CERTIFICATION OF APPROVAL

Modelling of Polymer Melt During Injection Moulding : Influence of Injection Pressure

by

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A project dissertation submitted to the
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Approved by,

(Mr. Muhamad Ridzuan B. Abdul Latif)

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TRONOH, PERAK
May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NORAZREEN BINTI HAJI MOHAMED ZABIDI

DISSERTATION

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ABSTRACT

A polymer, polyethylene (PE) is going through injection moulding process with different sets of injection pressure. The samples produced by this experimental work shows different results of flash, warpage and shrinkage visually. Another part of the project is the application of computer software. The actual dimension of the dog bone-shaped sample is modelled by using SolidWorks and it is then simulated by using SimpoeWorks. Simulation and measurement are done to investigate the polymer melt flow behaviour during the filling phase of injection moulding which vary with the changing of the injection pressure. Minimum defects of the sample will be the desired result for the optimum value of injection pressure for the polymer.

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The injection moulding process is the predominant method for producing plastic parts as it offers the ability to produce parts in large volumes, quickly, with precise detail, excellent repeatability and at minimum cost [1]. Injection mould parts are best designed and simulated through the use of the injection mould simulation which is able to evaluate the mould filling, packing, cooling, product shrinkage, warpage, and structural characteristics of the part before the actual process of injection moulding is ever begin.

The injection pressure consisted of more than one item; initial injection pressure, second- and up to fifth-stage injection pressure, holding pressure, back pressure and line pressure [2]. There will be a driving force given to push the plastic from the injection barrel, by the hydraulic system of the injection screw. Melt pressure distribution across a cavity during the mould filling will be at maximum at the gate and zero at the flow front [3]. In order to have short filling time, the greater pressure is needed to fill the cavity at high speed, thus the cycle time could be minimized.

1.2 Problem Statement

Injection pressure plays a vital role in ensuring the product quality. It is a complex technology that allows much more precise control over the speed of injection and the quality of articles produced. The problem arises as there are some possible production problems that concerns more on how the flash, shrinkage and warpage of the moulded part can be significantly influenced by the injection pressure for the polymer, polyethylene (PE). High injection pressure may cause over packing, thus damages, due to the collapse of the material used to make the mould. The mould will not be spread out enough across the face of the plate, causing lack support to the plate, thus resulting to plate warping while it moves during opening and closing [2]. In some cases, at lower pressure, the filling of the polymer melt will not make up the area of the vacuum envelope or the surface concavely.

Low injection pressure may result in flash or no filled part. Flash is material that squeezes out of a closed-mould because injection pressure forces it to out through any opening that allows material to flow. No filled part happens when the mould opens up slightly, keeping the prescribed amount of plastic from flowing into the entire shape of the mould [2]. Simulations are done in order to get the best value for the injection pressure as the parameter does have a crucial effect on the quality of the products [4]. Best value should be obtained to reduce the possible shrinkage and warpage of the product. Injection must be completed rapidly and with sufficient pressure so that the mould cavities are filled while the melt will still flow [15].

1.3 Objectives and Scope of Study

The aim of the project is to study the effect of the injection pressure on the flash, shrinkage and warpage of the part.

The scope of the study covers on the research, testing and analysis regarding the effect of the injection pressure on shrinkage and warpage, as well as the tools used for experimentation and simulation. The value of the injection pressure is a variable, thus the parts will experience different behaviour during the injection moulding, and it will be shown through the simulation program, indicating the growth of the shrinkage and the warpage on the parts' structure. In this study, the material involved for the product-making is polyethylene (PE). The software used for the purpose of this study is SolidWorks CAD and SimpoeWorks CAE. The desired part is designed first by using SolidWorks CAD, and then continued by the simulation process through SimpoeWorks CAE for the polymer melt flow behaviour investigation task. The plastic moulded part will be produced in a dogbone shape and the dimension of the model in the simulating software will be similar with the dimension of the dogbone mould in the machine.

CHAPTER 2
LITERATURE REVIEW

2.1 Overview

As the injection pressure and the mould flow properties are essential in the process of injection moulding, there are a number of studies done on the areas mentioned. Research has done on the analysis of the flow behaviour of plastic injection moulding [5]. Injection rate strongly influenced the flow behaviour of material in a complicated manner. Proper distribution of the melt polymer during the filling process is essential in order to get a uniform skin layer. Another research has mentioned about the simulation software that is used to predict and simulate the fill pattern, fill time, air trap, weld line, temperature and pressure distribution of the material [7]. Based from the results from the simulation software, the behaviour of the mould flow is investigated and noted [9].

Experiment by using the real injection moulding machine is executed to produce the samples for verification purposes. Polyethylene, PE (melt index 0.1g/10 min) were injection moulded at pressures ranging from 100 to 500 MPa using a modified conventional injection moulding machine. It is found that the mould shrinkage decreased and the crystalline increased with injection pressure [9]. Flow simulation is used dynamically to analyze the plastic melt flow in the runner system, filling the cavities and packing in the mould. The flow simulation provides the mould ability analysis to predict whether the part can be completely moulded, as well as to estimate the production cycle time, clamping force, optimal process conditions and operation configuration. Flow simulation is essential in identifying the moulding defects such as weld lines, melt lines and air traps as it provides the information about the flow path [10].

2.2 Theory

2.2.1 Process Description

Injection moulding process involves the injection of a polymer melt into a mould where the melt cools and solidifies to form a plastic product. A mould is bolted into the clamping section of the machine. The machine closes the mould, and applies a large force to "Lock" the mould closed. The cavity that has the exact shape of the plastic part is located in the mould. The hopper at the injection section is used to hold the plastic pellets. The barrel with heater bands is used for liquefying the plastic pellets while the feed screw is used to move the pellets forward in the barrel. A check valve functions to force the liquid plastic into the mould while the nozzle for sealing the injection section to the mould. The liquefied plastic is forced into the cavity of the mould with high pressure [1, 2].

Once the liquid plastic has been injected into the mould, the machine goes into the cooling phase. The liquid plastic must cool enough to turn solid so it takes on the shape of the cavity and stays that way. While the cooling takes place, the screw will rotate, bringing in more pellets for the next part. When the part is ready to be removed from the mould, the clamp will open, and the part will be removed from one half of the mould. Then the part will be ejected from the other half of the mould, and the machine will start a new cycle. The overall parts of the injection moulding machine are shown as Figure 1 [1, 2].

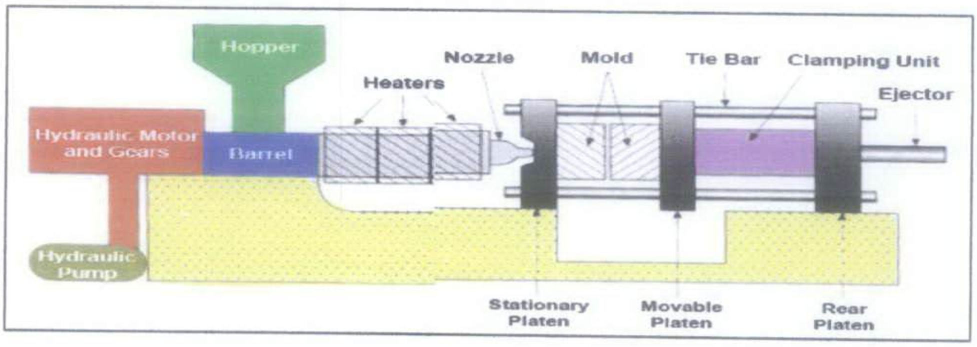


Figure 1 : Injection moulding machine diagram

2.2.2 Injection Pressure

The injection unit is the component which is exerting pressure to inject the material. Injection pressure is the pressure that is used to perform the initial filling of the mould. In another word, injection pressure is exerted on the screw by the hydraulic (or electric) system to move the screw forward. This pressure forces the melted plastic that is in front of the screw through the nozzle and into the mould. As soon as the melted plastic comes into contact with the cooler mould surface, it begins to cool and solidify [15].

Injection pressure is created by applying a line pressure to a hydraulic ram which is located at the back of the injection screw and pushes against that screw in order to inject the plastic into the mould [6]. Line pressure is transferred from the pump to the hydraulic ram through the screw and lastly to the nozzle and the molten plastic that is ready to be injected into the mould [6,9]. The pressure is multiplied during the transferring process, due to the mechanical advantage created by the hydraulic oil that pushes against the ram, thus pushing the screw forward. The pressure is then transferred all the way to the front of the screw at the nozzle [9].

The injection pressure that is actually required depends on the type of the material used, ranging up to its maximum value of the available injection pressure [2]. Figure 2 below show the example of injection units model.

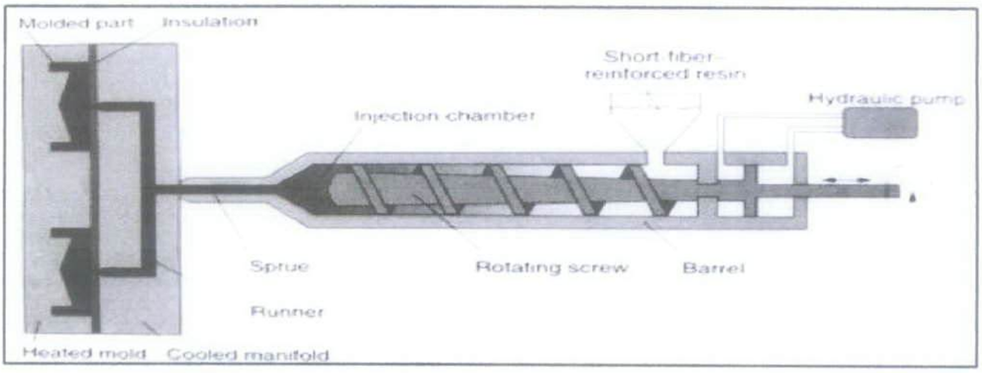


Figure 2 : Injection units

2.2.3 Flash

Flash occurs when a thin layer of material is forced out of the mould cavity at the parting line or ejector pins location. This excess material remains attached to the moulded article, and normally has to be manually removed. It is the excess material or leakage in thin layer exceeding normal part geometry.

High injection pressure may result to overpacking, which causes an increase in localized pressure. Overpacking will result to flash, thus injection pressure is directly influence the formation of flash. Figure 3 below shows the flash defect on the moulded part.

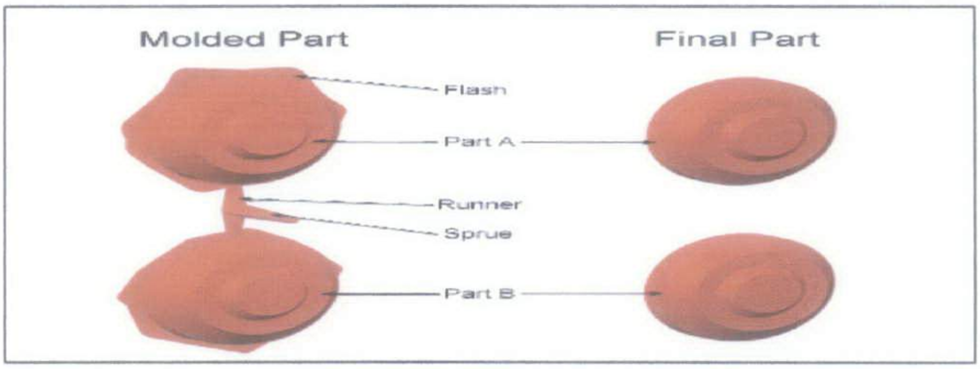


Figure 3 : Example of flash molded part

2.2.4 Shrinkage

Plastic expands when it is heated and shrinks when it is cooled and each plastic material has a distinct value for how much it will shrink after it is heated and cooled. This value is referred to as the shrinkage rate [12]. Plastics are either having low, medium or high shrinkage. Low shrinkage has the value ranged between 0.000 to 0.005 in./in, medium shrinkage value of between 0.006 to 0.010 and the high shrinkage is anything that is more than 0.010 [1].

Shrinkage rate is directly influenced by injection pressure. The higher the injection rates, the lower the shrinkage rate. This is because injection pressure has influence on the packing of molecules. Higher injection pressure leads to tighter packing of molecules, thus allowing less movement during cooling, which then results to lower shrinkage [1]. Figure 4 shows the picture of the shrinkage defects.

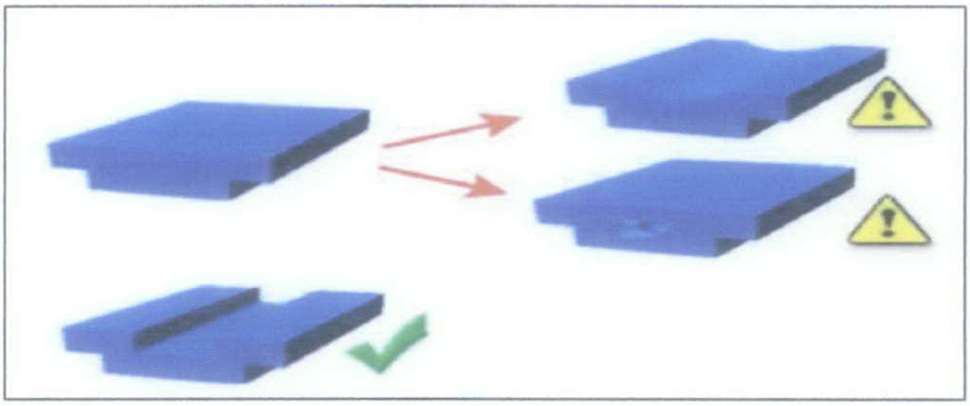


Figure 4 : Shrinkage defect

2.2.5 Warpage

Warpage occurs when there are variations of internal stresses in the material caused by a variation in shrinkage. Warpage analysis is essentially a structural analysis, which uses the residual stresses as the loading. Mesh density for the finite element analysis of the part condition at the end of the moulding cycle and the number of layers in the thickness direction must be adequate in order to capture these variations of pressure across the entire part [2].

Inadequate injection pressure will tend the plastic to cool down and solidify before the mould is packed out. The individual molecules of the plastic are not packed together, leaving them space to move into as the part is cooled. While the outer skin of the product may be solid, the internal sections are still cooling and the movement of molecules determines the degree of warpage [1]. The condition of warpage is shown as Figure 4.

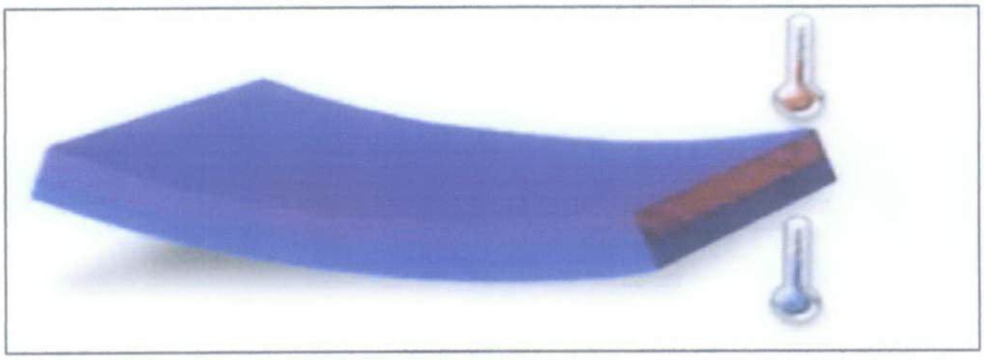


Figure 5 : Warpage defect

2.2.6 Gate and runner

The runner system is the passage way for plastic to travel from the sprue to the gate. The runner system is very important with respect to filling cavities. If the runners are too small in size the mould cavities will not fill properly. If the runners are too large, then the cooling time will be increased and cycle time decreased. Proper runner design can reduce the effects of stress, sink and weld marks [14].

A gate is the connection between the runner system and the moulded part. It must permit enough flow to fill the mould cavity, plus additional material to allow for part shrinkage and cooling. The gate is the most critical part of the runner system. The gate type, location, and size has a great effect on the moulding process. It affects physical properties, appearance, and size of the part [13]. Location of the runner and the gate in the mould are shown in Figure 6(a) while Figure 6 (b) shows the example of their location at the injection moulded part.

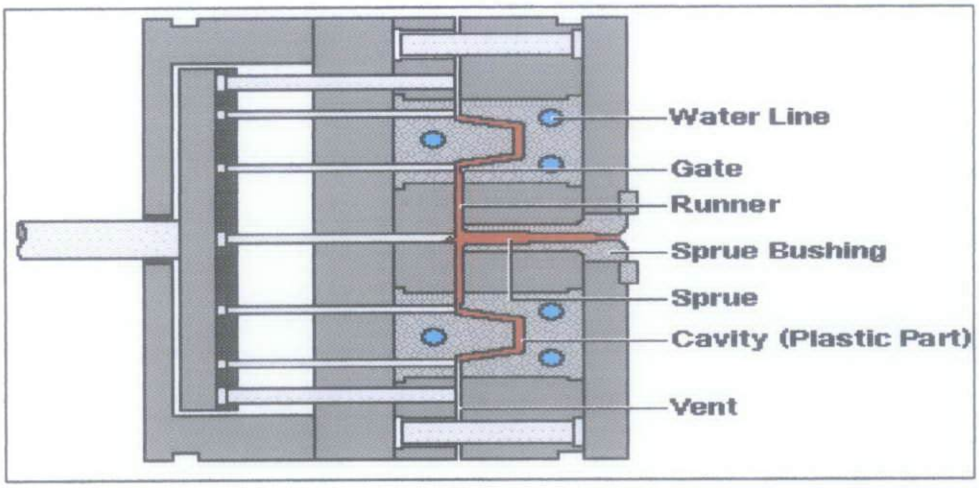


Figure 6(a): Location of the runner and gate at the mould

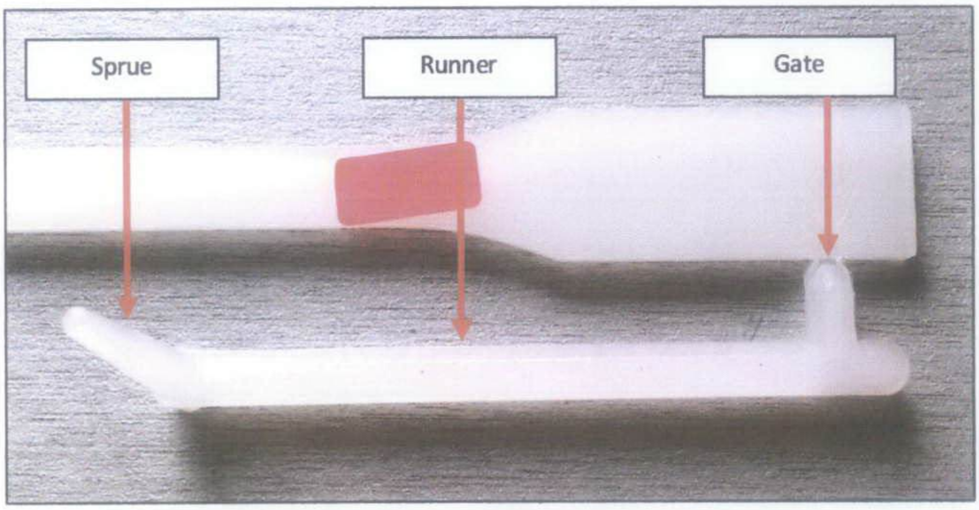


Figure 6(b): Location of the runner , gate and sprue at the injection moulded sample

CHAPTER 3
METHODOLOGY

3.1 Materials

The polymer used for the study is polyethylene, (PE) for the injection moulding process. Table 2 below shows the melting point temperature and quantity for the material.

Table 1: Melting point temperature and quantity needed for polyethylene (PE)

Physical Properties	Polyethylene (PE)
Repeat Unit	C_2H_4
Melting Point Temperature (°C)	110
Quantity (g)	500

Figure 7 : 500 g of Polyethylene (PE)

3.2 Tools and Equipments

3.2.1 Injection Moulding Machine

Figure 8: Injection moulding machine

ME 20 III Injection Moulding Machine is used to operate the actual injection moulding process onto the polymers for experimental purpose. It is a horizontal-type injection moulding machine as it injects the melting polymer in a horizontal direction, according to the shape of the mould.

3.2.2 Vernier Caliper

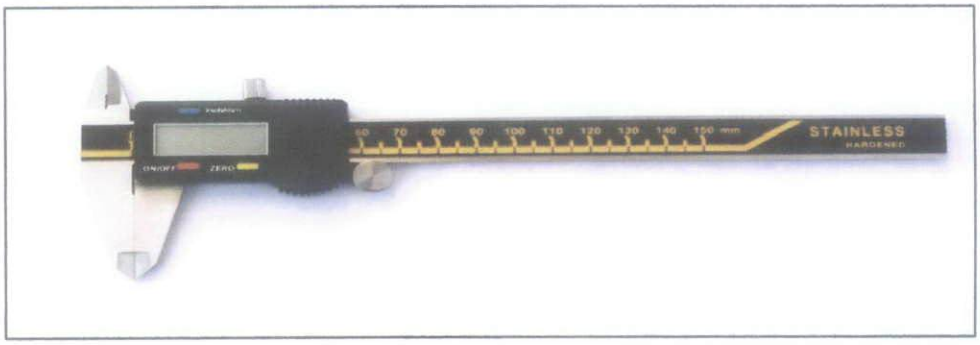


Figure 9: Vernier Caliper

The equipment used to measure the actual dimension of the mould in the machine is vernier caliper. Besides referring to the ISO standard dimension (ISO 527-2), the actual dimension that is measured directly by using the vernier calliper, as in Figure 12 is taken for comparison.

3.2.3 Micrometer

Figure 10: Micrometer

Micrometer, as shown in Figure 10 is the tool used to measure the thickness of the dogbone-shaped model after being injection moulded. The different in thickness of the samples for different set of injection pressure will show how they differ in the way of the polymer melt flow during the injection moulding process. Micrometer is used as it has high accuracy in dimensioning the thickness.

3.2.4 Computer Softwares

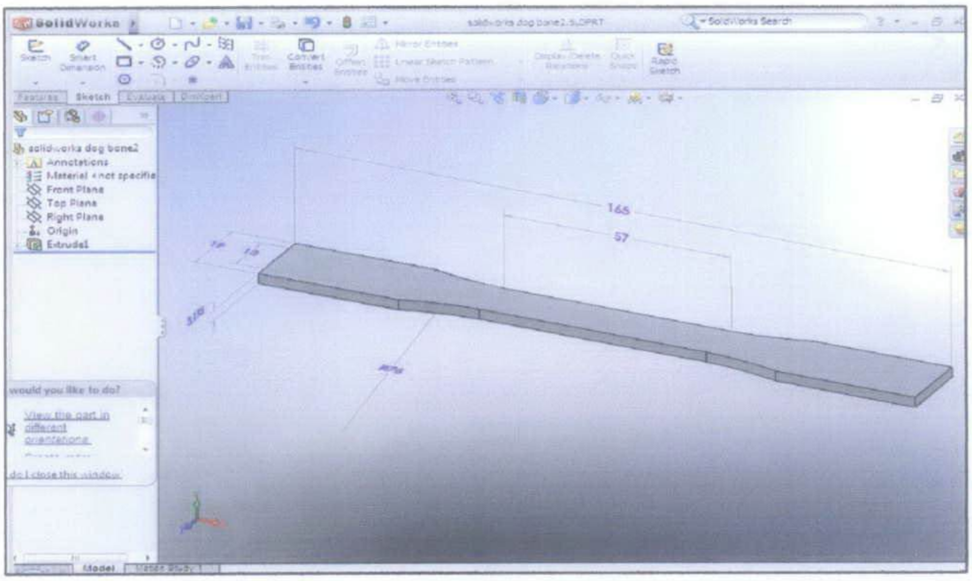


Figure 11 : SolidWorks CAD to model the part

SolidWorks CAD software is used in order to model the dogbone-shape part according to the exact dimension. The dimension is based on the actual dimension of the mould in the injection moulding machine.

3.3 Project Activities

3.3.1 Experimental Activities

The polymers are prepared at sufficient amount for the experiment. Polyethylene (PE), weighed 500 g is prepared to inject 25 parts out, including the first 5 trial samples. As the melting point temperature of Polyethylene (PE) is 110°C, so the three zones' temperatures at the injection components are set to 110°C, 130 °C and 130 °C.

Figure below shows the three zones at the injection component while the table is the data collecting table., while the table below shows the data collecting for samples of different injection pressure.

Table 2: Data collecting for samples of different injection pressure

Pressure (bar)	Part
30	Sample 1 Sample 2 Sample 3 Sample 4 Sample 5
40	Sample 1 Sample 2 Sample 3 Sample 4 Sample 5
50	Sample 1 Sample 2 Sample 3 Sample 4 Sample 5
60	Sample 1 Sample 2 Sample 3 Sample 4 Sample 5

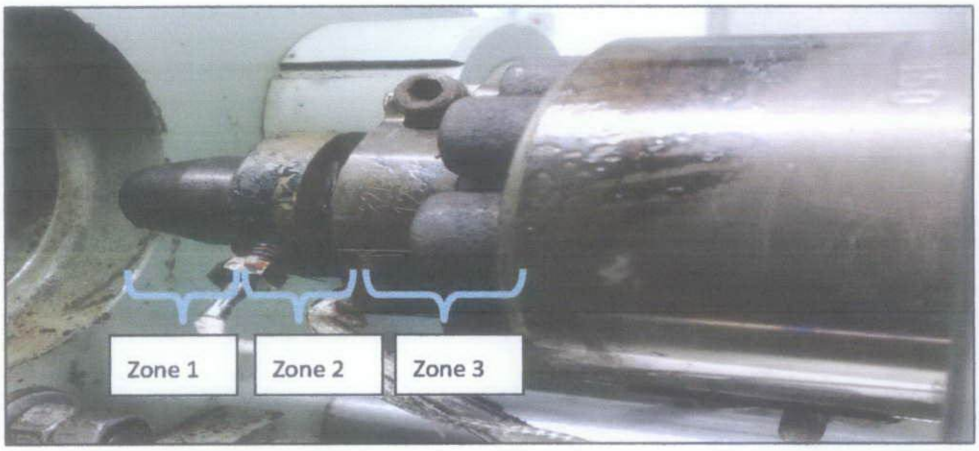


Figure 12: The three zones at the injection components

3.3.2 Software Activities

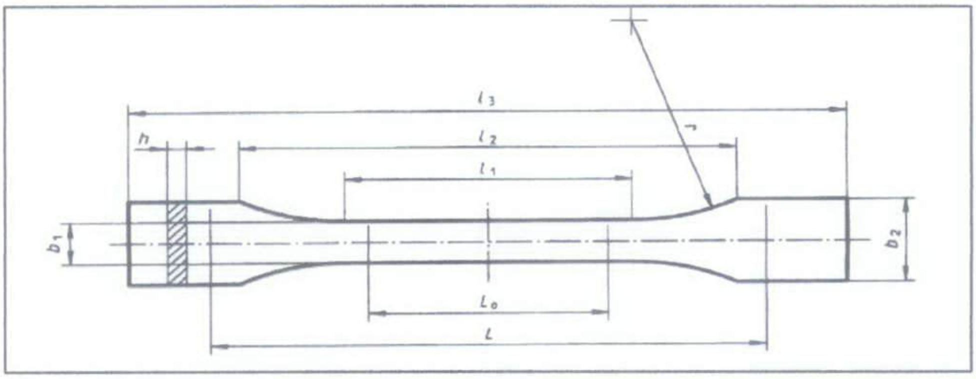


Figure 13: Dimension of dogbone shaped part (ISO 527-2)

The dimension of the actual dogbone-shaped model is identified by measuring the mould as well as comparing the value to the established ISO standards. It is identified that the mould is based on ISO 527-2 standard.

The exact value of the dimension is then applied during modelling process by using SolidWorks CAD. The part should be designed according to the actual condition so that the simulation process that will be done later will produce the wanted result based from the actual condition, as SimpoeWorks will directly analyze the model from SolidWorks CAD.

No.	Detail/Week	4	5	6	7		8	9	10	11	12	13	14	15
1	Research for experimental tools					Mid-Semester Break								
2	Experimental work (Injection moulding)													
3	Design and modelling													
4	Submission of Progress Report													
5	Experimental work (Injection moulding)													
6	Simulation													
7	Pre-EDX													
8	Submission of Draft Report													
9	Submission of Dissertation (soft bound)													
10	Submission of Technical Paper													
11	Oral Presentation													
12	Submission of Dissertation(hardbound)													

Table 3 : Gantt Chart

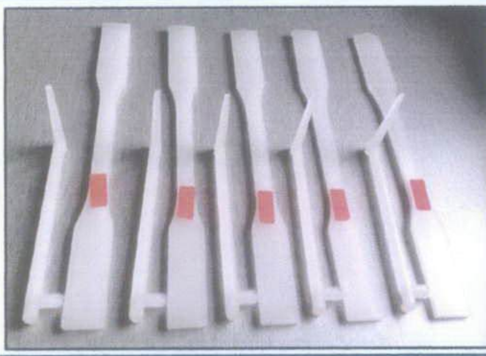
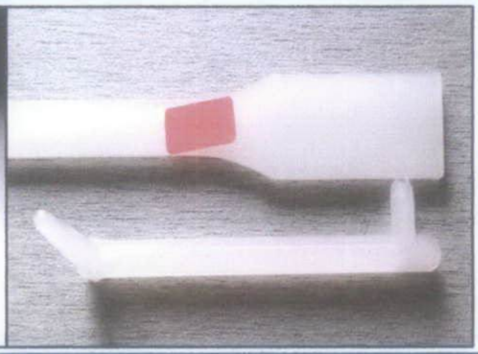
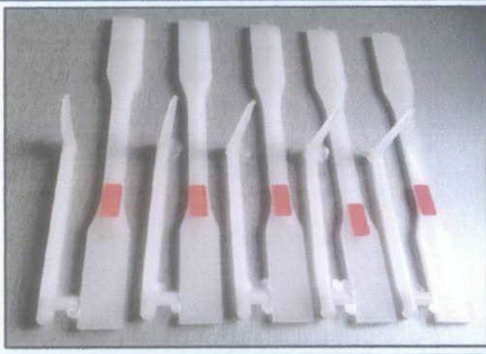
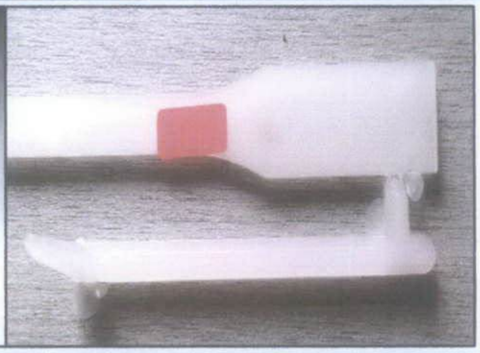
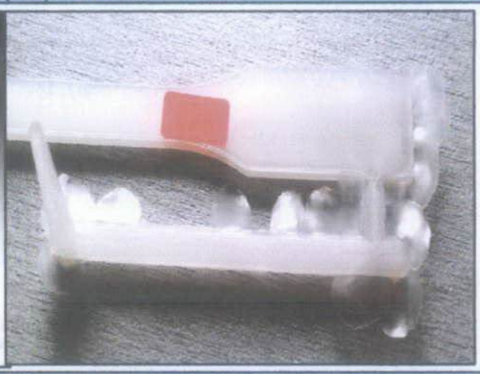
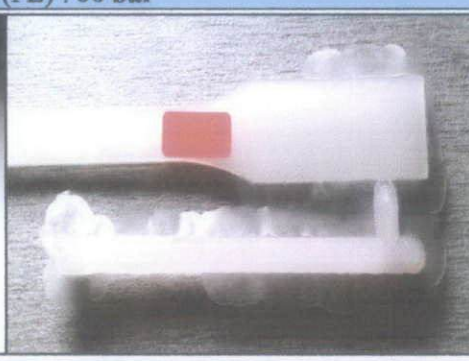
CHAPTER 4
RESULTS AND DISCUSSION

4.1 Experimentation

Through injection moulding process, 5 samples are produced for each value of injection pressure, so altogether, there are a total of 25 samples used for the analysis. Table 4 at the back shows the condition and physical appearance of the dogbone samples for different value of injection pressure.

The visual inspection may show the defects of the samples in term of the flash. The constant behaviour shown by the samples of the same value injection pressure will define the characteristic more clearly. The samples are labelled for further reference.

Table 4 : Visual Inspection for PE samples of different injection pressure value

Polyethylene (PE) : **30 bar**	
	
Polyethylene (PE) : **40 bar**	
	
Polyethylene (PE) : **50 bar**	
	
Polyethylene (PE) : **60 bar**	
	

4.2 Data Gathering

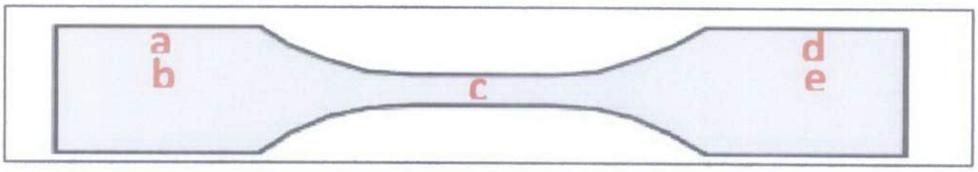


Figure 14 : The points of location on the sample to dimension the thickness

Points *a,b,c,d* and *e* which has been defined are located at the location shown on Figure 14. The characteristic on each of the points will be shown through the measurements data taken below. In order to show how each points differ with each other in term of their characteristic, the thickness and weight of each points and area of the samples are measured. Table 5, 6 and 7 below show the data for each test.

Table 5: Thickness at determined points of the dogbone model

Injection Pressure / Test	Points	1	2	3	4	5	Average
30 bar	*a*	3.42	3.41	3.45	3.41	3.42	3.422
	b	4.02	4.03	4.04	4.05	4.00	4.028
	c	3.40	3.45	3.44	3.45	3.44	3.436
	d	3.39	3.40	3.44	3.41	3.43	3.414
	e	3.48	4.00	3.46	3.47	3.48	3.578
40 bar	*a*	3.45	3.47	3.43	3.42	3.46	3.446
	b	4.02	4.01	4.01	4.00	4.00	4.008
	c	3.41	3.40	3.39	3.41	3.40	3.402
	d	3.36	3.37	3.37	3.39	3.37	3.372
	e	4.00	4.00	3.48	4.00	3.49	3.794
50 bar	*a*	3.43	3.43	3.41	3.41	3.44	3.424
	b	3.46	3.39	4.00	3.47	4.00	3.664
	c	3.40	3.40	3.44	3.42	3.43	3.418
	d	3.39	3.36	3.41	3.41	3.40	3.394
	e	4.01	3.47	4.04	4.02	4.02	3.912
60 bar	*a*	3.41	3.42	3.44	3.41	3.43	3.422
	b	4.03	4.03	4.03	4.02	4.02	4.026
	c	3.45	3.44	3.43	3.44	3.46	3.444
	d	4.00	4.01	4.00	4.02	4.00	4.001
	e	4.04	4.04	4.06	4.04	4.05	4.046

Table 6 : Weight of the samples for different injection pressure.

Injection Pressure (bar)	Weight (g)				
	a	*b*	*c*	*d*	*e*
30	16.43	16.29	16.35	16.33	16.40
40	16.55	16.42	16.47	16.44	16.41
50	16.54	16.70	16.56	16.37	16.70
60	16.88	16.82	16.74	16.75	16.75

Table 7 : Area of the samples for different injection pressure.

Injection Pressure (bar)	Weight (g)				
	a	*b*	*c*	*d*	*e*
30	156	160	158	156	155
40	172	173	170	176	170
50	188	184	191	190	184
60	224	230	225	224	222

4.3 Data Analysis

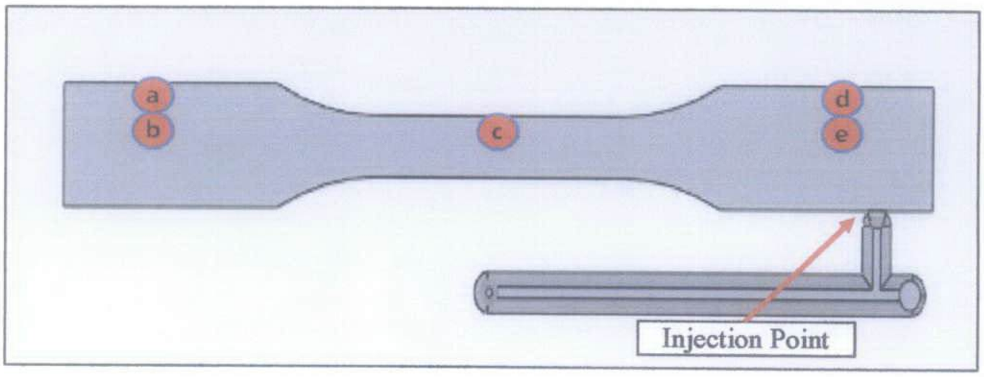


Figure 15 : Location of the defined points on the moulded part

Point *a,b,c,d* and *e* are as shown on Figure 15. The nearest point to the injection point is point *e*, followed by point *d, c, b* and *c*.

4.31 Thickness Analysis

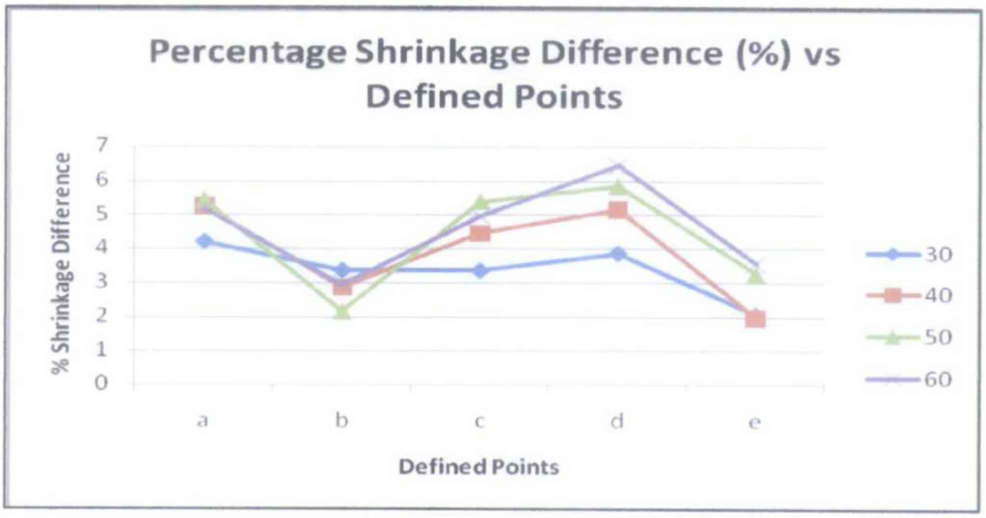


Figure 16 : Shrinkage difference of samples at the defined points at different injection pressure

Based from the gathered thickness data, the value is compared to the original thickness of the perfect dimension of the sample that has the accurate thickness of 4.00 mm. The difference value in thickness is calculated in percentage shrinkage and is then been plotted into a graph as shown in Figure 16. The green line, which represents the shrinkage difference of 30 bar injection bar samples, shows the most constant value amongst all lines. It shows that the changes of thickness do not vary too much as compared to the other samples' thickness of 40, 50 and 60 bar injection pressure that have big gap difference of thickness between points on the samples. The big difference of value at the 5 defined points causes the graph to produce inconsistent line and having big slope in between points. The only line with the most constant thickness is at 30 bar with more moderate flat surface.

In associate to location of the defined points, the difference in thickness is the highest at point *d*, followed by point *a, c, e* and *b*. The polymer has its own behaviour of melt flow, thus the molecules behave differently too during the injection moulding process. Point *b* and *e* have almost similar in shrinkage difference. These two points are located at the centre of each side, so they have similarities in the way the molecules moving and orienting during the thermal cooling. The molecules can spread evenly around as they have sufficient space around the area, making they have not much difference with the perfect dimension of 4.00 mm.

Point *a* almost the same shrinkage difference with point *c*. Point c has small space for molecules thermal distribution, no as point *b* and *e*, so the tendency of the molecules to spread to the top and bottom of the part is higher than to the side itself, making it to have a thicker surface than point *b* and *e*, resulting to higher shrinkage difference.

Point *d* has the highest shrinkage difference. The difference between point d and point *a*, even though they are located at the same spot but at different side, is that point *d* is situated near to the injection point, providing it to have extra polymer melt flow around the area. The force is higher at points situated near to the injection point, so the polymer melt is pushed stronger to the nearest area. The location of point *d* at the end of the part, and in addition the polymer melt flow even at high rate at the location, results to the molecules to spread even more to the top and bottom of the surface.

4.32 Weight Analysis

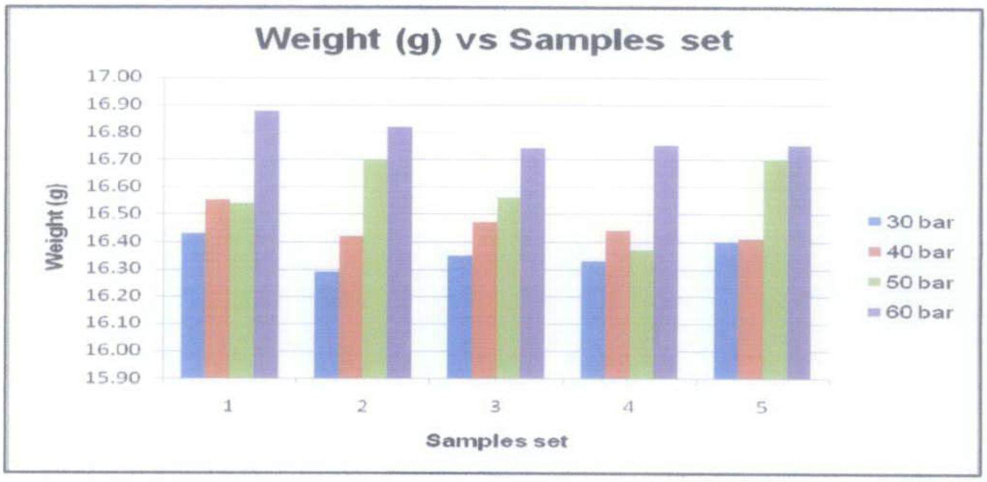


Figure 17 :Graph of weight for each samples

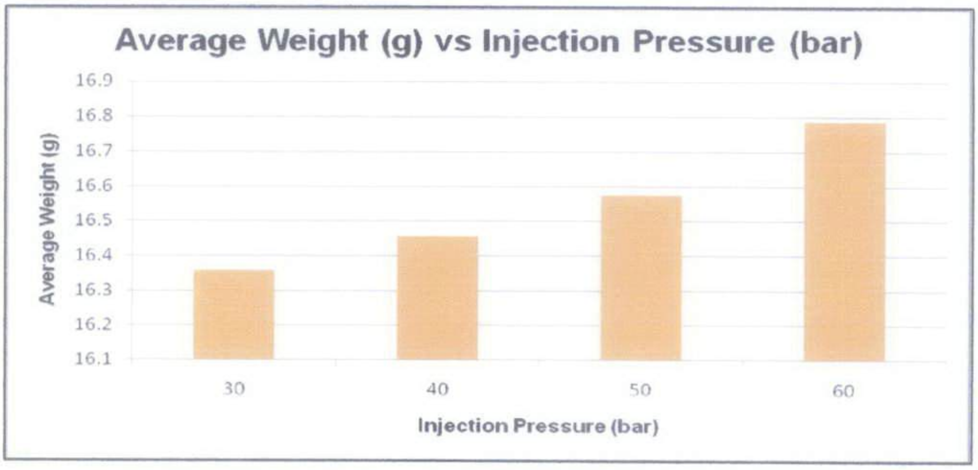


Figure 18 : Average weight of sample for different injection pressure

Figure 17 on the above shows the weight data of each of the samples for different injection pressure value and the data is then simplified into graph of Figure 18. It is clearly shows how flash actually influence on the weight of the sample. Flash is an excess amount of polymer that remains attach to the moulded part. The excess amount of polymer that attach contributes to additional weight on the moulded polymer.

The bar chart trend of Figure 18 is increasing, showing the higher injection pressure having more weight. It can be concluded that flash exist the most on samples of 60 bar injection pressure.

4.33 Area Analysis

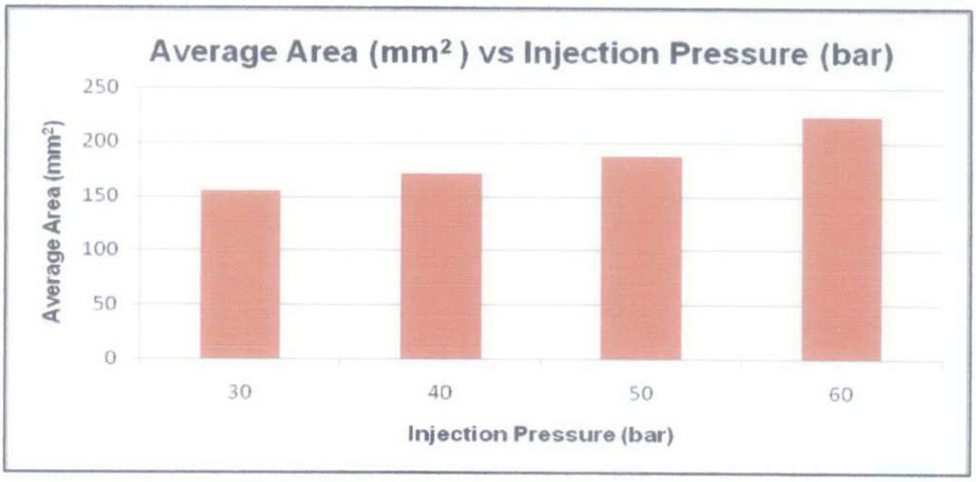


Figure 19: Average area of samples for different injection pressure

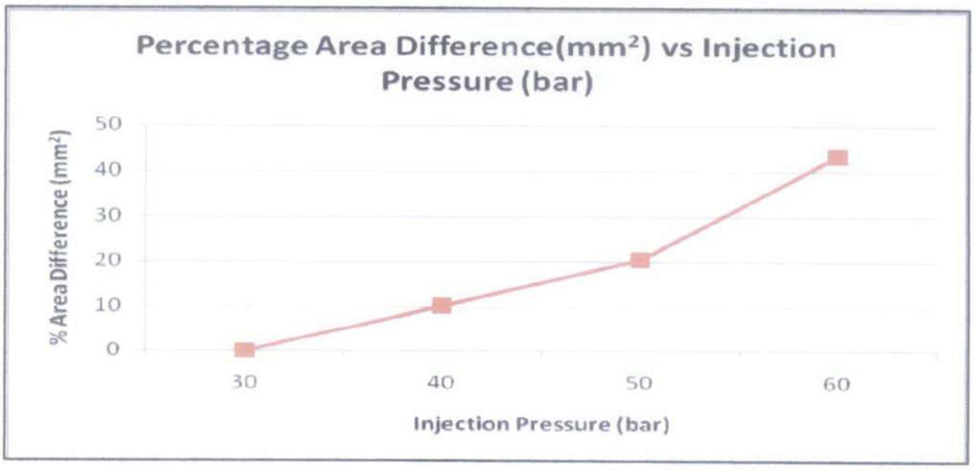


Figure 20 : Percentage of area difference for different injection pressure

Original dimension of the dogbone shape mould has a total area of 154 mm^2. Based from Figure 19, the 30 bar injection pressure sample has the closest value to 154 mm^2. It gives it having the smallest difference with the original piece, making it the best product as compared to 40, 50 and 60 bar samples. Figure 20 shows the percentage area difference increasing from 30 bar sample to 60 bar sample.

The flash is again, the major problem. The excess volume of polymer that is remain attach to the moulded dogbone contributes to the additional area to the total area of the sample. 60 bar sample shows the highest percentage of area difference. It means that the excess volume of polymer is wide spreading the most during the injection moulding process as the area the flash covers for 60 bar sample is the biggest.

Based from the results gained from the visual inspection on the polyethylene (PE) polymer, it is shown that the higher the injection pressure, the higher the flash defects they have. The perfect injection pressure is 30 bar as it neatly produce the least flash on the part. This may due to the higher forced exerted by the injection components that causes the polymer to be pushed even stronger and faster into the mould, which then causing it to leak out, producing flash.

In term of the thickness, the parts produced with 30 bar injection pressure have more constant thickness through the part surface. In another word, the melt polymer flow the best at the injection pressure of 30 bar as the thickness on the whole surface of the part is almost the same.

4.4 Design and Simulation

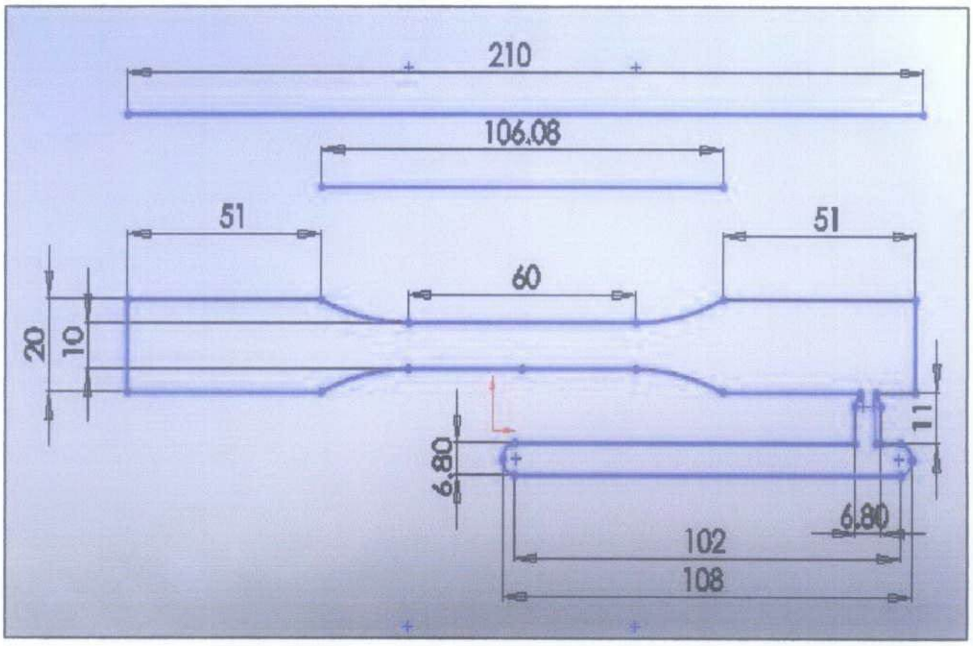


Figure 21: Modelling the dogbone-shaped polymer with the actual dimensions

The modelling is done by using SolidWorks CAD, according to the dimensions of the existence mould as shown in Figure 21. The mould is dimensioned based on ISO 527-2. The 3D model produced through this software will later be interpreted by SimpoeWorks CAE for polymer melt flow simulation. Figure 22 below shows the 3D model designed by using Solidworks.

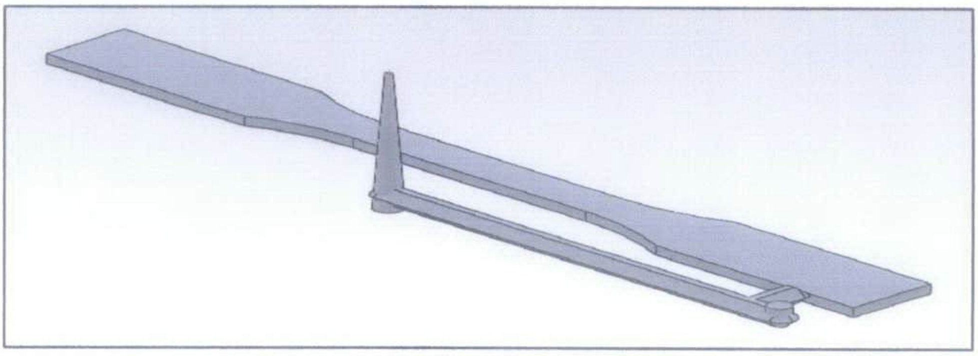


Figure 22 : The dogbone 3D model designed by using Solidworks

4.41 Flow Analysis

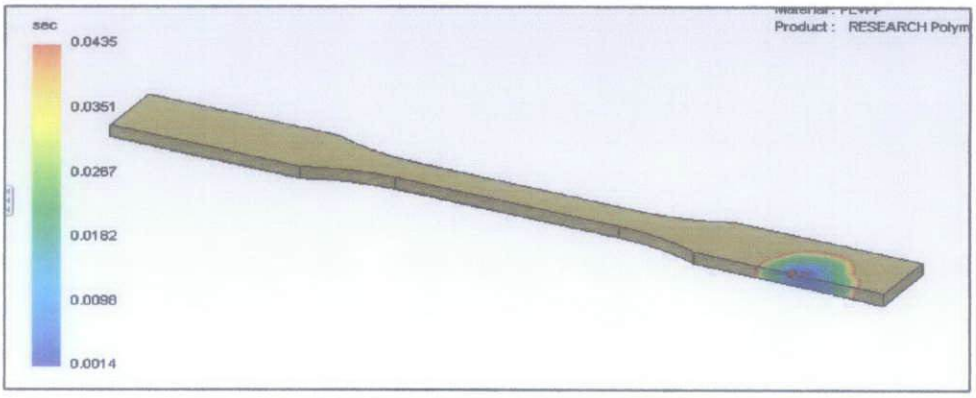


Figure 23 (a) : Polymer flow

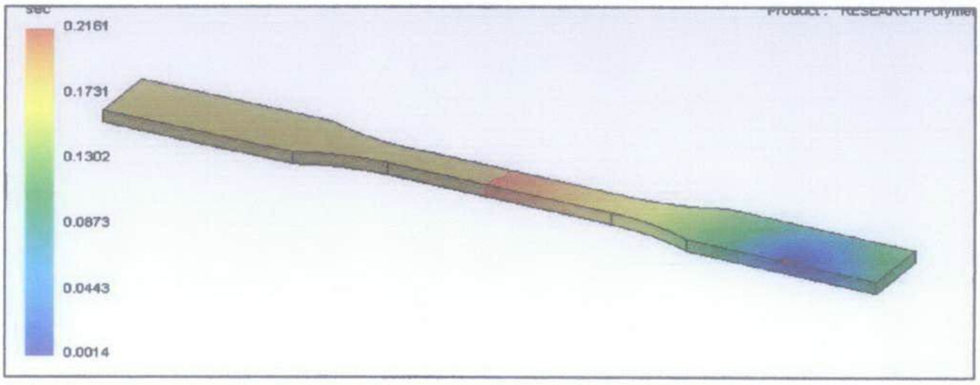


Figure 23 (b) : Polymer flow

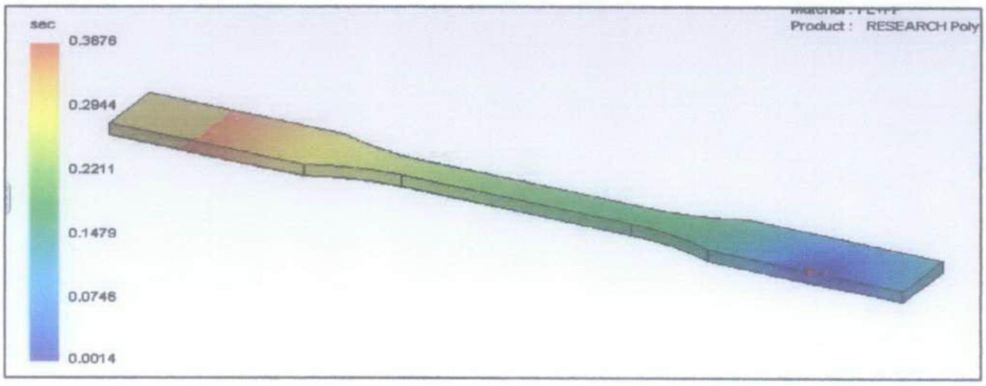


Figure 23 (c) : Polymer flow

Figure 23 *(a)*, *(b)* and *(c)* show the steps of the polymer flow, which flows from the point of injection to the rest of the area of the mould. Blue area refers to the earliest spot that the polymer flow while the red refers to the latest path the polymer takes. Referring to Figure 24, the pressure is the highest at the area near to the injection point, which indicates point *d* and *e*. Pressure is the highest at the point since it is the area where polymer is first injected into the mould, so the force and pressure is originally exerted there, and becoming lesser and lesser with the distance the polymer travels. As the polymer flows, the molecules reduce its energy through kinetic and thermal orientation. The polymer losses its pressure and force as it moves through the mould, thus providing lesser pressure at the other side of the sample.

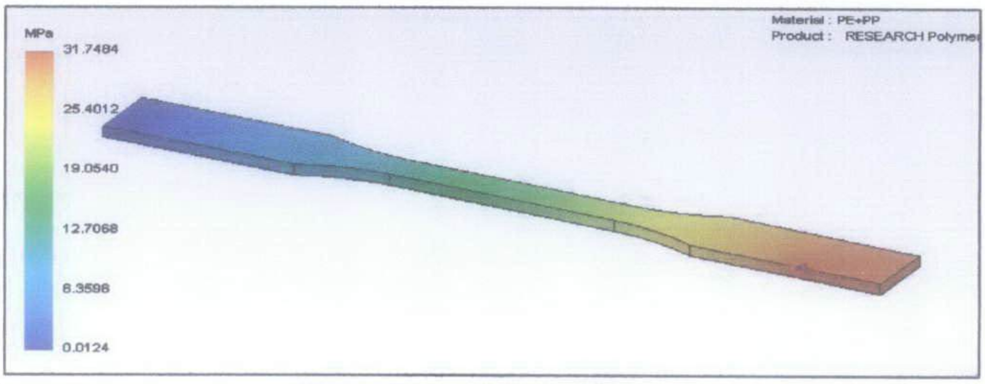


Figure 24 : Pressure at filling end

During the compensation phase of the mould filling cycle, the shear field will move more toward the centre as the outer laminates quickly freeze and thereby locking in high orientation. Despite the increase in the shear field near the centre, the rate of cooling is much slower. This allows the material to relax or disorient. The result is that the net shrinkage is a balance of the stain between each of the laminates. Figure 25 shows the shear stress at the filling end.

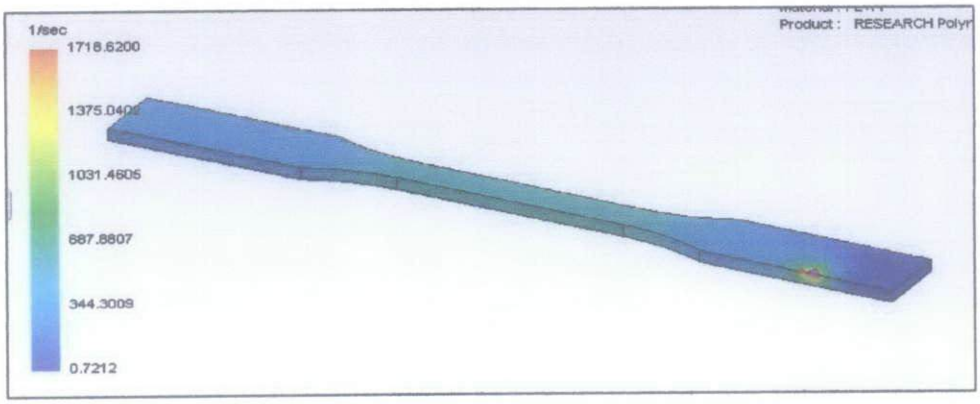


Figure 25 : Shear stress at filling end

From Figure 26, it can be seen that most of the thermal is concentrated at the opposite end of the dogbone shape. The thermal concentration is then affecting the behaviour of the molecular orientation of the polymer. The thermal provided energy to the molecules to move rapidly so mostly the area with sufficient energy, representing the *d* and *e* points area moves more even and the molecules spread well. The area of *a* ,*b* and *c* points have less energy provided by the heat transmission, thus having not much orientation evenly. The transmission of heat and eneygy reach point *a*, *b* and *c* latter than point *d* and *e*. This explains the graph of shrinkage difference shown in Figure 16 where point *b*,*c* and *e* having less shrinkage difference while point a and d having big difference as compared to the perfect dimension thickness of 4.00 mm.

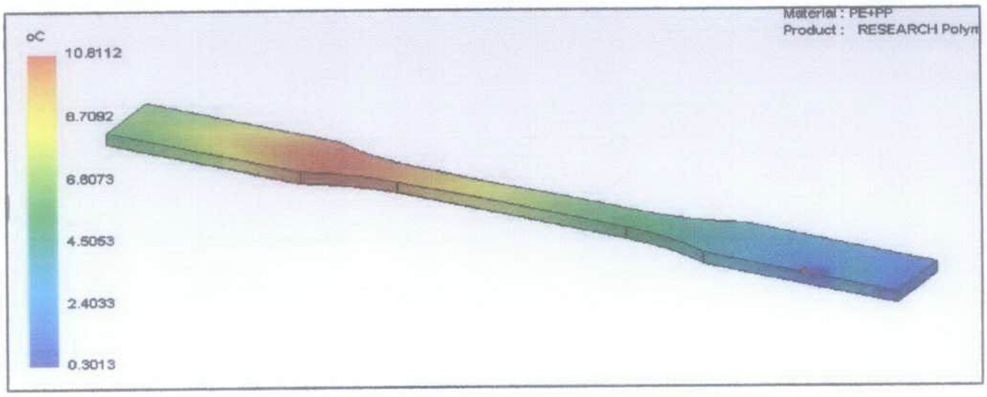


Figure 26 : Temperature growth at filling end

From the simulation of Figure 27, it shows the flow of the polymer melt during the injection moulding process. The blue arrows define the direction of the polymer melt flow which spread all over the mould .The flow path of the polymer melt is also defined by the figures followed:

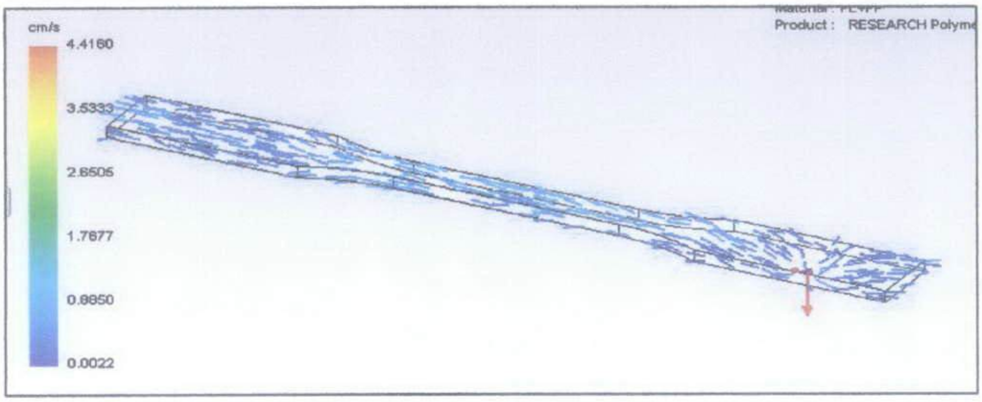


Figure 27 : Velocity vector

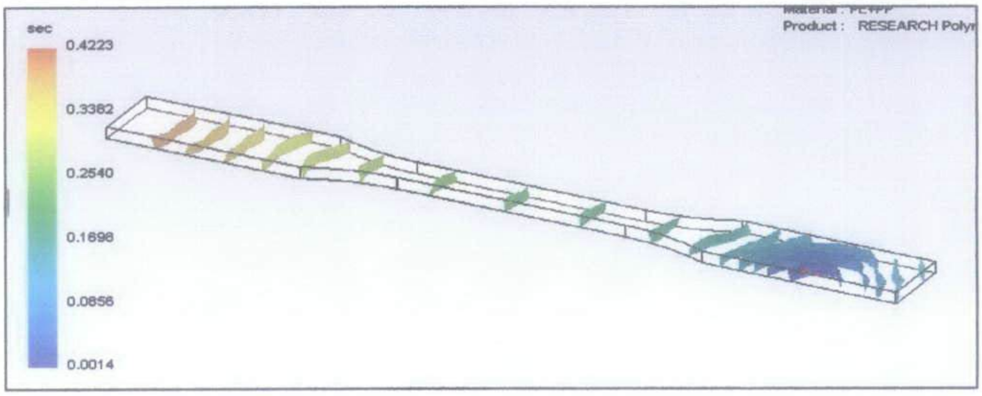


Figure 28 : ISO Surface array

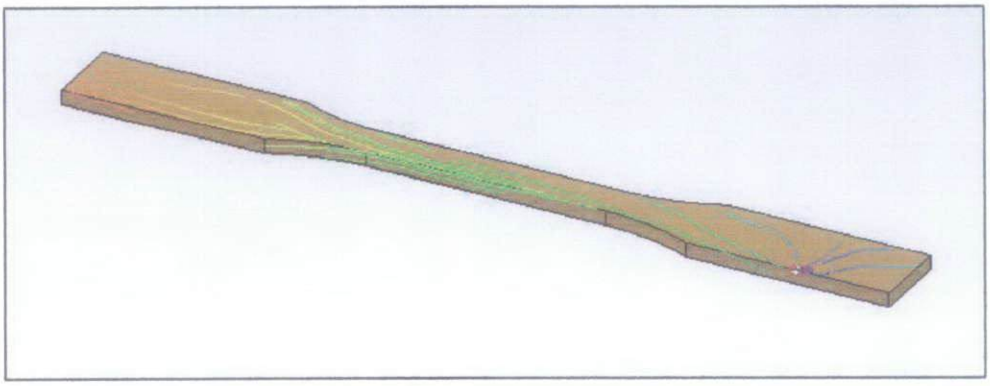


Figure 29 : Path line

Three figures above explain the travel of the polymer, thus explain the distribution of energy, pressure and force too. Referring to Figure 28, many layers are found near the injection point. That is due to the source point of polymer where the polymer begins its flow into the mould. The compact line of Figure 29 at the narrow section shows how pressure and force are compacted at the area due to the small space.

4.42 Pack Analysis

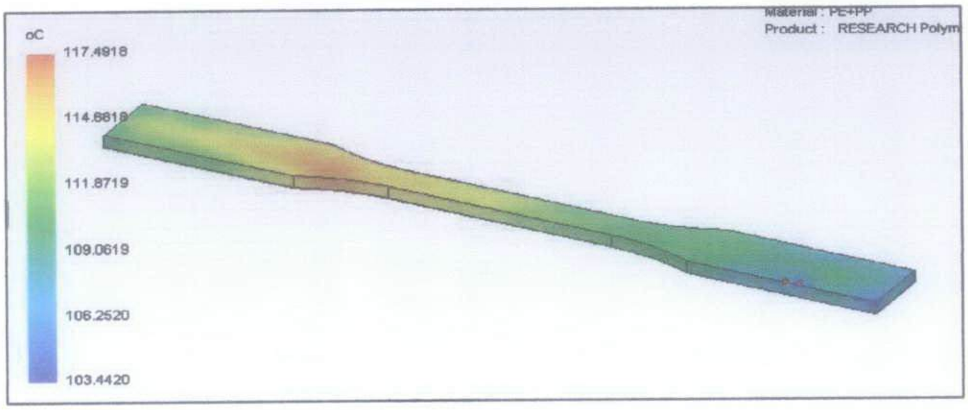


Figure 30 : Bulk temperature at packing end

The behaviour of the polymer during the thermal orientation is even convinced by Figure 30 above. The heat is higher at the middle part along the shape of the dogbone shape, leaving the part at the side around the dogbone shape with lesser heat. The molecules at the centre are provided with extra energy for molecules orientation than the molecules at the side, so the centred molecules spreading even at better orientation. As compared to the molecules at the side, they only can move to the top, bottom and one side as they have limitation of space at the other side, which then making them to move more to the top and bottom, resulting to extra thickness in dimension.

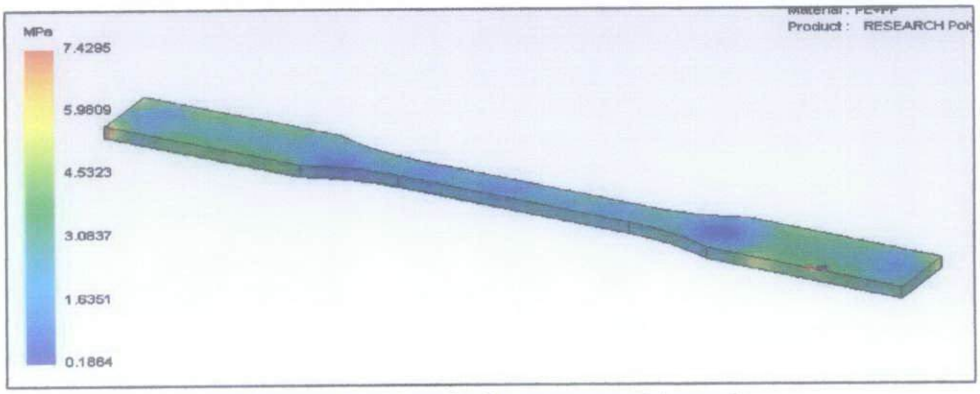


Figure 31 : Residual stress at packing end

Variations in shrinkage in a part will create residual stresses as. If these stresses can overcome the rigidity of the part, it will warp. Regardless if the part warps or not, stresses will remain in the part. Over time, these stresses may cause premature failure through a multitude of factors. The same mould and moulding factors identified as contributors to causing warpage will create residual stresses as in Figure 31. Non-uniform cooling with gradients of temperature and crystallinity leads to residual stresses in the moulded part.

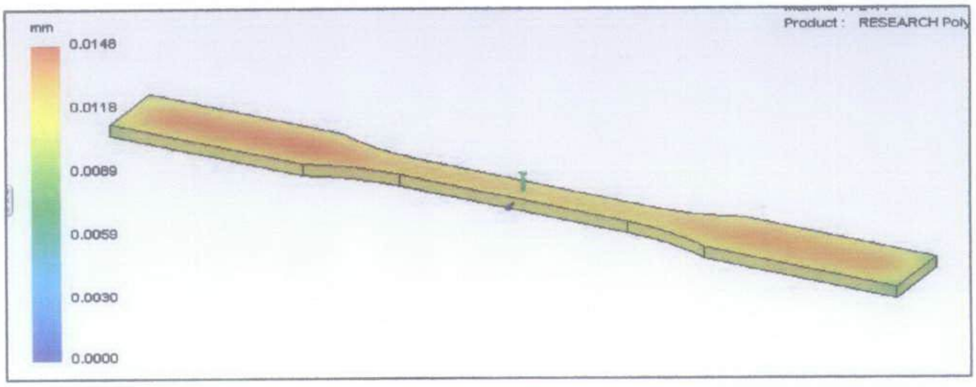


Figure 32 : Volume shrinkage at packing end

Figure 32 clearly shows the volume shrinkage of the moulded part. Shrinkage highly occur at the middle of the moulded part, and less at the edge around the moulded part. This result matches with the experimental part as both of the results show that the thickness is less at the middle of the part, compared to the edge-side around the part itself. Oppositely, at the area of the injection point, the shrinkage rate is rather at minimum. This is provided that the polymer is being supplied sufficiently around the area.

Based from the simulation that is why point *a* and *d* having high percentage of shrinkage difference compared to the other points. The volume shrinkage is low at the side of the sample, making them to have much thicker dimension than the middle part.

During the injection moulding process the polymer is subjected to thermal energy and plasticated in the injection barrel. The molten plastic is then forced under high pressure into a cold mould. The resultant shear field, as shown in Figure 33 below, acting on the expanded polymer mass, results in the molecules becoming oriented in the direction of the principle strain. The degree of orientation is a function of the applied shear stresses that are commonly over 100 000 pascals. This orientation or ordering of the molecules, results in a relatively high energy state which effect reduces its entropy. The shrinkage is increase in the direction of flow versus transverse to flow.

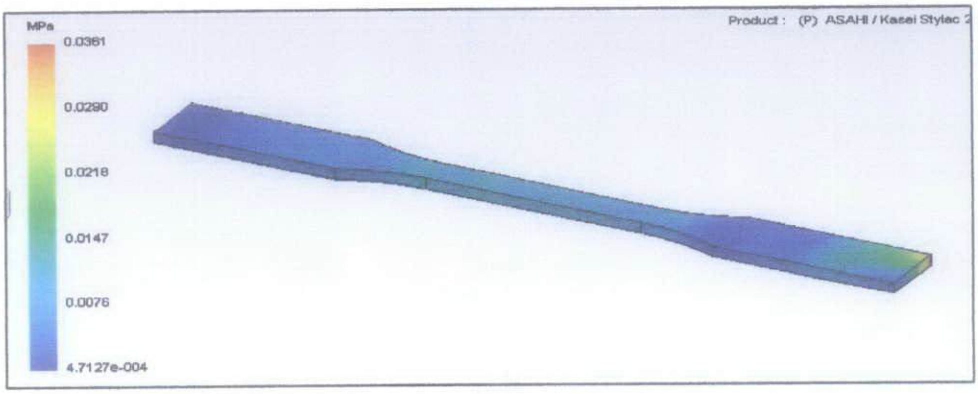


Figure 33 : Shear stress at packing end

4.43 Warp Analysis

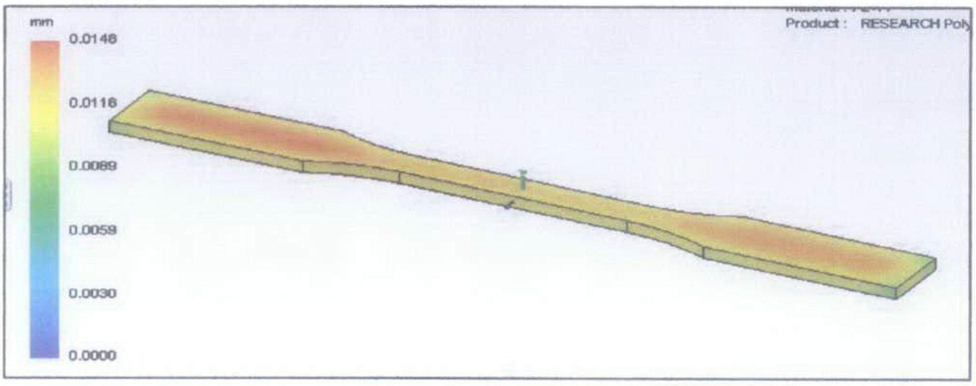


Figure 34 : Sink Mark Profile

A sink mark is a local surface depression that typically occurs in mouldings with thicker sections, or at locations above ribs, bosses, and internal fillets. Sink marks are caused by localized shrinkage of the material at thick sections without sufficient compensation when the part is cooling. After the material on the outside has cooled and solidified, the core material starts to cool. Its shrinkage pulls the surface of the main wall inward, causing a sink mark. Sink mark profile is shown in Figure 34 and as displayed in Figure 35.

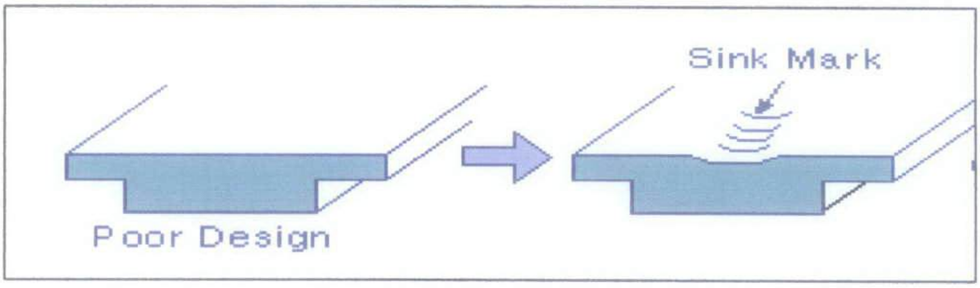


Figure 35 : Sink mark

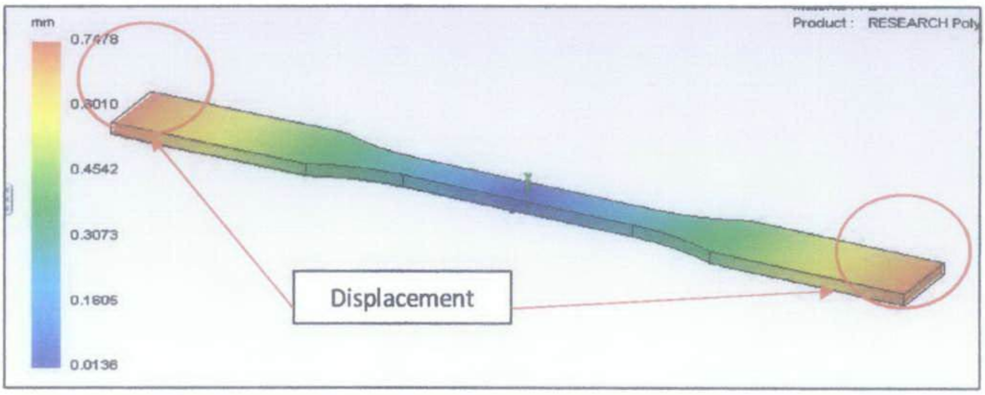


Figure 36 : Total displacement

Figure 36 shows how the condition and shape of the moulded part after shrinkage. The original dimension is shown by the transparent shape the coloured is the part after shrinkage. Again, the shrinkage is highest at the opposite end from the injection point of the part as the pressure and force is slowly transmitted to the other end, thus increase the shrinkage rate. Warpage is non-uniform stresses due to shrinkage. This is why warpage occur in the existence of shrinkage. Warpage is a non-uniform shape results from the problem. This can be displayed with exaggeration as well, as in Figure 36.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Recommendation

The purpose of this project is to investigate how injection pressure influenced the injection moulded part. The finding data could help in producing better quality of product as well as reducing the number of rejected part, thus will reduce the cost spent for the manufacturing process. The best injection pressure which produces the least defect of warpage, shrinkage and flash is be identified.

Based from the experimentation, the finding shows that the moulded dogbone part is best produced by 30 bar injection pressure value as it produces the least defects. The material laboratory of Universiti Teknologi Petronas is somehow uses the standard of 50 bar. Corrective action should be made to change the standard value to 30 bar, instead of 50 bar for specific type of material. The standardization of injection pressure value for the purpose of injection moulding should be made once the behaviour of the material has been analysed. The smart way of implementing the right pressure will enable the university itself to cut down the expenses for electricity, energy and materials.

5.2 Conclusion

Influenced by variation of injection pressures polyethylene (PE), has shown their own behaviour of melt flow. Having different characteristic of material causes it to react differently. For the purpose of dimensioning and modelling, SolidWorks CAD software are used. The model will then be used for further translation and simulation through SimpoeWorks CAE to investigate the characteristic of the polymer flow thus indicating the formation of the warpage and shrinkage.

The effects of flash on the injection moulded part can be visualized clearly during experimentation by using the injection moulding machine. The simulation results were also compared with the experimental data for verification of the developed programme. It was found that the predictions were in agreement with experimental data, especially in qualitative analysis.

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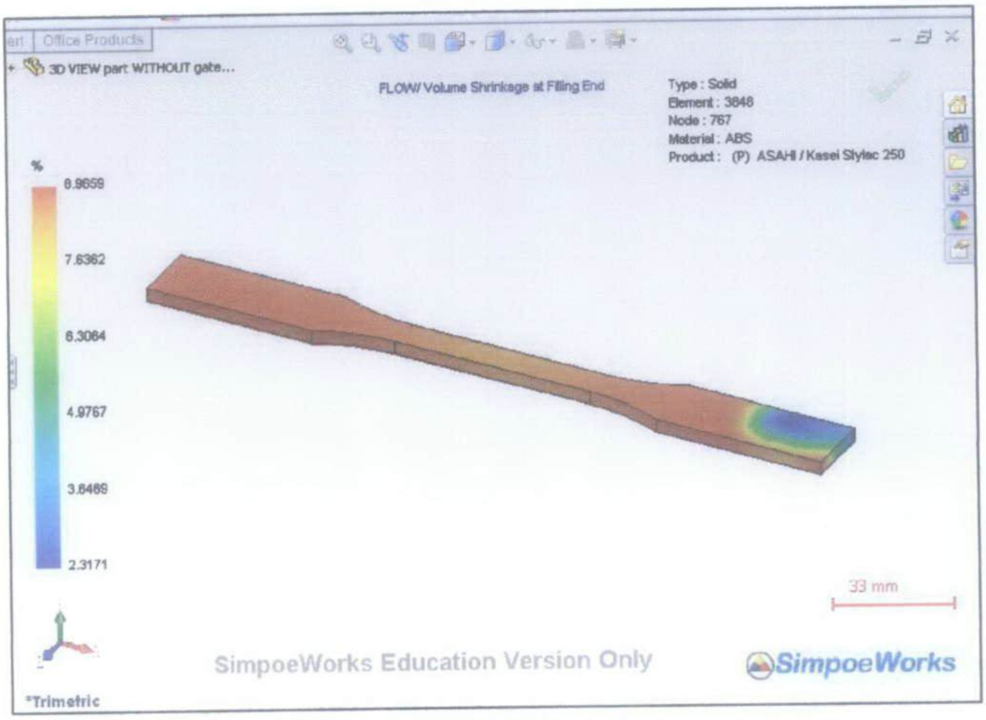
APPENDICES

Appendix 1

Location of the dogbone shaped mould in the machine

Appendix 2



Simulation in SimpoeWorks

Appendix 3

Model Information

Name: Dogbone
Type: Solid
Volume: 13.016 (cm3)
Weight: 11.714 (g)
Size:
X: 208.084 (mm)
Y: 4.000 (mm)
Z: 20.000 (mm)

Material Information

Group No = 59
Material No = 1
Material Name = PE+PP
Product Name = RESEARCH Polymers / RPI-299X
Melt Temperature = 2.300000e+002
Mold Temperature = 8.000000e+001
Eject Temperature = 1.200000e+002
Glass Transition Temperature = 1 1.000000e+002
Specific Heat = 1 2.200000e+007
Conductivity = 1 1.600000e+004
Viscosity = 5 1.900000e-001 5.390000e+003 3.730000e+005 3.400000e-001
0.000000e+000
Density = 1 9.000000e-001
Shear Modulus = -1
-1
Thermal Linear Expansional Coefficentf= 2 9.500000e-005 9.500000e-005
Young Modulus = 2 2.600000e+010 2.600000e+010
Poisson Ratio = 2 3.800000e-001 3.800000e-001
Curing Kinetics = -1
No-Flow Temperature = -1
Melt Flow Rate Index = -1
Fibers = -1
Stress Optical Coefficient = -1
Leonov Parameters = -1
WLF Parameters = -1

Model and Material Information

Process Condition Information

FLOW/PACK

Filling Time = 0.43 sec
Main Material Melt Temperature = 230 oC
Mold Wall Temperature = 80 oC
Max. Inject(Machine) Pressure = 80 MPa
Max. Inject(Machine) Flow Rate = 150 cc/s
Flow/Pack Switch Point in Filled Volume = 100 %
Post-filling(1: Exist, 0: Not) = 0
Pressure Holding Time = 3.12 sec
Total Time in Pack Stage = 13.12 sec
Residual Stress Calculation(1: Exist, 0: Not) = 1
Fiber Orientation Calculation(1: Exist, 0: Not) = 0
Co-Injection(1: Exist, 0: Not) = 0
2nd Material Melt Temperature = 230 oC
Multi general Gate Flow-rate/Press control(0: Equivalent, 1: Auto) = 1
Gravity Direction: = Z
Injection Domain = 0
Injection System = 0
Viscoelastic Birefringence Calculation(1: Exist, 0: Not) = 0

COOL

Inlet melt temperature = 230 oC
Min. Coolant temperature = 25 oC
Air temperature = 30 oC
Mold open time = 5 sec
Average coolant flow rate = 150 cc/s
Control type(1:Eject temp., 2:Cooling time) = 1
Eject temperature(If control type is "1") = 120 oC
Cooling time(If control type is "2") = 15.84 sec

WARP

Environment Temperature = 30 oC
Gravity Direction: = Z

Process Condition Information

Summary - Flow Result

X-dir. Clamping Force= 3.416555e-002 Tonne (3.77e-002 Ton U.S)
Y-dir. Clamping Force= 2.033091e+000 Tonne (2.24e+000 Ton U.S)
Z-dir. Clamping Force= 5.935354e-001 Tonne (6.54e-001 Ton U.S)
Requiring injection pressure= 2.065052e+001 Mpa (3.00e+003 psi)
Max. real temperature= 2.321961e+002 oC (4.50e+002 oF)
Max. bulk temperature= 2.322116e+002 oC (4.50e+002 oF)
Max. shear stress= 1.170994e+000 Mpa (1.70e+002 psi)
Max. shear rate= 8.969516e+002 1/sec
Total CPU Time = 82.97 sec

Summary - PACK Result

Max. real temperature= 1.938644e+002 oC (3.81e+002 oF)
Max. bulk temperature= 2.285009e+002 oC (4.43e+002 oF)
Max. shear stress= 3.608972e-002 Mpa (5.24e+000 psi)
Max. shear rate= 9.438806e-001 1/sec
Max. residual stress= 4.606448e+000 Mpa (6.68e+002 psi)

Summary - WARP Result

X direction displacement= 2.3039 mm (0.0907 in)
Y direction displacement= 0.1600 mm (0.0063 in)
Z direction displacement= 0.3496 mm (0.0138 in)
Max. total displacement= 1.2513 mm (0.0493 in)
CPU Time = 5.28 sec

Result summary for flow, pack and warp

Appendix 4

@@ Software Released Time: Simpoe3D FLOW-PACK/E-Style 2011/4/18 11:57 @@
# System machine information - Number of processor= 1
# Maximum number of treads of the run-time system= 1
~~~~~~
** Simpoe3D/Solid FLOW-PACK Report/Record File **

Date/time : Thu Aug 18 11:40:32 2011
File path : C:\Documents and Settings\Guest\Desktop\solid\3D VIEW part WITHOUT gate and sprew2\3D VIEW part WITHOUT gate and sprew2
Software type : x86
~~~~~~
@@@ Simpoe3D/Solid FLOW-PACK Analysis V2011.1 @@@
* SIMPOE-FLOW-PACK Analysis ...
# Calculating parameter information ......

Solver Type(1: AMG, 2: PCG-AMG) = 1.00e+000 (None)
Short shot (Factor of initial flow rate) = 1.00e-002 (None)
(#)Pressure/Velocity residual error criteria(1.E-4 ~ 1.E-2) = 1.00e-003 (None)
(#)Velocity field relaxation factor(0.1 ~ 1.0) = 7.50e-001 (None)
(#)Pressure correction relaxation factor(0.05 ~0.8) = 2.50e-001 (None)
(#)P/V field Max. iter, No.(40 ~ 100) = 8.00e+001 (None)
(#)Time acceleration factor during filling process(0.1 ~ 10.) = 2.00e+000 (None)
(#)Cell volume filled index during filling process(0.25 ~ 1.0) = 7.50e-001 (None)
(#)Fiber calculation acceleration factor(1 ~ 5) = 2.00e+000 (None)
(#)Finite volume solver(1: Coupled, 2: Segregated) = 2.00e+000 (None)
(#)Mold temperature profile from COOL(1: Cycle Averaged, 2: Transient) = 2.00e+000 (None)
(#)Volume of Fluid (VoF) Algorithm(1: Direct, 2: Indirect) = 2.00e+000 (None)
(#)Fiber Interaction Coefficient(0.0001 ~ 0.01.) = 1.00e-003 (None)

Geometric data information ......

Part Max. Extent= 20.81 cm (x: 20.808441 y: 0.400000 z: 2.000000)
Number of Cell = 2078 (Hexa=0, Prism=0, Pyramid=0, Tetra=2078)
Number of Node = 696

Process condition information ......
Domain number 1 with 1 injection systems

Filling Time = 4.30e-001 sec
Main Material Melt Temperature = 1.10e+002 oC (2.30e+002 oF)
Mold Wall Temperature = 8.00e+001 oC (1.76e+002 oF)
Max. Inject(Machine) Pressure = 8.00e+001 MPa (1.16e+004 psi)
Max. Inject(Machine) Flow Rate = 1.50e+002 cc/s (5.07e+000 Ounces/sec)
Flow/Pack Switch Point in Filled Volume = 1.00e+002 %
Post-filling(1: Exist, 0: Not) = 1.00e+000 (None)

Flow Report

```
Pressure Holding Time = 3.12e+000 sec
Total Time in Pack Stage = 1.31e+001 sec
Residual Stress Calculation(1: Exist, 0: Not) = 1.00e+000 (None)
Fiber Orientation Calculation(1: Exist, 0: Not) = 0.00e+000 (None)
Fiber % in Weight or Volume(1: Weight, 2: Volume) = 1.00e+000 (None)
Fiber % (from 0 to 100) = 2.00e+001 %
Co-Injection(1: Exist, 0: Not) = 0.00e+000 (None)
nd Material Melt Temperature = 1.10e+002 oC (2.30e+002 oF)
Reactive Control Type(1:Conversion, 2:Time) = 1.00e+000 (None)
Reactive Eject Conversion(x: 0 ~ 100, for Type "1") = 8.00e+001 %
Multi general Gate Flow-rate/Press control(0: Equivalent, 1: Auto) = 1.00e+000 (None)
Gravity Direction(+/-(X,Y,Z): +/-(1,2,3)) = 3.00e+000 (None)
Injection Domain = 0.00e+000 (None)
Injection System = 0.00e+000 (None)
Viscoelastic Birefringence Calculation(1: Exist, 0: Not) = 0.00e+000 (None)

/*=====================================================================
=
* Flow-rate control type(1 or 2) or not(0: P control)
* 1: abs. profile to max. mach. inject rate
* (X: % in voulme filled, Y: % in max. inject flow rate)
* 2: rel. profile to specify filling-time
* (X: % in filling time, Y: % in rel. flow rate)
* 0: Flow rate control no using, and using presure control
*(A). No. of profile for ram-speed control
*(B). Sequential point for ram-speed control(% in volume/time)
*(C). Sequential profile for ram-speed control(% in flow rate)
*=====================================================================
*/
2 0
A 6
B 0.00 20.00 40.00 60.00 80.00 100.00
C 20.00 20.00 20.00 20.00 20.00 20.00

/*=====================================================================
=
* Pressure control type(1 or 2)
* 1: abs. profile to max. machine P
* (X: % in packing time, Y: % in max. machine pressure)
* 2: rel. profile to entrance P(F/P swich pt.)
* (X: % in packing time, Y: % in entrance pressure)
*(A). No. of profile for P control
*(B). Sequential point for P control(% in packing time)
*(C). Sequential profile for P control(% in pressure)
*=====================================================================
*/
2 0
A 7
B 0.00 20.00 40.00 40.10 60.00 80.00 100.00
C 80.00 80.00 80.00 40.00 40.00 40.00 40.00
```

Flow Report

Material data information ......
[Polymer_Material] [First_Kind]
Group_No = 59
Material_No = 1
Material_Name = PE+PP
Product_Name = RESEARCH Polymers / RPI-299X | 2.300000e+002 8.000000e+001
Melt_Temp = 230.00
Mold_Temp = 80.00
Eject_Temp = 120.00
Glass_Temp = 1 1.00e+002
Specific_Heat = 1 2.20e+007
Conductivity = 1 1.60e+004
Viscosity = 5 1.90e-001 5.39e+003 3.73e+005 3.40e-001 0.00e+000
Density = 1 9.00e-001
Shear_Modulus = -1
-1
Thermal_Volume_Expans_Coeff= 2 9.50e-005 9.50e-005
Young_Modulus = 2 2.60e+010 2.60e+010
Poisson_Ratio = 2 3.80e-001 3.80e-001
Curing_Kinetics = -1
NoFlow_Temp = -1
Melt_Flow_Rate_Index = -1
Fiber = -1
Max_Shear_Rate = -1
Max_Shear_Stress = -1
MaxMin_MeltMold_Temp = 4 -274.00 -274.00 -274.00 -274.00
Stress_Optic_Coeff = -1
Leonov_VE_Data = -1
Leonov_VE_WLF = -1

Domain 1: Pure thermoPlastic injection molding process...
Tetra cell quality :
Total cell number= 2078
Number of cell for Aspect Ratio > 20= 0
Maximum Aspect Ratio= 12.978786, in Cell 2075
Minimum Aspect Ratio= 3.041391, in Cell 588
!! Recommendation value of Aspect Ratio to be < 20 !!
** COOL results file 'filename.TWL3'(Transient Wall Temperature) does not exist
** COOL results file 'filename.WL1/WL2/WL3'(Cycle Averaged Wall Temperature) does not exist

Part total volume = 13.016 cm3

No FLOW ReStart : Filling stage is from beginning ...

For Injection Domain: 1
Domain volume = 13.016 cm3
Injection system reconstruction :

Flow Report

Injection system 1 -
Inlet flow rate = 30.269 cm3/sec
Inlet normal velocity = 452.626 cm/sec
Inlet region area = 0.067 cm2
Inlet Reynolds No. = 0.031568
SIMPOE-FLOW

Domain 1 : Filling stage results summary :

11003 : X direction clamping force = 1.848794e-001 Tonne (2.04e-001 Ton U.S)
11004 : Y direction clamping force = 5.169463e+000 Tonne (5.70e+000 Ton U.S)
11005 : Z direction clamping force = 1.323217e+000 Tonne (1.46e+000 Ton U.S)
25001 : Requiring injection pressure = 3.174840e+001 Mpa (4.61e+003 psi)
25005 : Max. real temperature = 1.209597e+002 oC (2.50e+002 oF)
25004 : Max. bulk temperature = 1.209612e+002 oC (2.50e+002 oF)
25006 : Max. shear stress = 3.715169e-001 Mpa (5.39e+001 psi)
25007 : Max. shear rate = 1.718620e+003 1/sec
Filling end time = 0.422338
Total time = 0.422338

Welding line calculating ...
Filling stage is end.

FLOW Analysis CPU Time : 67.05 sec
Solver CPU Time : 20.96 sec (13.38 sec | 7.20 sec | 0.39 sec)
Others CPU Time : 46.08 sec
Post-filling stage is beginning ...
SIMPOE-PACK

Domain 1 : Post-filling stage results summary :

25005 : Max. real temperature(post-filling end) = 1.096329e+002 oC (2.29e+002 oF)
25004 : Max. bulk temperature(packing end) = 1.176418e+002 oC (2.44e+002 oF)
25006 : Max. shear stress(packing end) = 0.000000e+000 Mpa (0.00e+000 psi)
25007 : Max. shear rate(packing end) = 0.000000e+000 1/sec
25011 : Max. residual stress(post-filling end) = 7.429549e+000 Mpa (1.08e+003 psi)
Post-Filling end time = 13.442338 sec
Total time = 13.442338 sec
Additional filled plastic volume of packing stage = 0.000000 cc
----
Post-filling stage is end.

Total System Time : 74.00 sec
Total CPU Time : 73.94 sec
Solver CPU Time : 21.22 sec (13.38 sec | 7.20 sec | 0.64 sec)
Others CPU Time : 52.72 sec

Simpoe3D/Solid FLOW-PACK V2011.1 Analysis is Completed

Flow Report

Appendix 5

```
@@ Software Released Time: Simpoe3D WARP/E-Style 2011/4/18 12:0 @@
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
** Simpoe3D/Solid WARP Report/Record File **

Date/time : Thu Aug 18 11:41:48 2011
File path : C:\Documents and Settings\Guest\Desktop\solid\3D VIEW part WITHOUT
gate and sprew2\3D VIEW part WITHOUT gate and sprew2
Software type : x86
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
@@@ Simpoe3D/Solid WARP Analysis V2011.1 @@@
# SIMPOE-WARP #
# Calculating parameter information ......

Enlarge scale factor of warpage deformation(10 ~ 30) = 2.00e+001 (None)
Solver Type(1: AMG, 2: PCG-AMG) = 1.00e+000 (None)
Residual error tolerance(1.E-10 ~ 1.E-6) = 1.00e-008 (None)
Max. iteration No.(1000 ~ 30000) = 1.50e+004 (None)
The first fixed boundary node No. = 0.00e+000 (None)
The second fixed boundary node No. = 0.00e+000 (None)
The third fixed boundary node No. = 0.00e+000 (None)
PCG solver ILU decomposition fill index(1 ~ 6). = 3.00e+000 (None)
PCG solver ILU decomposition drop tolerance(1.E-6 ~ 1.E-2). = 1.00e-003 (None)

BC_node 1= 0
BC_node 2= 0
BC_node 3= 0

# Geometric data information ......

Part Max. Extent= 20.81 cm (x: 20.808441 y: 0.400000 z: 2.000000)
Number of Cell = 2078 (Hexa=0, Prism=0, Pyramid=0, Tetra=2078)
Number of Node = 696

# Process condition information ......
Filling Time = 4.30e-001 sec
Main Material Melt Temperature = 1.10e+002 oC (2.30e+002 oF)
Mold Wall Temperature = 8.00e+001 oC (1.76e+002 oF)
Max. Inject(Machine) Pressure = 8.00e+001 MPa (1.16e+004 psi)
Max. Inject(Machine) Flow Rate = 1.50e+002 cc/s (5.07e+000 Ounces/sec)
Flow/Pack Switch Point in Filled Volume = 1.00e+002 %
Post-filling(1: Exist, 0: Not) = 1.00e+000 (None)
Pressure Holding Time = 3.12e+000 sec
Total Time in Pack Stage = 1.31e+001 sec
```

Warp Report

```
Residual Stress Calculation(1: Exist, 0: Not) = 1.00e+000 (None)
Fiber Orientation Calculation(1: Exist, 0: Not) = 0.00e+000 (None)
Fiber % in Weight or Volume(1: Weight, 2: Volume) = 1.00e+000 (None)
Fiber % (from 0 to 100) = 2.00e+001 %
Co-Injection(1: Exist, 0: Not) = 0.00e+000 (None)
nd Material Melt Temperature = 1.10e+002 oC (2.30e+002 oF)
Environment Temperature = 3.00e+001 oC (8.60e+001 oF)
Gravity Direction(+/-(X,Y,Z): +/-(1,2,3)) = 3.00e+000 (None)

# Material data information ......

[Polymer_Material] [First_Kind]
Group_No = 59
Material_No = 1
Material_Name = PE+PP
Product_Name = RESEARCH Polymers / RPI-299X | 2.300000e+002 8.000000e+001
1.200000e+002
Glass_Temp = 1 1.00e+002
Specific_Heat = 1 2.20e+007
Conductivity = 1 1.60e+004
Viscosity = 5 1.90e-001 5.39e+003 3.73e+005 3.40e-001 0.00e+000
Density = 1 9.00e-001
Shear_Modulus = -1
-1
Thermal_Volume_Expans_Coeff= 2 9.50e-005 9.50e-005
Young_Modulus = 2 2.60e+010 2.60e+010
Poisson_Ratio = 2 3.80e-001 3.80e-001
Curing_Kinetics = -1
NoFlow_Temp = -1
Melt_Flow_Rate_Index = -1
Fiber = -1
Max_Shear_Rate = -1
Max_Shear_Stress = -1
MaxMin_MeltMold_Temp = 4 -274.00 -274.00 -274.00 -274.00
Stress_Optic_Coeff = -1
[Second_Kind]
Group_No = 1
Material_No = 1
Material_Name = ABS
Product_Name = (P) ASAHI / Kasei Stylac 250 | 2.300000e+002 8.000000e+001
1.200000e+002
Glass_Temp = 1 1.05e+002
Specific_Heat = 1 2.40e+007
Conductivity = 1 1.80e+004
Viscosity = 5 3.15e-007 1.32e+004 4.51e+005 3.50e-001 2.40e-009
Density = 13 9.49e-001 6.18e-004 1.72e+009 4.17e-003 9.49e-001 2.63e-004 2.56e+009
3.72e-003 3.70e+002 4.00e-008 0.00e+000 0.00e+000 0.00e+000
Shear_Modulus = -1
```

```
-1
Thermal_Volume_Expans_Coeff= 2 9.40e-005 9.40e-005
Young_Modulus = 2 2.60e+010 2.60e+010
Poisson_Ratio = 2 3.80e-001 3.80e-001
Curing_Kinetics = -1
NoFlow_Temp = -1
Melt_Flow_Rate_Index = -1
Fiber = -1
Max_Shear_Rate = -1
Max_Shear_Stress = -1
MaxMin_MeltMold_Temp = 4 -274.00 -274.00 -274

Stress_Optic_Coeff = -1


# ThermoPlastic warpage simulation of injection molding process...
# System machine information - Number of processor= 1
No. Bad cell (V/A < 0.1) = 0

Boundary node 1= 472
Boundary node 2= 551
Boundary node 3= 360

Degree of freedom = 2088

Effective Part volume(FEM)= 13.015550 cm3
Effective Part volume(FVM)= 13.015550 cm3
Searching processing ......
Allocate processing ......
Warpage stage results summary :
------------------------------------------------------------------------------------------
25201 : X direction displacement = 1.4705 mm (0.0579 in)
25202 : Y direction displacement = 0.0530 mm (0.0021 in)
25203 : Z direction displacement = 0.1525 mm (0.0060 in)
25204 : Total displacement = 0.7471 mm (0.0294 in)
------------------------------------------------------------------------------------------

** CPU Time ** : 6.02 sec
Recorded - C:\Documents and Settings\Guest\Desktop\solid\3D VIEW part WITHOUT
gate and sprew2\3D VIEW part WITHOUT gate and sprew2.WD3
____________________________________________________________________________

### Simpoe3D/Solid WARP V2011.1 Analysis is Completed ###
```

Warp Report