SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

Injection molding process is the predominant method for producing plastic parts. Injection molded parts like handset casing are best designed through use of injection molding computer simulation because it can save the time and cost. The development of handset casing needs the optimum manufacturability parameters to maximize the quality of the products at lowest cost and highest productivity. There are many defects occurs at finished products when the parameters not defined precisely. This project is to investigate and defined the optimum manufacturing parameters of handset casing using a computer simulation. After reverse engineering of the selected product, the manufacturability parameters will be determined after the properties of product was determined. The properties of the products and manufacturability of the product will be defined using CAE tools and Moldflow Plastic Insight (MPI).

ABSTRAK

Proses suntikan acuan adalah lebih menonjol untuk penghasilan produk plastik. Produk suntikan acuan seperti bekas telefon bimbit adalah terbaik direka melalui simulasi computer suntikan acuan kerana menjimatkan masa dan kos. Pembangunan bekas telefon bimbit memerlukan had-had pembuatan yang optimum untuk meningkatkan kualiti pada kos yang rendah dan produktiviti terbanyak. Banyak kecacatan berlaku pada produk siap kerana had-had tidak ditakrifkan secara tepat. Projek ini bertujuan menyiasat dan mentakrifkan had-had pembuatanyang optimum melalui simulasi komputer. Selepas melakukan pembalikan kejuruteraan pada produk terpilih, had-had pembuatan akan dikenalpasti. Sifat-sifat produk akan dikenal pasti melalui kejuruteraan bantuan computer (CAE) seperti Moldflow Plastic Insight.

ACKNOWLEDGEMENT

Grateful sense goes to Allah, The Most Beneficent and The Most Merciful on His blessing until this thesis produced properly. With a deep sense of gratitude I would like to express my sincere thanks to my supervisor, En Mohd Rashidi Maarof for his attention to guide me on doing this project thesis as well. Thank you too to other lecturers and staffs who help me in this project.

I am appreciates my parents supports, my brothers and my friends who involved during this project done. Thanks a lot. To mother and father, your pray is very meaningful to my life.

I had tried my best to apply the knowledge that you delivered and I hope this can show my full commitment about the project. I am also happy to present everybody who ever involved in one way or another, made significant contributions to various process of this project. I hope I can learn something from this project and everybody can understand all the input inside this thesis.

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INTRODUCTION

1.1 INTRODUCTION

The use of plastic material has grown phenomenally during the last several decades. Application are continually expanding and include both replacement of parts made of more traditional material and creation of new products that otherwise would be impractical, if not impossible to produce without plastics. Handset casing is a one of the applications of the use of plastic material.(Beaumont,2002)

The injection molding process is the predominant method for producing plastic parts. It provides significant advantages over many alternative manufacturing methods use with either plastic material or other competitive materials. This is particular true in the case of product that is to be produced in large quantity. The injection molding process offers the ability to produces parts in large volumes, quickly, with precise detail, excellent repeatability and at minimum cost.

The injection molded parts are best designed through use of injection molding simulation. These programs provide the unique opportunity to evaluate mold filling, packing, cooling, product shrinkage, warpage and structural characteristic before a mold is ever built. The software is useful in simulating and visualizing the performance of the injection molding process. Thus, the competitive edge between competitors is done at lowest possible cost.

1.2 PROBLEM STATEMENT

1.2.1 Problem

Plastic injection molding is one of the most important polymer processing in plastic industry today. However, to produce precise plastic part like handset casing, it need a high skill in mold making and injection molding machine control. Nonaccurate parameters will lead to the defects in product or mold. This can affect the productivity and the production will suffer the high loss.

1.2.2 Solution

To develop a handset casing, there are many manufacturing parameters need to investigate in order to maximize the quality of the casing at the lowest cost and highest productivity rate. There are many defects occurs at finished product when it is ejected from injection mould because the manufacturing parameters was not defined precisely or at optimum condition.

1.3 OBJECTIVE

To investigate manufacturability of handset casing using computer simulation

1.4 SCOPE OF WORK

(i) Do the reverse engineering of selected product

(ii) Use the CAE tool (Moldflow) to investigate the manufacturing parameters.

(iii) Recommend improvement design (if any)

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The objection of design concept for an injection –molded thermoplastic part with a thin shell feature in the computer, communication and consumer electronic product have more space for the tightly packed components. Therefore, the wall thickness of the housing parts will reduce to 1mm or less in thickness from the original of 2-3mm in thickness. [2]

2.2 REVERSE ENGINEERING

While conventional engineering creates a CAD model based on the functional specifications of a new product, reverse engineering uses a manufactured part to produce CAD model. [3] Reverse engineering typically starts with measuring a physical object to reconstruct a CAD model for applications. [4]

The most critical part of reverse engineering is the segmentation process because it seriously affects the quality of the resulting CAD model. To improve the quality of segmentation, it is essential to make use of features (sharp edges and symmetry planes). [4]

2.2.1 Solidworks

SolidWorks recently emerged as one of the 3D product design software for Windows, providing one of the most powerful and intuitive mechanical design solution in its class. In SolidWorks, parts are created by building a “base feature,” and adding other features such as bosses, cuts, holes, fillets or shells. The base feature may be an extrusion, revolution, swept profile or loft. To create a base feature, sketch a two dimensional geometric and move the profile through space to create volume. Geometry can be sketched on construction planes or on planes surfaces of parts. Feature-based solid-modeling program are making two-dimensional design techniques obsolete. [5]

2.2.2 Autocad

Besides the basic function, there are several features of AutoCad that greatly expedite the geometry construction. [6]

AutoCad stores the coordinates of all objects in drawing I a fixed reference frame known as the ‘World Coordinate System”. In the WCS, the X axis is east-west, the Y axis is north-south, and the Z axis. In addition to the WCS, it is possible to create one or more Users Coordinate System (UCSs), which involve a temporary shift of the origin point and orientation of X, Y and Z axis. Control of the coordinate system is provided by the UCS command. Autocad uses the standard mathematical convention for angles, with 0° along the positive X axis and positive angles measured counterclockwise. [7]

The integrated CAD system is composed of an input and shape treatment module, a production feasibility check module, a blank –layout module, strip layout module, die layout module and drawing edit module. [8]

2.2.3 3D Plotter

3D Plotter is a type of Coordinate Measuring Machine (CMM). CMMs have become very powerful parts of measuring tools. The CMM is a Cartesian robot, which has a touch-trigger probe in place of a gripper. They are CNC machines, flexible and repeatable for the faster measurement of real parts. CMMs are used in surface and boundary continuous probing or scanning of parts as well as the extraction of geometric feature data from point cloud data. The number of measurement touch point is determines by CMM according to the curvature change of the part surface measured on the tactile point. The measurement result are in suitable digital form, which unlike analog data, necessitate no further process. [9]

2.3 MATERIAL

2.3.1 Acrylonitrile Butadiene Styrene (ABS)

ABS plastics are two-phase system. Styrene- acrylonitrile (SAN) forms the continuous matrix phase. The second phase is composed of dispersed polybutadiene particles, which have a layer of SAN grafted onto the surface.[10]

ABS offer superior processibility and appearance as well as low cost, along with good balance of engineering properties.

Table 2.1: General properties of Acrylonitrile Butadiene Styrene

General properties of ABS	
Specific gravity	1.05
Tensile modulus @73 °F (MPsi)	0.3
Tensile strength @yield (Kpsi)	5.0
Notch izod impact @73 °F (ft-lb/in)	2.5-12.0
Thermal limits service temp (°F)	167-185
Shrinkage (%)	0.4-0.7
Tg(°F)	185-240
Process temp, (°F)	410-518
Mold temp(°F)	122-176
Drying temp(°F)	176-185
Drying time (s)	2.0-4.0

Source: Campo (2006)

2.3.2 Polycarbonate + Acrylonitrile butadiene styrene blend (PC+ ABS)

A compounded blend of polycarbonate and ABS. the PC contribute impact and heat distortion resistance, while the ABS contributes processability and chemical stress resistance and cost reduction below PC. [10]

Table 2.2: General properties of Polycarbonate+ Acrylonitrile Butadiene Styrene

General properties of PC+ABS	
Specific gravity	1.07
Tensile modulus @73 °F (MPsi)	0.8
Tensile strength @yield (Kpsi)	9.8
Notch izod impact @73 °F (ft-lb/in)	3.4-6.4
Thermal limits service temp (°F)	180-206
Shrinkage (%)	0.3-0.5
Tg(°F)	210-235
Process temp, (°F)	460-541
Mold temp, (°F)	154-193
Drying temp, (°F)	192-216
Drying time,(s)	2.0-4.0

Source: Campo (2006)

2.3.3 Polycarbonate (PC)

Polycarbonate is an amorphous engineering thermoplastic material with exceptional high impact strength, transparency, high temperature resistance and dimensional stability. Polycarbonate has high corona resistance and insulation resistance properties, as well as a dielectric constant that is independent of temperature [10]

Table 2.3: General properties of Polycarbonate

General properties of PC	
Specific gravity	1.40
Tensile modulus @73 °F (MPsi)	1.25
Tensile strength @yield (Kpsi)	19
Notch izod impact @73 °F (ft-lb/in)	1.7-3.0
Thermal limits service temp (°F)	220-265
Shrinkage (%)	0.15-0.6
Tg(°F)	293-300
Process temp, (°F)	430-620
Mold temp, (°F)	175-220
Drying temp, (°F)	250-260
Drying time, (s)	2.0-4.0

Source: Campo (2006)

2.4 INJECTION MOLDING

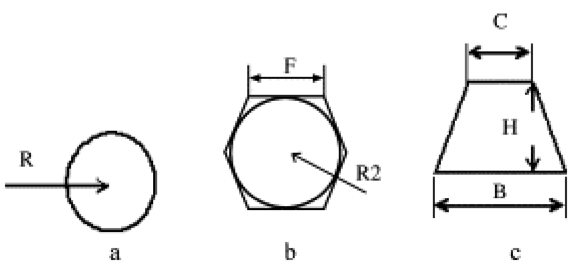
2.4.1 Thin wall molding

Thin wall molding is a high speed, high pressure injection molding process for producing parts with a nominal wall thickness less than 1.2mm or flow-length-to-wall-thickness ratios ranging from 100:1 to 150:1 or more. This process becomes increasingly important due to the economic advantages of using thin walls and the unpredicted growth of portable electronic and communication devices that require thinner, smaller and lighter housings. [11]

In thin wall molding, the packing pressure is the most influential factor. The second is mold temperature, followed by the melt temperature and the packing time. The less influential factors are the gate dimension and filling time. [12]

2.4.2 Runner layout

Depending on the requirement, many type of runner cross section can be used. The appropriate lengths and the areas of the cross sections are computer from this constant value of area by the equations given below: [14]



$$\text{(a) } A = \pi R^2 \tag{1}$$

$$\text{(b) } A = \frac{3FR_2}{2}, \quad R_2 = F\sqrt{3} \tag{2}$$

$$\text{(c) } A = \frac{(B+C)\times H}{2} \tag{3}$$

Source: Ozcelik (2005)

2.4.3 Undercut

Undercut features parameters are undercut feature volume and undercut feature direction. The undercut features can be determined based on the geometric entities of the undercut features, while undercut direction can be determined by the visibility map of the undercut surface. [15]

2.4.4 Cavity balancing

Cavity balancing is still one area that depends heavily on human interaction and input. The primary aim of cavity balancing is to fulfill the design criteria whereby the flow front of the plastic melt reaches the boundary or extremities of the mold at about the same with equal pressure. Balance flow is critical to the quality of the final product, as unbalanced flow during filling often leads to warping. [16]

2.5 MOLDFLOW

Moldflow Plastic Insight (MPI) software is an integrated suite of analysis tools that utilize CAD files and apply advanced Finite Element Analysis (FEA) techniques to quickly and easily enable a virtual design environment before initiating mold construction.

2.5.1 Gate location

The placement of gate in an injection mold is one of the most important variables of the total mold design. The quality of the molded part is greatly affected by the gate location, because it influences the manner in which the plastic flows into the mold cavity. Some defects, such as overpack and warpage can be effectively controlled by the gate location. Therefore, product quality can be greatly improved by having an optimum gate location. [17]Proper gate location leads to a better resin flow and shorter hesitation time. [18]

The success of filling and curing stages in liquid composite (LCM) depends in many variables such as location of gates and vents, temperature distribution, flow rate, injection pressure, etc. the process performance index based on gate-distance of the resin located on the flow front at different time steps. A good process should have short filling time and a vent –oriented flow with a desired resign flow pattern. At a given time step, the distances from the nodes located on the resin flow front to the outlet are associated with the quality of the filling process. The standard deviation of those distances is used to evaluate the shape of the flow front (the smaller the better). [19]

2.5.2 Fill time

The fill time represent the behavior of the melt polymer at regular intervals. Thermoplastic flow inside the mold using calculates a flow front that grows from interconnecting nodes at each element, starting at the injection nodes.[20]

2.5.3 Warpage

Warpage is the result of differential shrinkage. If the shrinkage of a material were completely isotropic with respect to thickness, flow direction and distance and pack pressure, plastic part would not warp. [21]

The small packing pressure can lead to high warpage value. The increasing of melt temperature can causes a decreasing on warpage.[22]

Mold thicknesses have an effect on the warpage of the part. The graph shows that the thicker package reduces warpage, because of the rigidity of the package increases. [23] The residual warpage on part can be decreased using an additional film on top of the package or by increasing the mold thickness.[24]

Thermal warpage resulting from unbalanced cooling in a flat plate of amorphous polymer. The thinnest part warps the greatest amount because its relatively small second moment of area in bending. The warpage is predicted from the temperature difference between the upper and lower surfaces, the temperature distribution, flow-induced shear stress, shrinkage, and anisotropic mechanical properties caused by fiber orientation. Higher shear stress on the material and more molecular orientation will be expected contribute to warpage. The higher L: T (length to thickness) ratio will also result in more warpage[25]

CHAPTER 3

METHODOLOGY

3.1 FLOW CHART/ PROJECT FLOW

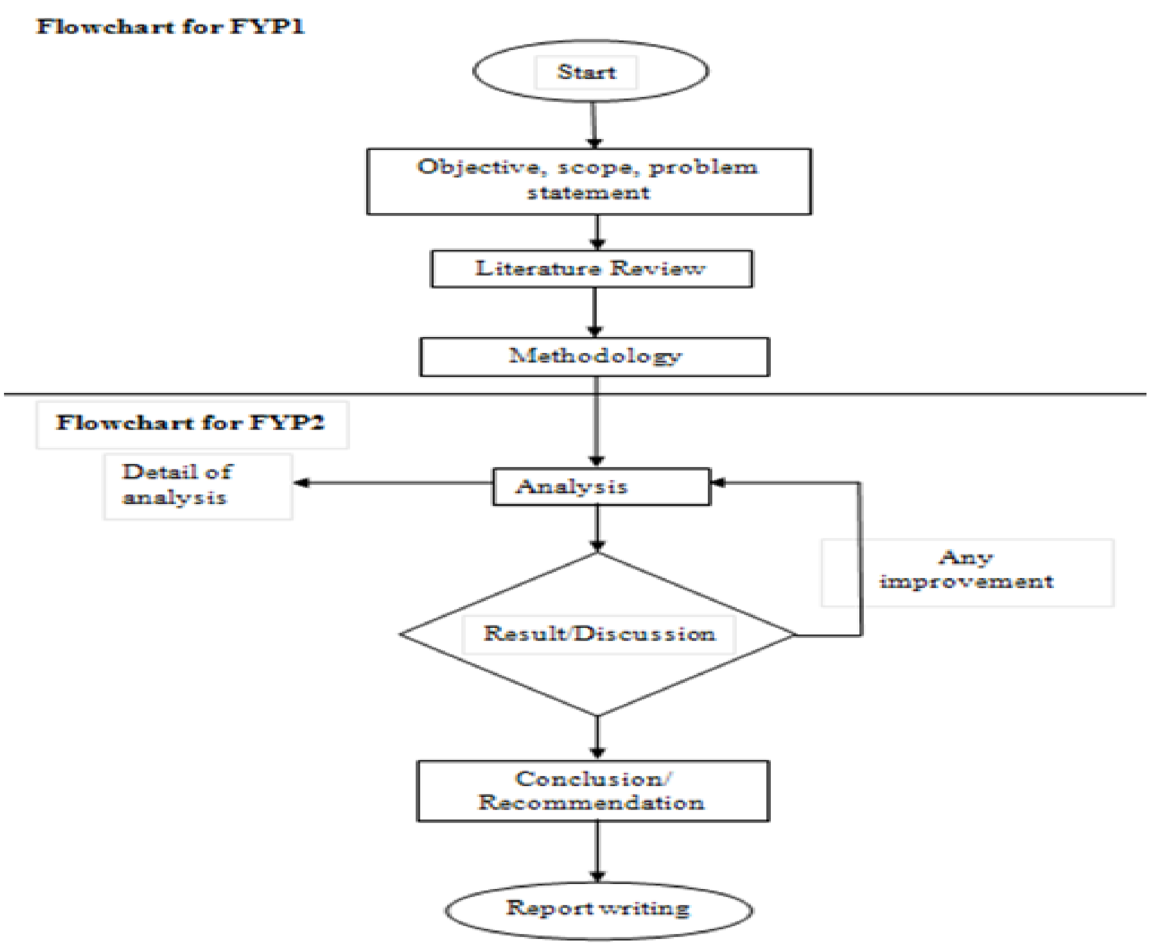


Figure3.1: Project flow chart for FYP1 and FYP2

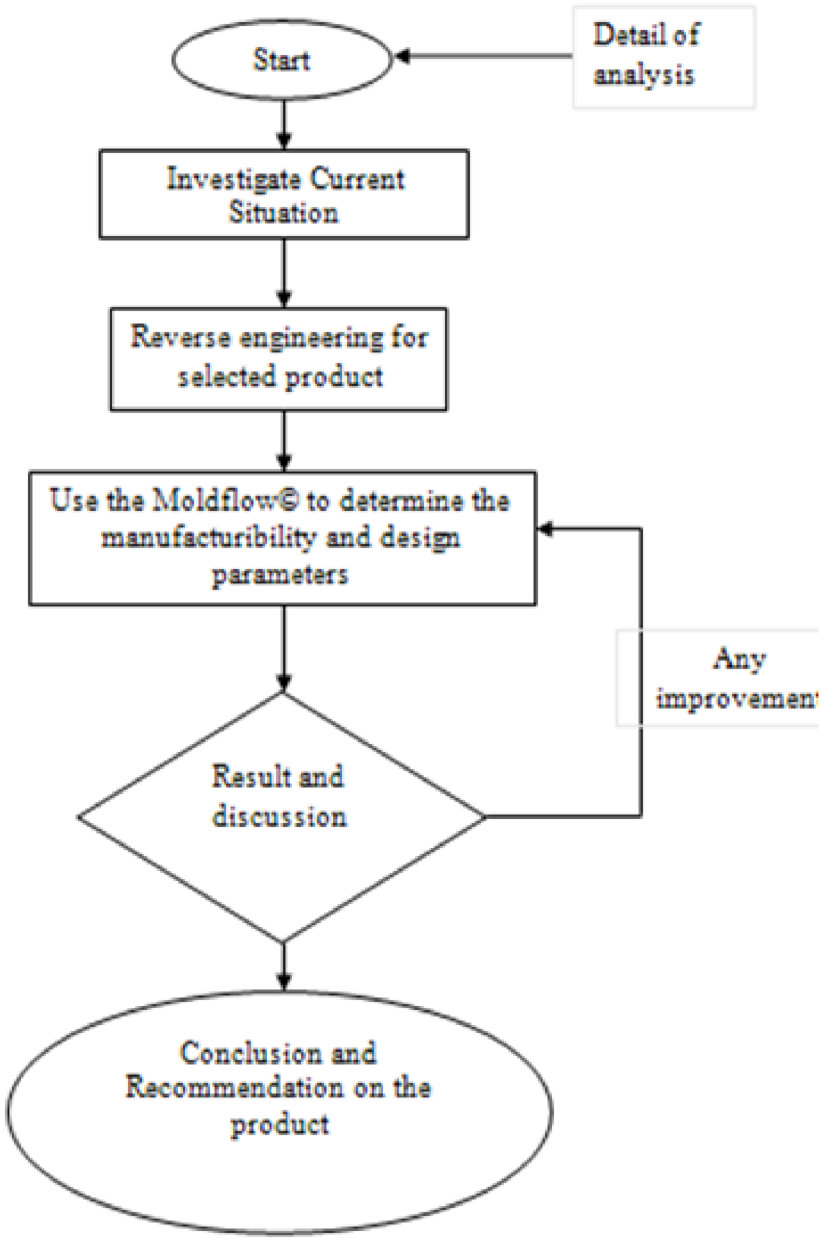


Figure 3.2: Project Flow Chart for Detail of Analysis

3.2 RECEIVED FYP TITLE

After received the title of final year project, my supervisor and I make discussion about it. We discuss about problem statement, objective and scopes of work of this project.

3.3 LITERATURE REVIEW

After discuss about the project detail, I make a literature review. I got the information about the project in journal, book and others project.

3.4 METHODOLOGY

Methodology is a important element in a project where it specifically describes the method to be used in the project. It is also can be a guideline to ensure we are following the project flow that we have planned at the beginning. Methodology also will help in order to make sure that the research run smoothly until we get the result and achieve the project objective.

3.4.1 Analysis Current Situation

Before getting start to make analysis, I make some review on current situation like the material that commonly use in production of handset casing, the latest innovation and the problem that being face by selected model. I choose NOKIA 1100 casing as my model.

Figure 3.3: selected model (NOKIA 1100)

Figure 3.4: casing of NOKIA 1100

3.4.2 Reverse Engineering

3.4.2.1 CMM measurement and Creation of Point Cloud

The major system components are the 3 axes mechanical set-up, the probe head, control unit and PC. The CMM which is used here is a Roland 3D Plotter. The main application software utilized is the Autocad 2007 and DrPicza measurement software. The operating is Windows XP on PCs.

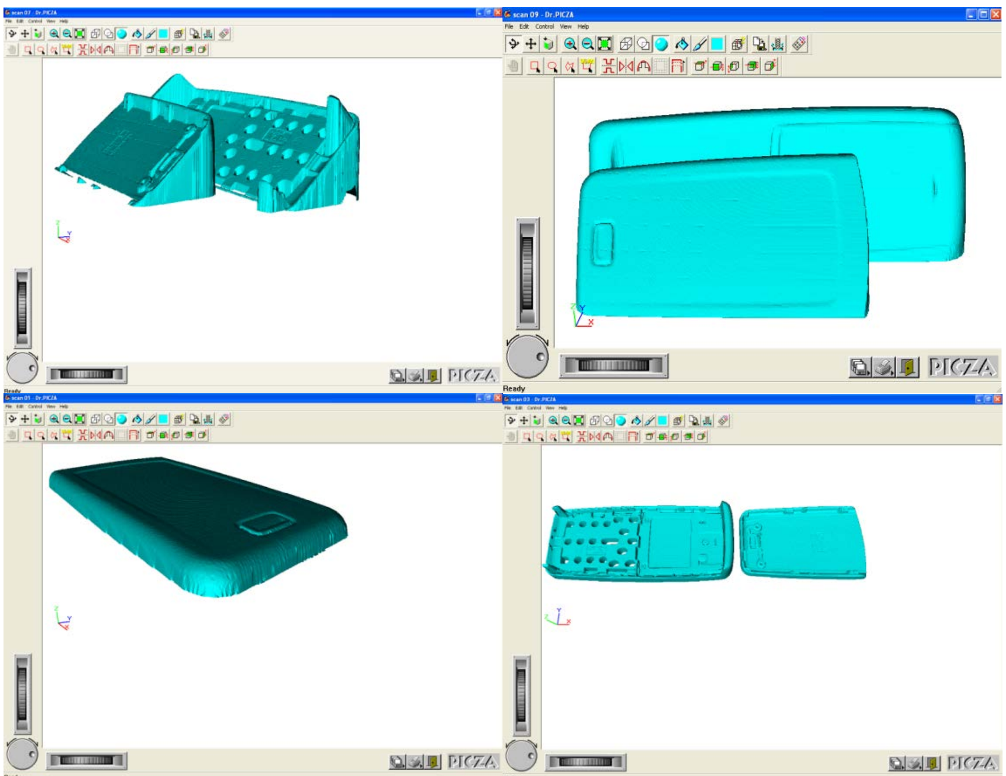


Figure3.5: measured contour in point cloud format

The data which in point cloud format cannot be exported directly to the Polyworks for editing. This is because the geometry error and there are break point in that measured data. Thus, the data are converted to DFX format which will be exported to Autocad to get their dimension.

3.4.2.2 Processing of measurement data

The output data of the CMM is created directly from measurement data using AutoCad 2007 software after processing of measurement data and transforming of data format. To the model the part surface in CAD model, we need to define surface features from the cloud of points obtained by digitization. The surface features contain surface segments and boundaries. After the data imported to the AutoCad, we can determined their dimensions.

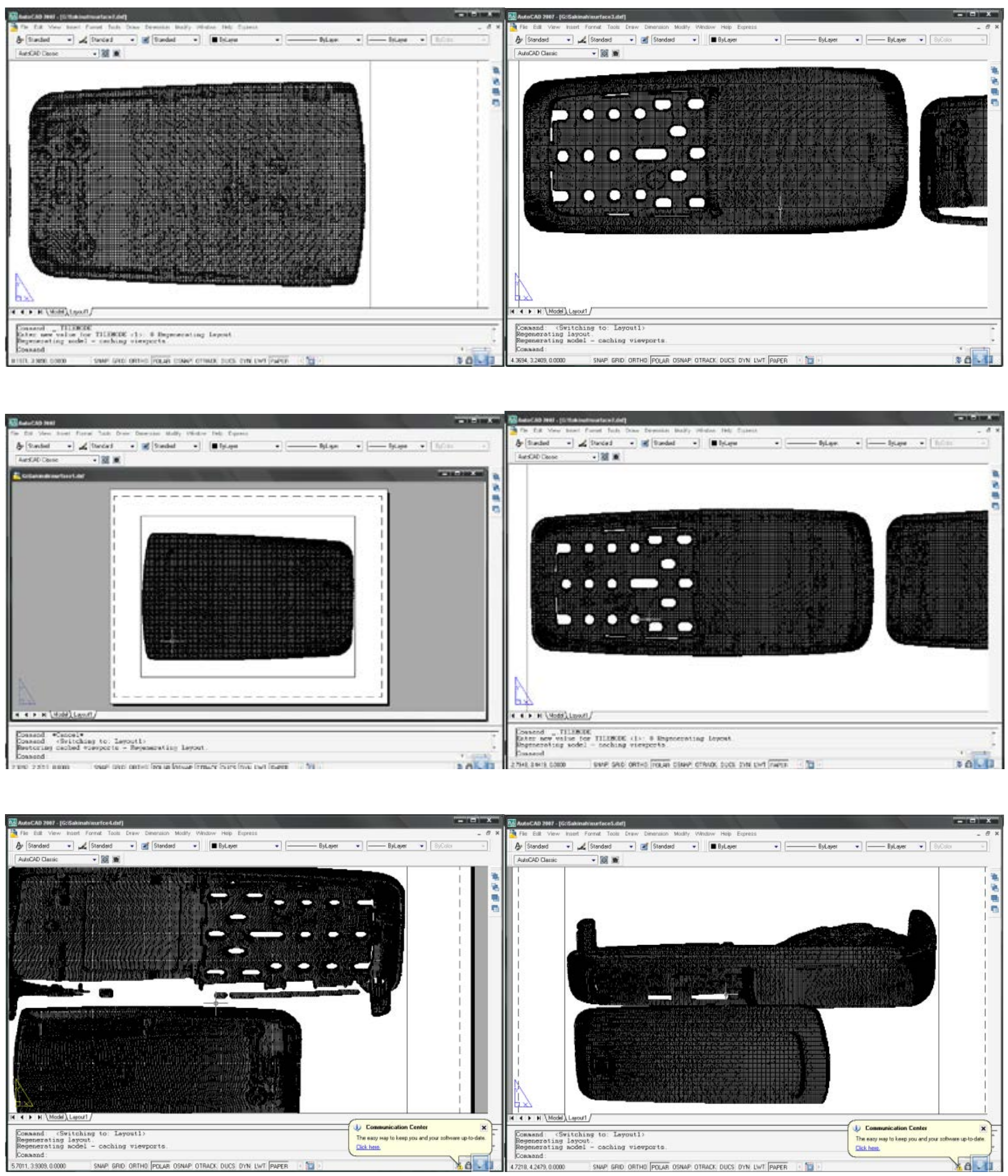


Figure 3:6: Measured data in DFX format

3.4.2.3 CAD Model construction

After getting the model dimension, we can reconstruct the model using the dimension that we get in CAD software. Here, I use SolidWorks 2007. The finishes reconstructed model will be save in STEP format because it will be used in MoldFlow Plastic Insight.

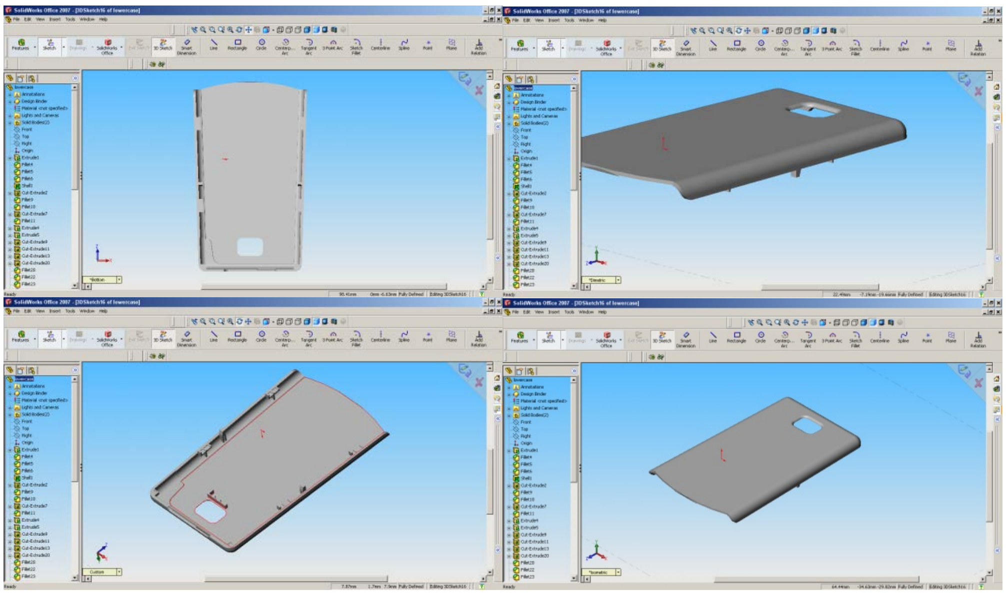


Figure 3.7: lower case reconstructed model

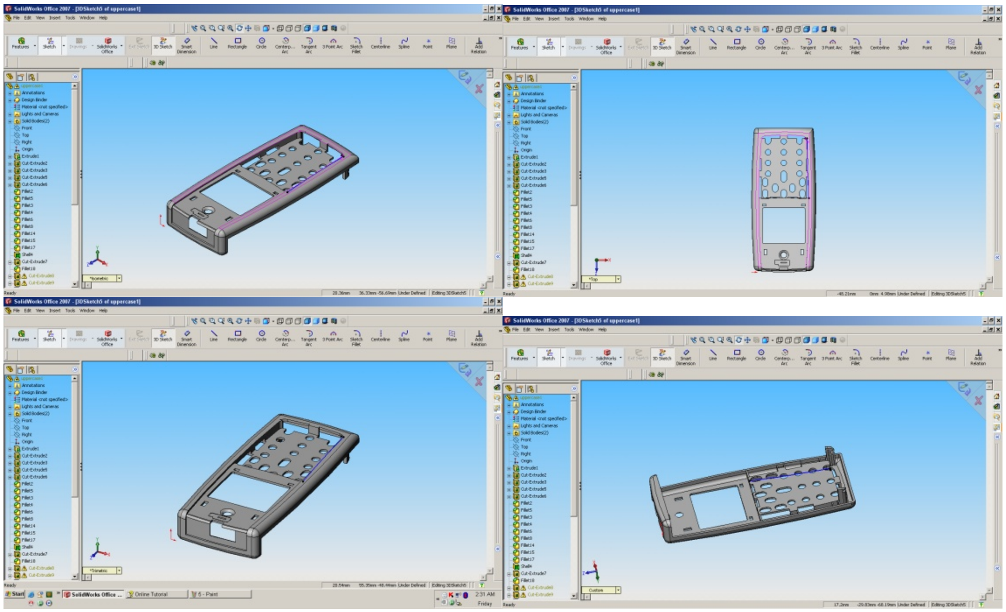


Figure 3.8: upper case reconstructed model

3.4.3 MOLDFLOW PLASTIC INSIGHT

Moldflow Plastic Insight was used to analysis and test the manufacturing parameters of the handset casing.

3.4.3.1Material Selection

Three most commonly used materials in plastic thin shell part are selected. For ABS, I choose Toyolac Parrel TP90-X02. For PC+ABS, I choose Toyolac Parrel TX100 and for PC, I choose Macrolon 2803.

3.4.3.2 Gate Location

After the material was selected, we must determine the best gate location. It is because gate location is the most main factor in injection molding analysis. It has a big affect in injection molding design and will affect the quality of the part that will produce.

3.4.3.3Fill Analysis

After the gate location was determined, the fill analysis can be determined. From this analysis we can know the pressure, fill time, weld line, air trap and injection velocity.

The effect of injection velocity on pressure also was be experimented. This is because we want to see the relationship between the injection velocity and injection pressure.The variables and parameters as below:

Table 3.1: effect of injection velocity on pressure to fill

fill time (s)	pressure to fill (Mpa)		
	ABS	PC+ABS	PC
0.1			
0.2			
0.3			
0.4			
0.5			
0.6			
0.7			
0.8			
0.9			
1			

As we know, the lower fill time mean the higher injection velocity. The range is set between 0.1s to 1 s because the normal fill time is about 0.5s to 1.0s. If the fill time is higher than that, there is error on the geometry of the part.[]

3.4.3.4Warping Analysis

The warpage is like an indicator of the quality of the injection molding part. The effect of the temperature, pressure and fill time on warpage was being experimented. The variables and parameters as below.

Table3.2: Effect of melting point on warpage

melting point (°C)	warpage (mm)		
	ABS	PC+ABS	PC
190			
200			
210			
220			
230			
240			
250			
260			
270			
280			

The values of melting point are set from the lowest melting point of ABS till the highest melting point of PC.

Table 3.3: Effect of mold temperature on warpage

mold temp (°c)	warpage (mm)		
	ABS	PC+ABS	PC
50			
60			
70			
80			
90			
100			

The values of mold temperature are set from the lowest mold temperature of ABS till the highest mold temperature of PC.

Table 3.4: Effect of filling time on warpage

filling time (s)	warpage (mm)		
	ABS	PC+ABS	PC
0.2			
0.3			
0.4			
0.5			
0.6			
0.7			
0.8			
0.9			
1			

The ranges of variables are set between 0.1s to 1 s because the normal fill time is about 0.5s to 1.0s.

Table 3.5: effects of packing pressure on warpage

packing pressure(MPa)	warpage (mm)		
	ABS	PC-ABS	PC
30			
40			
50			
60			
70			
80			
90			

The values of packing pressure are set from the lowest packing pressure of ABS till the highest packing pressure of PC.

3.5 RESULT AND DISCUSSION

The results that being get from the reverse engineering and analysis will be define. That result also will be compared will others findings or journal to make sure that result is valid.

3.6 CONCLUSION AND RECOMMENDATION

Conclusion and recommendation will be made based on the result and discussion that being got in reverse engineering and analysis.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will discuss the analysis result. All the handset casing manufacturing parameters must be considered in this chapter before making any conclusion. This parameter need to be considered because they have main effect in quality and productivity. All the manufacturing parameters were being design and analysis through Moldflow Plastic Insight. Before analysis being started, CAD model was being mesh at 1.6 mm density. All the error in geometry was corrected before the analysis can be made. All the analysis taking about 20 hour using HP Workstation Intel Pentium Dual Core.

4.2 REVERSE ENGINEERING

The CAD model that being reconstructed through reverse engineering are used in the analysis. There are some error in the geometry of CAD model and some of the error can’t be repaired. This make a CAD model not perfect but still can go through the MPI analysis.

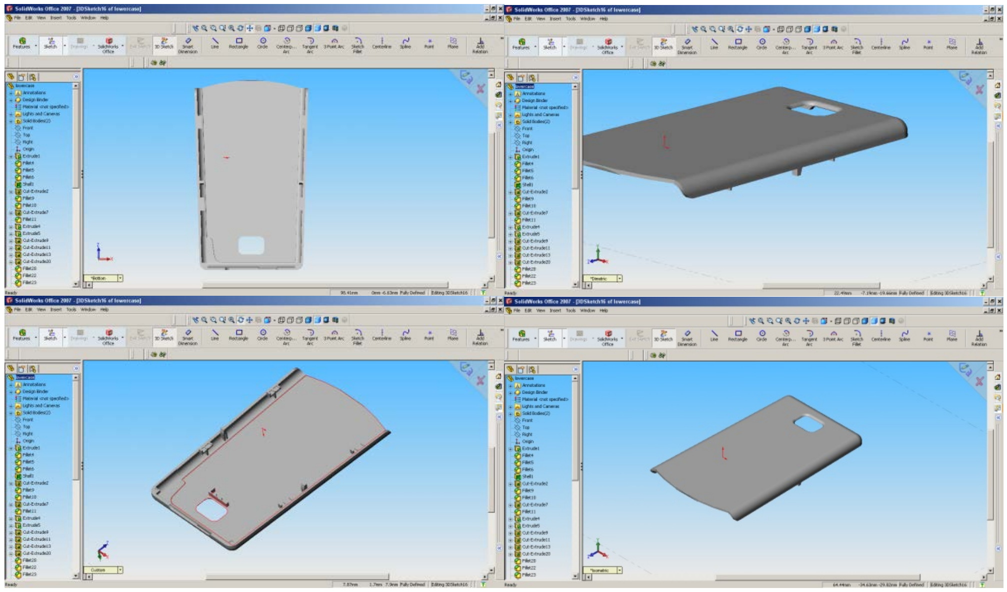


Figure 4.1: reconstructed lower case

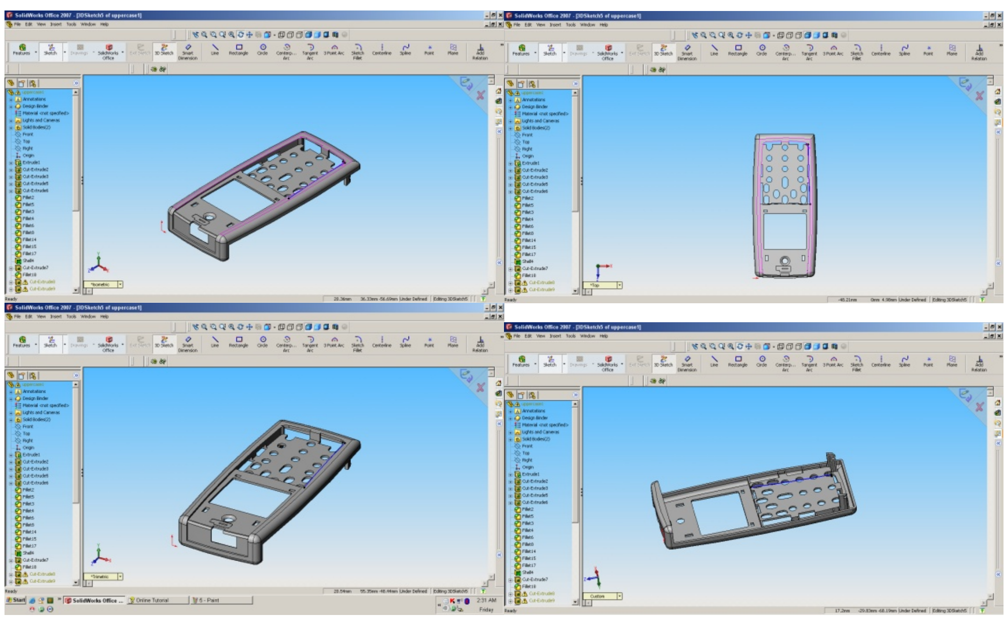


Figure 4.2: reconstructed upper case

4.3 MOLDFLOW ANALYSIS

4.3.1 Best Gate Location

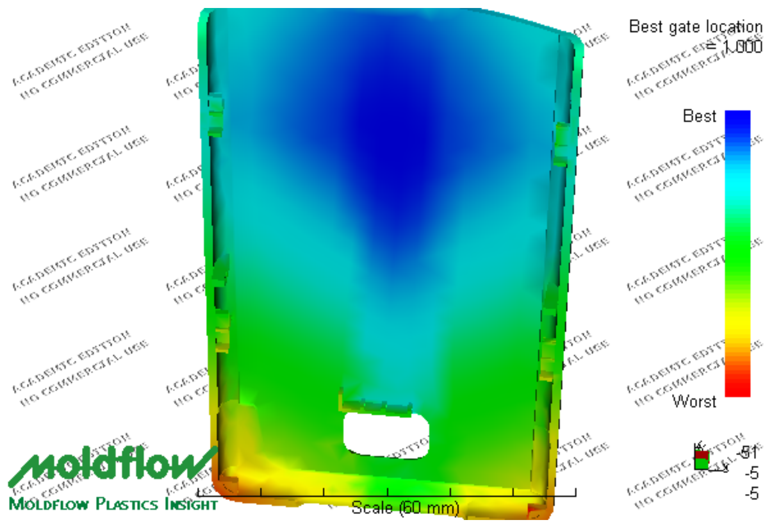


Figure 4.3: lowercase best gate location

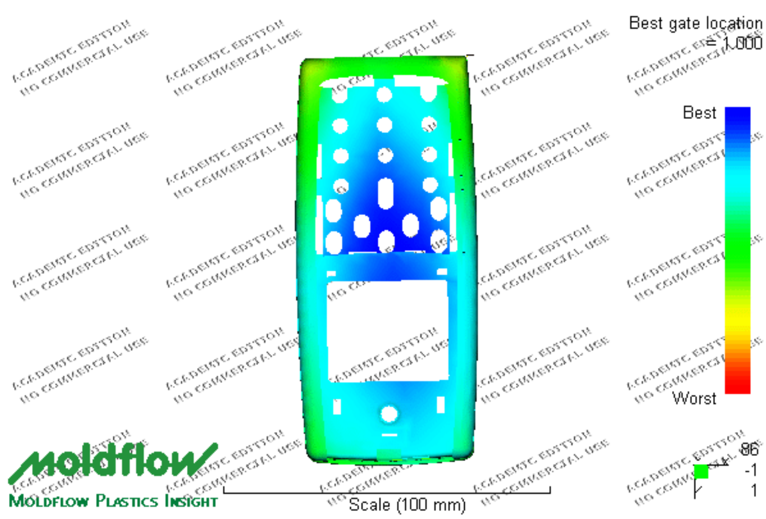


Figure 4.4: uppercase best gate location

From the result of the best gate location, we can determine the type of mold. Hence the gate location is at the center of the casing, 3 plates mold is the most suitable type and the pinpoint gate is the best gate type for this casing.[26]

4.3.2 Fill Analysis

4.3.2.1 Fill time

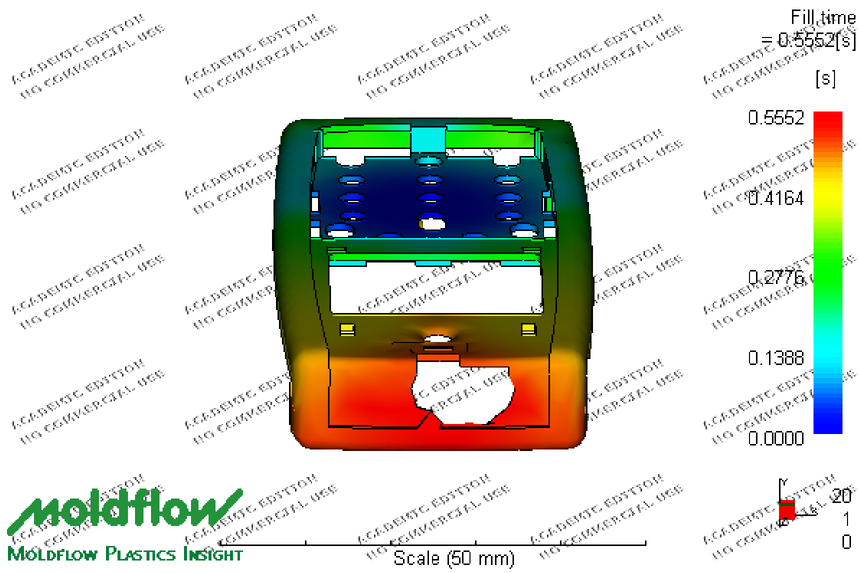


Figure 4.5: Fill time

Table 4.1: Fill time on different material

Material	ABS	PC+ABS	PC
Fill time(s)	0.5552	0.5563	0.5614

The result show different fill time value for different material. The more viscous material has greater fill time value. The more viscous material faced with bad liquidity which leads to greater fill time. [27] Thus, ABS which has lowest viscosity time is better than other material in term on fill time.

4.3.2.2 Pressure

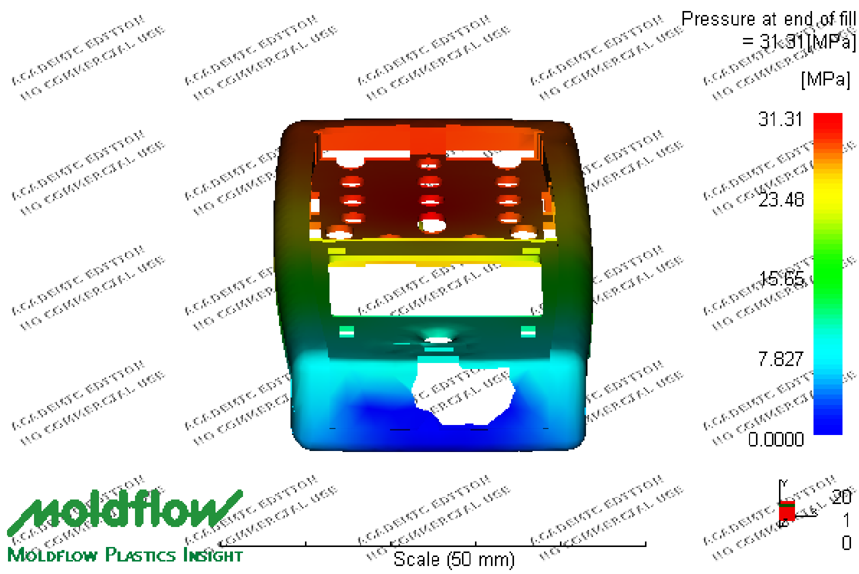


Figure 4.6: pressure at the end of fill

Table 4.2: pressure at the end of fill at different material

Material	ABS	PC+ABS	PC
Pressure (MPa)	31.31	36.14	38.29

The result shows different value of pressure at different material. The material that has greater viscosity has greater pressure. This is because the larger pressure needs to overcome the shear stress in the fountain flow [27]. The larger pressure sometimes can lead to the defect like air trap, flash and burn marks. The ABS is better because it require the less pressure.

4.3.2.3 Freezing

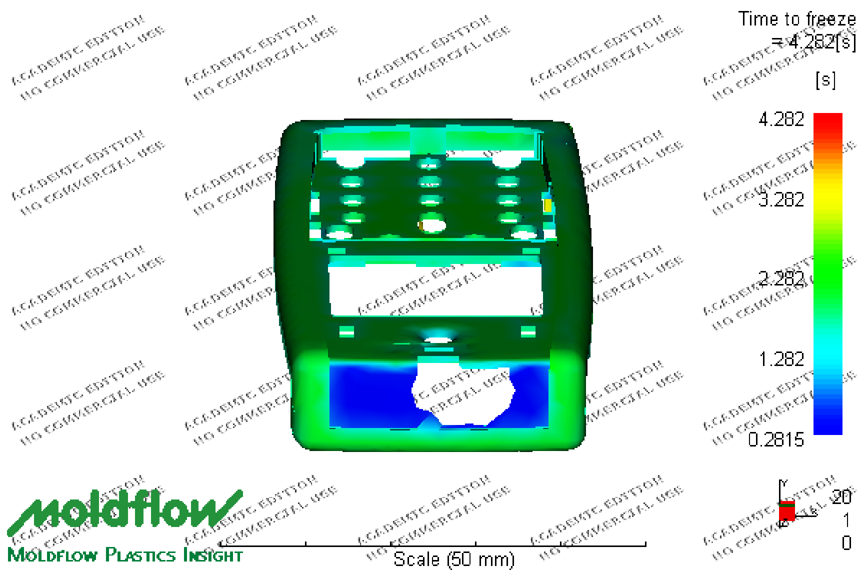


Figure4.7: time to freeze

Table 4.3: time to freeze for different material

Material	ABS	PC+ABS	PC
Time to freeze (s)	4.282	4.576	4.927

The PC has greater time to freeze because it has a greater thermal limit service temperature. Thus, it will freeze slower than PC+ABS and ABS. The part will have the smallest thickness will be freeze easily compared at other part.

4.3.2.4 Weld line

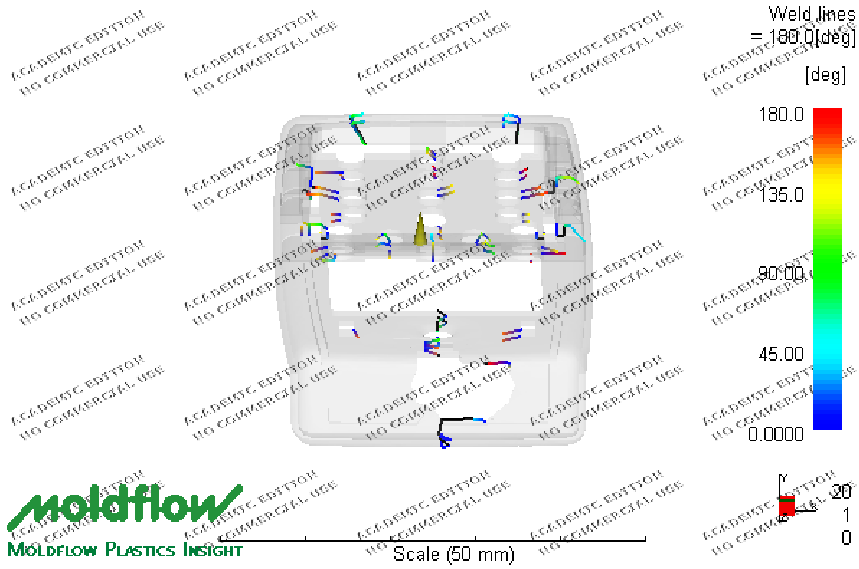


Figure 4.8: prediction of weld line

For the all material that being used, the weld line locations are same. Thus, we can say that the material do nothing about the weld lines. The weld lines occur because of the geometry of the model and the gate location. The weld line occurs at the part where the flows from opposite direction meet. Thus, to improve the weld line, we need to improve the gate location and the geometry.

4.3.2.5 Air trap

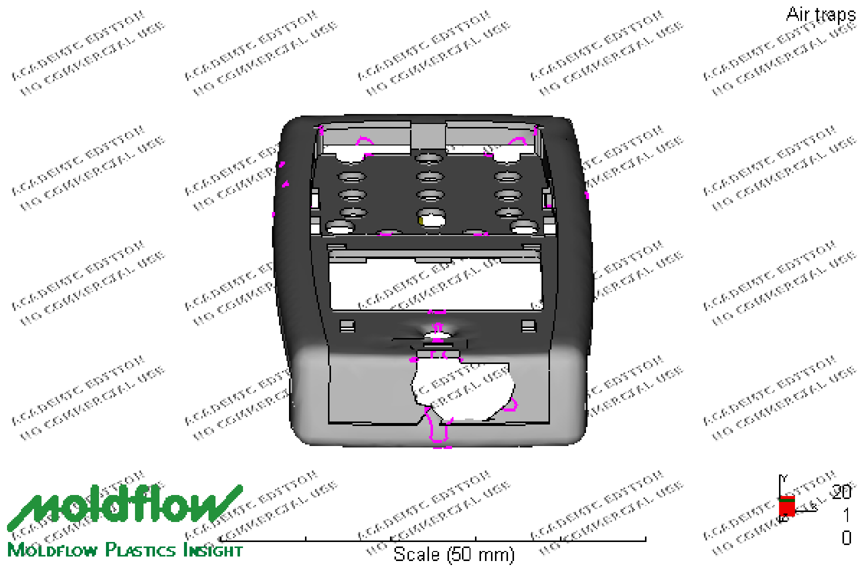
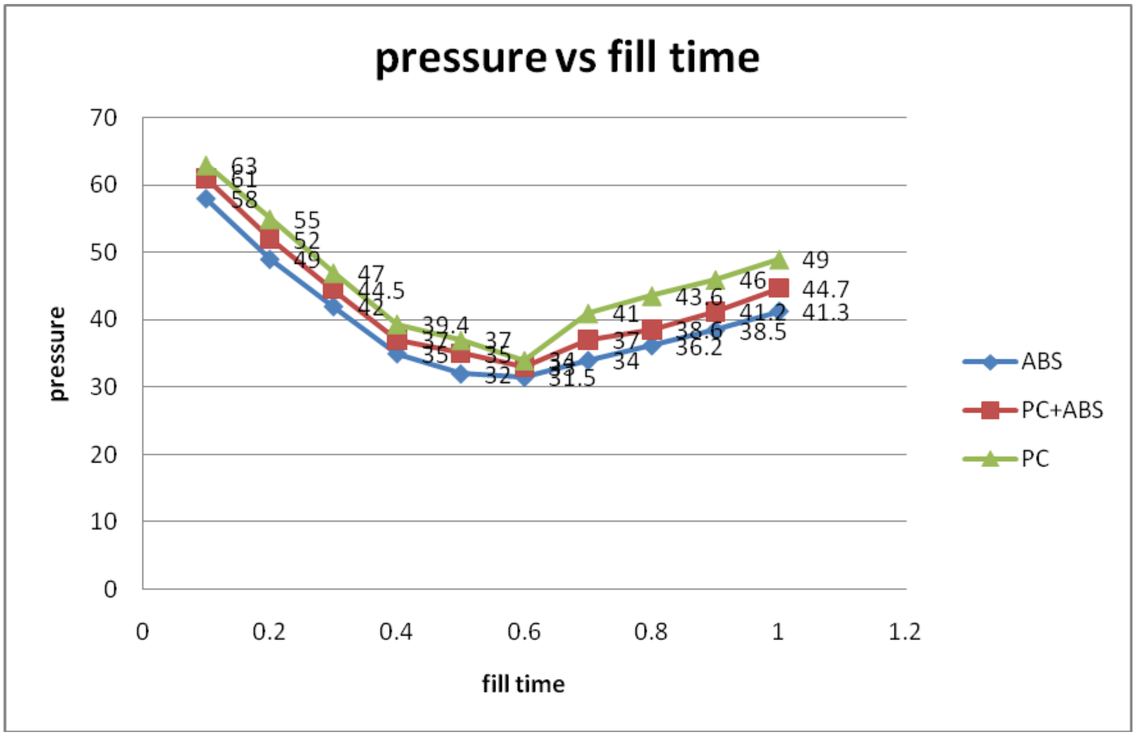


Figure 4.9: prediction of air trap

For the all material that being used, the air trap location are same. Thus, we can say that the material do nothing about the air trap too. The air trap occurred because of no air vent at that location. Thus, we can put some air vent or put the ejector pin as a vent at that location.

4.4 EFFECT OF FILL TIME OVER INJECTION PRESSURE



Graph 4.1: Effect of fill time on injection pressure

From the graph, the pressure was decreasing linearly from fill time 0.1s to 0.6s.From 0.6s, the pressure increasing. The fill time is about 0.5s-0.6s depending on the material. That show that before fill time reach optimum value, the pressure will drop. When the fill over the optimum value, the pressure will increase. The more viscous material has greater injection pressure because it wants to overcome the shear stress that occurred in fountain flow. The greater injection pressure will lead to the defects like flash, burn marks, short shot and so on [28]. Thus, we must consider the lowest injection pressure as possible as the optimum injection pressure.

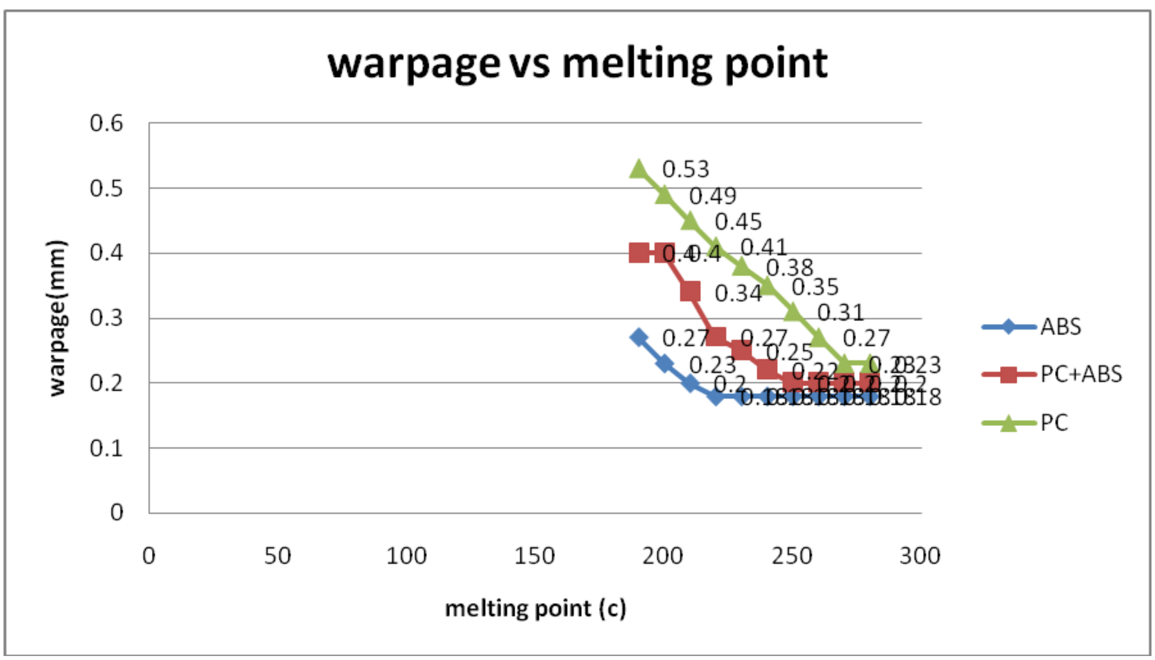
Table 4.4: optimum injection pressure at different material

material	ABS	PC+ABS	PC
Optimum injection pressure (MPa)	31.5	33	34

4.5 WARPAGE ANALYSIS

4.5.1 Effect of Melting Point

The handset casing is 102mm length, 44 mm width, 16mm height and 0.8mm thicknes. The warpage is quantified by the out-of plane displacement, which is the sum of maximum upward deformation with reference to the default plane in Moldflow.[29]



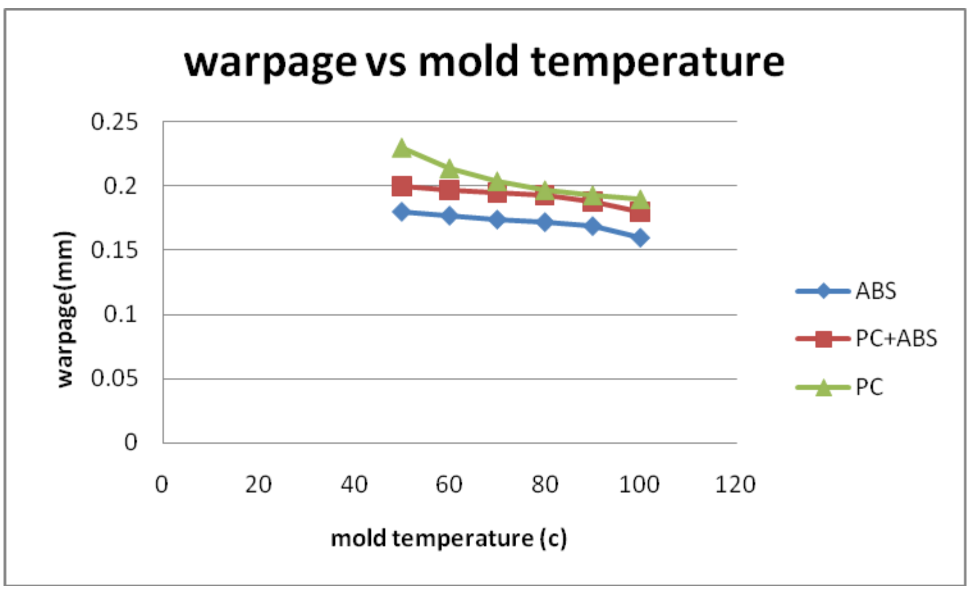
Graph 4.2: Effect of melting point on warpage

The value of warpage decreasing nonlinearly until at certain temperature point. After that ,the warpage become constant. At the point warpage become constant, there is optimal melting point. The value of warpage decreasing at first because the low melt temperature has bad liquidity and can lead to early formation of frozen skin layer, which can generate higher shear stress and block flow[30]. If there is no enough time to release the shear stress, the warpage will increase. thus, high melt temperature is desirable.

Table 4.5: Optimum melt temperature at different material

material	ABS	PC+ABS	PC
Optimum melt temperature (°C)	220	250	270

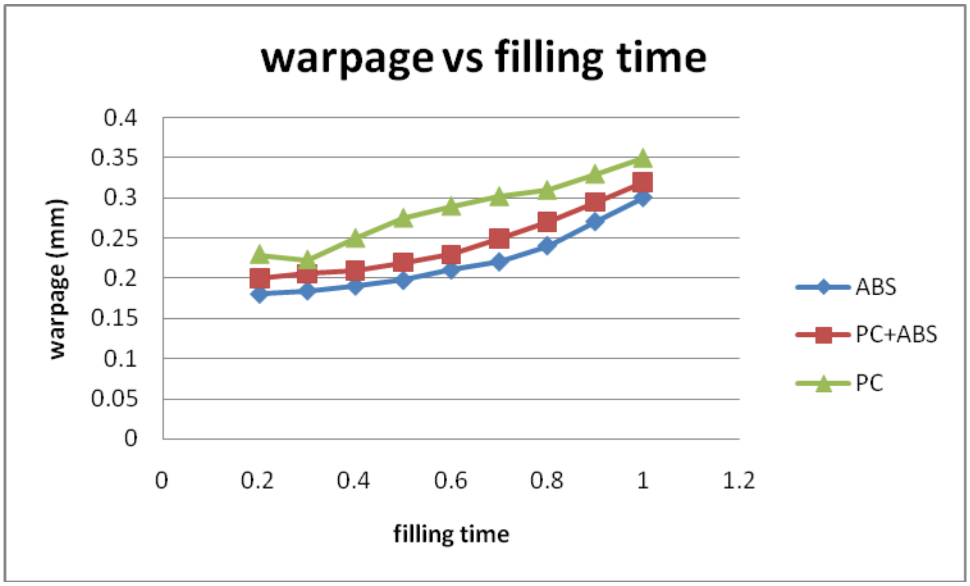
4.4.2 Effect of mold temperature on warpage



Graph 4.3: Effect of mold temperature on warpage

Same as the melting point, higher mold temperature will offer better liquidity which will result the smaller warpage. But the mold temperature just has a little effect on the warpage unlike the melting temperature. [31]

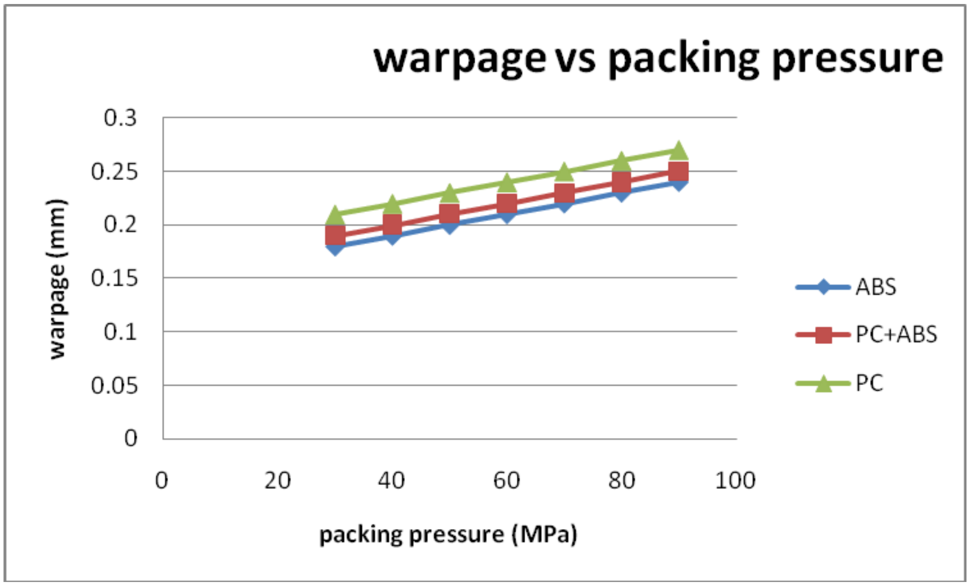
4.4.3 Effect of filling time on warpage



Graph 4.4: Effect of filling time on warpage

Filling time has an important effect on warpage. For the thin wall injection molding, the frozen layer plays an important role. Long filling time will increase the ratio of frozen skin layer to the molten core layer [32]. This can block the flow and lead to higher shear stress and more molecular orientation in the material. Thus, warpage will increase sharply from 0.6s to 0.8s.

4.4.4 Effect of packing pressure on warpage



Graph 4.5: effect of packing pressure on warpage

It can be noted that warpage increasing linealy with packing pressure. High packing pressure can push more melt into the cavity, but will generate high residual stress induced by melt flow. High packing pressure also will make more pressure difference between the locations near gate.[33] High residual stress and pressure difference both contribute to warpage, so high packing pressure is undesirable for thin wall parts.[34]

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this study, the manufacturing parameters of handset casing for different materials were being investigated.

Table 5.1: comparison manufacturability at different type of thermoplastic

	ABS	PC +ABS	PC
Fill time (s)	0.5552	0.5563	0.5614
Pressure (MPa)	31.31	36.14	38.29
Time to freeze	4.282	4.576	4.927
Optimum injection pressure	31.5	33	34
Optimum melt temperature (°C)	220	250	270

From the table, we can see that ABS has greater manufacturability than others. Thus, ABS can be appropriate material in injection molding process.

The warpage can be controlled by a setting the injection molding parameters at optimum value. For ABS, the optimum melting temperature is 230 °C, the optimum mold temperature is 100°C, the optimum filling time is 0.5s -0.6s and the optimum packing pressure is 30 MPa.

For PC+ABS, the optimum melting temperature is 250 °C, the optimum mold temperature is 100°C, the optimum filling time is 0.5s -0.6s and the optimum packing pressure is 30 MPa.

For ABS, the optimum melting temperature is 280 °C, the optimum mold temperature is 100°C, the optimum filling time is 0.5s -0.6s and the optimum packing pressure is 30 MPa.

5.2 RECOMMENDATION

The runner and gate size are also important variables in injection molding. The runner and gate size can be analysis for different size and type. The size and type of runner can be varying for different type of mold and product.

The product or part can be analysis using family mold. The family mold can affected the production rate. Thus, we can analysis how family mold affected the quality of the product.

REFERENCES

[1] J.P. Beaumont, R. Nagel and R. Sherman, *Successful Injection Molding: Process, Design, and Simulation*, Hansers Publisher, 2002

[2] C.A. Griffiths, S.S. Dimov, E.B. Brousseau and R.T. Hoyle, The effects of tool surface quality in micro-injection moulding, *Journal of Material Processing Technology. DOI:10.1016/j.jmatprotec.2007.02.02*

[3] Y.C Lam, G.A Britton and Y.-M Deng, A computer-aided system for an optimal moulding condition design using simulation-based approach, *International Journal Advanced Manufacturing Technology, DOI 10.1007/s00770.003-1558-5*

[4] J. Barreiro, S. Martinez, J.E. Labarga and E. Cuesta, Validation of an information model for inspection with CMM, *International Journal of Machine Tools & Manufacture (2005)*

[5] Karl Kuzman, Blaz Nardin, Marjan Kovac and Boris Jurkosek, The integration of rapid prototyping and CAE in mould manufacturing, *Journal of Material Processing Technology (2001)*

[6] Minho Chang and Sang C. Park, Reverse engineering of a symmetric object, *Computer & Industrial Engineering (2008)*

[7] C. K. Kwong and G. F. Smith, a Computational System for Process Design of Injection Moulding: Combining a Blackboard-Based Expert System and a Case-Based Reasoning Approach, *International Journal Of Advanced Manufacturing Technology*, 1998

[8] D.M. Gao, K.T. Nguyen, J.-F. H´ etu, D. Laroche and A. Garcia-Rejon, Modeling of Industrial Polymer Processes: Injection Molding and Blow Molding, *Advanced Performance Materials 5, Kluwer Academic Publisher, Netherlands,* 1998

[9] H. S. Kim, J.S. Son and Y.T Im, Gate Location Design in Injection Molding of an Automobile Junction Box With Integral Hinges, *Journal of Material Processing Technology, South Korea*, 2003

[10] Douglas M Bryce, *Plastic Injection Molding: Material Selection and Product Design Fundamental*, Society of Manufacturing Engineer, 1997

[11] Hasan Kurtaran and Tuncay Erzurumlu, Efficient Warpage Optimization of Thin Shell Plastic Parts Using Response Surface Methodology and GeneticAlgorithim, *International Journal of Advanced Manufacturing Technology(2006), DOI 10.1007/s00170-004-2321-2*

[12] Y. C. Lam, G.A. Britton and D.S. Liu, Optimisation of Gate Location With Design Constraints, *International Journal of Advanced Manufacturing Technology(2004), DOI 10.1007/s00170-004-1633-6*

[13] K. M. Au and K. M. Yu, A scaffolding architecture for conformal cooling design in rapid plastic injection moulding, *International Journal of Advanced Manufacturing Technology (2007), DOI 10.1007/s00170-006-0628-x*

[14] Zhe Zhang, Joseph C. Chen and Jie Zhu, Development of an in-process,gap-caused flash monitoring system in injection molding process, *International Journal of Advanced Manufacturing Technology (2005), DOI 10.1007/s00170-004-2112-9*

[15] E Alfredo Campo, *The Complete Part Design Handbook for Injection Mold of Thermoplastic*, Hanser Publisher, 2006

[16] Ko-Ta Chiang and Fu-Ping Chang, Analysis of shrinkage and warpage in injection-molded part with a thin shell feature using the response surface methodology, *International Journal of Advanced Manufacturing Technology, DOI 10.1007/s00170-006-0739-4*

[17] Banghong Hu, Development of a core magnesium die casting technology for thin wall electronic hardware component, *Precision Metal Forming Group, Process Technology Division, Singapore Institute of Manufacturing Technology(2006)*

[18] Yuehua Gao and Xicheng Wang, Surrogate-based process optimization for reducing warpage in injection molding, *Department of Engineering Mechanics, Dalian University of Technology (2008)*

[19] Nagahanimaiah, K. Subburaj and B.Ravi, Computer aided rapid tooling process selection and manufacturability evaluation for injection mold development, *Mechanical Engineering Department, Indian Institute of Technology, India (2008)*

[20] F. Sanchez, J. A. Garcia, F. Chinesta, LI. Gascon, C. Zhang, Z Liang and B Wang, A process performance index based on gate-distance and incubation time

for the optimization of gate locations in liquid composite molding process, *Applied Science and Manufacturing (2006)*

[21] Jung- Tang Huang and Shao- Chang Cheng, Study of injection molding pressure sensor with low cost and small probe, *Institute of Mechatronics, National Taipei University of Technology (2002)*

[22] Jay Shoemaker, *Moldflow Design Guide: A Resource for Plastic Engineer*, Moldflow Corporation, 2005

[23] M.W. Fu, J.Y.H. Fuh and A.Y.C Nee, Undercut feature recognition in an injection mould design system, *Department of Mechanical and Production Engineering, National University of Singapore (1999)*

[24] Ali Gokce and Suresh G Advani, Simultaneous gate and vent location optimization in liquid composite molding processes, *Applied Science and Manufacturing (2004)*

[25] Shyh- shin Hwang, Peming P. Hsu and Chi-wei Chiang, Shrinkage study of textile roller molded by conventional/microcellular injection- molding process, *Internal Communications in Heat and Mass Transfer (2008)*

[26] Yung- Kang Shen, Chih-Wei Wu, Ya- Feng Yu and Hung-Wei Chung, Analysis for optimal gate design of thin-walled injection molding, *International Communication in Heat and Mass Trasnfer (2008)*

[27] L.Kong. J.Y.H. Fuh, K.S.Lee, X.L. Liu, L.S. Ling, Y.F. Zhang and A.Y.C Nee, A Windows-native 3D plastic injection mold design system, *Journal of Material Processing Technology (2003)*

[28] Guy Courbebaise and David Garcia, Shape analysis and injection molding optimization, *Computational Material Science (2002)*

[29] Z.N. Yin, L.F. Fan and T.J. Wang, Experimental investigation of the viscoelastic deformation of PC, ABS and PC/ABS alloys, *Material Letter (2008)*

[30] Tong- Hong Wang and Wen-Bin Young, Study on residual stresses of thin-walled injection molding, *European Polymer Journal (2005)*

[31] Gayatri Kansal, P.N. Rao and S.K. Atreya, Study: temperature and residual stress in an injection moulded gear, *Journal of Material Processing Technology (2001)*

[32] Ming-Chih Huang and Ching-Chih Tai, The effective factors in the warpage problem of an injection-molded part with thin shell feature, *Journal of Materias Processing Technology (2001)*

[33] Babur Ozcelik and Ibrahim Sonat, Warpage and structural analysis of thin shell plastic in the plastic injection molding, *Gebze Institute of Technology, Department of Design and Manufacturing Engineering, Turkey (2008)*

[34] Ko- Ta Chiang, The optimal process conditions of an injection-molded thermoplastic part with a thin shell feature using grey-fuzzy logic: A case study on machining the PC/ABS cell phone shell, *Department of Mechanical Engineering, Hsiu- Ping Institute of Technology, Republic of China (2006)*

APPENDIX A

Example of analysis log

```
----------------------------------------
          Flow
----------------------------------------
Copyright Moldflow Corporation and its worldwide subsidiaries. All rights reserved.
(C)2000 2001 2002 2003 2004 2005 2006 2007
This product may be covered by
  US patent 6,096,088 ,
  Australian Patent No. 721978 ,
and foreign patents and pending applications


Flow Analysis


Version: mpi610  (Build 07511)
      32-bit build

Analysis commenced at       Fri Oct 10 15:07:01 2008

Analysis running on host: fkm-m03-07
     Operating System: Windows XP Service Pack 2
      Processor type: GenuineIntel x86 Family 6 Model 15 Stepping 11 ~1995 MHz
  Number of Processors: 8
  Total Physical Memory: 3071 MBytes


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


Filling Analysis

Packing Analysis

Residual Stress Analysis

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

Date : OCT10-08
```

Time : 15:07:01

Allocating memory for analysis...
... finished allocating memory
Flow has detected a mesh change since initial mesh
generation ... recalculating mesh match and thickness information
Processing fusion mesh...
Computing match using the maximal-sphere algorithm
... finished processing fusion mesh
Reading input data...
  File name : lowercase_study_(copy)_(copy_2)~1
  Reading solver parameters...
  Reading material data...
  Reading process settings...
  Reading finite element mesh...

** WARNING 98780 ** No cooling channel is specified
  Reading cooling data...

NOTE: In the analysis sequence for this study, a cooling analysis has not
      been run before the flow analysis. The flow analysis will use the
      constant mold temperature setting in the Process Settings Wizard.
      Running a cooling analysis before flow provides more detailed information
      about mold temperatures and heat fluxes.

  No mesh for the cores was found.
  Core shift analysis switched OFF
  Reading restart data...
  Note: No restart data was found.
Finished reading input data
Checking input data...

** WARNING 98731 ** The thickness of element   144 is outside the expected
                    range. Please use Modeling -> Query Entities to locate
                    the element, check the element properties and, if
                    necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element   145 is outside the expected
                    range. Please use Modeling -> Query Entities to locate
                    the element, check the element properties and, if
                    necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element   146 is outside the expected
                    range. Please use Modeling -> Query Entities to locate
                    the element, check the element properties and, if
                    necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 147 is outside the expected
range. Please use Modeling -> Query Entities to locate
the element, check the element properties and, if
necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 150 is outside the expected
range. Please use Modeling -> Query Entities to locate
the element, check the element properties and, if
necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 151 is outside the expected
range. Please use Modeling -> Query Entities to locate
the element, check the element properties and, if
necessary, rerun the analysis.

** WARNING 98742 ** Triangle element 316 has a large aspect ratio (
6.3697E+11),
which may affect the analysis. Try running the Auto
Repair and Fix Aspect Ratio commands from the Mesh Tools
to fix the problem.

** WARNING 98731 ** The thickness of element 643 is outside the expected
range. Please use Modeling -> Query Entities to locate
the element, check the element properties and, if
necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 644 is outside the expected
range. Please use Modeling -> Query Entities to locate
the element, check the element properties and, if
necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 647 is outside the expected
range. Please use Modeling -> Query Entities to locate
the element, check the element properties and, if
necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 648 is outside the expected
range. Please use Modeling -> Query Entities to locate
the element, check the element properties and, if
necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 664 is outside the expected
range. Please use Modeling -> Query Entities to locate
the element, check the element properties and, if
necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 665 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 668 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 817 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 818 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 819 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 820 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 821 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 822 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 823 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 824 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 825 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 826 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 1952 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 1955 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 1956 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 1957 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 1958 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98731 ** The thickness of element 1959 is outside the expected range. Please use Modeling -> Query Entities to locate the element, check the element properties and, if necessary, rerun the analysis.

** WARNING 98743 ** The average aspect ratio is > 5.0 for triangle elements.

The recommended average aspect ratio for elements is
approximately 5.0.

** WARNING 98790 ** The mesh appears to be too coarse for this part. To
improve the accuracy or results, mesh the part more
finely.

... finished checking input data
Optimizing memory usage...
... finished optimizing memory usage
Initializing variables...
... finished initializing variables

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
Flow rate convergence tolerance = 0.5000 %
Melt temperature convergence tolerance = 0.0200 C
Mold-melt heat transfer coefficient
Filling = 5000.0000 W/m^2-C
Packing = 2500.0000 W/m^2-C
Detached, cavity side = 1250.0000 W/m^2-C
Detached, core side = 1250.0000 W/m^2-C
Maximum no. of flow rate iterations = 125
Maximum no. of melt temperature iterations = 200
Nodal growth mechanism = Multiple
Pressure trace sample frequency = 10 Hz
Total number of pressure trace nodes = 1
Node 1 = 1177
Pressure work option = 1

Material data :

Polymer : Generic PP : Generic Default

PVT Model: 2-domain modified Tait
coefficients: b5 = 388.7500 K
b6 = 2.2000E-07 K/Pa
Liquid phase Solid phase
----
b1m = 0.0012 b1s = 0.0011 m^3/kg
b2m = 9.8600E-07 b2s = 2.8500E-07 m^3/kg-K
b3m = 6.9456E+07 b3s = 1.6407E+08 Pa
b4m = 0.0038 b4s = 0.0027 1/K
b7 = 0.0001 m^3/kg
b8 = 0.1190 1/K
b9 = 3.0100E-08 1/Pa

Specific heat (Cp) = 2740.0000 J/kg-C

Thermal conductivity = 0.1640 W/m-C

Viscosity model: Cross-WLF
coefficients: n = 0.2751
TAUS = 2.4200E+04 Pa
D1 = 4.6600E+12 Pa-s
D2 = 263.1500 K
D3 = 0.0000 K/Pa
A1 = 26.1200
A2T = 51.6000 K

Transition temperature = 111.0000 C

Mechanical properties data: E1 = 1340.0000 MPa
E2 = 1340.0000 MPa
v12 = 0.3920
v23 = 0.3920
G12 = 481.0000 MPa

Transversely isotropic coefficent of
thermal expansion (CTE) data: Alpha1 = 9.0500E-05 1/C
Alpha2 = 9.0500E-05 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 = 0.4000 s
Injection time has been determined by automatic calculation.
Stroke volume determination = Automatic
Cooling time = 20.00 s

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

% shot volume	% ram speed
0.0000	100.0000
100.0000	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

---

Model details :

Mesh Type = Fusion

Mesh match percentage = 86.2 %

Reciprocal mesh match percentage = 77.6 %
Total number of nodes = 2201
Total number of injection location nodes = 1
The injection location node labels are:
1177

Total number of elements = 4414
Number of part elements = 4414
Number of sprue/runner/gate elements = 0
Number of channel elements = 0
Number of connector elements = 0
Parting plane normal (dx) = 0.0000
(dy) = 0.0000
(dz) = 1.0000
Average aspect ratio of triangle elements = 1.4431E+08
Maximum aspect ratio of triangle elements = 6.3697E+11
Element number with maximum aspect ratio = 316
Minimum aspect ratio of triangle elements = 1.1587
Element number with minimum aspect ratio = 1019
Total volume = 2.7715 cm^3
Volume filled initially = 0.0000 cm^3
Volume to be filled = 2.7715 cm^3
Part volume to be filled = 2.7715 cm^3
Sprue/runner/gate volume to be filled = 0.0000 cm^3
Total projected area = 2.2869 cm^2

Filling Analysis

Packing Analysis

Residual Stress Analysis
analysis is beginning ....

Filling phase: Status: V = Velocity control
P = Pressure control
V/P= Velocity/pressure switch-over

Time (s)	Volume (%)	Pressure (MPa)	Clamp force (tonne)	Flow rate (cm^3/s)	Status
0.02	4.16	2.81	0.00	6.32	V
0.04	8.93	3.81	0.00	6.80	V
0.06	13.59	4.66	0.00	6.73	V
0.08	18.49	5.48	0.00	6.76	V
0.10	22.97	6.29	0.00	6.68	V
0.12	27.53	7.04	0.00	6.84	V
0.14	32.48	7.86	0.00	6.82	V
0.16	37.45	8.46	0.01	6.84	V
0.18	41.91	9.12	0.01	6.81	V

0.20	46.36	10.34	0.02	6.75	V
0.22	51.01	11.80	0.02	6.79	V
0.24	55.50	12.94	0.03	6.85	V
0.26	59.96	14.15	0.04	6.87	V
0.28	64.78	15.24	0.04	6.96	V
0.30	69.25	16.81	0.05	6.88	V
0.32	73.53	18.38	0.07	6.71	V
0.34	77.88	19.31	0.07	6.88	V
0.36	82.06	20.78	0.09	6.88	V
0.38	86.27	22.50	0.10	6.93	V

** WARNING 98960 ** The melt temperature calculation does not converge after 200 iterations. Try selecting a more relaxed convergence tolerance or set a higher maximum number of melt temperature iterations in the Advanced options of the Process Settings Wizard.

0.40	89.91	24.50	0.12	6.93	V
0.42	93.63	25.65	0.14	6.93	V
0.44	97.15	27.13	0.16	6.93	V
0.44	97.97	27.93	0.17	6.64	V/P
0.45	99.29	22.35	0.14	5.24	P
0.46	99.61	22.35	0.16	2.77	P
0.47	99.97	22.35	0.16	3.45	P
0.47	100.00	22.35	0.16	3.24	Filled

Execution time in Filling Phase = 780.53 s

Packing phase:

Time (s)	Packing (%)	Pressure (MPa)	Clamp force (tonne)	Status
1.63	3.87	22.35	0.07	P
3.13	8.87	22.35	0.01	P
4.63	13.88	22.35	0.01	P
6.13	18.88	22.35	0.01	P
7.63	23.88	22.35	0.00	P
9.13	28.89	22.35	0.00	P
10.46	33.33	0.00	0.00	P
10.46				Pressure released
10.50	33.45	0.00	0.00	P
12.10	38.82	0.00	0.00	P
13.60	43.82	0.00	0.00	P

15.10	48.83	0.00	0.00	P
16.60	53.83	0.00	0.00	P
18.10	58.83	0.00	0.00	P
19.60	63.84	0.00	0.00	P
21.10	68.84	0.00	0.00	P
22.60	73.84	0.00	0.00	P
24.10	78.85	0.00	0.00	P
25.60	83.85	0.00	0.00	P
27.10	88.86	0.00	0.00	P
28.60	93.86	0.00	0.00	P
30.10	98.86	0.00	0.00	P
30.60	100.00	0.00	0.00	P

Filling phase results summary :

Maximum injection pressure (at 0.445 s) = 27.9327 MPa

End of filling phase results summary :

Time at the end of filling = 0.4672 s
Total weight (part + runners) = 2.1692 g
Maximum Clamp force - during filling = 0.1733 tonne
Recommended ram speed profile (rel):

%Shot volume	%Flow rate
0.0000	33.5417
10.0000	74.3250
20.0000	84.9434
30.0000	100.0000
40.0000	97.7159
50.0000	60.9503
60.0000	60.3486
70.0000	57.3565
80.0000	51.5473
90.0000	46.8961
100.0000	29.2655

Melt front is entirely in the cavity at % fill = 0.0000 %

Filling phase results summary for the part :

Bulk temperature - maximum (at 0.445 s) = 232.4250 C
Bulk temperature - 95th percentile (at 0.022 s) = 229.6900 C
Bulk temperature - 5th percentile (at 0.467 s) = 188.3090 C
Bulk temperature - minimum (at 0.467 s) = 41.1600 C

Wall shear stress - maximum (at 0.321 s) = 7.1613 MPa
Wall shear stress - 95th percentile (at 0.022 s) = 0.1914 MPa

Shear rate - maximum (at 0.467 s) = 4.3863E+05 1/s
Shear rate - 95th percentile (at 0.022 s) = 7176.7002 1/s

End of filling phase results summary for the part :

Total part weight (excluding runners) = 2.1692 g

Bulk temperature - maximum = 231.3640 C
Bulk temperature - 95th percentile = 225.8310 C
Bulk temperature - 5th percentile = 188.3090 C
Bulk temperature - minimum = 41.1600 C
Bulk temperature - average = 207.7890 C
Bulk temperature - root-mean-square deviation = 11.5092 C

Wall shear stress - maximum = 2.6133 MPa
Wall shear stress - 95th percentile = 0.1556 MPa
Wall shear stress - average = 0.1091 MPa
Wall shear stress - root-mean-square deviation = 0.0415 MPa

Frozen layer fraction - maximum = 1.0000
Frozen layer fraction - 95th percentile = 0.2086
Frozen layer fraction - 5th percentile = 0.0364
Frozen layer fraction - minimum = 0.0000
Frozen layer fraction - average = 0.1273
Frozen layer fraction - root-mean-square deviation = 0.0519

Shear rate - maximum = 1.2853E+05 1/s
Shear rate - 95th percentile = 1051.6400 1/s
Shear rate - average = 376.2500 1/s
Shear rate - root-mean-square deviation = 500.2630 1/s

Packing phase results summary :

Peak pressure - minimum (at 0.000 s) = 0.0000 MPa
Clamp force - maximum (at 0.445 s) = 0.1733 tonne
Total weight - maximum (at 30.604 s) = 2.3910 g

End of packing phase results summary :

Time at the end of packing = 30.6040 s
Total weight (part + runners) = 2.3910 g

Packing phase results summary for the part :

Bulk temperature - maximum (at 1.627 s) = 230.0210 C
Bulk temperature - 95th percentile (at 1.627 s) = 210.8610 C
Bulk temperature - 5th percentile (at 30.604 s) = 40.0030 C
Bulk temperature - minimum (at 6.127 s) = 40.0000 C

Wall shear stress - maximum (at 6.127 s) = 3.0406E+06 MPa
Wall shear stress - 95th percentile (at 1.627 s) = 0.1531 MPa

Volumetric shrinkage - maximum (at 1.627 s) = 14.0027 %
Volumetric shrinkage - 95th %ile (at 1.627 s) = 12.2932 %
Volumetric shrinkage - 5th %ile (at 21.104 s) = 0.4542 %
Volumetric shrinkage - minimum (at 6.127 s) = 0.1002 %

Total part weight - maximum (at 30.604 s) = 2.3910 g

End of packing phase results summary for the part :

Total part weight (excluding runners) = 2.3910 g

Bulk temperature - maximum = 40.3770 C
Bulk temperature - 95th percentile = 40.1950 C
Bulk temperature - 5th percentile = 40.0030 C
Bulk temperature - minimum = 40.0000 C
Bulk temperature - average = 40.0360 C
Bulk temperature - root-mean-square deviation = 0.0641 C

Frozen layer fraction - maximum = 1.0000
Frozen layer fraction - 95th percentile = 1.0000
Frozen layer fraction - 5th percentile = 1.0000
Frozen layer fraction - minimum = 1.0000
Frozen layer fraction - average = 1.0000
Frozen layer fraction - root-mean-square deviation = 0.0000

Volumetric shrinkage - maximum = 9.3504 %
Volumetric shrinkage - 95th percentile = 8.1679 %
Volumetric shrinkage - 5th percentile = 0.4548 %
Volumetric shrinkage - minimum = 0.2859 %
Volumetric shrinkage - average = 3.3190 %
Volumetric shrinkage - root-mean-square deviation = 2.4711 %

Sink index - maximum = 1.4618 %
Sink index - 95th percentile = 0.7769 %
Sink index - minimum = 0.0835 %
Sink index - root-mean-square deviation = 0.2594 %

Preparing interface data...
  Preparing PPC file for cooling analysis...
  Preparing LSP file for warpage analysis...
Finished preparing the interface data

Filling Analysis

Packing Analysis

Residual Stress Analysis
has completed successfully.

Weld line/air trap analysis completed

Preparing output data...
Finished preparing output data

SYNERGY Weld-line and air trap
has completed successfully.

Execution time
   Analysis commenced at   Fri Oct 10 15:07:01 2008
   Analysis completed at   Fri Oct 10 15:23:18 2008
   CPU time used   975.80 s

Warp

Warpage Analysis

Version: mpi610 (Build 07511)
        32-bit build

Analysis running on host: fkm-m03-07
Operating System: Windows XP Service Pack 2
Processor type: GenuineIntel x86 Family 6 Model 15 Stepping 11 ~1995 MHz
Number of Processors: 8
Total Physical Memory: 3071 MBytes

Analysis commenced at Fri Oct 10 15:23:20 2008

Model file name: lowercase_study_(copy)_(copy_2).udm

Fusion mesh statistics:
Percentage edge elements (by count) 13.6 %
Percentage edge elements (by area) 4.4 %
Percentage matched elements 88.9 %
Percentage reciprocal matched elements 80.5 %

** WARNING 200300 ** There are a few defects in the model

Element 316 aspect ratio: 1000000000.0000

Edge connecting nodes 1 and 457 is a free edge.

Edge connecting nodes 232 and 1 is a free edge.

Edge connecting nodes 399 and 394 is a intersecting edge.

Edge connecting nodes 457 and 232 is a intersecting edge.

Edge connecting nodes 473 and 250 is a intersecting edge.

Edge connecting nodes 477 and 473 is a intersecting edge.

Edge connecting nodes 477 and 254 is a intersecting edge.

Edge connecting nodes 575 and 377 is a intersecting edge.

Edge connecting nodes 576 and 575 is a intersecting edge.

Edge connecting nodes 576 and 386 is a intersecting edge.

Edge connecting nodes 583 and 394 is a intersecting edge.

Edge connecting nodes 588 and 583 is a intersecting edge.

Edge connecting nodes 588 and 399 is a intersecting edge.

Edge connecting nodes 657 and 663 is a free edge.

Edge connecting nodes 658 and 657 is a free edge.

Edge connecting nodes 663 and 658 is a free edge.

Reading solver parameters...
Corner effect is OFF
Reading mechanical property and residual stress data...

Analysis model: residual stress without crims.

Establishing MPC constraint relationship...

Defining anchor plane...
Number of separate cavities = 1

Writing input file for structural analysis program...

Launching structural analysis program...

Reading structural analysis input file...
...finished reading structural analysis input file.

Beginning load incrementation loop...

Setting structure information...

Assembling stiffness matrix...

Solving finite element static equilibrium equations...
Using direct matrix solver

Kstep	Kstra	Nref	Nite	Node	Ipos	Negpv	Detk	Rfac	Displacement
1	1	1	0	0	0	0	1.0e+00	1.000e+00	1.000e+00

Minimum/maximum displacements at last step (unit: mm):

	Node	Min.	Node	Max.
Trans-X	0	1.0000e+00	0	-1.0000e+00
Trans-Y	0	1.0000e+00	0	-1.0000e+00
Trans-Z	0	1.0000e+00	0	-1.0000e+00

Support reactions at last step (unit: N)
(G = Global, L = Local)

```
Node  G/L   Trans-X      Trans-Y      Trans-Z
----------------------------------------------
 297  L   0.0000e+00 0.0000e+00-1.0000e+00
 908  L   0.0000e+00-1.0000e+00-1.0000e+00
1162  L  -1.0000e+00-1.0000e+00-1.0000e+00
----------------------------------------------
Sum   G  -1.0000e+00-1.0000e+00-1.0000e+00
```

Elapsed wall clock time in structural analysis: 171.14 secs.

Writing result file...

** WARNING 200300 ** There are a few defects in the model

Element   316 aspect ratio: 1000000000.0000

Edge connecting nodes   1 and   457 is a free edge.

Edge connecting nodes   232 and   1 is a free edge.

Edge connecting nodes   399 and   394 is a intersecting edge.

Edge connecting nodes   457 and   232 is a intersecting edge.

Edge connecting nodes   473 and   250 is a intersecting edge.

Edge connecting nodes   477 and   473 is a intersecting edge.

Edge connecting nodes   477 and   254 is a intersecting edge.

Edge connecting nodes   575 and   377 is a intersecting edge.

Edge connecting nodes   576 and   575 is a intersecting edge.

Edge connecting nodes   576 and   386 is a intersecting edge.

Edge connecting nodes   583 and   394 is a intersecting edge.

Edge connecting nodes   588 and   583 is a intersecting edge.

Edge connecting nodes   588 and   399 is a intersecting edge.

Edge connecting nodes 657 and 663 is a free edge.

Edge connecting nodes 658 and 657 is a free edge.

Edge connecting nodes 663 and 658 is a free edge.

Best-fit transformation will be used to display warpage deflections
if no anchor plane is defined.

Execution time
Analysis commenced at Fri Oct 10 15:23:20 2008
Analysis completed at Fri Oct 10 15:26:13 2008
CPU time used 171.39 s
Warpage analysis has completed successfully.

APPENDIX B

EXAMPLE OF MACHINE SETUP

Injection Machine Setup Sheet

General Information

Project Name: lowercase_study_(copy)_(copy_2).udm

Version: mpi610

Date: Fri Oct 10 15:23:17 2008

Processing Type: Thermoplastics injection molding

Machine Name: Default injection molding machine

Material Name: Generic PP : Generic Default

Machine Specification:

Maximum pressure: 180.0000 MPa

Screw intensification ratio: 10.0000

Machine response time: 0.010 s

Machine maximum clamp force: 7000.2198 tonne

Temperature Settings

Melt temperature: 230.0000 C

Mold cavity_side temperature: 40.0000 C

Mold core-side temperature: 40.0000 C

Injection Settings

Injection control method: Injection Time

Injection Time: 0.4000 s

Nominal Flow rate: 6.9288 cm^3/s

Packing pressure profile

Duration (s)	Pressure (MPa)
0.0000	22.3462
7.6821	22.3462

Cooling time: 20.0000 s

Results from Flow Analysis

Total volume of the part and cold runners: 2.7715 cm^3

Switch-over Pressure: 27.9327 MPa

Maximum clamp force required: 0.1733 tonne