify that the project entitled *Optimization of Molding Parameter Effect to Warpage of Car Bumper Based on Plastic Flow Simulation Software* is written by *Mohd Nasrul Mahmudi Bin Mahmud*. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfilments of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

Dr. Daw Thet Thet Mon ..……………………

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OPTIMIZATION OF MOLDING PARAMETER EFFECT TO WARPAGE OF CAR BUMPER BASED ON PLASTIC FLOW SIMULATION SOFTWARE

MOHD NASRUL MAHMUDI BIN MAHMUD

Report submitted in fulfillment of the requirements
for the award of the Bachelor of
Mechanical Engineering with Automotive Engineering

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NOVEMBER 2009

SUPERVISOR'S DECLARATION

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Date : 21 November 2009

STUDENT DECLARATION

I hereby declare that this thesis “Optimization of Molding Parameter Effect to Warpage of Car Bumper Based on Plastic Flow Simulation Software” is the result of my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

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Date : 21 November 2009

To my beloved family

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ABSTRACT

This research is specially focused on finding optimum molding parameter effect to warpage of a car bumper. The objectives of this research are to study the influence of injection molding parameters on a car bumper and analysis model car bumper using plastic flow simulation software. The idea of this project came when injection molding is the most widely used process in automotive industry. Since the qualities of injection molded plastic part are mostly influenced by process condition, how to determine the optimum process conditions becomes the key to improving the part quality. The optimization of molding parameter effect is very important for the automotive industry because it gives beneficial effects in production costs due to less material being used and shorter cycle times. In this project, plastic flow simulation method is proposed to optimize the molding parameter effect to warpage of a car bumper. The car bumper will be analyzing using three different parameters such as mold temperature, melt temperature, and injection pressure. This parameter will be changed to see the effect on car bumper. The result shows that the plastic flow simulation method is an effective tool for the process optimization of injection molding.

ABSTRAK

Penyelidikan ini adalah memfokuskan kepada pencarian kesan parameter injection molding yang paling optimum ke atas bumper kereta. Objektif kajian ini adalah untuk mengkaji pengaruh parameter injection molding ke atas bumper kereta dan menganalisis model bumper kereta menggunakan perisian komputer 'Plastic Flow Simulation'. Idea projek ini bermula apabila proses injection molding ini banyak digunakan secara meluas dalam bidang industri automotif. Disebabkan kualiti bahagian plastik injection molding kebanyakannnya dipengaruhi oleh keadaan proses, untuk mencari keadaan proses yang paling optimum menjadi kunci untuk meningkatkan lagi kualiti bahagian itu. Kesan parameter molding yang paling optimum adalah sangat penting dalam industri automotif kerana ia memberi lebih keuntungan dalam kos pengeluaran disebabkan oleh kurangnya bahan yang digunakan dan penggunaan masa yang lebih singkat. Dalam tesis ini, kaedah simulasi 'plastic flow' digunakan untuk mengoptimumkan kesan parameter molding ke atas bumper kereta. Bumper kereta itu akan dianalisis menggunakan tiga parameter yang berbeza seperti suhu acuan, suhu leburan plastic, dan tekanan suntikan. Parameter-parameter ini akan diubah untuk melihat kesan keatas bumper kereta. Keputusan menunjukkan kaedah simulasi 'plastic flow' ini adalah sangat berkesan untuk mengoptimumkan proses injection molding.

TABLE OF CONTENTS

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULTS AND DISCUSSION

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Injection molding is the most common method of production, especially in car manufacturing from the smallest component to entire body panels of car. Injection molding can also be used to manufacture parts from aluminum or brass (die casting). The melting points of these metals are much higher than those of plastics. This makes for substantially shorter mold lifetimes despite the use of specialized steels. Nonetheless, the costs compare quite favorably to sand casting, particularly for smaller parts. Hence, majority of injection molding is applied to thermoplastic polymers. The process started from heating thermoplastic material until it melts and forced into a steel mold. It cools down and solidifies before part is ejected.

There are numerous variables affect the injection-molding process. In fact, a recent study itemized more than 200 different parameters that had a direct or indirect effect on the process. It was found that the parameter can be categorized in three major divisions: temperature, pressure, and time. An adjustment to any one of these has a direct influence on some, or all of the other parameter. For a minimum-defect, high quality production, it is critical to control as many parameters as possible. The more parameters that are controlled, the higher the quality level of the products being molded. [6]

Many companies always strive to produce high-quality parts while lowering their costs; however, significant time delays and increasing costs may occur if part design is not carefully evaluated or the injection process is not completely understood. Injection molding process allowed success in the production of newer material, especially for complex shape parts. Using injection molding technology, various parts can be made in shorter cycle times Therefore, optimization of molding parameter effect is very important for the industry.

The process of injection molding offers many advantages which are unattainable using other methods. Over the years, injection molding technology has developed into a standard and popular machining technology. In many operations, especially in automotive industry, the injection molding process was chosen because of high quality part surfaces, good mechanical properties, low cost, and light weight. It also gives beneficial effects in production costs due to less material being used and shorter cycle times.

1.2 Background

In this study, the optimization of molding parameter effect to warpage of car bumper was investigated using plastic flow simulation software. The simulation was conducted using different parameters like mold temperature, melt temperature, and injection pressure. The objective of the process optimization is to select the optimal control variables in injection molding under certain given constraints, in order to obtain the best part quality. It is found that different values of parameter give different result of finished molded product. A car bumper was modeled using CAD software before being analyzed using plastic flow simulation software.

1.3 Problem statement

The objective of finding optimum molding parameter is to achieve high quality products, cut product development, cycle times, and cost. Previously, production engineers used trial-and-error method to determine optimal process parameter setting for plastic injection molding. However, this method is unsuitable in present plastic injection molding because the increasing complexity of product design and the requirement of multi-response quality characteristics However, the selection of parameter is still not completed. For every parameter that had found, another would appear. Even items such as humidity and ambient temperature had an effect on the molding process. Although there are so many different variables, it is not impossible to get control of the injection-molding process. What is needed is a more practical approach to understanding all these parameters, and targeting those that have the greatest effect on the overall quality and cost-effectiveness of finished molded product.

1.4 Objectives of the study

The objectives of this thesis are as follows:-

1. Study the influence of injection molding parameters effect to warpage of a car bumper.
2. Analyze model car bumper using plastic flow simulation software.

1.5 Scope and limitation

1. A proton saga car bumper was modeled using CAD software.
2. The model car bumper will be analyzed using plastic flow simulation software.
3. The parameter of injection molding process were selected such as mold temperature, melt temperature, and injection pressure.
4. Study the effect of warpage in injection-molded part.

1.6 Organization of the thesis

This thesis consists of five chapters. Chapter 1 is the introduction about this study. Chapter 2 is the review of literature which discusses the methods and findings previously done by the other people which are related to the study. Chapter 3 is methodology which explains the approaches and methods used in performing the thesis. Chapter 4 is the chapter which reports the outcomes or results and discussion from the project and chapter 5 consists of the recommendation and conclusion.

CHAPTER 2

LITERATURE REVIEW

2.1 Injection molding

Injection molding is one of the most exploited industrial processes in the production of plastic parts. Its success relies on the high capability to produce 3D shapes at higher rates. The part of injection molding machines are mold clamp, ejector pins, moving die, stationary die, barrel hopper and motor. The pellets or granules are fed into the heated cylinder, and melt is forced into the mold either by a hydraulic plunger or by the rotating screw system of an extruder. As in plastic extrusion, the barrel is heated externally to promote melting of the polymer. In injection molding machines, however, a far greater portion of the heat transferred to the polymer is due to frictional heating.

Modern machines are of the reciprocating or plasticating screw type with the sequence of operation. As the pressure builds up at the mold entrance, the rotating screw begins to move backward under pressure to a predetermined distance. This movement controls the volume of material to be injected. The screw then stops rotating and is pushed forward hydraulically, forcing the molten plastic into the mold cavity. The pressure developed usually range from 70 to 200 MPa.

For thermoplastic, the molds are kept relatively cool at about 90ºC. Thermoset part are molded in heated mold at about 200ºC, where polymerization and cross-linking take place.

After the part has cooled sufficiently (for thermoplastic) or cured (for thermoset), the molds are opened and the part is removed from the mold using ejector. Elastomers also are injection molded into discrete products by this processes. Because the material is molten when injected into the mold, complex shapes with good dimensional accuracy can be obtained.

2.2 Machine components

2.2.1 Injection system

The injection system consists of a hopper, a reciprocating screw and barrel assembly, and an injection nozzle, as shown in Figure 2.1. This system confines and transports the plastic as it progresses through the feeding, compressing, degassing, melting, injection, and packing stages.

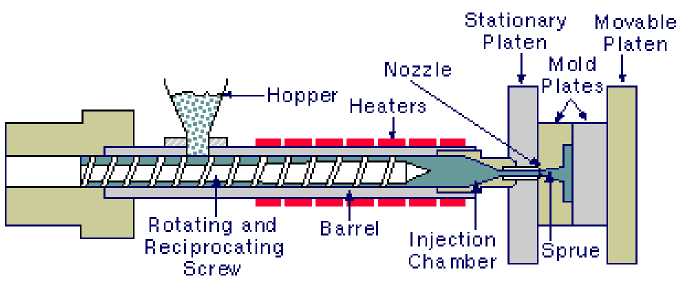


FIGURE 2.1: A single screw injection molding machine for thermoplastics.

·The hopper

Thermoplastic material is supplied to molders in the form of small pellets. The hopper on the injection molding machine holds these pellets. The pellets are gravity-fed from the hopper through the hopper throat into the barrel and screw assembly. [9]

·The barrel

As shown in Figure 2.1, the barrel of the injection molding machine supports the reciprocating plasticizing screw. It is heated by the electric heater bands. [9]

•The reciprocating screw

The reciprocating screw is used to compress, melt, and convey the material. The reciprocating screw consists of three zones (illustrated below):

1. the feeding zone
2. the compressing (or transition) zone
3. the metering zone

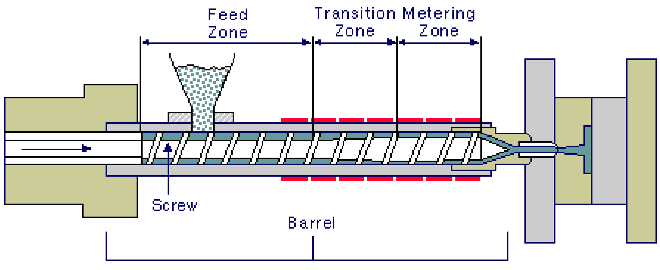


FIGURE 2.2: A reciprocating screw

·The nozzle

The nozzle connects the barrel to the sprue bushing of the mold and forms a seal between the barrel and the mold. The temperature of the nozzle should be set to the material's melt temperature or just below it, depending on the recommendation of the material supplier. When the barrel is in its full forward processing position, the radius of the nozzle should nest and seal in the concave radius in the sprue bushing with a locating ring. During purging of the barrel, the barrel backs out from the sprue, so the purging compound cans free fall from the nozzle. These two barrel positions are illustrated below [9]:

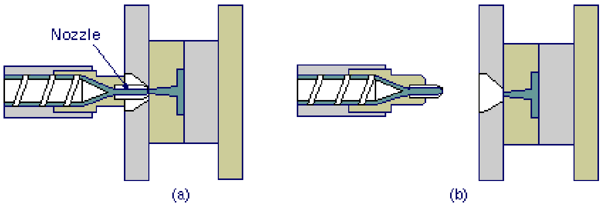


FIGURE 2.3: (a) Nozzle with barrel in processing position. (b) Nozzle with barrel backed out for purging.

2.3 Theory of injection molding

The theory of injection molding can be reduced to four simple individual steps: Plasticizing, Injection, Chilling, and Ejection. Each of those steps is distinct from the others and correct control of each is essential to the success of the total process. [8]

1. Plasticizing - describes the conversion of the polymer material from its normal hard granular form at room temperatures, to the liquid consistency necessary for injection at its correct melt temperature.
2. Injection - is the stage during which this melt is introduced into a mold to completely fill a cavity or cavities.
3. Chilling - is the action of removing heat from the melt to convert it from a liquid consistency back to its original rigid state. As the material cools, it also shrinks.
4. Ejection - is the removal of the cooled, molded part from the mold cavity and from any cores or inserts.

Repetition of these basic steps in sequence is the process of injection

2.3.1 The operations of an injection molding are:

1) Closing the mold: the mold closes so the cycle can begin.

2) Plasticizing the resin: (Figure 2.4a) the hopper feeds solid pellets or grains of the plastic resin into the barrel where it becomes molten due to the heating bands and

friction caused by the rotating screw. The molten plastic accumulates at the front of the barrel (the nozzle side) as the screw retracts to the rear of the barrel.

3) Injecting the resin: (Figure 2.4b) when enough molten plastic has accumulated for a full shot, a valve in the nozzle is opened and the screw rapidly advances forward, quickly injecting the plastic into the mold cavity.

4) Cooling the part: (Figure 2.4c) The screw continues to push plastic into the mold in order to create a holding pressure. This ensures adequate filling. As this happens, the molten plastic begins to cool and solidify toward the inside. This natural cooling is expedited by convection due to coolant flowing through channels inside the mold.

5) Ejecting the part: (Figure 2.4d) After adequate cooling time has elapsed, the mold is opened. Some sort of ejector device is actuated in this process and the part is ejected from the mold and collected. After this, the cycle repeats from step 1.

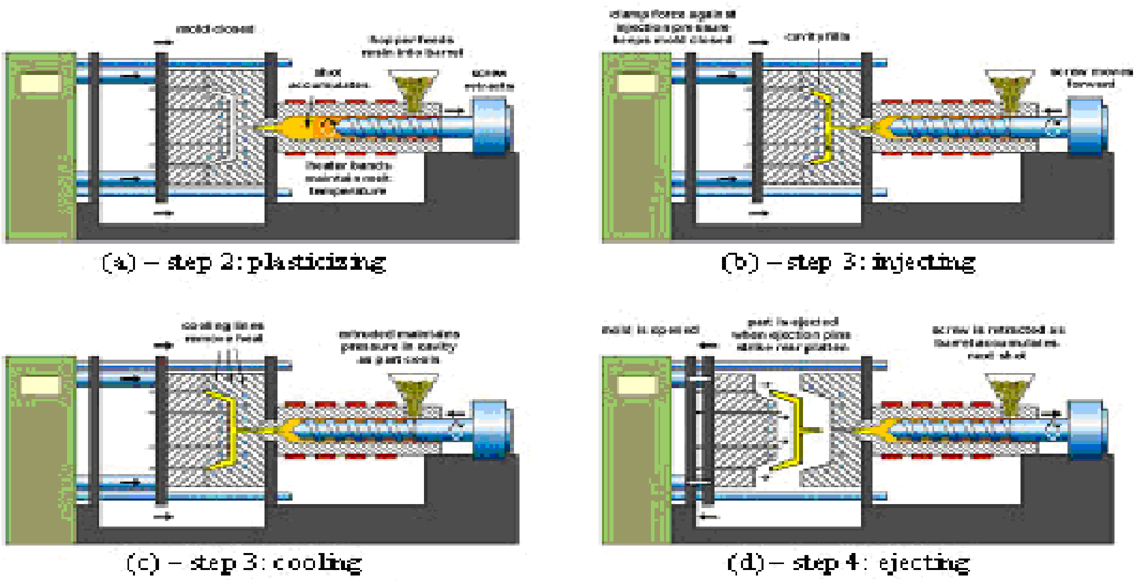


Figure 2.4: Schematic of the injection molding process

2.4 Parameter of the molding process

2.4.1 Identifying the parameters

There are numerous variable affect the injection molding process. For instance, injection pressure consisted of more than one item. There are initial injection pressures, second and up to fifth stage injection pressure, holding pressure, back pressure, and line pressure. All of these give direct effect on each other. Humidity and ambient temperature also have effect on the molding process. Shift changes, relief operators, fan blowing, housekeeping, age of equipment, size of machine, location of press, pressure of cooling water, all seemed to have direct or indirect effect on the injection molding process.

Figure 2.5 shows that all of the parameters involved can be placed into two main categories: temperature and pressure. All these relative importance of the categories is shown by size of the circles. Thus, temperature is the most important, followed by pressure. However, each is dependent on the other, and changing one will affect one or all of the others. [6]

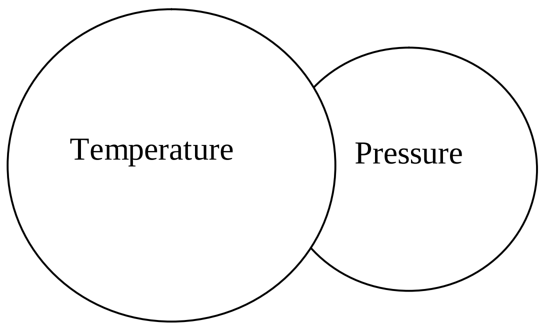


Figure 2.5: Main processing parameters

2.4.2 Temperature

A variety of temperatures affect the injection molding process, ranging from melt temperature to mold temperature, and including even ambient temperature.

2.4.2.1 Melt Temperature Control

Melt temperature is the temperature at which the plastic material is maintained throughout the flow path. This path begins where the plastic material is transferred from the machine hopper into the cylinder of the injection unit. Then the material is augered through the heating cylinder and into the machine nozzle. From there it is injected into the mold, where it must travel along a runner system (if one exists), through the gates, and into the cavities that are machined into the mold. The temperature of the melt must be controlled along the path, starting with the heating cylinder. [6]

Figure 2.6 shows the heating cylinder is wrapped with heater bands. These are electrical heaters shaped like hinged bracelets that mount around the outside of the heating cylinder. There are three main heating zones to the heating cylinder: the rear zone, the center zone, and the front zone. In addition, there is usually at least one heater band fastened around the machine nozzle, an area referred to as the nozzle zone. [6]

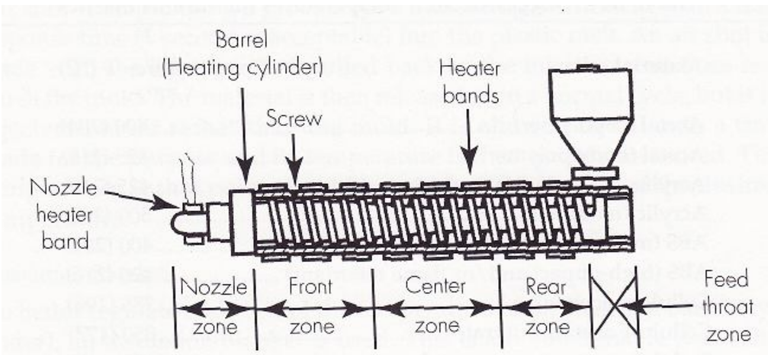


Figure 2.6: Heating cylinder

The plastic for the injection process should be brought up to proper temperature gradually as the material drops from the hopper into the rear zone, where the initial heat begins to soften the material. Then the material is augered forward by the screw into the center zone where the temperature is generally 10 to 20°F (5.6 to 11°C) higher than the in the rear zone. As the material travels to the front zone, the temperature is gain increased by 10 to 20°F, and finally the material is ready to be injected into the mold. It is held at this point until the previous molding cycle is complete, at which time the mold opens, parts are ejected, the mold closes, and the next cycle begins. The charge of preheated plastic is then injected into the mold. [6]

Besides absorbing heat from the externally mounted heater bands, the plastic material absorbs a large amount of heat from the friction caused by the augering action of the injection screw. The screw rotates to bring fresh material into the heating cylinder and prepare it for the coming cycle. While being pulled along, the new material is squeezed between the flights of the screw and the inside wall of the injection barrel. The friction generates heat, which is absorbed by the plastic. [6]

The main point here is that plastic must be heated to the proper temperature for injection. Melt temperature is measured at the nozzle as the plastic exit the machine, before it enters the mold. It is measured by taking an “air shot” and plunging a probe from a measuring instrument with a fast response time (1 second id acceptable) into the plastic melt. An air shot is made with the injection sled pulled back so the injection unit does not touch the mold. The material is then released as in a normal cycle, but it is injected into air rather than the mold. It is allowed to fall onto a tray made for the purpose and its temperature is then quickly measured. The temperature at that point should be within 10°F (5.6°C) of the desired temperature. [6]

2.4.2.2 Mold Temperature Control

The plastic material is now ready to flow into the mold. First, it must travel through the machine nozzle, which is the last heating zone provided by the machine. After the material exits the nozzle and enters the mold, it immediately begins to cool down as the mold absorbs heat from it. The rate at which this heat is absorbed determines how far the plastic will flow before it begins to solidify and stop moving. Each product depending on its design and plastic material, demand specific cooling rates, and this rate of cooling is critical to product quality. Therefore, the mold temperature must be regulated in order to regulate the cooling rate of the plastic. This is done by connecting the mold to a temperature control unit that normally utilizes water as medium. The water is circulated through the mold and held at a preset temperature by heating or cooling in cycles. [6]

Every combination of plastic and product has a specific temperature at which the mold should be maintained to ensure quality molding. The mold temperature is measured directly from the molding surface of the tool with a solid probe on a pyrometer device. Usually, readings from several areas are averaged. The object of the cooling process is to lower the temperature of the molded plastic to the point at which it solidifies again. When the plastic reaches that point, it can be ejected from the mold with relative structural safety. That simply means that the plastic part will not move excessively, causing warpage, twisting, or other shrinkage related problem as the plastic continues to cool. [6]

2.5 Pressure

There are two areas in the injection machine that required pressure and pressure control: the injection unit and the clamp unit. They are closely related in that they are opposing pressure – the clamp unit must develop enough clamp pressure to overcome the pressure developed by the injection unit during the molding process.

2.5.1 Injection unit

Three basic types of pressure are developed by the injection unit: initial pressure, hold pressure, and back pressure.

2.5.2 Initial Injection Pressure

This is the first pressure that applied to the molten plastic. It develops as result of main system hydraulic pressure pushing against the back end of the injection screw (or plunger) (figure 2.7)

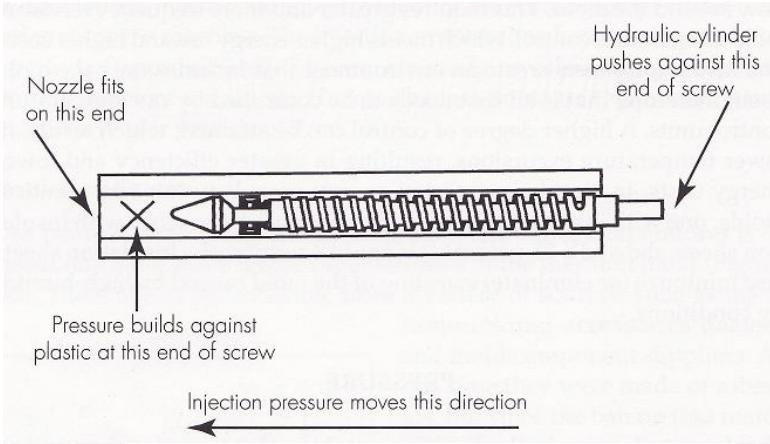


Figure 2.7: Initial injection pressure

The amount of pressure developed by the main system is on the order of 2000 psi (13,789 kPa). Some systems are capable of producing more than that, but 2000 psi is the most common line pressure. This pressure is converted to a maximum of 20,000 psi (137,890 kPa) at the nozzle of the injection unit (where the plastic first enters the mold) by the design and shape of the injection screw. In most cases, the full 20,000 psi is not required for filling a mold, and most products can be molded in a range of from 5000 to 15,000 psi (34,472 to 103,418 kPa). The pressure actually required depends on the plastic being molded, the viscosity and flow rate of the plastic, and the temperatures of the plastic and the mold. [6]

To summarize, initial injection pressure is used to create the initial filling of the mold. It should be set at the highest practical value to fill the mold with the fastest practical speed.

2.5.3 Holding Pressure (Secondary Pressure)

This pressure is applied at the end of the initial injection stroke (figure 2.8) and is intended to complete the final filling of the mold and hold pressure against the plastic that was injected so it can solidify while staying dense and “packed”. As a rule, the amount of pressure used here can be half the initial injection pressure or less. So, if initial pressure was 12,000 psi (82,734 kPa), the holding pressure can be approximately 6000 psi (41.367 kPa). The holding pressure is actually applied against a cushion or pad of material. [6]

To summarize, holding pressure is used to finish the filling of the mold and pack the plastic material into the cavity image

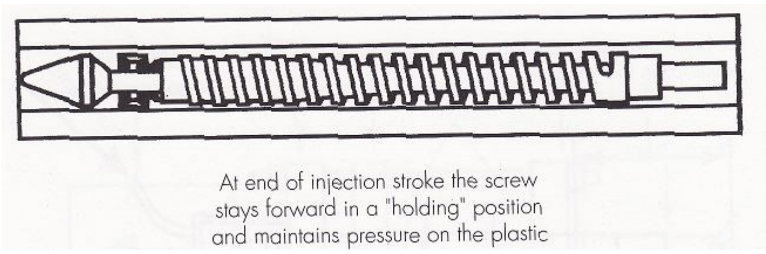


Figure 2.8: Holding Pressure

2.5.4 Back Pressure

Back pressure is applied after the injection phases mentioned above. When the hold pressure phase is complited, a signal is sent to the machine to start turning the screw to bring new material to the front of the barrel in preparation for the next cycle, or shot (so called because plastic shoots into the mold). The screw is not pulled back. Instead, the churning, or augering, action of the screw brings new material forward, and as that material fills up in front of the screw, the material itself begins to push the screw backward (figure 2.9). [6]

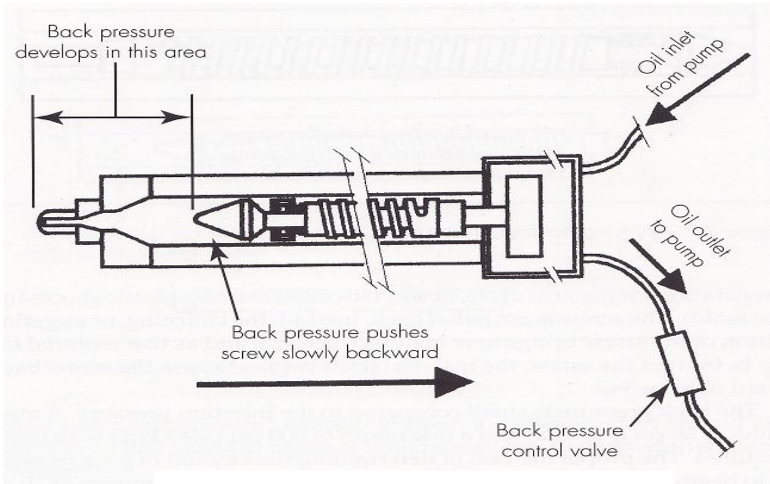


Figure 2.9: Back Pressure

2.6 Optimization methodology

The application of injection-molded plastic parts is increasing significantly in almost every industry. The product quality is a function of the product design, the material used, the mould design and the process conditions. One of the most common quality problem experienced by injection-molded parts is warpage. Warpage is a distortion where the surfaces of the molded part do not follow the intended shape of the design. Part warpage results from molded-in residual stresses, which, in turn, is caused by differential shrinkage of material in the molded part. If the shrinkage throughout the part is uniform, the molding will not deform or warp, it simply becomes smaller.

However, achieving low and uniform shrinkage is a complicated task due to the presence and interaction of many factors such as molecular and fiber orientations, mold cooling, part and mold designs, and process conditions. Injection-molded parts exhibit very complex patterns of warpage. This makes it difficult to achieve the specified dimensions in many cases. In order to obtain the minimum warpage and the specified quality, the optimization methodology can be applied for improving the design and the injection-molding process parameters.

2.6.1 Causes of warpage

Before constructing the optimization methodology, it is necessary to understand the cause of warpage in an injection-molded part. The causes of warpage in injection-molded parts are very complex and numerous. The most common basic cause of warpage is the variation in shrinkage throughout the injection-molded part. The factors contributing to variations in the part shrinkage are numerous. They could be material properties, part design, injection-molding process and mould design.

Part geometry and mechanical property of the material also play a very important role in the warpage. The final warpage of the part greatly depends on its mechanical stiffness, which is a function of the geometrical configuration and the material's mechanical properties. A part with higher mechanical stiffness will be less likely to warp even through experiencing considerable variations in the shrinkage. On the other hand, a part having less mechanical stiffness will more likely warp due to small variation. Therefore in some cases reducing variations in the shrinkage will solve the warpage problem, while in other cases the warpage problem may only be solved through increasing the mechanical stiffness of the part.

2.6.2 Classifying the causes of warpage

- Differences in filled and unfilled materials

Differential shrinkage for filled and unfilled materials is shown in Figure 2.10 below. When shrinkage is differential and anisotropic across the part and part thickness, the internal stresses created can lead to part warpage. [7]

Filled materials

For fiber-filled thermoplastics, reinforcing fibers inhibit shrinkage due to their smaller thermal contraction and higher modulus. Therefore, fiber-filled materials shrink less along the direction in which fibers align (typically the flow direction) compared to the shrinkage in the transverse direction. Similarly, particle-filled thermoplastics shrink much less than unfilled grades. [7]

Unfilled materials

On the other hand, if an unfilled molded part contains high levels of molecular orientation, shrinkage is anisotropic because aligned chains shrink to a greater extent in the direction of orientation. [7]

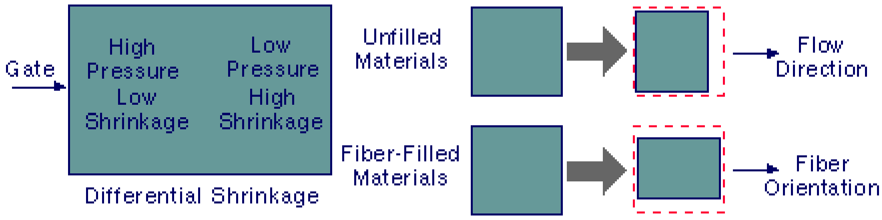


FIGURE 2.10. Differential shrinkage for both unfilled and filled materials

• Non-uniform mold cooling across the part thickness

Non-uniform cooling in the part and asymmetric cooling across the part thickness from the mold cavity and core can also induce differential shrinkage. The material cools and shrinks inconsistently from the mold wall to the center, causing warpage after ejection. [7]

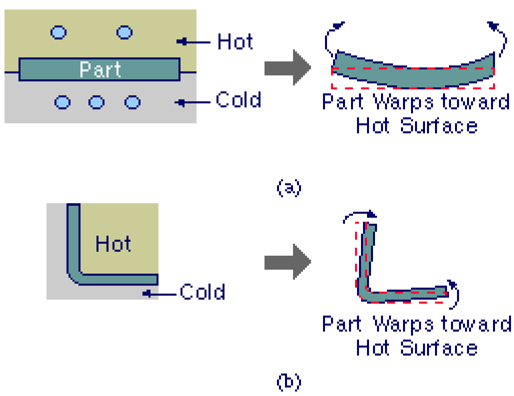


FIGURE 2.11. Part warpage due to (a) non-uniform cooling in the part, and

(b) asymmetric cooling across the part thickness.

• Part thickness variation

Shrinkage increases as the wall thickness increases. Differential shrinkage due to non-uniform wall thickness is a major cause of part warpage in unreinforced thermoplastics. More specifically, different cooling rates and crystallization levels generally arise within parts with wall sections of varying thickness. This causes differential shrinkage, resulting in part warpage, as shown in Figure 2.12 below. [7]

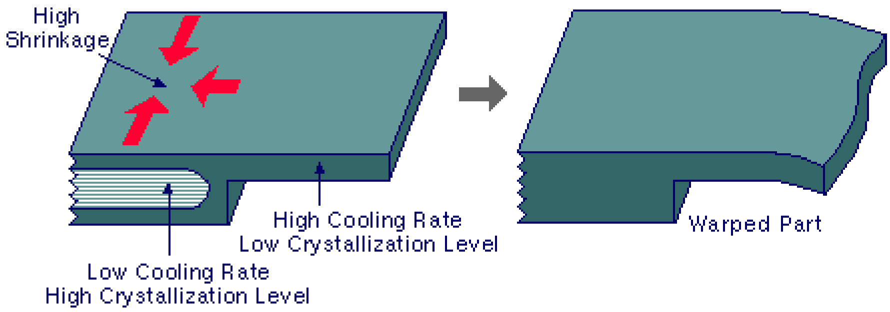


FIGURE 2.12. Larger volumetric shrinkage due to the high crystallization level in the slow cooling areas (e.g., the thick sections) leads to differential shrinkage and thus part warpage

• Part geometry asymmetry or curvature

Geometric asymmetry (e.g., a flat plate with a large number of ribs that are aligned in one direction or on one side of the part) will introduce non-uniform cooling and differential shrinkage that can lead to part warpage, as shown in Figure 2.13 below. [7]

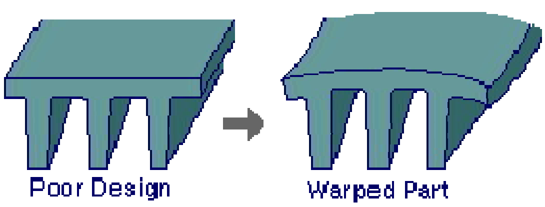


FIGURE 2.13. The poor cooling of the mold wall on the ribbed side causes a slower cooling of the material on that one side, which can lead to part warpage

2.7 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 pf applications"(La Selle)

Moldflow's easy-to-learn 3D solids-based plastics flow simulation products allow you to determine the manufacturability of your part in the early design stages and avoid potential downstream problems which can lead tp production delays and cost overruns.

Moldflow software has been developed by Moldflow International Pvt. Ltd., Australia. It helps in finite element analysis used in the design of plastic product, mould design and production of plastic component. Following are the modules of MOLDFLOW software. Flow Analysis (MF/FLOW); The flow analysis is used to determine the gate position filling pattern. It analysis polymer flow within the mould, optimizes mould cavity layout, balances runners and obtains mould processing conditions for filling and packing phases of the moulding cycle.

Cooling Analysis (MF/COOL); it analyses the effect of cooling on flow, optimizes cooling line geometry and processing conditions. Process Optimization Analysis (MF/OPTIM); it gives optimized-processing parameters for a component considering injection-molding conditions. Warpage Analysis (MF/WARP);this analysis simulates the effect of Moldings on product geometry, isolates the dominant cause of warpage so that the correct remedy can be applied.

Shrinkage Analysis (MF/SHRINK); This analysis gives dimension of mould cavities, using shrinkage determined from specified grade material shrinkage data and flow analysis results. Stress Analysis (MF/STRESS); this is nonlinear structural analysis program that determines component thickness to meet performance requirements. It evaluates product strength and stiffness. One of the MoldFlow product is MoldFlow Plastic Insight (MPI).

2.7.1 Moldflow Plastic Insight (MPI)

Moldflow Plastic Insight products are a complete suite of advanced plastics process simulations tools for predicting and eliminating potential manufacturing problems and optimizing part design, mold design and the injection molding processes. MPI products simulate the broadest range of manufacturing process and support all design geometry type associated with plastics molding processes. With MPI, one can stimulate the filling, packing, and cooling stages of thermoplastics injection molding process and also predict post-molding phenomena such as part warpage. MPI user 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 also allows us to do some trouble shooting very easily. Some of the materials we use are very expensive. Therefore, less time on the production floor working through a problem saves labor and material costs. Using MPI, we have been able to run simulations and locate and eliminate unsightly nit lines.

MPI is being employed in both tooling design and simulation of molding. MPI used to simulate mold designs before the tool is actually built. The simulations help users determine different gate designs and location, placement of cooling lines, and melt overflows.

The MoldFlow Plastic Insight suite software is the world's leading product for in-depth simulations to validate part and mold design. Companies around the world have chosen Moldflow's solution because they offer, Unique, Patented Fusion Technology. MPI/Fusion, which is based on Moldflow's patented Dual Domain™ technology, allows you to analyze CAD solid models of thin-walled parts directly, resulting in a significant decrease in model preparation time. The time-savings allow you to analyze more design iterations as well as perform more in–depth analyses.

Powerful Workflow and Productivity Tools. The user-friendly environments in MPI employ visualization and project management tools that allow you to undertake extensive design analysis and optimization. After your analyses are complete, you can produce detailed, Web-ready design reports quickly and easily.

Proven Solution for all Types of Application. Moldflow's analysis products can simulate plastics flow and packing, mold cooling, part shrinkage and warpage for thermoplastics injection-molding, gas assisted injection molding, co-injection molding and injection-compression molding processes. Additional modules simulate reactive molding processes including thermoset and rubber injection molding, raction injection molding (RIM), structural reaction injection molding (SRIM), resin transfer molding, microchip encapsulation and Underfill (flip-chip) encapsulation.

Using a proven solution technique based on a solid tetrahedral finite element volume mesh, MPI/3D allows you to perform true 3-dimensional flow simulations on parts that tend to be very thick and solid in nature as well as those that have extreme changes from thin to thick.

Moldflow's MPI technology can be used on all CAD model geometry types, including traditional midplane models, wire frame and surface models, thin-walled solids and thick or difficult-to-midplane solids. Regardless of your design geometry, you can accomplish simulation tasks in an easy-to-use, consistent, integrated environment that works with your model.

CHAPTER 3

METHODOLOGY

3.1 Injection molding

Methodology need to be determined first to achieve the objectives of the project. The methodology described the steps in conducting the project from start until its finish. A good methodology can be the guideline in managing the project. In developing a project, methodology is the most important element to be considered to make sure that the development of the research is smooth in order to get the expected result.

In this project, modeling part using CAD software is the main step in preceding the methodology. After the part had been modeled, it will be analyzed using plastic flow simulation software. Through the analysis, result of parameter effect due to warpage will get. It is important that the analysis going through follow the objective and also the project scope. The results also have to achieve the project objective.

3.2 Flow chart

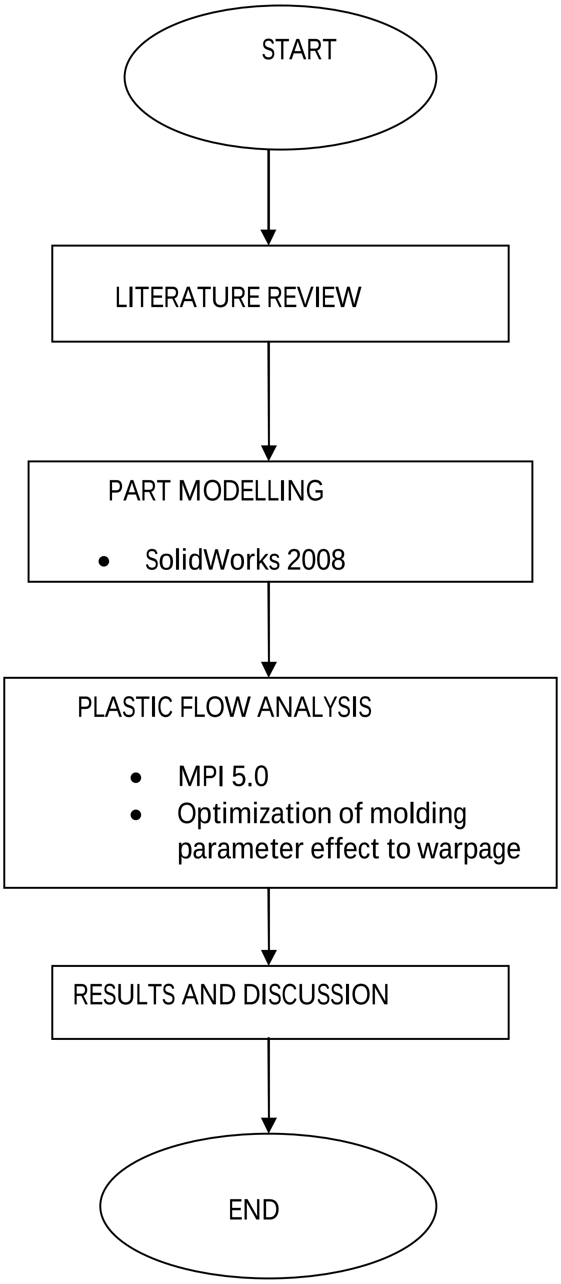


Figure 3.1: Project flow chart

3.3 Part Modeling

Next is modeling the product in design software. For this project, the software called SolidWorks is chosen. SolidWorks is a 3D mechanical CAD (computer-aided design) program that runs on Microsoft Windows and was developed by SolidWorks Corporation. This software was used because it is a parasolid-based solid modeler, and utilizes a parametric feature-based approach to create models and assemblies.

The bumper will be modeled with accurate dimension. Building a model in SolidWorks usually starts with a 2D sketch. The drawing consists of geometry such as points, lines, arcs, conics, and splines. Dimensions are added to the sketch to define the size and location of the geometry.

3.4 Material selection

MPI offers nineteen distinct modules that can be used to simulate nine unique molding processes using more than 7,800 materials characterized for use in plastic flow analysis. For this project, Polypropylenes (PP) has been choosing as the plastic material that will be used in the analysis. Specifically, the polymer that will be use in the analysis is Atofina Polypropylenes PPC 7760 from Atofina manufacturer. This polymer is in the PP family. Below are the ranges of the parameter for material PP that will be used as parameter for using in moldflow software.

Parameter range (°C)	Minimum	maximum
Mold temperature	10	60
Melt temperature	190	270

Absolute maximum melt temperature = 310°C

Ejection temperature = 60°C

3.5 Plastic flow analysis

Optimization of parameter effect to warpage of the car bumper will be analyzed using Moldflow Plastics Insight 5.0 (MPI).The analysis part will be imported from the SolidWorks software. Moldflow Plastics Insight 5.0 (MPI) software represents the most comprehensive suite of definitive tools for simulation, analysis, optimization, and validation of plastic parts and mold designs. MPI 5.0 includes a more efficient meshing tool for faster and more accurate analysis results as well as numerous 3D simulation capabilities for gas-assisted injection molding, part insert overmolding, 2-shot sequential overmolding and reactive molding.

MPI 5.0 also is more in-depth analysis capabilities such as improved warpage predictions for thin-walled parts and models with corners and contoured surfaces. Highly acclaimed for its speed and accuracy, MPI addresses the broadest range of design geometry types and manufacturing issues associated with plastics molding processes.

3.5.1 Analysis Sequence

In this project, there are three types of analysis that have been chosen. First is the melt temperature analysis. In the analysis, melt temperature change in order to get the effect on molded part. Then, the analysis will be the mold temperature analysis. The purpose of mold temperature analysis also same as the melt temperature analysis, which is to study the effect on the molded part if the value change and choose the best parameter value.

The injection pressure will be the final analysis by MPI 5.0 in this project. The value of injection pressure change in order to differentiate the effect on filling time, air traps, volumetric shrinkage, weld lines, and deflection.

As a conclusion, from all these result, it will be compared to determine the best parameter by referring to the fill time, air traps, volumetric shrinkage, weld lines, and defects that occur as a result of the moldflow analysis.

3.5.2 Analysis

After decided the analysis sequence and parameter, the analysis using MPI 5.0 started. Below are the general steps in conducting analysis:

1. Import model into MPI 5.0
2. Mesh model
3. Set analysis sequence
4. Select material
5. Set injection location
6. Set cooling circuit
7. Run the analysis

CHAPTER 4

RESULT AND DISCUSSION

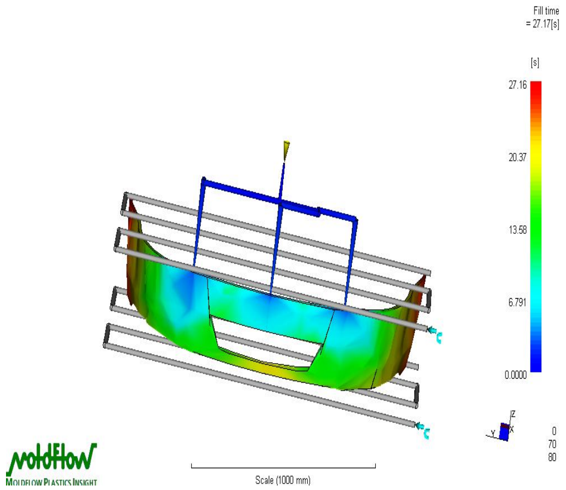
4.1 Introduction

In this chapter, the results that have been taken from the Moldflow analysis had been compared. The parameter that were selected such as mold temperature, melt temperature, and injection pressure. After the analysis completed, the result was compared based on fill time, air traps, volumetric shrinkage, weld lines, and deflection. The trend of the result also had been investigated. Most of the discussion based on the figure and data that have been collected.

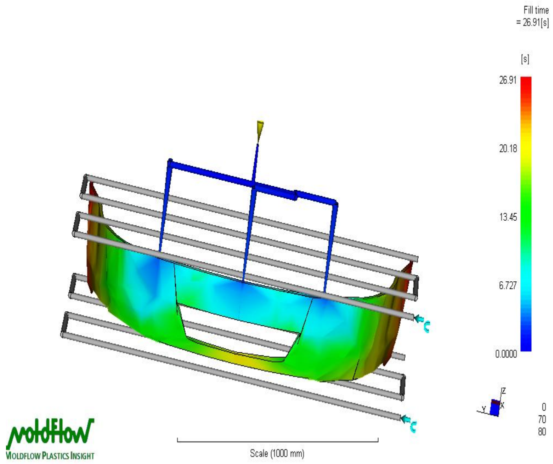
4.2 SolidWorks Software

In this project, solidworks software had been used to draw proton saga car bumper (refer to appendix). The bumper will be modeled with accurate dimension. The drawing consists of geometry such as points, lines, arcs, conics, and splines. Dimensions are added to the sketch to define the size and location of the geometry

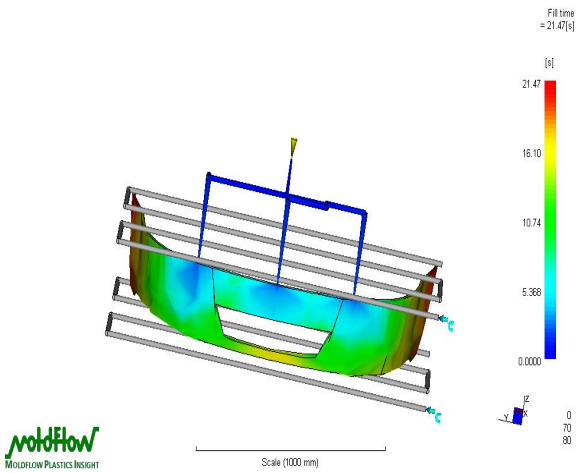
4.3 Melt Temperature Analysis



a) 230°C



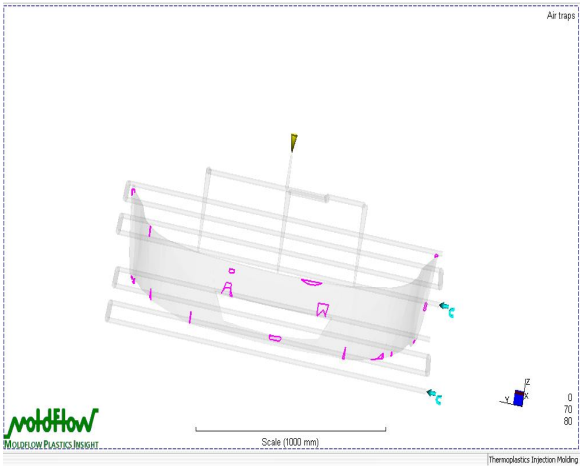
b) 240°C



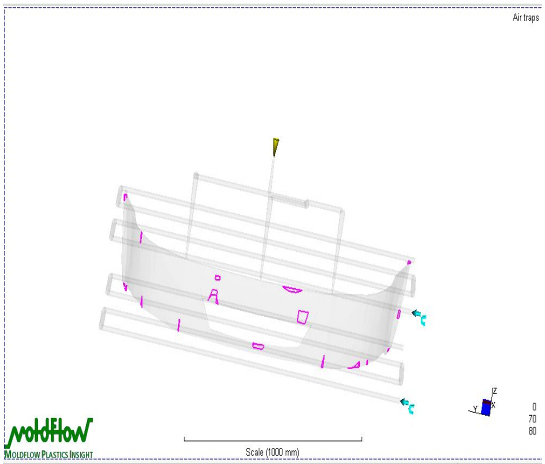
c) 250°C

Figure 4.1: Fill time for different melt temperatures (a) 230°C (b) 240°C (c) 250°C

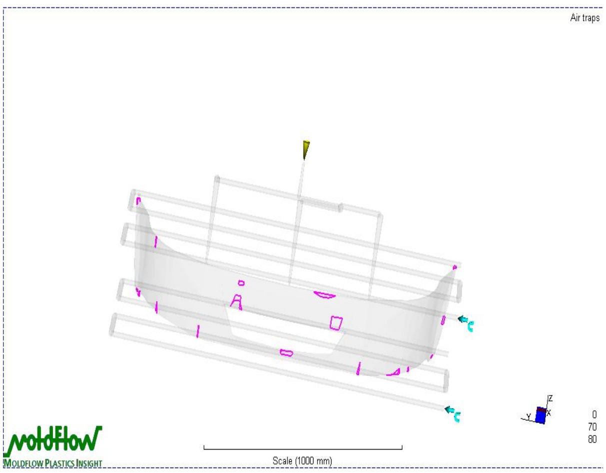
Figure 4.1 shows the fill time melt temperature of (a) 230°C, (b) 240°C, (c) 250°C. MPI simulates the filling flow through color-coded contour that range from blue to red. During the simulation, red contour indicates the start of the injection, while blue indicates the last place to be filled. If the material does not fill any parts of the product (short shot), then the affected section shall appear translucent. At melt temperature 230°C, the fill time is 27.16s. At melt temperature 240°C, the fill time is 26.91s. For melt temperature 240°C, the product fills with the melt plastic in 21.47s.



a) 230°C



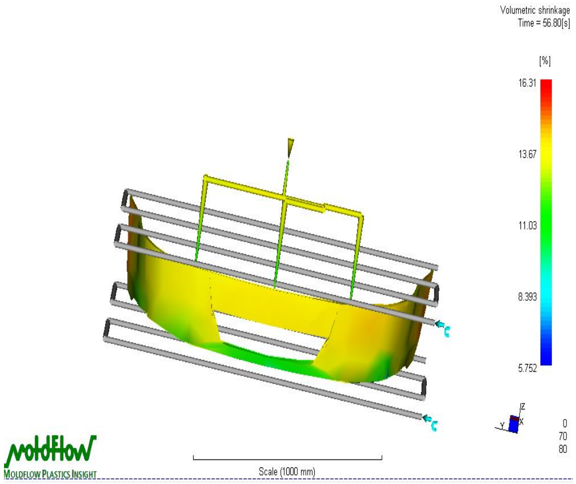
b) 240°C



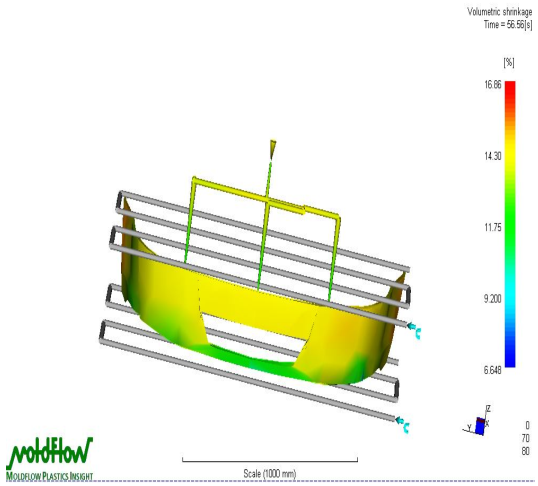
c) 250°C

Figure 4.2: Air traps for different melt temperatures (a) 230°C (b) 240°C (c) 250°C

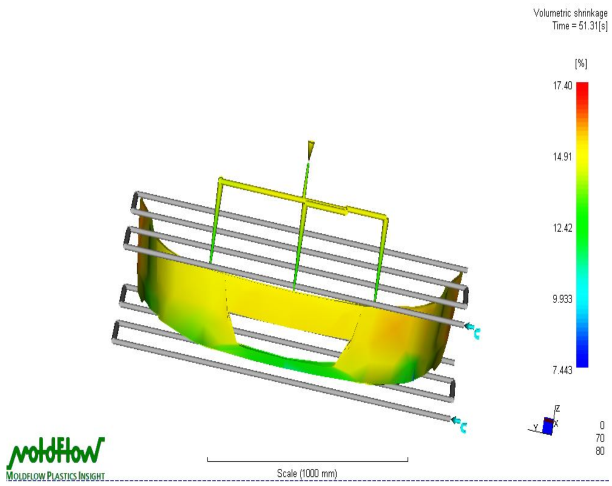
Figure 4.2 show the air traps defect in the product that have been analyzed. The air traps represent by the pink color circle. The air traps in the product for 230°C, 240°C, and 250°C melt temperature are same in location. There's no different in the air traps defects for different melt temperature.



a) 230°C



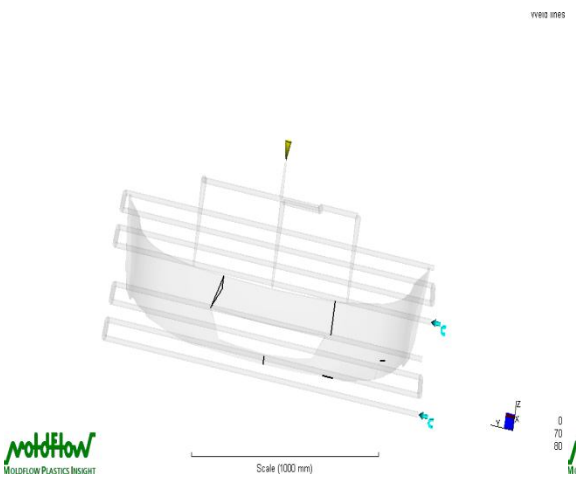
b) 240°C



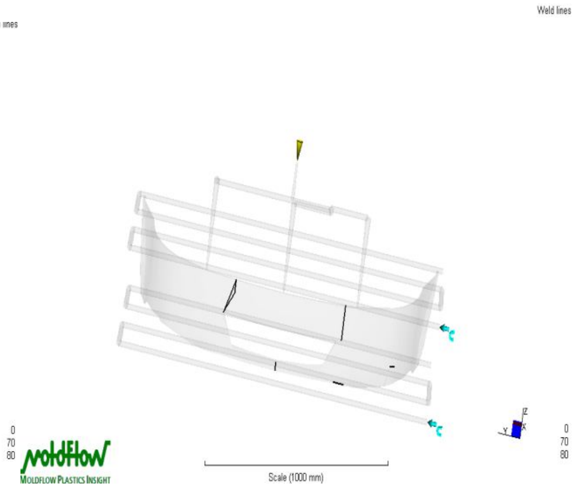
c) 250°C

Figure 4.3: Volumetric shrinkage for melt different temperatures (a) 230°C (b) 240°C (c) 250°C

Figure 4.3 shows the percentage of volumetric shrinkage in the product that has been analyzed. The percentage of volumetric shrinkage for melt temperature 230°C is 16.31%. While for melt temperature 240°C, the percentage of volumetric shrinkage is 16.86%. For the product with melt temperature 250°C, the percentage of volumetric shrinkage is 17.40%. The area that marks with blue color is the lowest area of shrinkage. While the biggest area of shrinkage is represented by red color.



a) 230°C

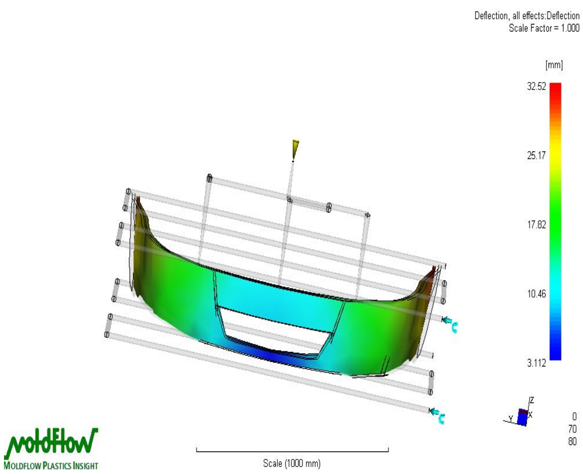


b) 240°C

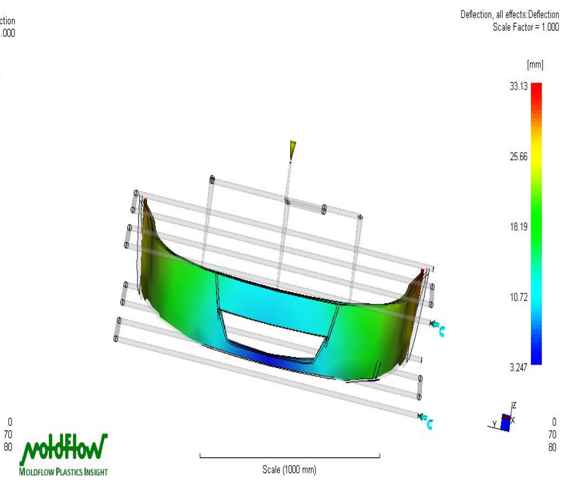
c) 250°C

Figure 4.4: Weld lines for different melt temperatures (a) 230°C (b) 240°C (c) 250°C

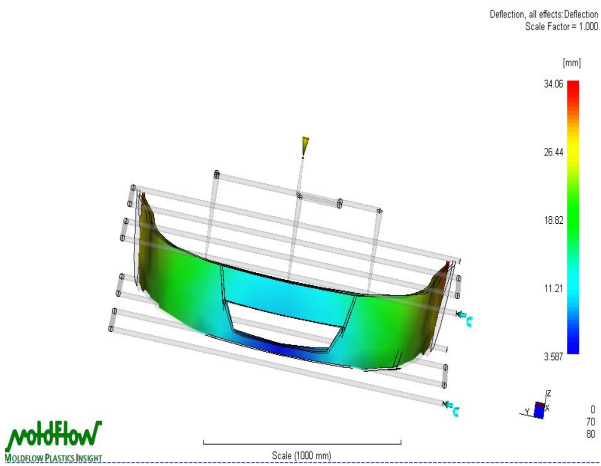
Figure 4.4 shows the weld lines occur in the product that has been analyzed with different melt temperature. The black line represents the weld line. Weld line is the line where two flow fronts meet when there is the inability of two or more flow fronts to "knit" together, or "weld", during the molding process. This line occurs usually around holes or obstructions and cause locally weak areas in the molded part. Weld lines are considered molding defects, and occur when the mold or/and material temperatures are set too low: thus the materials will be cold when they meet, so that they do not bond perfectly. By the comparison of these three melt temperature, there's no different for the weld line, same as the air traps.



a) 230°C



b) 240°C



c) 250°C

Figure 4.5: Deflection for different melt temperatures (a) 230°C (b) 240°C (c) 250°C

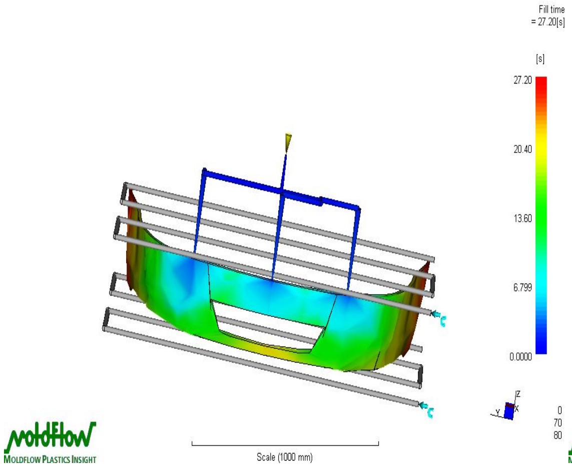
Figure 4.5 shows deflection in the product that has been analyzed. The deflection for melt temperature 230°C is 32.52mm after start to deflect at 3.112. While for melt temperature 240°C, the deflection start at 3.247mm and end at 33.13mm. For the product with melt temperature 250°C, it starts to deflect at 3.587mm and end at 34.06mm. The area that marks with blue color is the lowest area of deflection. While the biggest area deflection represented by red color.

Result summary

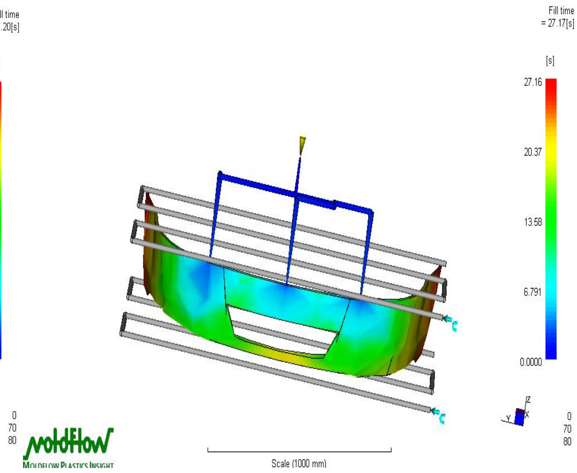
Melt Temperature, T (°C)	230	40	250
Fill time (s)	27.16	26.91	21.47
Volumetric shrinkage (%)	16.31	16.86	17.40
Maximum deflection (mm)	32.52	33.13	34.06

From the table, the result shows that melt temperature effect the filling time of the products. When the melt temperature is increase, the filling of the products become faster. The range of blue to red at each section of the product indicates that all flow paths did not finish at the same time due to the complexities of design. Each flow path should have ended with dark blue contours to guarantee a balanced fill time. It is also noted that overpacking might have occurred in the product since the result shows that one flow path finishes before others do. Such condition causes high part weight, warpage and non-uniform density distribution throughout the part [10]. In order to avoid the result of warpage during the forming, the temperature distribution of forming must be uniformed and controlled to reduce obtain small shrinkage and reduce the deformation. Although the fill time becomes shorter, the deflection is increase. Other than that, the percentage of volumetric shrinkage also increases when the melt temperature is increases

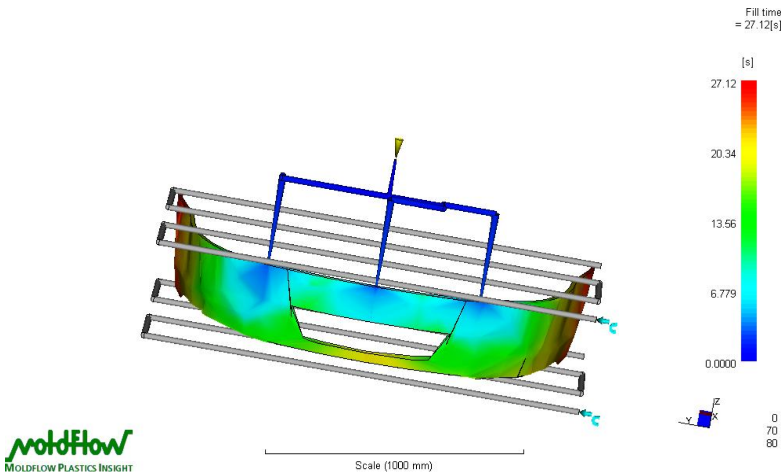
4.4 Mold Temperature Analysis



(a) 40°C



(b) 50°C

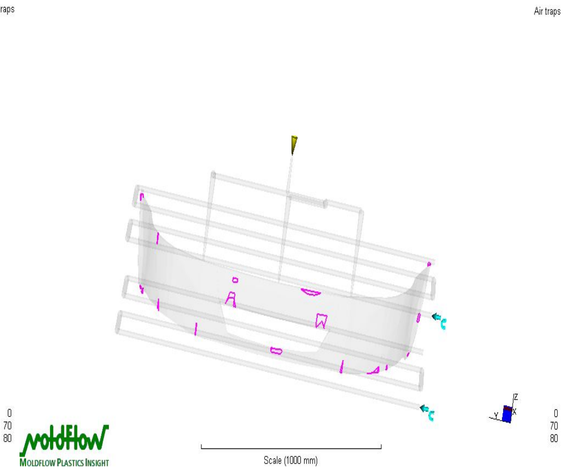


(c) 60°C

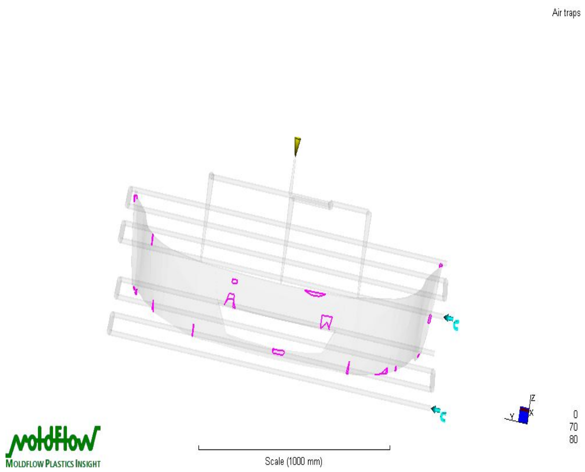
Figure 4.6: Fill time for different mold temperatures (a) 40°C (b) 50°C (c) 60°C

Figure 4.6 shows the fill time mold temperature of (a) 40°C, (b) 50°C, (c) 60°C. At mold temperature 40°C, the fill time is 27.20s. At mold temperature 50°C, the fill time is 27.16s. For melt temperature 60°C, the product fills with the melt plastic in 27.12s.

(a) 40°C



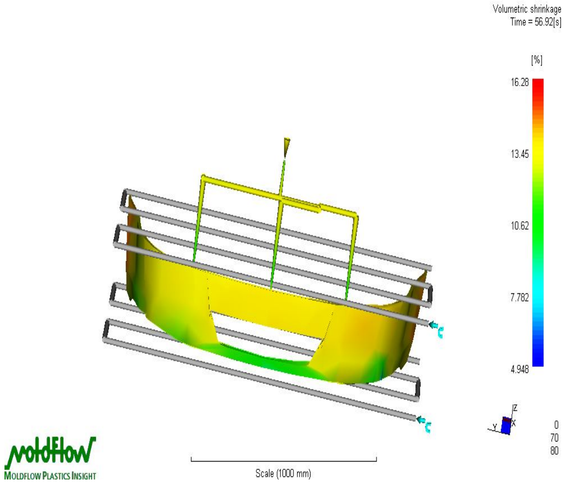
(b) 50°C



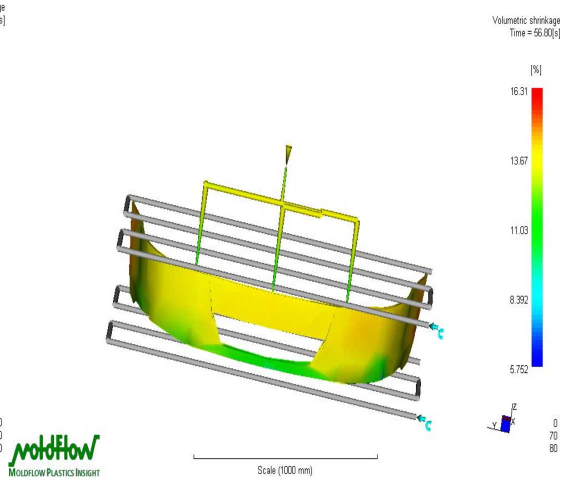
(c) 60°C

Figure 4.7: Air traps for different mold temperatures (a) 40°C (b) 50°C (c) 60°C

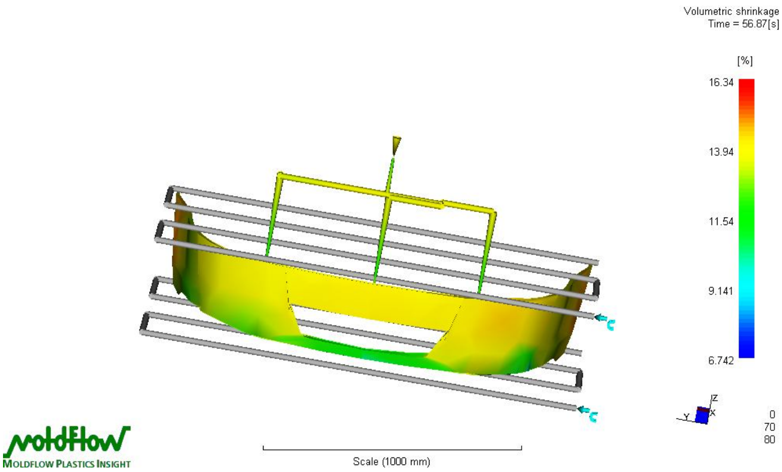
Figure 4.7 show the air traps defect in the product that have been analyzed. The air traps location mark by the pink color circle. By comparing these three mold temperature, there are no different spot on the figure. Meanings that, although the mold temperature changes, there are no changes for the air traps.



(a) 40°C



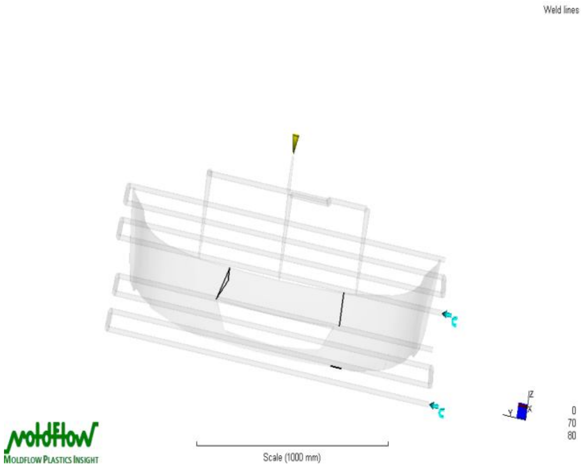
(b) 50°C



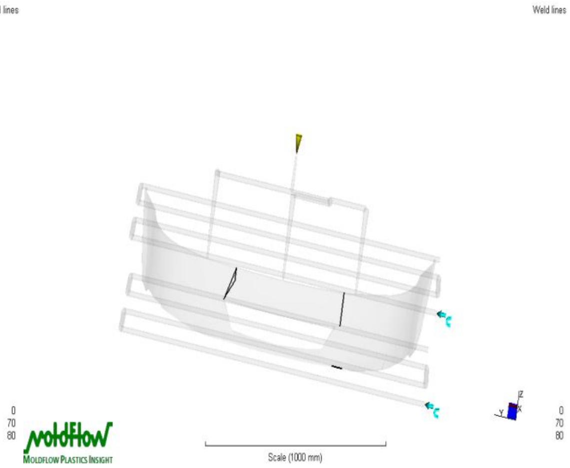
(c) 60°C

Figure 4.8: Volumetric shrinkage for different mold temperatures (a) 40°C (b) 50°C (c) 60°C

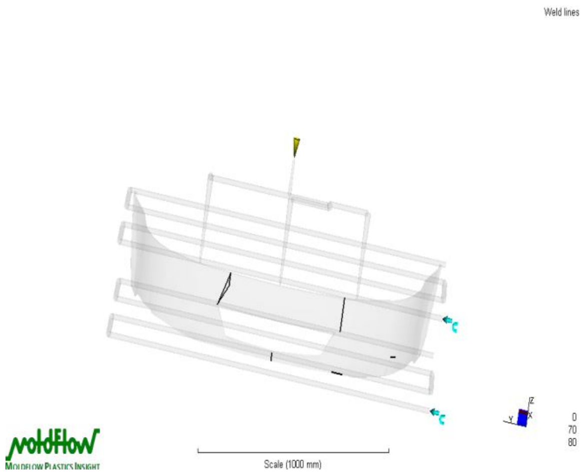
From the figure 4.8, it shows the percentage of volumetric shrinkage in the product that has been analyzed. The percentage of volumetric shrinkage for mold temperature 40°C is 16.28%. While for mold temperature 50°C, the percentage of volumetric shrinkage is 16.31%. For the product with mold temperature 60°C, the percentage of volumetric shrinkage is 16.34%. The area that marks with blue color is the lowest area of shrinkage. While the biggest area of shrinkage is represented by red color.



(a) 40°C



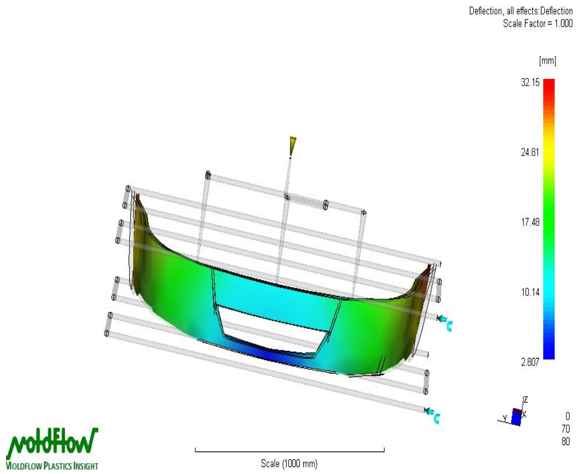
(b) 50°C



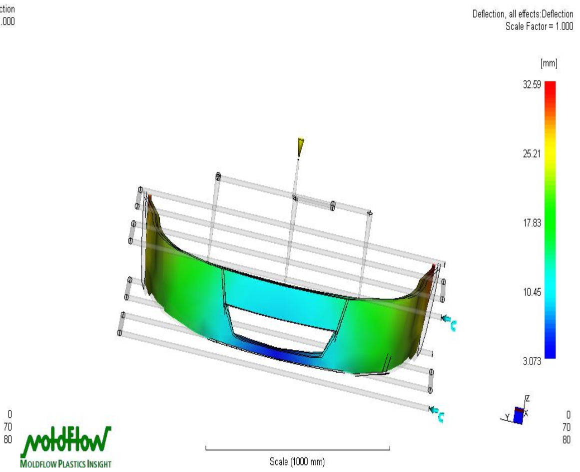
(c) 60°C

Figure 4.9: Weld lines for different mold temperatures (a) 40°C (b) 50°C (c) 60°C

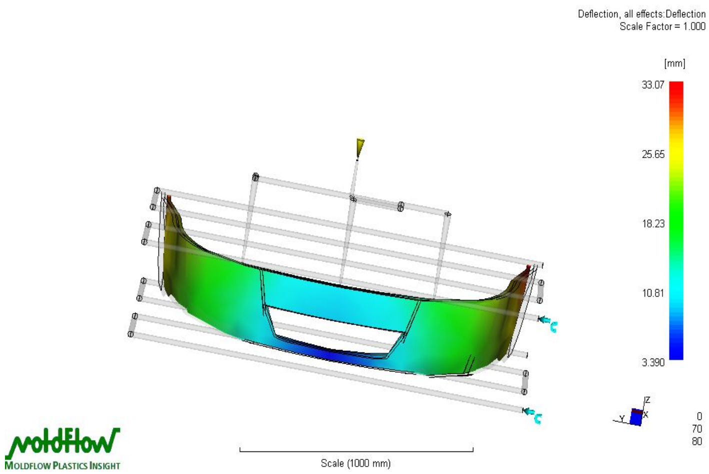
Figure 4.9 shows the weld lines occur in the product when the mold temperature is different. Although the mold temperatures are not same, the patterns of the weld lines that occur in the product are same.



(a) 40°C



(b) 50°C



(c) 60°C

Figure 4.10: Deflection for different mold temperatures (a) 40°C (b) 50°C (c) 60°C

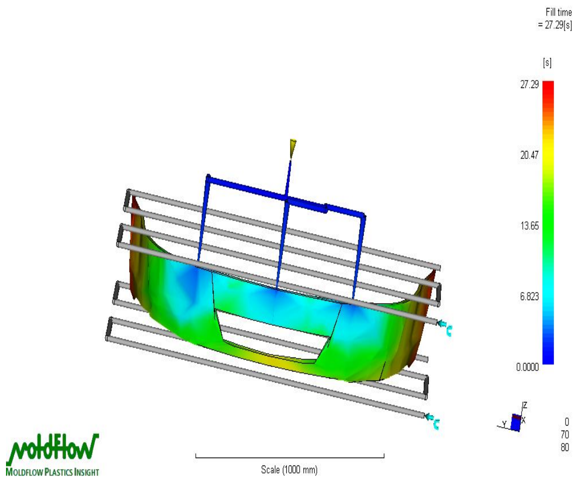
Figure 4.10 shows deflection in the product that has been analyzed. The deflection for mold temperature 40°C is 32.15mm after start to deflect at 2.807. While for the mold temperature 50°C, the deflection start at 3.073mm and end at 32.59mm. For the product with mold temperature 60°C, it starts to deflect at 3.390mm and end at 33.07mm. The area that marks with blue color is the lowest area of deflection. While the biggest area deflection represented by red color.

Result summary

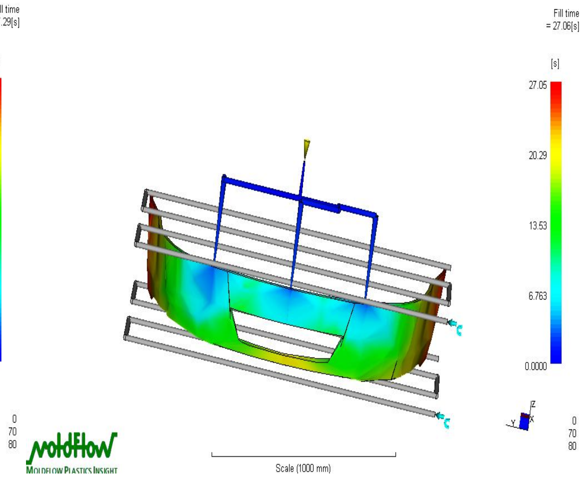
Mold Temperature, T (°C)	40	50	60
Fill time (s)	27.20	27.16	27.12
Volumetric shrinkage (%)	16.28	16.31	16.34
Maximum deflection (mm)	32.15	32.59	33.07

From the table, the result shows that when the mold temperature increases, the fill time also become shorter. This means that the product will fill fast at higher mold temperature. Other than that, when the mold temperature is increase, it also effect the volumetric shrinkage. Lower mold temperature will result less volumetric shrinkage which gives better final product. The deflection also effect when the mold temperature changed. Result shows that at lower mold temperature, the product deflect less than at higher mold temperature.

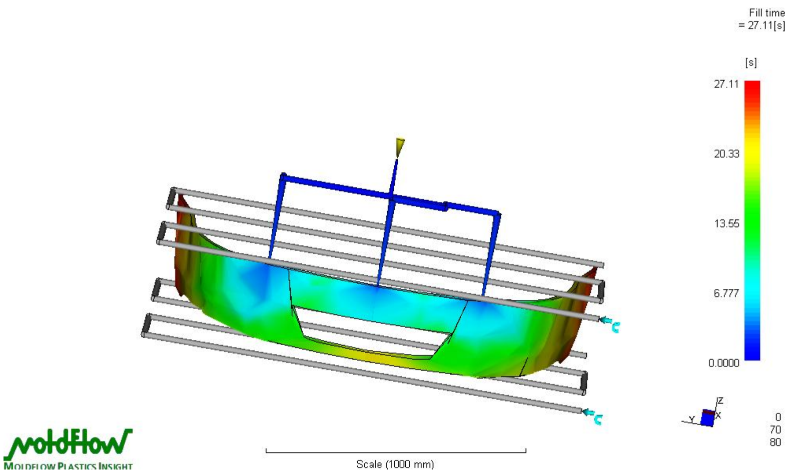
4.5 Injection Pressure Analysis



a) 18 MPa



b) 20 MPa



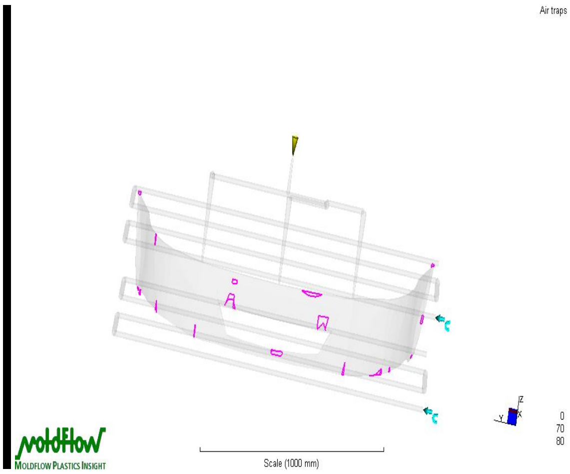
c) 22 MPa

Figure 4.11: Fill time for different injection pressure (a) 20 MPa (b) 30MPa (c) 40MPa

Figure 4.11 compare the fill time for the product when the injection pressure change from 18MPa (a), 20MPa (b), and 22MPa (c). At 18MPa, the product fill time is 27.29s.

When the injection pressure increases to 20MPa, the time for the product fill more faster which is 27.06s. For the injection pressure 22MPa, it takes 27.11s to fill the product.

a) 20 MPa

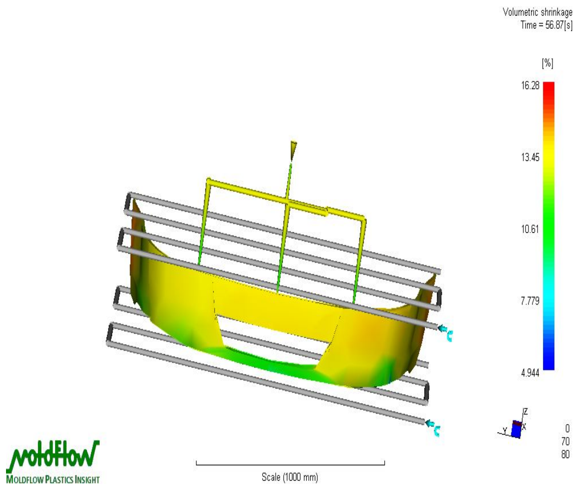


b) 30 MPa

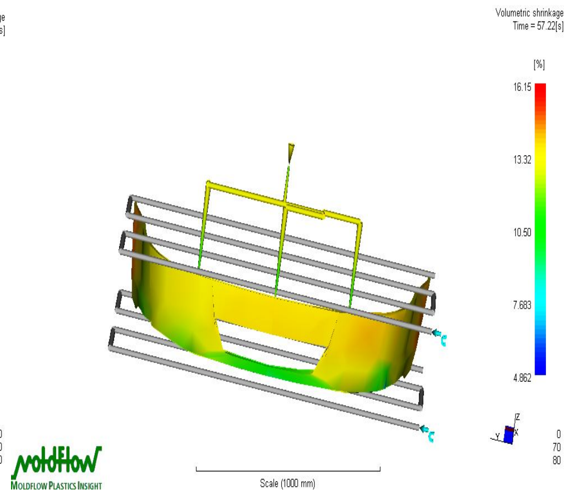
c) 40 MPa

Figure 4.12: Air traps for different mold temperatures (a) 30 MPa (b) 40 MPa (c) 50 MPa

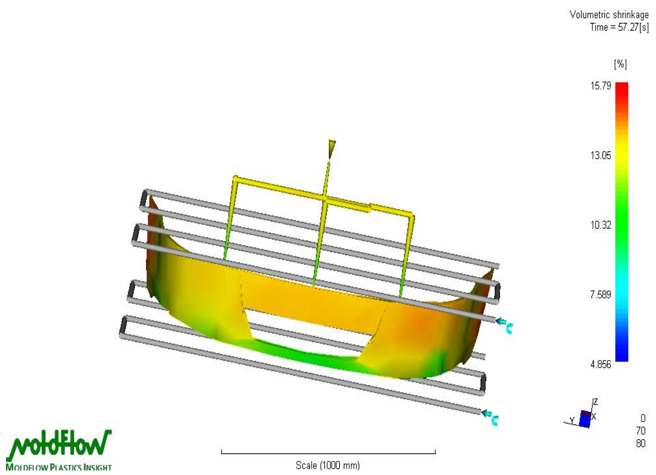
Figure 4.12 compared to each other to see the different in air traps that occur since the injection pressure is different. As a result, there's no different in air traps that occur in the product with different injection pressure. The patterns of air traps are same.



a) 18 MPa



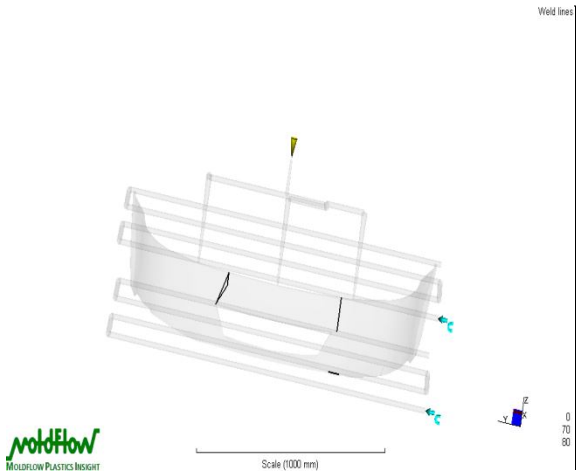
b) 20 MPa



c) 22 MPa

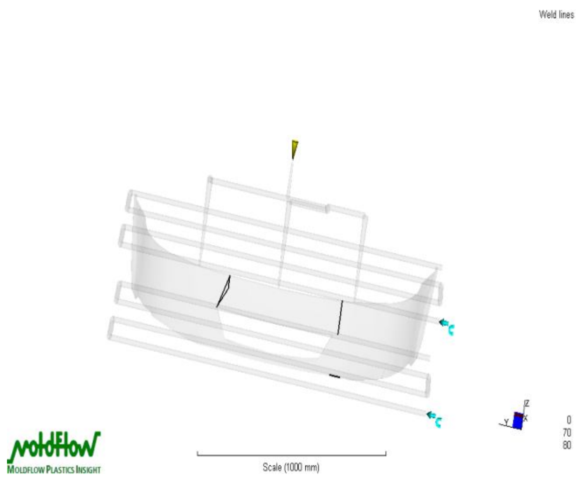
Figure 4.13: Volumetric shrinkage for different mold temperatures (a) 18 MPa (b) 20MPa (c) 22 MPa

From the figure 4.13, it shows that volumetric shrinkage percentage is higher when the injection pressure is 18 MPa, which is 16.28%. When the injection pressure increase to 20 MPa, the volumetric shrinkage percentage is 16.15%. At 22 MPa, the volumetric shrinkage percentage is 15.79%.



a) 18 MPa

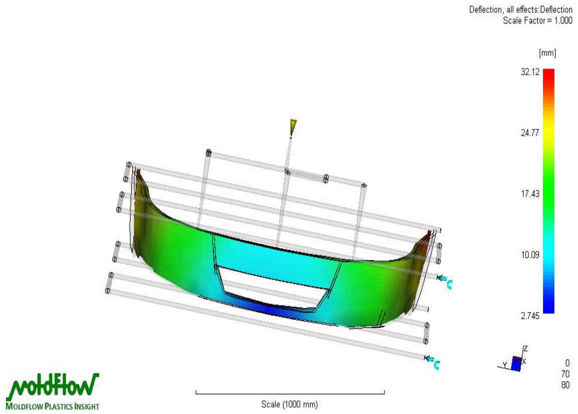
b) 20 MPa



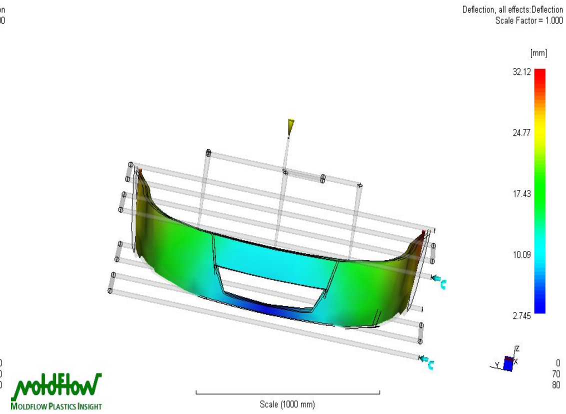
c) 22 MPa

Figure 4.14: Weld lines for different mold temperatures (a) 18 MPa (b) 20 MPa (c) 22 MPa

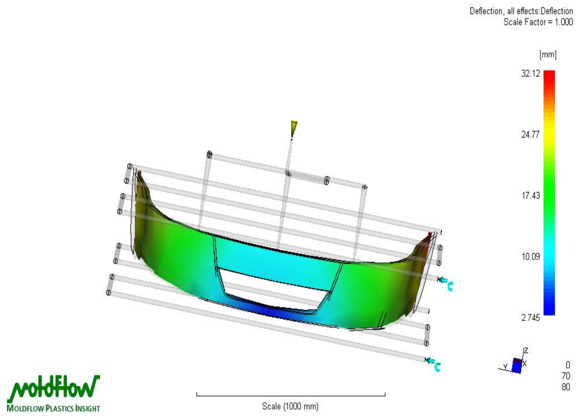
From the figure 4.14, there's weld line occur after analyze the product. By comparing the pattern of weld lines in Figure 4 (a), (b), (c), there are nothing different. The location and the number of weld lines also same even though the injection pressure is different.



a) 18 MPa



b) 20 MPa



c) 22 MPa

Figure 4.15: Deflection for different mold temperatures (a) 18 MPa (b) 20 MPa (c) 22 MPa

From the figure 4.15 above, it shows the deflection for the product with injection pressure 18 MPa, 20 MPa, and 22 MPa. The deflection for injection pressure 18 MPa is 32.16mm after start to deflect at 2.745mm. At injection pressure 20 MPa and 22 MPa, the deflection value is same which is 32.12mm.The area that marks with blue color is the lowest area of deflection. While the biggest area deflection represented by red color.

Result summary

Injection pressure (MPa)	18	20	22
Fill time (s)	27.06	27.12	27.12
Volumetric shrinkage (%)	16.28	16.15	15.79
Maximum deflection (mm)	32.16	32.12	32.12

From the table, the result shows that the fill time increase when the injection pressure is increase. But at certain injection pressure, the fill time remains constant although the injection pressure is increased. It means that the product is already at maximum pressure to fill. The fusion mesh of the part model also enables a study of pressure distribution through the flow path inside the mold, at the end of the filling phase. Polymer melts flow due to pressure difference from one location to another, i.e., from higher to lower pressure (negative pressure gradient) [10]. Larger pressure gradient or higher pressure to fill is also required for products with restricted areas such as thin sections or small runners. For the volumetric shrinkage, the product shrinks less when the injection pressure is high. Lastly for the deflection, the result shows that the difference value for higher injection pressure and lower injection pressure are not much and the product deflects most at lower injection pressure.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objective of this study is to investigate the injection molding parameter effect to warpage of a car bumper. For this study, various parameters were analyzed by using Moldflow Plastic Insight software (MPI 5.0). The analysis includes the effect of the mold temperature, melt temperature, injection pressure on fill time, air traps, volumetric shrinkage, weld lines, and deflection.

By using moldflow software, it recommends the best and optimum parameter for the product. In this study, the product that had been analyzed was proton saga car bumper. The parameters that can be obtained were melt temperature (230°C), mold temperature (40°C), and injection pressure (22MPa).

This study shows that increasing injection molding parameter such as mold temperature and melt temperature will effect the cycle time. Higher temperature will produced faster filling time. However, filling time is not the only result being considered to find the optimum parameter for the product. The analysis also considers how much deflection and volumetric shrinkage of the product. Other than that, the pattern of weld lines and air traps also one of the elements that were being investigated.

Pressure distribution in the cavity of a product can be controlled using multiple gates. However this action causes weld lines. Weld lines occur when two flow fronts met and converged. In plastics products, weld lines are unavoidable especially if more than one gate is used. Weld lines can cause structural problem should the weld lines occur at high stress areas. This causes the part to be more likely deformed or fracture at the weld lines. Secondly, weld lines also makes the part visually unacceptable since they incur a line, notch or color change on the surface part.

The product design is the most important in order to avoid defect such as air traps and weld lines. Since the mold temperature, melt temperature and injection pressure did not effect in reducing these defects, the design have to reconsider the location of the gate. Analysis makes the redesigning process become easier because it shows the potential defect that will occur in the product. From there, the designer can repair the design in order to reduce the defects.

As a conclusion, molding parameter such as mold temperature, melt temperature an injection pressure effect the process in making the product. Higher mold temperature and melt temperature will give faster filling time. The location of the gate also influences the defect. The design of the product needs to be concerned to avoid defects such as air traps and weld lines. By using Moldflow software, the best and optimum parameters can be obtained for the product.

5.2 Recommendation

Thus in order to improve the current result indicated by the Moldflow study, a few modifications on both product design and mold design are proposed. They are:

• increase the wall thickness;

• adjust gate position and gate number;

• increase melt temperature, mold temperature, or injection pressure;

• placing vent in the area of weld line to remove air traps that would weaken the weld line.

The product design need to analyze before fabricate in order to get the best design and also obtain the suitable parameter for the injection molding machine. The study by using Moldflow software can be expand in analyze design of product before fabricate the mold.

REFERENCES

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[5] S.L.B. Woll and D.J. Cooper, Pattern-based closed-loop quality control for the injection molding process, *Polym. Eng. Sci.* **37** (5) (1997), pp. 801–812.

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[7] http://www.scudc.scu.edu/cmdoc/dg_doc/develop/process/physics/b3500001.htm

[8] http://www.morganindustriesinc.com/injection-molding-process.htm

[9] http://www.scudc.scu.edu/cmdoc/dg_doc/develop/process/control/b1000002.htm

[10] Moldflow Plastic Insight Manual, Release 13; 1996

APPENDIX A

MELT TEMPERATURE 230°C

Flow

Flow Analysis

Version: mpi500 (Build 04453)

Analysis running on host: sdn-3caf01b6f59

Operating System: Windows XP Service Pack 2

Processor type: AuthenticAMD x86 Family 15 Model 36 Stepping 2 ~1790 MHz

Number of Processors: 1

Total Physical Memory: 894 MBytes

Date : OCT05-09

Time : 16:48:34

File name : melt_temperature=230~1

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 : Atofina Polypropylene PPC 7760 : Atofina

PVT Model: 2-domain modified Tait

coefficients: b5 = 449.1500 K

b6 = 6.2500E-08 K/Pa

Liquid phase Solid phase

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b1m = 0.0012 b1s = 0.0012 m^3/kg

b2m = 8.7170E-07 b2s = 6.1410E-07 m^3/kg-K

b3m = 8.0484E+07 b3s = 1.1012E+08 Pa

b4m = 0.0049 b4s = 0.0051 1/K

b7 = 7.4350E-05 m^3/kg

b8 = 0.1016 1/K

b9 = 8.6730E-09 1/Pa

Specific heat: Tabulated data:

Temperature T (K)	Specific Heat Cp (J/kg-K)
293.1500	1700.0000
333.1500	1700.0000
373.1500	2400.0000
438.1500	2700.0000

Thermal conductivity: Tabulated data:

Temperature T (K)	Thermal Conductivity K (W/m-K)
293.1500	0.2200
473.1500	0.1700

Viscosity model: Cross-WLF

coefficients: n = 0.3037

TAUS = 2.7405E+04 Pa

D1 = 4.6352E+14 Pa-s

D2 = 263.1500 K

D3 = 0.0000 K/Pa

A1 = 32.3360

A2T = 51.6000 K

Transition temperature = 135.0000 C

Mechanical properties data: E1 = 1200.0000 MPa

E2 = 1200.0000 MPa

v12 = 0.4200

v23 = 0.4200

G12 = 422.5400 MPa

Transversely isotropic coefficent of

thermal expansion (CTE) data: Alpha1 = 0.0001 1/C

Alpha2 = 0.0001 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 = 26.7572 s

Injection time has been determined by automatic calculation.

Stroke volume determination = Automatic

Cooling time = 20.0000 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
20.0000 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: Mold wall temperature data from cooling analysis not available

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Model details :

Mesh Type = Fusion

Match ratio = 72.4 %

Total number of nodes = 710

Total number of injection location nodes = 1

The injection location node labels are: 428

Total number of elements = 934

Number of part elements = 816

Number of sprue/runner/gate elements = 118

Number of channel elements = 0

Number of connector elements = 0

Average aspect ratio of triangle elements = 11.0981

Maximum aspect ratio of triangle elements = 477.9830

Minimum aspect ratio of triangle elements = 1.2632

Total volume = 1.2048E+04 cm^3

Volume filled initially = 0.0000 cm^3

Volume to be filled = 1.2048E+04 cm^3

Sprue/runner/gate volume to be filled = 897.1610 cm^3

Total projected area = 1020.0500 cm^2

Filling phase results summary :

Maximum injection pressure (at 26.638 s) = 18.2895 MPa

End of filling phase results summary :

Time at the end of filling = 27.1684 s

Total weight = 1.0227E+04 g

Maximum Clamp force - during filling = 52.6111 tonne

Recommended ram speed profile (rel):

% stroke	% speed
0.0000	29.5937
6.9661	29.5937
20.0000	100.0000
30.0000	91.5310
40.0000	74.1252
50.0000	59.6122
60.0000	43.4771
70.0000	29.1978
80.0000	38.4066
90.0000	51.8047
100.0000	14.1537

Melt front is entirely in the cavity at % fill = 6.9661 %

Filling phase results summary for the part :

Bulk temperature - maximum (at 7.213 s) = 233.2780 C

Bulk temperature - 95th percentile (at 11.082 s) = 232.2300 C

Bulk temperature - 5th percentile (at 27.158 s) = 227.8040 C

Bulk temperature - minimum (at 27.158 s) = 170.0250 C

Wall shear stress - maximum (at 20.142 s) = 0.0836 MPa

Wall shear stress - 95th percentile (at 2.745 s) = 0.0346 MPa

Shear rate - maximum (at 27.093 s) = 260.9920 1/s

Shear rate - 95th percentile (at 2.745 s) = 71.9721 1/s

End of filling phase results summary for the part :

Total part weight = 9510.6897 g

Bulk temperature - maximum = 232.7650 C

Bulk temperature - 95th percentile = 231.5720 C

Bulk temperature - 5th percentile = 227.9300 C

Bulk temperature - minimum = 170.0290 C

Bulk temperature - average = 230.1200 C

Bulk temperature - RMS deviation = 1.5205 C

Wall shear stress - maximum = 0.0667 MPa

Wall shear stress - 95th percentile = 0.0272 MPa

Wall shear stress - average = 0.0084 MPa

Wall shear stress - RMS deviation = 0.0091 MPa

Frozen layer fraction - maximum = 0.3117

Frozen layer fraction - 95th percentile = 0.1566

Frozen layer fraction - 5th percentile = 0.0633

Frozen layer fraction - minimum = 0.0000

Frozen layer fraction - average = 0.1071

Frozen layer fraction - RMS deviation = 0.0270

Shear rate - maximum = 146.0080 1/s

Shear rate - 95th percentile = 25.1385 1/s

Shear rate - average = 6.5907 1/s

Shear rate - RMS deviation = 9.5037 1/s

Filling phase results summary for the runner system :

Bulk temperature - maximum (at 26.665 s) = 234.3580 C

Bulk temperature - 95th percentile (at 7.213 s) = 232.3210 C

Bulk temperature - 5th percentile (at 1.346 s) = 230.6340 C

Bulk temperature - minimum (at 27.168 s) = 230.1620 C

Wall shear stress - maximum (at 20.142 s) = 0.3104 MPa

Wall shear stress - 95th percentile (at 11.082 s) = 0.0896 MPa

Shear rate - maximum (at 20.142 s) = 2.5278E+04 1/s

Shear rate - 95th percentile (at 20.142 s) = 722.8660 1/s

End of filling phase results summary for the runner system :

Total sprue/runner/gate weight = 716.8330 g

Bulk temperature - maximum = 233.2320 C

Bulk temperature - 95th percentile = 231.7450 C

Bulk temperature - 5th percentile = 231.0960 C

Bulk temperature - minimum = 230.1620 C

Bulk temperature - average = 231.4020 C

Bulk temperature - RMS deviation = 0.2536 C

Wall shear stress - maximum = 0.2022 MPa

Wall shear stress - 95th percentile = 0.0698 MPa

Wall shear stress - average = 0.0356 MPa

Wall shear stress - RMS deviation = 0.0145 MPa

Frozen layer fraction - maximum = 0.1573

Frozen layer fraction - 95th percentile = 0.1559

Frozen layer fraction - 5th percentile = 0.0623

Frozen layer fraction - minimum = 0.0617

Frozen layer fraction - average = 0.1139

Frozen layer fraction - RMS deviation = 0.0373

Shear rate - maximum = 1.2639E+04 1/s

Shear rate - 95th percentile = 346.6190 1/s

Shear rate - average = 99.1157 1/s

Shear rate - RMS deviation = 170.2380 1/s

Packing phase results summary :

Peak pressure - minimum (at 35.578 s) = 11.0445 MPa

Clamp force - maximum (at 35.578 s) = 119.8498 tonne

Total weight - maximum (at 36.650 s) = 1.0413E+04 g

End of packing phase results summary :

Time at the end of packing = 56.7969 s

Total weight = 1.0315E+04 g

Packing phase results summary for the part :

Bulk temperature - maximum (at 27.169 s) = 232.7650 C

Bulk temperature - 95th percentile (at 27.169 s) = 231.5720 C

Bulk temperature - 5th percentile (at 56.797 s) = 206.0700 C

Bulk temperature - minimum (at 56.797 s) = 94.4770 C

Wall shear stress - maximum (at 27.169 s) = 0.0660 MPa

Wall shear stress - 95th percentile (at 27.169 s) = 0.0243 MPa

Volumetric shrinkage - maximum (at 27.169 s) = 16.3144 %

Volumetric shrinkage - 95th %ile (at 27.169 s) = 15.5130 %

Volumetric shrinkage - 5th %ile (at 36.650 s) = 11.8904 %

Volumetric shrinkage - minimum (at 45.797 s) = 5.7517 %

Total part weight - maximum (at 36.650 s) = 9687.2101 g

End of packing phase results summary for the part :

Total part weight = 9591.7397 g

Bulk temperature - maximum	=	229.7700 C
Bulk temperature - 95th percentile	=	228.8220 C
Bulk temperature - 5th percentile	=	206.0700 C
Bulk temperature - minimum	=	94.4770 C
Bulk temperature - average	=	223.1480 C
Bulk temperature - RMS deviation	=	7.9862 C

Frozen layer fraction - maximum	=	1.0000
Frozen layer fraction - 95th percentile	=	0.2914
Frozen layer fraction - 5th percentile	=	0.1183
Frozen layer fraction - minimum	=	0.0947
Frozen layer fraction - average	=	0.1870
Frozen layer fraction - RMS deviation	=	0.0510

Volumetric shrinkage - maximum	=	15.2487 %
Volumetric shrinkage - 95th percentile	=	14.9255 %
Volumetric shrinkage - 5th percentile	=	12.3492 %
Volumetric shrinkage - minimum	=	5.7517 %
Volumetric shrinkage - average	=	13.8411 %
Volumetric shrinkage - RMS deviation	=	0.7645 %

Sink index - maximum	=	2.8349 %
Sink index - 95th percentile	=	2.6100 %
Sink index - minimum	=	2.1669 %
Sink index - RMS deviation	=	0.4169 %

Packing phase results summary for the runner system :

Bulk temperature - maximum (at 27.169 s) = 233.2230 C

Bulk temperature - 95th percentile (at 27.169 s) = 231.7460 C

Bulk temperature - 5th percentile (at 56.797 s) = 217.4450 C

Bulk temperature - minimum (at 56.797 s) = 176.9160 C

Wall shear stress - maximum (at 27.169 s) = 0.2040 MPa

Wall shear stress - 95th percentile (at 27.169 s) = 0.0699 MPa

Volumetric shrinkage - maximum (at 36.650 s) = 15.1559 %

Volumetric shrinkage - 95th %ile (at 27.169 s) = 14.7068 %

Volumetric shrinkage - 5th %ile (at 35.578 s) = 11.8103 %

Volumetric shrinkage - minimum (at 36.650 s) = 10.9967 %

Sprue/runner/gate weight - max. (at 35.578 s) = 727.9460 g

End of packing phase results summary for the runner system :

Total sprue/runner/gate weight = 723.2070 g

Bulk temperature - maximum = 226.5340 C

Bulk temperature - 95th percentile = 226.4850 C

Bulk temperature - 5th percentile = 217.4450 C

Bulk temperature - minimum = 176.9160 C

Bulk temperature - average = 224.8210 C

Bulk temperature - RMS deviation = 3.1031 C

Frozen layer fraction - maximum = 0.6149

Frozen layer fraction - 95th percentile = 0.3739

Frozen layer fraction - 5th percentile = 0.2244

Frozen layer fraction - minimum = 0.2240

Frozen layer fraction - average = 0.2583

Frozen layer fraction - RMS deviation = 0.0478

Volumetric shrinkage - maximum = 13.7535 %

Volumetric shrinkage - 95th percentile = 13.7389 %

Volumetric shrinkage - 5th percentile = 12.0699 %

Volumetric shrinkage - minimum = 11.6693 %

Volumetric shrinkage - average = 13.2411 %

Volumetric shrinkage - RMS deviation = 0.5005 %

Sink index - maximum = 2.1973 %

Sink index - 95th percentile = 2.1933 %

Sink index - minimum = 1.9818 %

Sink index - RMS deviation = 0.2239 %

Execution time

Analysis commenced at Mon Oct 05 16:48:33 2009

Analysis completed at Mon Oct 05 16:49:20 2009

CPU time used 38.56 s

APPENDIX B

MOLD TEMPERATURE 40°C

Flow

Flow Analysis

Version: mpi500 (Build 04453)

Analysis running on host: sdn-3caf01b6f59

Operating System: Windows XP Service Pack 2

Processor type: AuthenticAMD x86 Family 15 Model 36 Stepping 2 ~1790 MHz

Number of Processors: 1

Total Physical Memory: 894 MBytes

Date : OCT04-09

Time : 22:01:02

File name : mold_surface_temperature=40~1

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 : Atofina Polypropylene PPC 7760 : Atofina

PVT Model: 2-domain modified Tait

coefficients: b5 = 449.1500 K

b6 = 6.2500E-08 K/Pa

Liquid phase Solid phase

----

b1m = 0.0012 b1s = 0.0012 m^3/kg

b2m = 8.7170E-07 b2s = 6.1410E-07 m^3/kg-K

b3m = 8.0484E+07 b3s = 1.1012E+08 Pa

b4m = 0.0049 b4s = 0.0051 1/K

b7 = 7.4350E-05 m^3/kg

b8 = 0.1016 1/K

b9 = 8.6730E-09 1/Pa

Specific heat: Tabulated data:

Temperature T (K)	Specific Heat Cp (J/kg-K)
293.1500	1700.0000
333.1500	1700.0000
373.1500	2400.0000
438.1500	2700.0000

Thermal conductivity: Tabulated data:

Temperature T (K)	Thermal Conductivity K (W/m-K)
293.1500	0.2200
473.1500	0.1700

Viscosity model: Cross-WLF

coefficients: n = 0.3037

TAUS = 2.7405E+04 Pa

D1 = 4.6352E+14 Pa-s

D2 = 263.1500 K

D3 = 0.0000 K/Pa

A1 = 32.3360

A2T = 51.6000 K

Transition temperature = 135.0000 C

Mechanical properties data: E1 = 1200.0000 MPa

E2 = 1200.0000 MPa

v12 = 0.4200

v23 = 0.4200

G12 = 422.5400 MPa

Transversely isotropic coefficent of

thermal expansion (CTE) data: Alpha1 = 0.0001 1/C

Alpha2 = 0.0001 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 = 26.7572 s

Injection time has been determined by automatic calculation.

Stroke volume determination = Automatic

Cooling time = 20.0000 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
20.0000 s	0.0000

Ambient temperature = 25.0000 C

Melt temperature = 230.0000 C

Ideal cavity-side mold temperature = 40.0000 C

Ideal core-side mold temperature = 40.0000 C

NOTE: Mold wall temperature data from cooling analysis not available

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Model details :

Mesh Type = Fusion

Match ratio = 72.4 %

Total number of nodes = 710

Total number of injection location nodes = 1

The injection location node labels are: 428

Total number of elements = 934

Number of part elements = 816

Number of sprue/runner/gate elements = 118

Number of channel elements = 0

Number of connector elements = 0

Average aspect ratio of triangle elements = 11.0981

Maximum aspect ratio of triangle elements = 477.9830

Minimum aspect ratio of triangle elements = 1.2632

Total volume = 1.2048E+04 cm^3

Volume filled initially = 0.0000 cm^3

Volume to be filled = 1.2048E+04 cm^3

Sprue/runner/gate volume to be filled = 897.1610 cm^3

Total projected area = 1020.0500 cm^2

Filling phase results summary :

Maximum injection pressure (at 26.757 s) = 19.0722 MPa

End of filling phase results summary :

Time at the end of filling = 27.2001 s

Total weight = 1.0248E+04 g

Maximum Clamp force - during filling = 56.7786 tonne

Recommended ram speed profile (rel):

% stroke	% speed
0.0000	29.6190
6.9661	29.6190
20.0000	100.0000
30.0000	91.1223
40.0000	73.6640
50.0000	60.7112
60.0000	44.4513
70.0000	29.4599
80.0000	38.5721
90.0000	52.0930
100.0000	15.0184

Melt front is entirely in the cavity at % fill = 6.9661 %

Filling phase results summary for the part :

Bulk temperature - maximum (at 7.224 s) = 233.3130 C

Bulk temperature - 95th percentile (at 11.097 s) = 232.2460 C

Bulk temperature - 5th percentile (at 27.190 s) = 227.8190 C

Bulk temperature - minimum (at 27.190 s) = 166.9930 C

Wall shear stress - maximum (at 26.757 s) = 0.0828 MPa

Wall shear stress - 95th percentile (at 2.749 s) = 0.0348 MPa

Shear rate - maximum (at 27.131 s) = 290.4250 1/s

Shear rate - 95th percentile (at 2.749 s) = 71.8394 1/s

End of filling phase results summary for the part :

Total part weight = 9529.0298 g

Bulk temperature - maximum = 232.8270 C

Bulk temperature - 95th percentile = 231.5750 C

Bulk temperature - 5th percentile = 227.9510 C

Bulk temperature - minimum = 166.9970 C

Bulk temperature - average = 230.1160 C

Bulk temperature - RMS deviation = 1.5335 C

Wall shear stress - maximum = 0.0702 MPa

Wall shear stress - 95th percentile = 0.0287 MPa

Wall shear stress - average = 0.0090 MPa

Wall shear stress - RMS deviation = 0.0097 MPa

Frozen layer fraction - maximum = 0.3406

Frozen layer fraction - 95th percentile = 0.1688

Frozen layer fraction - 5th percentile = 0.0672

Frozen layer fraction - minimum = 0.0000

Frozen layer fraction - average = 0.1146

Frozen layer fraction - RMS deviation = 0.0296

Shear rate - maximum = 162.5820 1/s

Shear rate - 95th percentile = 27.6666 1/s

Shear rate - average = 7.1840 1/s

Shear rate - RMS deviation = 10.4146 1/s

Filling phase results summary for the runner system :

Bulk temperature - maximum (at 26.810 s) = 234.3510 C

Bulk temperature - 95th percentile (at 7.224 s) = 232.3400 C

Bulk temperature - 5th percentile (at 1.348 s) = 230.6400 C

Bulk temperature - minimum (at 27.200 s) = 230.1610 C

Wall shear stress - maximum (at 26.757 s) = 0.3224 MPa

Wall shear stress - 95th percentile (at 11.097 s) = 0.0895 MPa

Shear rate - maximum (at 26.757 s) = 2.5508E+04 1/s

Shear rate - 95th percentile (at 20.099 s) = 726.1260 1/s

End of filling phase results summary for the runner system :

Total sprue/runner/gate weight = 718.7310 g

Bulk temperature - maximum = 233.3670 C

Bulk temperature - 95th percentile = 231.7720 C

Bulk temperature - 5th percentile = 231.1110 C

Bulk temperature - minimum = 230.1610 C

Bulk temperature - average = 231.4020 C

Bulk temperature - RMS deviation = 0.2705 C

Wall shear stress - maximum = 0.2102 MPa

Wall shear stress - 95th percentile = 0.0718 MPa

Wall shear stress - average = 0.0372 MPa

Wall shear stress - RMS deviation = 0.0146 MPa

Frozen layer fraction - maximum = 0.1678

Frozen layer fraction - 95th percentile = 0.1664

Frozen layer fraction - 5th percentile = 0.0656

Frozen layer fraction - minimum = 0.0648

Frozen layer fraction - average = 0.1249

Frozen layer fraction - RMS deviation = 0.0408

Shear rate - maximum = 1.3747E+04 1/s

Shear rate - 95th percentile = 362.9820 1/s

Shear rate - average = 107.3850 1/s

Shear rate - RMS deviation = 184.4410 1/s

Packing phase results summary :

Peak pressure - minimum (at 35.610 s) = 11.5040 MPa

Clamp force - maximum (at 35.610 s) = 124.9621 tonne

Total weight - maximum (at 36.770 s) = 1.0438E+04 g

End of packing phase results summary :

Time at the end of packing = 56.9167 s

Total weight = 1.0336E+04 g

Packing phase results summary for the part :

Bulk temperature - maximum (at 27.200 s) = 232.8270 C

Bulk temperature - 95th percentile (at 27.200 s) = 231.5750 C

Bulk temperature - 5th percentile (at 56.917 s) = 205.2400 C

Bulk temperature - minimum (at 56.917 s) = 86.6060 C

Wall shear stress - maximum (at 27.200 s) = 0.0695 MPa

Wall shear stress - 95th percentile (at 27.200 s) = 0.0258 MPa

Volumetric shrinkage - maximum (at 27.200 s) = 16.2848 %

Volumetric shrinkage - 95th %ile (at 27.200 s) = 15.4508 %

Volumetric shrinkage - 5th %ile (at 36.770 s) = 11.6571 %

Volumetric shrinkage - minimum (at 45.917 s) = 4.9482 %

Total part weight - maximum (at 36.770 s) = 9710.3796 g

End of packing phase results summary for the part :

Total part weight	=	9611.0401 g
Bulk temperature - maximum	=	229.7410 C
Bulk temperature - 95th percentile	=	228.8810 C
Bulk temperature - 5th percentile	=	205.2400 C
Bulk temperature - minimum	=	86.6060 C
Bulk temperature - average	=	222.9560 C
Bulk temperature - RMS deviation	=	8.3225 C
Frozen layer fraction - maximum	=	1.0000
Frozen layer fraction - 95th percentile	=	0.3139
Frozen layer fraction - 5th percentile	=	0.1284
Frozen layer fraction - minimum	=	0.1005
Frozen layer fraction - average	=	0.2012
Frozen layer fraction - RMS deviation	=	0.0544
Volumetric shrinkage - maximum	=	15.1723 %
Volumetric shrinkage - 95th percentile	=	14.8345 %
Volumetric shrinkage - 5th percentile	=	12.0304 %
Volumetric shrinkage - minimum	=	4.9482 %
Volumetric shrinkage - average	=	13.6678 %
Volumetric shrinkage - RMS deviation	=	0.8013 %
Sink index - maximum	=	2.8116 %
Sink index - 95th percentile	=	2.5814 %
Sink index - minimum	=	2.1362 %
Sink index - RMS deviation	=	0.4213 %

Packing phase results summary for the runner system :

Bulk temperature - maximum (at 27.200 s) = 233.3570 C

Bulk temperature - 95th percentile (at 27.200 s) = 231.7730 C

Bulk temperature - 5th percentile (at 56.917 s) = 217.3160 C

Bulk temperature - minimum (at 56.917 s) = 173.5880 C

Wall shear stress - maximum (at 27.200 s) = 0.2118 MPa

Wall shear stress - 95th percentile (at 27.200 s) = 0.0718 MPa

Volumetric shrinkage - maximum (at 36.770 s) = 15.0646 %

Volumetric shrinkage - 95th %ile (at 27.200 s) = 14.6022 %

Volumetric shrinkage - 5th %ile (at 35.610 s) = 11.5733 %

Volumetric shrinkage - minimum (at 36.770 s) = 10.5186 %

Sprue/runner/gate weight - max. (at 35.610 s) = 729.9540 g

End of packing phase results summary for the runner system :

Total sprue/runner/gate weight = 724.9570 g

Bulk temperature - maximum = 226.4740 C

Bulk temperature - 95th percentile = 226.4740 C

Bulk temperature - 5th percentile = 217.3160 C

Bulk temperature - minimum = 173.5880 C

Bulk temperature - average = 224.7350 C

Bulk temperature - RMS deviation = 3.1741 C

Frozen layer fraction - maximum = 0.6531

Frozen layer fraction - 95th percentile = 0.3977

Frozen layer fraction - 5th percentile = 0.2393

Frozen layer fraction - minimum = 0.2389

Frozen layer fraction - average = 0.2760

Frozen layer fraction - RMS deviation = 0.0505

Volumetric shrinkage - maximum = 13.5690 %

Volumetric shrinkage - 95th percentile = 13.5622 %

Volumetric shrinkage - 5th percentile = 11.7025 %

Volumetric shrinkage - minimum = 11.3252 %

Volumetric shrinkage - average = 13.0312 %

Volumetric shrinkage - RMS deviation = 0.5325 %

Sink index - maximum = 2.1760 %

Sink index - 95th percentile = 2.1720 %

Sink index - minimum = 1.9498 %

Sink index - RMS deviation = 0.2244 %

Execution time

Analysis commenced at Sun Oct 04 22:01:01 2009

Analysis completed at Sun Oct 04 22:01:46 2009

CPU time used 23.34 s

APPENDIX C

INJECTION PRESSURE 18MPa

Flow

Flow Analysis

Version: mpi500 (Build 04453)

Analysis running on host: sdn-3caf01b6f59

Operating System: Windows XP Service Pack 2

Processor type: AuthenticAMD x86 Family 15 Model 36 Stepping 2 ~1790 MHz

Number of Processors: 1

Total Physical Memory: 894 MBytes

Date : OCT19-09

Time : 22:04:37

File name : injection_pressure_18~1

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 : Atofina Polypropylene PPC 7760 : Atofina

PVT Model: 2-domain modified Tait

coefficients: b5 = 449.1500 K

b6 = 6.2500E-08 K/Pa

	Liquid phase		Solid phase	
b1m =	0.0012	b1s =	0.0012	m^3/kg
b2m =	8.7170E-07	b2s =	6.1410E-07	m^3/kg-K
b3m =	8.0484E+07	b3s =	1.1012E+08	Pa
b4m =	0.0049	b4s =	0.0051	1/K

b7 = 7.4350E-05 m^3/kg

b8 = 0.1016 1/K

b9 = 8.6730E-09 1/Pa

Specific heat: Tabulated data:

Temperature T (K)	Specific Heat Cp (J/kg-K)
293.1500	1700.0000
333.1500	1700.0000
373.1500	2400.0000
438.1500	2700.0000

Thermal conductivity: Tabulated data:

Temperature T (K)	Thermal Conductivity K (W/m-K)
293.1500	0.2200
473.1500	0.1700

Viscosity model: Cross-WLF

coefficients: n = 0.3037

TAUS = 2.7405E+04 Pa

D1 = 4.6352E+14 Pa-s

D2 = 263.1500 K

D3 = 0.0000 K/Pa

A1 = 32.3360

A2T = 51.6000 K

Transition temperature = 135.0000 C

Mechanical properties data: E1 = 1200.0000 MPa

E2 = 1200.0000 MPa

v12 = 0.4200

v23 = 0.4200

G12 = 422.5400 MPa

Transversely isotropic coefficent of

thermal expansion (CTE) data: Alpha1 = 0.0001 1/C

Alpha2 = 0.0001 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 = 26.7572 s

Injection time has been determined by automatic calculation.

Stroke volume determination = Automatic

Cooling time = 20.0000 s

Velocity/pressure switch-over by injection pressure= 18.0000 MPa

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

20.0000 s 0.0000

Ambient temperature = 25.0000 C

Melt temperature = 230.0000 C

Ideal cavity-side mold temperature = 40.0000 C

Ideal core-side mold temperature = 40.0000 C

NOTE: Mold wall temperature data from cooling analysis not available

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Model details :

Mesh Type = Fusion

Match ratio = 72.4 %

Total number of nodes = 710

Total number of injection location nodes = 1

The injection location node labels are:

428

Total number of elements = 934

Number of part elements = 816

Number of sprue/runner/gate elements = 118

Number of channel elements = 0

Number of connector elements = 0

Average aspect ratio of triangle elements = 11.0981

Maximum aspect ratio of triangle elements = 477.9830

Minimum aspect ratio of triangle elements = 1.2632

Total volume = 1.2048E+04 cm^3

Volume filled initially = 0.0000 cm^3

Volume to be filled = 1.2048E+04 cm^3

Sprue/runner/gate volume to be filled = 897.1610 cm^3

Total projected area = 1020.0500 cm^2

Filling phase results summary :

Maximum injection pressure (at 26.706 s) = 18.3688 MPa

End of filling phase results summary :

Time at the end of filling = 27.2968 s

Total weight = 1.0246E+04 g

Maximum Clamp force - during filling = 52.7940 tonne

Recommended ram speed profile (rel):

% stroke	% speed
0.0000	29.8727
6.9661	29.8727
20.0000	100.0000
30.0000	91.0669
40.0000	73.6765
50.0000	60.8032

60.0000	44.3748
70.0000	29.3791
80.0000	38.5580
90.0000	51.8938
100.0000	14.2845

Melt front is entirely in the cavity at % fill = 6.9661 %

Filling phase results summary for the part :

Bulk temperature - maximum (at 7.224 s) = 233.3130 C

Bulk temperature - 95th percentile (at 11.097 s) = 232.2460 C

Bulk temperature - 5th percentile (at 27.287 s) = 227.7950 C

Bulk temperature - minimum (at 27.287 s) = 166.7770 C

Wall shear stress - maximum (at 26.706 s) = 0.0782 MPa

Wall shear stress - 95th percentile (at 2.749 s) = 0.0348 MPa

Shear rate - maximum (at 27.239 s) = 253.2730 1/s

Shear rate - 95th percentile (at 2.749 s) = 71.8394 1/s

End of filling phase results summary for the part :

Total part weight = 9527.4000 g

Bulk temperature - maximum = 232.7470 C

Bulk temperature - 95th percentile = 231.5590 C

Bulk temperature - 5th percentile = 227.8610 C

Bulk temperature - minimum = 166.7810 C

Bulk temperature - average = 230.0970 C

Bulk temperature - RMS deviation = 1.5429 C

Wall shear stress - maximum = 0.0664 MPa

Wall shear stress - 95th percentile = 0.0270 MPa

Wall shear stress - average = 0.0084 MPa

Wall shear stress - RMS deviation = 0.0090 MPa

Frozen layer fraction - maximum = 0.3442

Frozen layer fraction - 95th percentile = 0.1692

Frozen layer fraction - 5th percentile = 0.0675

Frozen layer fraction - minimum = 0.0000

Frozen layer fraction - average = 0.1150

Frozen layer fraction - RMS deviation = 0.0297

Shear rate - maximum = 142.1420 1/s

Shear rate - 95th percentile = 24.3307 1/s

Shear rate - average = 6.3977 1/s

Shear rate - RMS deviation = 9.2130 1/s

Filling phase results summary for the runner system :

Bulk temperature - maximum (at 26.753 s) = 234.4170 C

Bulk temperature - 95th percentile (at 7.224 s) = 232.3400 C

Bulk temperature - 5th percentile (at 1.348 s) = 230.6400 C

Bulk temperature - minimum (at 27.297 s) = 230.1590 C

Wall shear stress - maximum (at 21.458 s) = 0.3148 MPa

Wall shear stress - 95th percentile (at 11.097 s) = 0.0895 MPa

Shear rate - maximum (at 25.432 s) = 2.5410E+04 1/s

Shear rate - 95th percentile (at 20.099 s) = 726.1260 1/s

End of filling phase results summary for the runner system :

Total sprue/runner/gate weight = 718.4530 g

Bulk temperature - maximum = 233.1750 C

Bulk temperature - 95th percentile = 231.6600 C

Bulk temperature - 5th percentile = 231.0710 C

Bulk temperature - minimum = 230.1590 C

Bulk temperature - average = 231.3440 C

Bulk temperature - RMS deviation = 0.2493 C

Wall shear stress - maximum = 0.2000 MPa

Wall shear stress - 95th percentile = 0.0695 MPa

Wall shear stress - average = 0.0356 MPa

Wall shear stress - RMS deviation = 0.0144 MPa

Frozen layer fraction - maximum = 0.1682

Frozen layer fraction - 95th percentile = 0.1668

Frozen layer fraction - 5th percentile = 0.0665

Frozen layer fraction - minimum = 0.0659

Frozen layer fraction - average = 0.1254

Frozen layer fraction - RMS deviation = 0.0405

Shear rate - maximum = 1.2344E+04 1/s

Shear rate - 95th percentile = 338.7910 1/s

Shear rate - average = 97.2290 1/s

Shear rate - RMS deviation = 166.9870 1/s

Packing phase results summary :

Peak pressure - minimum (at 35.456 s) = 10.9254 MPa

Clamp force - maximum (at 35.456 s) = 118.9895 tonne

Total weight - maximum (at 36.719 s) = 1.0431E+04 g

End of packing phase results summary :

Time at the end of packing = 56.8657 s

Total weight = 1.0335E+04 g

Packing phase results summary for the part :

Bulk temperature - maximum (at 27.297 s) = 232.7470 C

Bulk temperature - 95th percentile (at 27.297 s) = 231.5590 C

Bulk temperature - 5th percentile (at 56.866 s) = 205.3800 C

Bulk temperature - minimum (at 56.866 s) = 86.5730 C

Wall shear stress - maximum (at 27.297 s) = 0.0667 MPa

Wall shear stress - 95th percentile (at 27.297 s) = 0.0242 MPa

Volumetric shrinkage - maximum (at 27.297 s) = 16.2824 %

Volumetric shrinkage - 95th %ile (at 27.297 s) = 15.4540 %

Volumetric shrinkage - 5th %ile (at 36.719 s) = 11.7179 %

Volumetric shrinkage - minimum (at 45.616 s) = 4.9440 %

Total part weight - maximum (at 36.719 s) = 9703.3997 g

End of packing phase results summary for the part :

Total part weight = 9610.0702 g

Bulk temperature - maximum = 229.7430 C

Bulk temperature - 95th percentile = 228.8830 C

Bulk temperature - 5th percentile = 205.3800 C

Bulk temperature - minimum = 86.5730 C

Bulk temperature - average = 222.9670 C

Bulk temperature - RMS deviation = 8.3146 C

Frozen layer fraction - maximum = 1.0000

Frozen layer fraction - 95th percentile = 0.3138

Frozen layer fraction - 5th percentile = 0.1283

Frozen layer fraction - minimum = 0.1004

Frozen layer fraction - average = 0.2011

Frozen layer fraction - RMS deviation = 0.0544

Volumetric shrinkage - maximum = 15.1810 %

Volumetric shrinkage - 95th percentile = 14.8428 %

Volumetric shrinkage - 5th percentile = 12.0453 %

Volumetric shrinkage - minimum = 4.9440 %

Volumetric shrinkage - average = 13.6765 %

Volumetric shrinkage - RMS deviation = 0.8013 %

Sink index - maximum = 2.8206 %

Sink index - 95th percentile = 2.5934 %

Sink index - minimum = 2.1443 %

Sink index - RMS deviation = 0.4216 %

Packing phase results summary for the runner system :

Bulk temperature - maximum (at 27.297 s) = 233.1730 C

Bulk temperature - 95th percentile (at 27.297 s) = 231.6620 C

Bulk temperature - 5th percentile (at 56.866 s) = 217.2010 C

Bulk temperature - minimum (at 56.866 s) = 173.3950 C

Wall shear stress - maximum (at 36.808 s) = 0.2033 MPa

Wall shear stress - 95th percentile (at 27.297 s) = 0.0694 MPa

Volumetric shrinkage - maximum (at 36.719 s) = 15.0768 %

Volumetric shrinkage - 95th %ile (at 27.297 s) = 14.6402 %

Volumetric shrinkage - 5th %ile (at 36.719 s) = 11.6377 %

Volumetric shrinkage - minimum (at 36.719 s) = 10.5916 %

Sprue/runner/gate weight - max. (at 35.456 s) = 729.3510 g

End of packing phase results summary for the runner system :

Total sprue/runner/gate weight	=	724.8370 g
Bulk temperature - maximum	=	226.5050 C
Bulk temperature - 95th percentile	=	226.5050 C
Bulk temperature - 5th percentile	=	217.2010 C
Bulk temperature - minimum	=	173.3950 C
Bulk temperature - average	=	224.7390 C
Bulk temperature - RMS deviation	=	3.2226 C
Frozen layer fraction - maximum	=	0.6542
Frozen layer fraction - 95th percentile	=	0.3985
Frozen layer fraction - 5th percentile	=	0.2392
Frozen layer fraction - minimum	=	0.2387
Frozen layer fraction - average	=	0.2758
Frozen layer fraction - RMS deviation	=	0.0507
Volumetric shrinkage - maximum	=	13.5878 %
Volumetric shrinkage - 95th percentile	=	13.5810 %
Volumetric shrinkage - 5th percentile	=	11.6787 %
Volumetric shrinkage - minimum	=	11.3307 %
Volumetric shrinkage - average	=	13.0457 %
Volumetric shrinkage - RMS deviation	=	0.5360 %
Sink index - maximum	=	2.1806 %
Sink index - 95th percentile	=	2.1765 %
Sink index - minimum	=	1.9543 %
Sink index - RMS deviation	=	0.2252 %

Execution time

Analysis commenced at	Mon Oct 19 22:04:37 2009
Analysis completed at	Mon Oct 19 22:05:26 2009
CPU time used	25.03 s