

# Development of Mould of Rheology Test Sample via CadMould 3D-F Simulation.

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**Abstract.** This research was about the development of mould for rheology test sample via simulation. The development work concerned with stages of design, simulation, analysis, and fabrication of the mould to produce good quality samples. In the design stage, three mould concepts have been prepared via Solid Works software. The simulation of injection moulding was conducted by using CadMould 3D-F software. Then, in the analysis stage, the main factor that has been studied were the cavity system, runner system and the gating system. For each design, different type of systems were applied to compare different simulation result. Through the simulation software, it was rectified that the parameter such as the number of cavities, filling time, shear stress were the main factors to contribute good rheological properties of the sample. The final result shows that Design 2 was chosen as the suitable mould due to number of cavities and good results in the analysis, as compare to other mould design. Finally, Design 2 have been fabricated and undergo fitting test to see whether the dimension had been done correctly. Based on this research findings, it was proven that to develop a mould suitable for rheology sample, the mould design selection should be made based on the type of system in simulations.

## 1. Introduction

Injection moulding was one of the most widely use process in the manufacturing industry in order to process plastic material especially thermoplastic. It was a complex process which involved many factors to regulate the process, such as injection speed, injection pressure, melt temperature and mould temperature (Crawford, 1998). Meanwhile, rheology was a study of flow and deformation of matter under an applied forces. Rheological properties can be measured from liquid state until solid polymer using a mechanical rheometer. Good rheology properties of the polymer were essential in the plastics injection moulding process (Winter & Mours, 1997).

The mould was a shaped structure which will give a definite form to a fluid or plastic material. Mould usually consist of two halves where each half is the impression of the part to be moulded is cut. In mould design, factor such as mould size, number of cavities, cavity layout, runner system, gating system, shrinkage, ejection system and mould cooling systems cannot be neglected in order to determine the fault relating to mould manufacture (Crawford, 1998).

According to (Bimo, 2010), there were basically three types of mould, based on the number of cavities which were the single cavity, multi cavity and family cavity. For this research, the mould will only focus on single and multi-cavity mould. For the runner system, the mould was designed



according to the cold runner two plate mould system, which consist of two plates along with the cavity and the core. It is called two plate mould because it has one parting line in between the two halves mould (Rosato, & Rosato, 2012).

The gate function is like an orifice which it will allow the melt to flow and enter the mould cavity. According to (Mesfin, 2014) there were many types of gate that are available and their function was different based on their own design. Gate size also contributes towards the weld line strength (Othman, Shamsudin, Hasan, & Rahman, 2012). Pin gate is quite successful because they will cause a high shear rate which will reduce the viscosity of the plastic and this will allow the mould to be filled more easily (Crawford, 1998). A higher shear rate was needed in order to obtain an optimum rheological behaviour. According to (Barnes, Hutton and Walters, 1989), at temperatures above melting temperature, the polymer is a liquid with a measurable shear-thinning viscosity. It is possible to observe a normal stresses in simple shear flow and also relatively high extensional viscosities which indicate the melt as viscoelastic. As the temperature is reduced, the viscosity will increase and this is the effect of the polymer rheology (Aho, 2011).

Injection moulding analysis can be conducted with the help of the simulation software CadMould 3D-F due to the ability to predict important results in the flow of plastic part that will be produced at the end on the injection moulding process. The simulation could propose the processing parameter that involved in injection moulding such as the melt temperature, filling time, packing pressure and the remaining cooling time as well as shrinkage and warpage behaviour. By using this software, user can calculate and determine all the processing parameter needed. Thus, this software can help to compare different condition and suppositions (Othman, Shamsudin, & Hasan, 2012).

Therefore, this research was conducted to develop a mould for rheology test sample via simulation. The development work concerned with stages of design, simulation, analysis, and fabrication of the mould to produce good quality samples. The criteria that need to be considered in mould development were good parameter such is filling time, temperature when filled and velocity. The other criteria that also have been chosen were the defects such as air traps, weld lines and sink marks.

## **2. Material, Equipment and Method of Research**

This research is mainly about the development of the mould design and compare all the results of the analysis using the simulation. In this research there were three moulds that have been designed according to the specification of an injection moulding machine.

### **2.1. Material and Equipment**

Mould material could be made from D2 tool steel, aluminum and mild steel based on the product and usage. In this research, the aluminium was chosen as the mould material. This is because aluminium possesses many advantages over steel such as it can generate natural protective oxide coating which are good against corrosion. It also has good thermal conductivity and it is lighter compare to steel (Othman, Sulaiman, Ibrahim & Li, 2013). The polymer that was chosen in the simulation poses was polypropylene.

In this project, the mould design that had been selected is fabricated by the help of mould manufacture. The process of fabrication used CNC milling machine. Afterward, the mould had undergo fit test at Nissei NP 1F injection moulding machine, located at the Polymer Ceramic Laboratory in University of Tun Hussein Onn Machine (UTHM) for dimension validation.

### **2.2. Method of Research**

This research started with design stage. The designed mould was deferred in the runner system, gate system and cavity system. Other parameters such as filling time, ejection time, ejection temperature, mould temperature, injection pressure and material selection were set to be constant at certain values. Table 1 shows the specifications of the mould that were created and the material that was used to fabricate the mould. The tolerance of the mould must be accurately  $\pm 0.03$  mm.

Table 1 : Specification of Mould

Material	Aluminium
Cassette Dimension	99.5 x 68 x 25 mm
Depth design	1.2 mm
Volume part injection	According to part dimension
Ejector Holes	2 holes with diameter of 6 mm
Sprue Holes	1 holes with diameter of 5 mm

The shape of rheology test samples or part design for this research was created by using the Solid Works software. Then the process of injection moulding for this design was simulated by using CadMould 3D-F software after converting it into STL format. Figure 1 shows the part design of a cassette which was created using the Solid Works software. Based on the available cassette at the Polymer Ceramic Laboratory, the cassette design was designed according the same specification of the machine cassette. The mould at the laboratory consist of 5 ejector pins and a small hole for plastic injection, but for this mould only 3 ejector pins were needed. Figure 2 shows an example of the design of a cassette according to the standard geometries of the rheometer test sample.

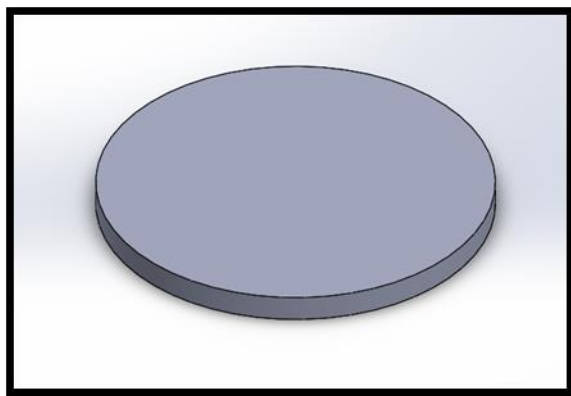


Figure 1 : Part Design of Cassette

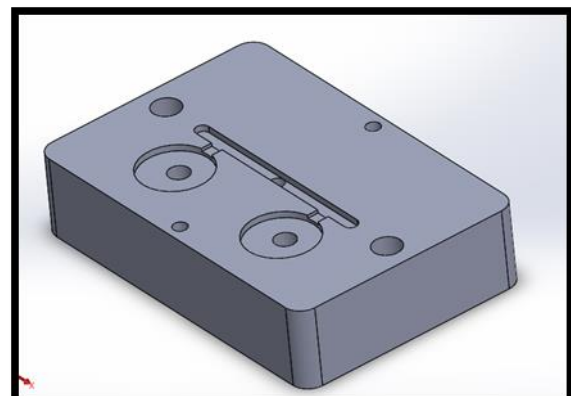


Figure 2 : Example of Mould Design

There were 3 different designs that were tested by using the simulation software. Based on the result, the most suitable design was selected to be fabricated and then tested on the real injection moulding machine. Figure 3 show type of system used for Design 1 while Figure 4 shows the system for Design 2. The system for Design 3 is shown in Figure 5.

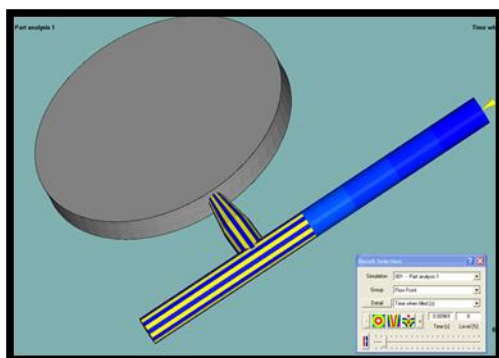


Figure 3 : Design 1

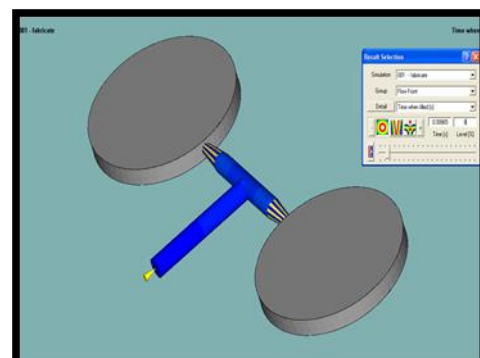


Figure 4 : Design 2

Figure 6 shows an example of design specification that was used for mould Design 1. Based on this research, a round shape ('O shape') have been chosen as the end part and this shape for simulation and to undergo fitting test. Both processes were performed by adopting the same parameter. Figure 7 shows the process flow in CadMould 3D-F simulation.

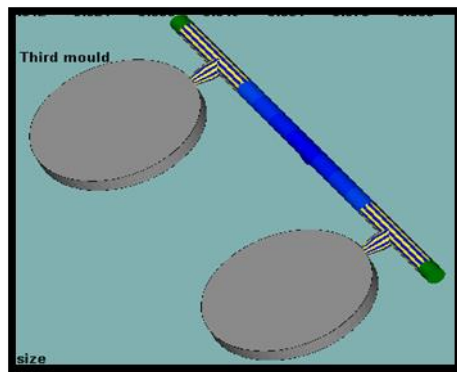


Figure 5 : Design 3

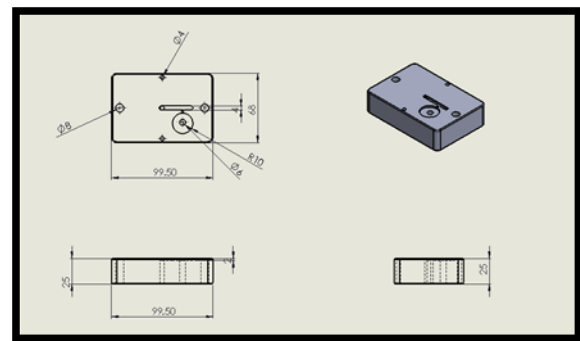


Figure 6 : Example of Design Specification

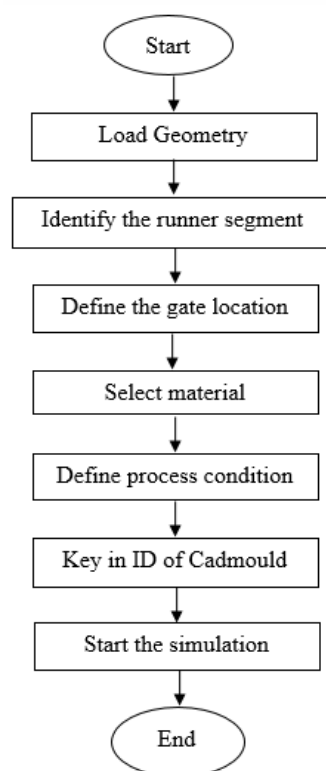


Figure 7 : Process flow in CadMould 3D-F Software

All mould designs were verified by carrying out the injection moulding simulation in the software. The initial processing parameters that were used during the simulation process followed the default value of the simulation software as shown in Figure 8.

**Process Parameters**

Filling Time [s]: 0.115

Pressure-Controlled Filling [%]: 99.0

Melt Temperature [°C]: 240.0

Uniform wall temperature [°C]: 30.0

Ejection Temperature [°C]: 70.0

☐ Packing Duration [s]:

☐ S + W Duration [s]:

☐ Injection Compression Input:

Buttons: Default, Load, Options, Vary, OK, Cancel

**Recommended Process Temperatures [°C]**

Material	Melt	Wall	Ejection
PBT-FE	230 - 260	60 - 100	80 - 130
PBT-FR	240 - 260	60 - 90	80 - 130
PBT-GB	240 - 280	70 - 90	80 - 130
PBT-GF	240 - 280	70 - 90	80 - 130
PBT-GF-FR	240 - 260	70 - 90	80 - 130
PC	260 - 320	85 - 120	90 - 140
PC+ABS	240 - 270	70 - 90	80 - 120
PC+ABS-GF	250 - 280	70 - 90	80 - 120
PC-GF	230 - 325	80 - 115	100 - 140
PE-GF	220 - 260	40 - 70	60 - 120
PE-HD	210 - 230	10 - 60	60 - 110
PE-LD	190 - 270	10 - 60	60 - 110
PMMA	210 - 250	40 - 80	110 - 110
PMP	270 - 330	30 - 70	90 - 150
POM	170 - 210	60 - 120	90 - 150
POM-GF	190 - 220	60 - 120	90 - 150
PP	220 - 270	20 - 90	60 - 100

Figure 8 : Default Parameter for Simulation

Based on the simulation, the factor that should be considered during mould selection are divided into 2 categories which were the parameter and the defect which are shown as in Table 2.

Table 2 : Factors to be considered after simulation

Parameter	Defects
1. Filling time	1. Air traps
2. Temperature when filled	2. Weld line
3. Velocity when filled	3. Sink marks
4. Pressure loss	
5. Shear stress	

The selection of the mould design was made based on the comparison of data between each of the three designs. Each of the analysis from the simulation software had been taken into consideration and the data was selected carefully so that the mould that was going to be fabricated will followed according to the justification. The selection of the mould is also been made based on the costing and the most applicable mould to be used in the future.

### 3. Results and Discussion

Based on the simulation findings, the mould design that was selected to be fabricated is the mould design 2. This mould had shown a lot of positive data from the result of the simulation software. The mould had shown to be more applicable than Design 1 because it had 2 cavities whereas Design 1 only use single cavity. Although Design 3 also use 2 cavities, but the runner system is too long and it will also cost more money. Besides, the design also had the lowest filling time, which means that it is able to be used for a mass production application. Figure 9 shows the filling time of Design 2 which are the lowest compared to the other mould design. Moreover, the design also had the highest velocity value when the cavity is filled compared to the other design. Even though the mould had the same temperature when filled as the other mould it is still better cause it show a lower value for the pressure loss during injection moulding. The design also had a high shear stress applied even though it is a bit lower than Design 1.

For the defect analysis, each of the mould that have been designed shows almost the same result. Design 2 have a minimum value for the air traps and the weld line. Figure 10 shows the formation of air traps that occurred in the three mould design using software simulation. Although both of the data shows that Design 1 is lower but in the other aspect of data, Design 2 have shown the quality to be the most suited mould to be fabricated.

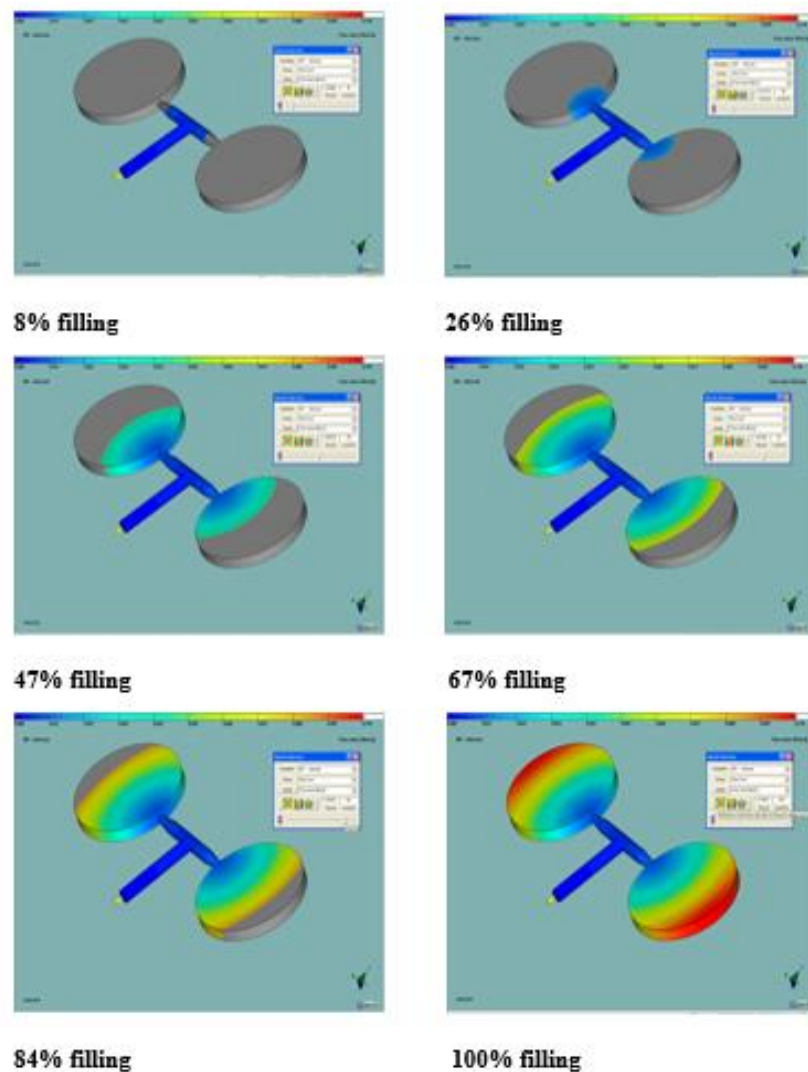


Figure 9 : Filling Process of Selected Mould (Design 2)

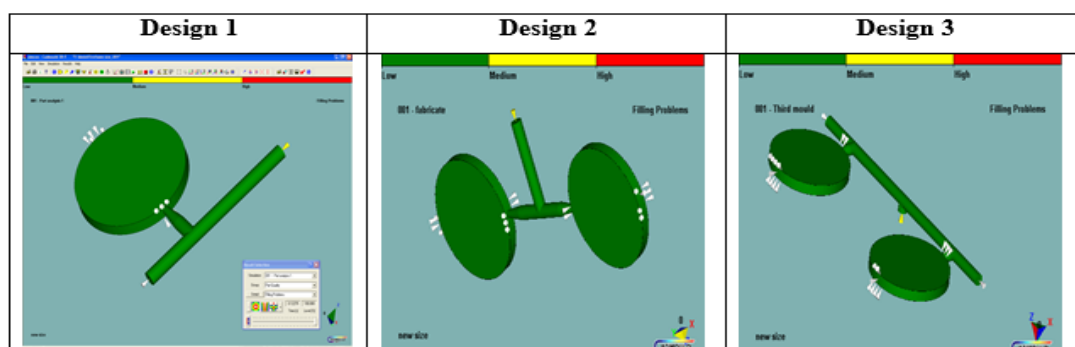


Figure 10: Air Traps

For air traps, Design 1 shows the best result with the least number of air traps followed by Design 2 and Design 3. This is due to the fact that Design 1 had the least number of cavities. For weld line the result is the same as for the air traps where design 1 show the least number of weld line formation. Figure 11 shows the formation of weld line for each of the mould design. All of these defect analysis



shows that number of cavities were affecting the defect produced by the injected parts. But for individual part, Design 2 will show the least number of defect formation on each individual part.

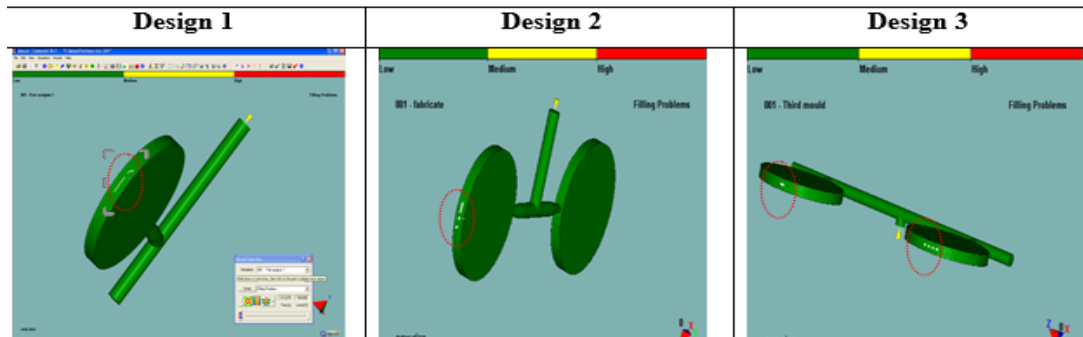


Figure 11 : Weld Line

Table 3 shows the comparison that had been recorded from the data of the simulation analysis. The result of each data from the simulation had been compared for the purpose to ease the selection of mould design. However, for sink marks result, all designs have high value so no comparison can be made.

Table 3 : Comparison of Data

Parameter Setting / Quality	Design 1	Design 2	Design 3
Time when completely filled / s	0.123	0.110	0.122
Temperature when filled / °C	240.4	240.4	240.4
Velocity when filled / mm/s	2147.4	4958.5	4317.3
Pressure loss / bar	92.8	91.5	84.5
Shear stress / kPa	267	243	221
Air Traps	14	20	30
Weld line	2	4	5
Sink marks	High	High	High

In this research the data, such as the flow front, the filling temperature, the shear rate and the defect were important to produce a result for a rheological testing. The defect such as the sink mark indicated that the product had been injected with a low injection pressure due to a low shear rate. This prediction was important to explain the behaviour of the molten plastic at that time. Rheological testing is important for plastic because once the knowledge of rheological properties of the polymer, could be used to propose a solution related to injection moulding quality problem. This was because rheology sample provides the most sensitive method for material characteristic due to the flow behaviour that are responsive to molecular weight and molecular weight distribution (Winter & Mours, 1997). Therefore, this research had produced all the required information for the rheological test sample, as stated in Table 2 for Design 2. All the analysis that had been done towards the mould. If the mould need to be run in the real injection moulding machine, the sample produced should able to be tested out in a rheology equipment such as the rheometer to get the result of the viscosity and the shear rate.

The fitting test is where the mould that have been fabricated was forced to fit in into the mould base of the injection moulding machine. The fitting test was needed in order to test whether the mould have been fabricated with the right dimension. Figure 12 shows the mould that had been fitted into the mould base. Based on the figure, it shows that the fitting process had been done accurately and it proves that the dimension of the mould was acceptable.



Figure 12 : Fitting Test

#### 4. Conclusion

As for the conclusion, the main factors selected for this project were the cavity system, runner system and the gating system. For each design, the system will also differ from each other because of the different analysis that needed to be collected from the simulation analysis. According to the simulation analysis, the chosen design for fabrication of mould is Design 2 which had 2 cavities to increase the rate of production compared to other mould design. As for the third and final objective, the chosen mould have been successfully fabricated and passed the fitting test to confirm the dimension and the usability of the mould.

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