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Injection Moulding Simulation: The Development of Integral Hinges Test Samples Mould Design via Cadmould 3D-F

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Abstract: Injection moulding process ability's in producing intricate parts such as component with integral hinges, had been established for decades. However, to produce a good product, a niche verification process called simulation need to be performed first. Hence, this research was conducted for the development an integral hinges test samples mould design via injection moulding simulation. The simulation output was used to analyse the injection moulding parameter setting and defects towards the prepared mould design. The runner size and shape was fixed, same as well for the gate location and number of cavities. The test sample that needed to be developed was a sample with an integral hinge at the middle of the injected mould article. Polypropylene PPC 8780 (Total Petrochemical) was selected as the reference material. The research methodology started from using SolidWorks as the solid modelling-computer aided design software to prepare the design. This design was then converted into the stereolithography (STL) format. Cadmould 3D-F injection moulding simulation software was chosen as the computed added engineering analysis tools. Parameters such as temperature and time was monitored. The defects such as sink marks, volumetric shrinkage, warpage, weld lines, and air traps were observed. The results show that the mould design had produced 232°C temperature and 0.179 s time when the molten polymer was completely filled. It also produced several defects such as 0.882 % of volume shrinkage and 0.025 mm of warpage. Some sink marks occurred at the above part of the hinge, with 1 weld line and 9 air traps were also detected after the simulation completes. The conclusion of this finding is, the simulation could assist the mould designer to prepare necessary countermeasures in the actual process, and to prepare a better mould with minimum alteration/repair and accelerating setup/preparation time. Hence, the time and cost of a mould could be reduced, especially for new mould design for integral hinge products.

Keywords: Integral hinges, mould design, injection moulding, simulation

1. Introduction

In the production of plastic components, injection moulding is the preferred procedure because it has many advantages, for examples ability to produce mass products, a more complex dimension and shape with achievable accuracy, operative production cycles, and better strength-to-weight ratio as compared with metal, and good recyclability. However, one of the disadvantages of this process is an expensive mould cost, depending on the size and complexity. In injection moulding related industries, the mould was made for mass production and complex geometries. As the volumes of the injected parts grow, so does the competition. To stay competitive, manufacturers need to meet the various and challenging demands on product quality. Still, the main challenge is in determining the optimum design and processing parameter, in order to achieve the desired productivity and to manage the defects in parts. Injection moulding simulation software could be used to control defects such as warpage, volume shrinkages, entrapped air, porosity, joint lines and deformation. One of the examples is plastic connectors whereby the demands come from the increase of the complexity, tighter tolerances and the goal is zero defect production. Therefore, software

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simulation is the perfect tool for a plastic part manufacturer to perform the design and process optimization, with a better understanding of the manufacturing process. Simulation software is proven to be useful in reducing the number of prototypes, detecting the potential manufacturing defects, and promote faster and interactive marketing [1].

1.1 Injection Moulding Simulation

Simulation of mould filling in three dimensions has been widely used in plastic manufacturing industries. With more than 20 years of research and development, the injection moulding software could achieve up to 99% accuracy of predictions. Products such as automotive steering wheels, door handles, encapsulate moulding of semiconductors are some of the examples of outcomes from research related to mould filling simulations. Computer programs such as MF/FLOW3D (Moldflow), SUNDYMOLD (Plamedia), TIMON3D (Toray), and Remylop (Toyota CRDL), are now commercially available for computer-aided equipment (CAE) of injection moulding processes. The mould filling simulations provide highly accurate predictions of pressure, temperature, and velocity because the flow in all directions is considered. Therefore, it will be a useful tool for understanding complex flow phenomena in detail and developing novel moulding techniques and products. However, this systematic tool requires special skills and competent person to utilize the information obtained from the analysis and to ensure the information fed into the software must be accurate, whereby the material data for simulation should be similar to the one used in production [2].

Some researchers have successfully obtained valuable findings by using injection moulding numerical and simulation. To quote one example, an injection moulding simulation by using Sigmasoft software was utilised to study the surface properties of acrylonitrile butadiene styrene and polycarbonate/acrylonitrile butadiene styrene parts. According to the findings, a higher simulated shrinkage could potentially affect the etching process [3]. Hence, it was proven that the simulation process could predict the defects and potential effects. Meanwhile, other researchers have assessed the effects of moulding processing conditions and mould design towards the efficiency of an injection process for a product made from polystyrene. The assessment was accomplished through process simulation for verification and experimental methods for validation. The simulation process had utilised the SolidWorks Plastic software and analysis was performed by considering the absence/presence of venting in mould design. Based on the results from the experimental method, the injection pressure, injection temperature and the mould temperature were varied with the simulation findings for both conditions (vent/not vent). However, it can be summarized that numerical and simulation have provided a significant impact on the development of new plastic product design [4].

1.2 Cadmould 3D-F

In mould design, the process simulation and analysis software could assist the mould designer in many ways. The development of this software was initiated through flow behaviour-fundamental principles and scientific data. Rheology principle was manipulated to compute and predict the molten polymer flow behaviour, according to the flow studies and matter's deformation. This computer-aided engineering (CAE) program could identify the potential errors in the mould design and parameters before the actual process took place. It was very useful for process optimization such as reducing defects, improving cycle time, or minimizing part weight. It can also support the mould designer in fixing certain problems, which would otherwise have to be solved by trial and error method. The typical trial and error method usually time-consuming and wasting energy/material as well. In this research, the Cadmould 3D-F was chosen as the simulation tools. This software was proven to assist the mould design in terms of cost and time reduction, with cycle time optimization up to 30 %, the proven of 50 % minimization of mould iterations after moulding with sustainable decisions and front loading for mould development. Besides that, the advantages of this software in the injection moulding simulations are displayed in Fig. 1 [5]:

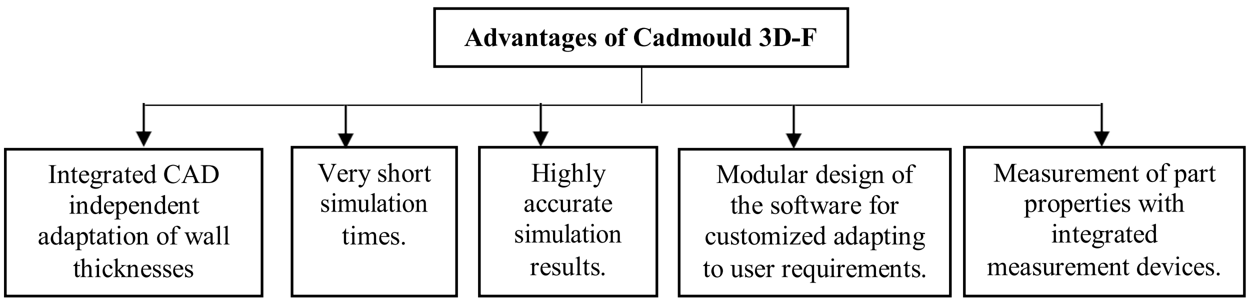

Fig. 1 - Advantages of Cadmould 3D-F [5]

1.3 Integral Hinges

As for the product, this research had chosen a sample with an integral hinge at the middle of the part. This integral and flexure hinge can be combined in a multitude of instruments and mechanisms. It can be applied in precision positioning, micro/nano measurement and plastic manufacturing. Several gains could be obtained by incorporating the integral hinge, such as the reduction of backlash, lubricants and friction [6]. Typical integral or living hinges require a specific flow direction so that the polymer chains will be oriented perpendicular to the hinge line. Therefore the mould designer should apprehend the flow behaviour while designing the parts with hinges. Failure in hinge mould design will reduce the life cycle of hinges [7].

1.4 Mould Design and Product Defects

In this research, the mould design was limited to a runner system and gate location. There are other factors such as mould material and cooling system that may affect the quality of injected mould parts. Mould material like aluminium or mild steel might produce different findings. The cooling system also needs to be effective and efficient, such as a rectangular cooling channel is better in the sense of the minimum time required for molten polypropylene to solidify [8]. In terms of product defects, shrinkage and warpage also could be reduced by using longer cooling time in the injection mould. A lower mould temperature and thinner product walls also could help. Furthermore, the usage of fillers such as clay, talc or fibres may also reduce the amount of volume shrinkage [9]. Sink mark is one of several important flaws of injection moulded parts. Part thickness, holding pressure, melt temperature and mould temperature were found to be the principal factors affecting the sink marks of the injection moulded parts [10]. Hence, the unsuitable parameter could allow a sink mark to happen. Therefore, in order to control sink marks, the processing parameter such as the injection rates, packing, and mould temperatures need to be controlled and monitored [11].

Since producing the good test sample is very important, therefore the motivation of this research was to develop and analyse a prepared mould design via simulation process. The mould design was prepared based on a sample with a hinge at the centre of the body. This objective is vital in order to produce a good mould design with controlled defects and optimum processing parameter, which can be used by the plastic manufacturing industries.

2. Methodology

The research methodology starts with selecting the appropriate material for producing the integral hinges test samples. The next step is about determining the initial setup and preliminary design for the simulation. Finally, the selection of outcomes from the simulation will take place for wrapping up the analysis of this research.

2.1 Material Selection

The test sample that needed to be developed is a sample with an integral hinge at the middle of the injected mould article. The chosen material is polypropylene PPC 8780. This material was chosen because it has a good combination of flexibility and low warpage. Therefore, it is suitable to be used as a living integral hinge. This material is a controlled rheology polymer with the thermal conductivity of 0.0017 watts/centimetre/°C and the effective thermal diffusivity of 0.0818 mm²/s. Table 1 shows the physical, mechanical and thermal properties of polypropylene PPC 8780 produced by Total Petrochemical [12].

Table 1 - Physical, Mechanical and Thermal Properties of Polypropylene PPC 8780 [12]

Physical Properties	**Metric**
Specific Gravity	0.905 g/cc
Bulk Density	0.525 g/cc
Melt Flow	18 g/10 min @Load 2.16 kg, Temperature 230 °C
Mechanical Properties	**Metric**
Hardness, Rockwell R	80
Tensile Strength, Yield	25.0 MPa
Elongation at Yield	5.5 %
Tensile Modulus	1.05 GPa
Flexural Modulus	0.950 GPa
Izod Impact, Notched (ISO)	5.50 kJ/m² @Temperature -20.0 °C 11.0 kJ/m² @Temperature 23.0 °C
Thermal Properties	**Metric**
Melting Point	165 °C
Deflection Temperature at 0.46 MPa (66 psi)	92.0 °C

Polypropylene PPC 8780 is also suitable for extrusion coating. When it comes to the component material selection, it is essential to enter the exact polymer type from the Cadmould 3D-F material's database into the software. This data can be edited by the software user. However, it is good engineering practice to check the approximate material data, for the calculations, verification and validation purposes [13].

2.2 Initial setup and preliminary design

The test sample with hinge was firstly designed through SolidWorks software. The next process is transferring the design to Cadmould 3D-F. The basic file format used by the Cadmould 3D-F is the stereolithography (STL) format. STL is the default document for the automatic net formation of the final elements, typically used in most of the CAD software. Hence the SolidWorks files need to be converted into this format [5]. The initial processing parameters were stated in Table 2. In this research, the chosen type of runner is the trapezoid runner, with the size as mention in Fig 2. The initial processing parameters and the type of runner were obtained from the preliminary experiment [14, 15]. The mould cavity design was displayed in Fig. 3, whereby the mould had only 1 cavity and the gate location was proportional to the hinge.

Table 2 - Initial processing parameters for injection moulding simulation [14]

Parameter	Value
Melt temperature	230 ºC
Packing duration	2s
Shape of runner	Trapezoidal
Shrinkage and warpage duration	4s
Uniform wall temperature	30 ºC
Filling time	0.179 s

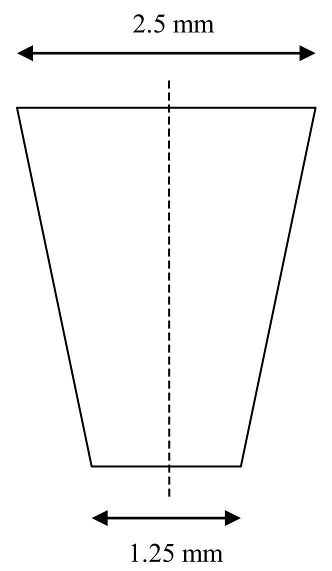

Fig. 2 - Runner Size Description [15]

2.3 Outcomes of Simulations

Cadmould 3D-F could provide quality and sufficient prediction based on calculation tool. The quality of the injected mould product could be forecasted, and at the same time minimizing mould repair and accelerating the preparation of the new product. The results were proven better than trial and repair method [5]. However, there are limitations in considering the outcomes of the simulation. As for this research, the outcomes were divided into two groups, which are the parameter and the defects, as shown in Table 3. These selected outcomes shall be analysed so that the real mould fabrication have minimum alteration and producing good quality samples [16]

Table 3 - Outcomes of simulation [16]

Parameter	Defects	
1. Time when completely filled	1. Volume Shrinkage	3. Sink marks
2. Temperature when filled	2. Warpage	4. Air traps
		5. Weld line

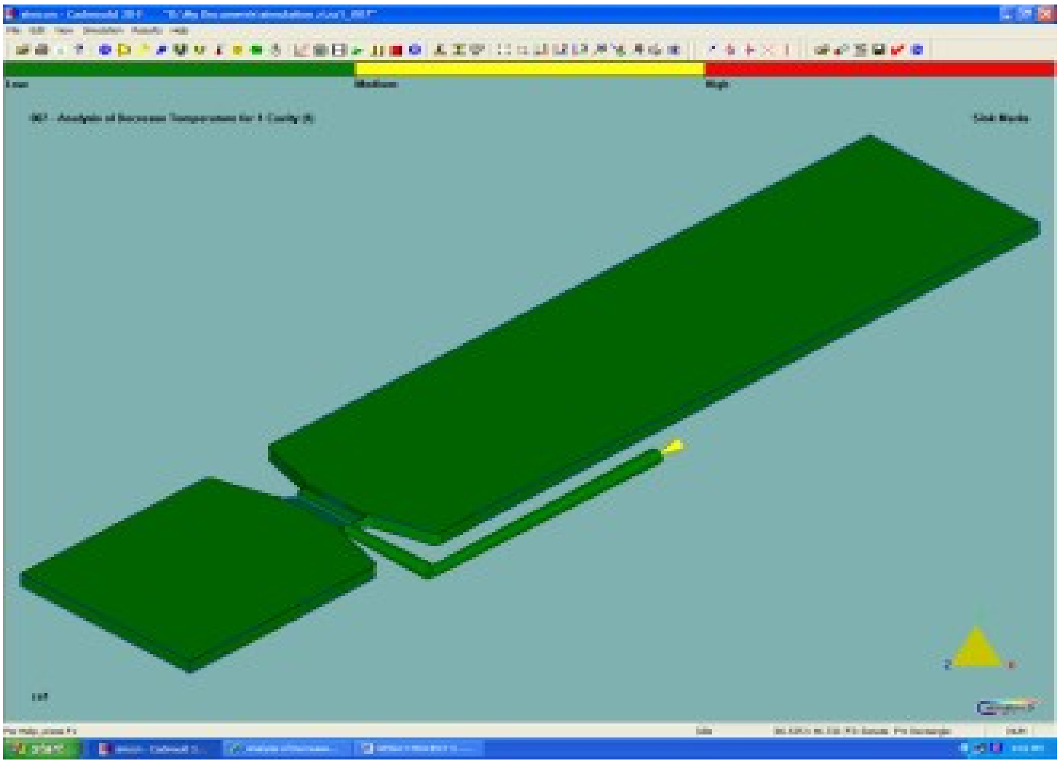

Fig 3 - Mould Cavity Design [15]

3. Results and Discussions

The results of this research were summarised in Table 4, particularly for parameter and defects occurred after the simulation process. In terms parameter results, the molten polypropylene had reached 232°C temperature and used 0.179 seconds for the filling time when the molten polymer was completely filled. During filling, some important part of the design might affect the end results. For example, based on previous research, the position of the gate might affect the distributed temperature through the sample [17]. Based on this research design, the gate location was located normal to the thinnest part. Hence, minimum time was required for the molten polypropylene to solidify. Therefore, the filling time will be less. The mould cavity filling time critically depends on the gate location, in order to gain accurate dimension and achieving high yield production in injection moulding processes [18]. It is because plastic molecules are very long, many of them with branches and one end of the molecule can be in a liquid phase while the other isn't. The molecule will stretch out, giving the property of viscosity. Hence, adjusting the gate size is necessary until every cavity provides an identical part weight within 5% of the overall part's weighted average. If the cavity's part is too heavy, it will be filled first and causing over packing. This condition will create problems that the cavity will stick all the time. If it's too light, the other cavity will be over packed to fill this one out, otherwise, it will be full of flow lines, sinks and voids. Because of this phenomenon, it is in the best interest to fill the mould as quickly as possible with liquid plastic and then hold it under pressure to offset the thermal shrink, because it allows the plastic to reform back into its preferred molecular orientation.

Table 4 - Summary of Simulation Findings

Parameters/Defects	Simulation Findings
Time When Completely Filled (s)	0.179
Temperature When Filled (°C)	232.0
Volume Shrinkage (%)	0.882
Warpage (mm)	0.025

Based on the defects outcomes, this mould design produced volume shrinkage of 0.882 %, 0.025 mm of warpage. Fig. 4 show some sink marks at the above part of the hinge. As for sink marks, these defects are basically a “designed in” problem and hence it is to be attended during the design stages [19]. Therefore, optimising parameters or processing conditions was proposed as the way to control warpage and shrinkage [20], and weld lines as well [21]. In this research, there is only 1 weld line detected, as shown in Fig. 5. Based on previous reports, typical weld line’s characteristics depends on four process variables, that are melt temperature, mould temperature, injection speed, and packing pressure [21].

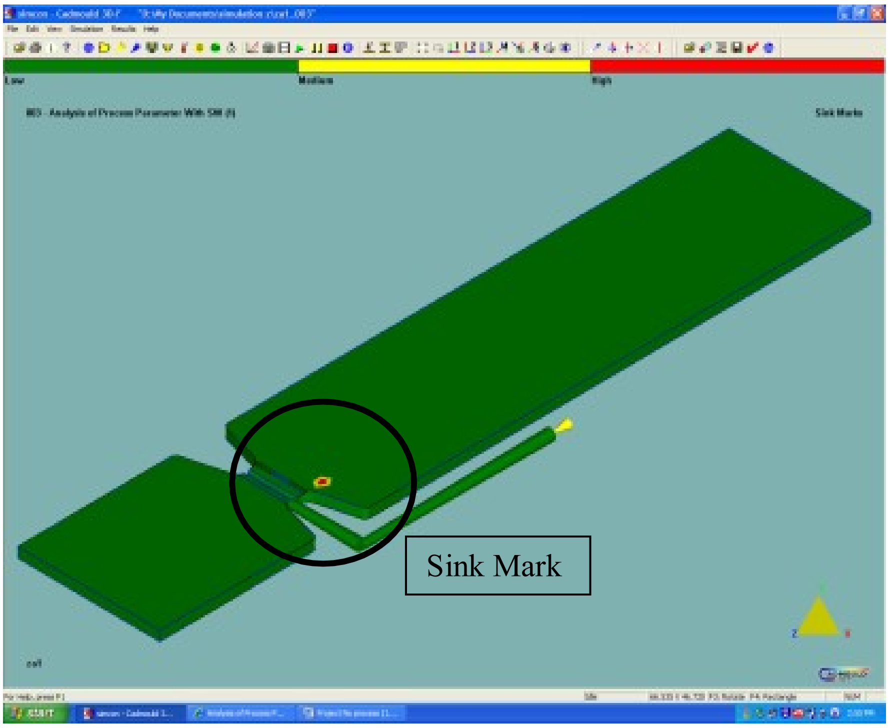

Fig 4 - Sink Mark

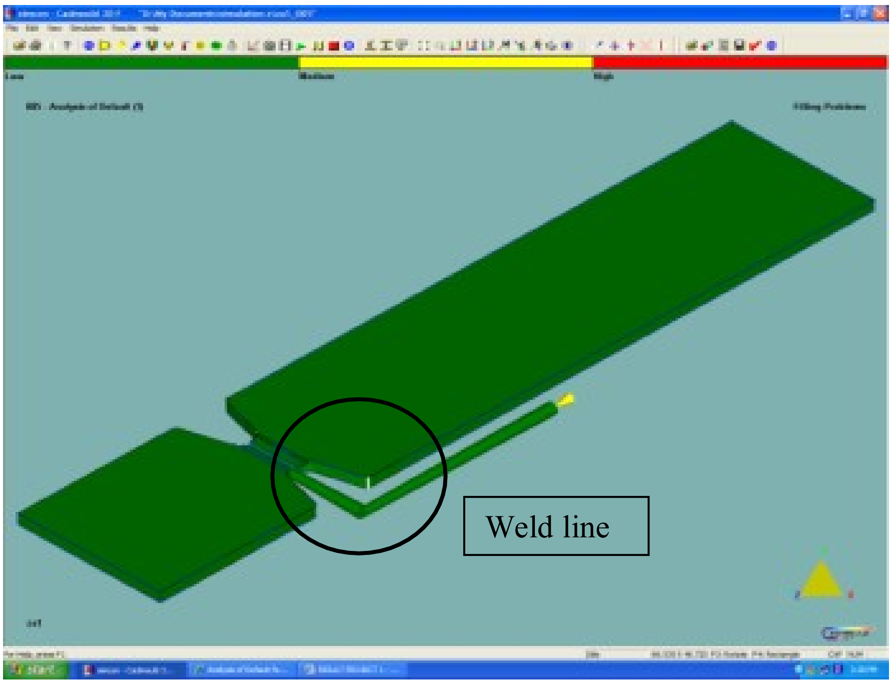

Fig 5 - Weld line

In terms of air traps, there are 9 air traps detected during simulation, as shown in Fig. 6. These air traps usually happened due to the improper filling that could be reduced by optimising the process parameters, such as the inlet pressure, the mould temperature regime, the temperature of the feed. Additionally, an optimal mould shape and the best feeding channel position can be found reducing the air traps [22]. The influence of different gate sizes, such as the size of the film gate also could reduce air traps as well as various process parameters such as clamping force and fill time. Changing the type of gate, for instance, a submarine gate could reduce the air traps as well [23].

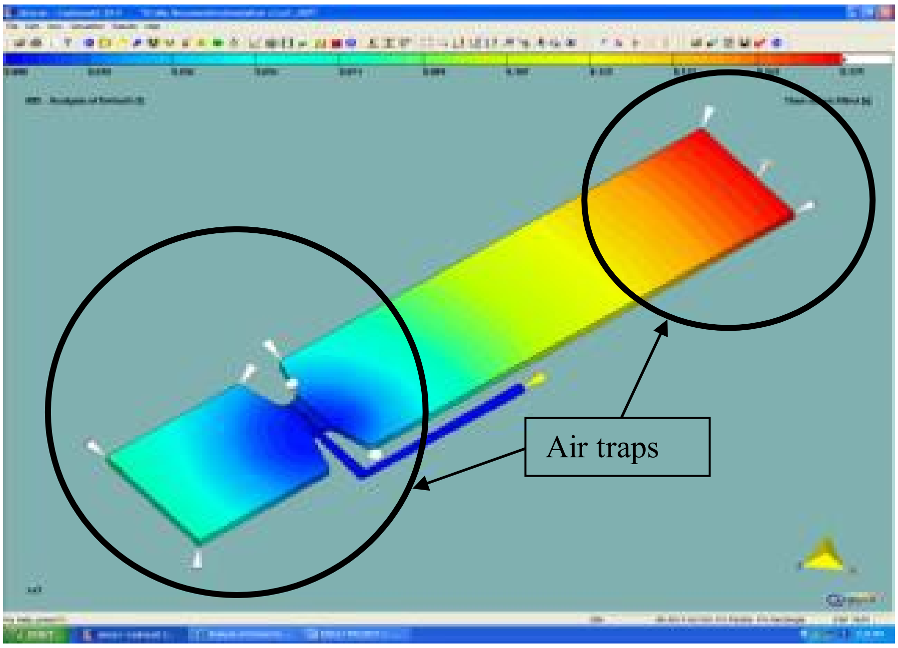

Fig 6 - Air traps

Several improvements and further research could be proposed for the extension of this research. For instance, different runner size and shape could affect the findings. Some previous finding showed that the design of the new geometry of a cold runner system could reduce scrap and cycle time. Reduction in the contact surface of the runner system with mould walls improved the easier ejection of runner system out of the cavity as well [24]. Beside runner, the gate location also could be changed to produce different outcomes. The real practical injection moulding also could be performed to verify the findings, by preparing the real mould according to this proposed design.

4. Conclusion

This research deals with the simulation of the injection moulding process by using Cadmould 3D-F. The software enables a very effective prediction by proposing a suitable parameter and rectifying potential defects. From the simulation analysis, Cadmould 3D-F provides sufficient results such as filling time, temperature when completely filling and the defects as well. This mould design had produced 232°C temperature and 0.179 seconds by filling time when the molten polymer was completely filled. It also produced several defects such as 0.882 % of volume shrinkage, 0.025 mm of warpage, some sink marks at the above part of the hinge, 1 weld line and 9 air traps. These results could assist the mould designer to prepare necessary countermeasures in the actual process and to prepare a better mould with minimum alteration/repair and accelerating setup/preparation time. Hence, the time and cost of a mould could be reduced, especially for new mould design.

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