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Plastic Flow Analysis of Hand Drill Casing Using Injection Moulding

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ABSTRACT

Injection moulding process is widely used in manufacturing and producing daily plastic products. The gate location and sprue significantly influence the stability of molten plastic flow, especially for complex products. Without the proper gate location and parameters, the plastic flow will cause insufficient filling and defects. This paper analyses the effect of gate location and sprue design during the filling and packing process through the simulation method. The simulation software was utilised in the current study. The plastic casing of the power tool hand drill was considered for the injection moulding process. The molten plastic behaviour was visualised via the filling contour. The pressure, shear stress, and volumetric shrinkage were also analysed. The result obtained shows that the molten plastic flow behaviour depends on the selected parameters. The selected parameter significantly changes a few variables chosen where gate locations are the most significant to the plastic flow.

Keywords: Plastic flow, Injection moulding, Gate location, Sprue design, Simulation

1. INTRODUCTION

Injection moulding is a well-known process which produces a simple and complex shaped product in the various fields of industry [1]. The injection moulding process usually uses raw plastic materials in pallet form. It only requires a short processing time with minimum cost to produce a plastic part or plastic product. Today, the manufacturing process of plastic injection moulding is widely used to substitute for metals [2]. The injection moulding process comprises a machine, raw plastic material, and mould. The injection moulding process divides into three phases: filling, packing, and cooling [3]. The injection moulding can be used to fabricate the micro component [4]. The development of micro component technology is one of the technologies of the 21st century that deals with the mass production of micro components [5]. Micro injection moulding is an economical and dependable replication process in producing a wide range of micro components. Various fields involved in micro components include micromechanics [6], information storage devices [7], microfluidic systems [8], medical technology [9], microreactors, biomedical applications [10], communication, and automotive sectors [11].

The classifications of the micro product or components [12] include the weight in the milligrams, overall dimension, functional features, and tolerance requirements that are expressed in terms of micrometres. However, components with large dimensions and masses more significant than 10g with a low aspect ratio of the microstructure of depth to width are considered micro components. Moreover, microstructure parts with masses between 0.1g and 10g of high aspect ratio in the surface structure are classified as micro components [5]. Besides, the classification of micro part falls into two types: type A with dimensions less than 1 mm and type B, having larger sizes on overall dimension but incorporates micro features with sizes typically smaller than 200 μm [13].

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Thus, any plastic product and component that fulfils these criteria are considered micro components, such as the casing of a power tool hand drill. Prior to fabricating the micro components, the trial and error method may raise the cost. Thus, simulation analysis is the popular way to predict the molten plastic flow and increase understanding of the injection moulding process with software [14].

Plastic simulation software for injection moulding is crucial in designing mould before the prototype mould is fabricated. Commercial software such as Solidwork Plastic [15] represents the most comprehensive style of definitive tools for simulation, analysing, optimisation and mould design. The simulation can show all the details during the plastic flow. When imperfections are recognised in the mould, they can be minimised or disposed of by rolling out improvements to the part configuration, including forming the outline, plastics material, preparing the parameters, spare vitality, common assets, time, and cost. Due to the simulation system and interface, the simulation has successfully helped engineers and designers with numerical feedback and visualisation of the part properties. It discards the try and error approach to optimise injection moulding [16]. There are other types of plastic simulation in the market, and one of the most generally used by researchers is Moldflow software [17]. Moldflow software is always used for flow and warpage simulation. The moulded part can be created using CAD software and then meshed with triangular elements in the Moldflow software.

Previous scholars [18] simulated a model in the Moldflow software with boundary conditions such as material properties, cooling channel properties, and process parameters. They analysed the process with input parameter variation to obtain a response value. Chen et al. [16] utilised a combination of parameters with Taguchi's three levels of L18 orthogonal array table based on the Moldflow analysis on four controlling factors: melt temperature, mould temperature, injection speed, and packing pressure. Mohamed et al. [19] used Autodesk Moldflow Insight (AMI) simulation to examine four different types of the cooling channel. They applied the Cool+Flow+Pack+Wrap analysis and found that the conformal channel is more suitable than other cooling type cooling channels. The feeding system analysis was carried out using the Moldflow software to simulate different locations of the feeding system in fixed partial dentures of polyether ether ketone (PEEK) with varying the number of injection points [20]. Besides, Moldflow was also used to analyse incomplete filling defects. Shin et al. [1] used Acrylonitrile butadiene styrene (ABS) resin, and they found that inadequate mould design resulted in poor plastic filling behaviour and decreased filling rate. Sahputra [21] compared the plastic flow software between MPI 5.0 and SIMPOL and found that MPI generated more simulation analysis reports of injection moulding.

In the injection moulding process, the gate location and parameters significantly influence the stability of molten plastic flow, especially for complex products [22]. The moulding parameters also determine the plastic flow properties during the injection process. Without the proper location of gate design and parameters, the plastic flow will cause insufficient filling towards the mould that will cause defects in the products. This problem will cause losses in cost and time in production. Thus, the sprue design and gate location were considered in the current study. The criteria of sprue design and gate locations can become a source of reference for future knowledge or study that can be optimised more with the development of nowadays technology. The simulation software applications can also contribute to a safe and low-cost research activity.

2. MATERIAL AND METHODS

The product criteria selected for this simulation analysis involve complex shapes. The thickness for the entire hand drill casing are also crucial for this analysis. The thickness of the casing is considered a constant. The selection of the hand drill's material must depend on its application. The hand drill must have the durability of impact and heat insulator. Thus, the material used in the simulation is polystyrene because its properties meet the desired requirement. As shown in Figure 1, the hand drill casing was created using Solidwork software. The CAD model is then simulated for the injection moulding process, and the parameter taken from the simulation is analysed.

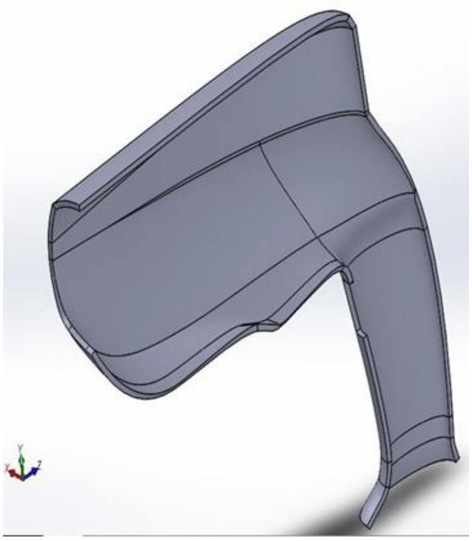


Figure 1: Casing of the hand drill used in the simulation.

Gate and sprue variables were considered in this study. The gate parameter, such as gate locations, gate type, and dimension, is the control parameter. In contrast, the sprue parameter is the design of the sprue. In this research, the locations of the injection moulding are determined based on the surface factors. After analysing the product's surface, three different locations were determined on the inner side of the casing (Figure 2). The inner side surface was selected due to the consideration of the surface finish. The uneven product's surface is also a limitation for the gate locations. The selected gate locations are namely L1, L2 and L3.

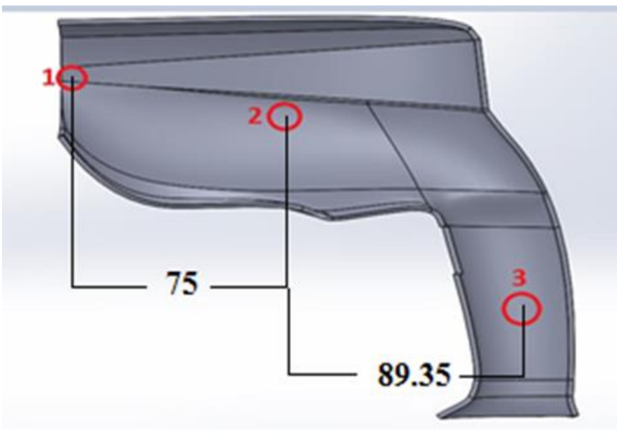


Figure 2: Three gate locations (L1, L2 & L3) of the hand drill casing.

In this research, the sprue design involves the inlet and outlet dimensions. The length of the sprue is kept constant, and only the outlet and inlet dimension is changed. Table 1 shows the dimension and the design of the sprue. Three sprue designs are namely S1, S2 and S3. Three gate locations and three sprue designs were combined in a design experiment, as shown in Table 2. The effect of the combination gate location and sprue design was studied on the flow behaviour during the injection moulding process. There are plenty of outcome parameters that the software can produce. Several results were compared based on the design of the sprue and gate. The fill time, shear stress, and pressure focus on the simulation. The Fill analysis was used to predict the thermoplastic polymer flow inside the mould in the filling phase. The Packing analysis was also considered after the filling analysis in the packing phase of injection moulding.

Table 1: Dimension and sprue design.

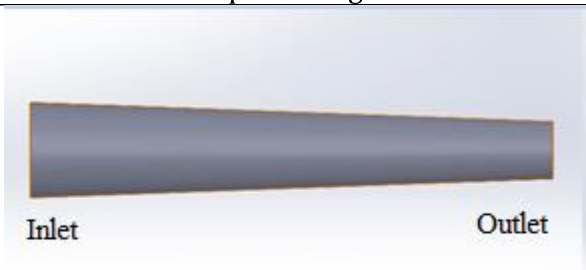
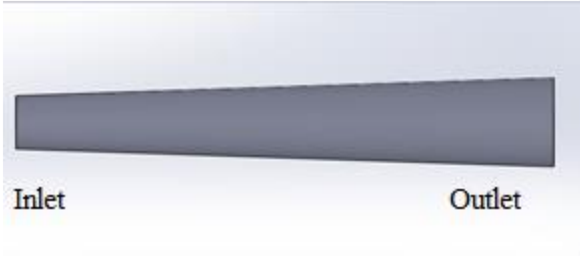
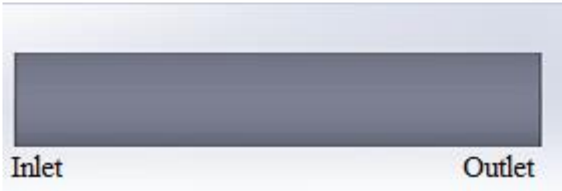
Dimension		Sprue Design
Sprue 1 (S1)	Length: 50mm Inlet Ø: 3mm Outlet Ø: 5mm	
Sprue 2 (S2)	Length: 50mm Inlet Ø: 5mm Outlet Ø: 3mm	
Sprue 3 (S3)	Length: 50mm Inlet Ø: 4mm Outlet Ø: 4mm	

Table 2: Design of numerical experiment for gate location and sprue.

No of run	Location (L)/Sprue (S)
1	L1/S1
2	L1/S2
3	L1/S3
4	L2/S1
5	L2/S2
6	L2/S3
7	L3/S1
8	L3/S2
9	L3/S3

3. RESULTS AND DISCUSSION

A total of 18 simulation runs were carried out according to the design of the numerical experiment in Table 2. Nine simulation runs are for Fill analysis and another nine runs for Packing analysis. The results were analysed based on the generated data from the software, such as fill time, shear stress, and pressure. The combination of gate location and sprue design in the simulation is labelled as L and S. The first simulation is location 1 (L1) and sprue 1 (S1). Thus, it is labelled as L1S1. Then, each simulation parameter is changed from location 1 to locations 2 and 3. Table 3 summarises the edge gate result for Fill analysis. The results revealed that runs 1-9 show an insignificant effect on the filling time and shear stress. However, the pressure variation is noticed in the Fill analysis. The pressure drops from Run 1 to Run 3 for gate location 1. This situation demonstrated that the combination of gate location and sprue significantly affects the flow behaviour and the pressure of the molten plastic flow. The results show a minor difference in values of 0.001 for Runs 4 & 5 compared to others. The similar filling time is attributed to the hand drill casing's similar shape and constant volume. Thus, the effect of location and sprue can be neglected.

Table 3: Edge gate result for Fill analysis.

No of run	Location (L)/Sprue (S)	Filling time (s)	Shear stress (MPa)	Pressure (MPa)
1	L1/S1	1.809	0.254	56.06
2	L1/S2	1.809	0.254	55.66
3	L1/S3	1.809	0.254	55.23
4	L2/S1	1.808	0.254	43.52
5	L2/S2	1.808	0.260	43.80
6	L2/S3	1.809	0.255	43.55
7	L3/S1	1.809	0.253	48.91
8	L3/S2	1.809	0.253	49.26
9	L3/S3	1.809	0.255	48.53

In Figure 3, the trends show almost constant value in location 1 when changing the sprue design. Similarly, the changes in sprue design at locations 2 and 3 also showed slight pressure variation. Gate location 2 yielded the lowest pressure and followed by location 3. This observation may attribute that molten plastic is easier to fill the cavity at location 2 compared to locations 1 and 3. At locations 1 and 3, the molten plastic may restrict by the end of the hand drill casing, leading to more pressure to push the molten plastic moving in the narrow space. This situation is obviously shown in Figure 4.

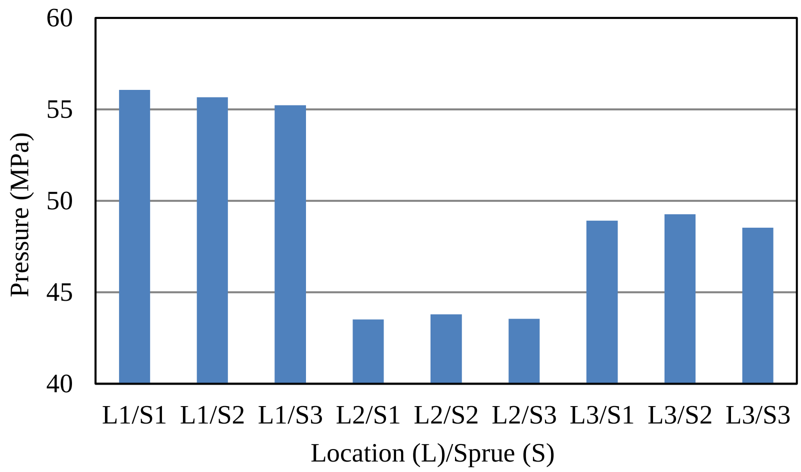
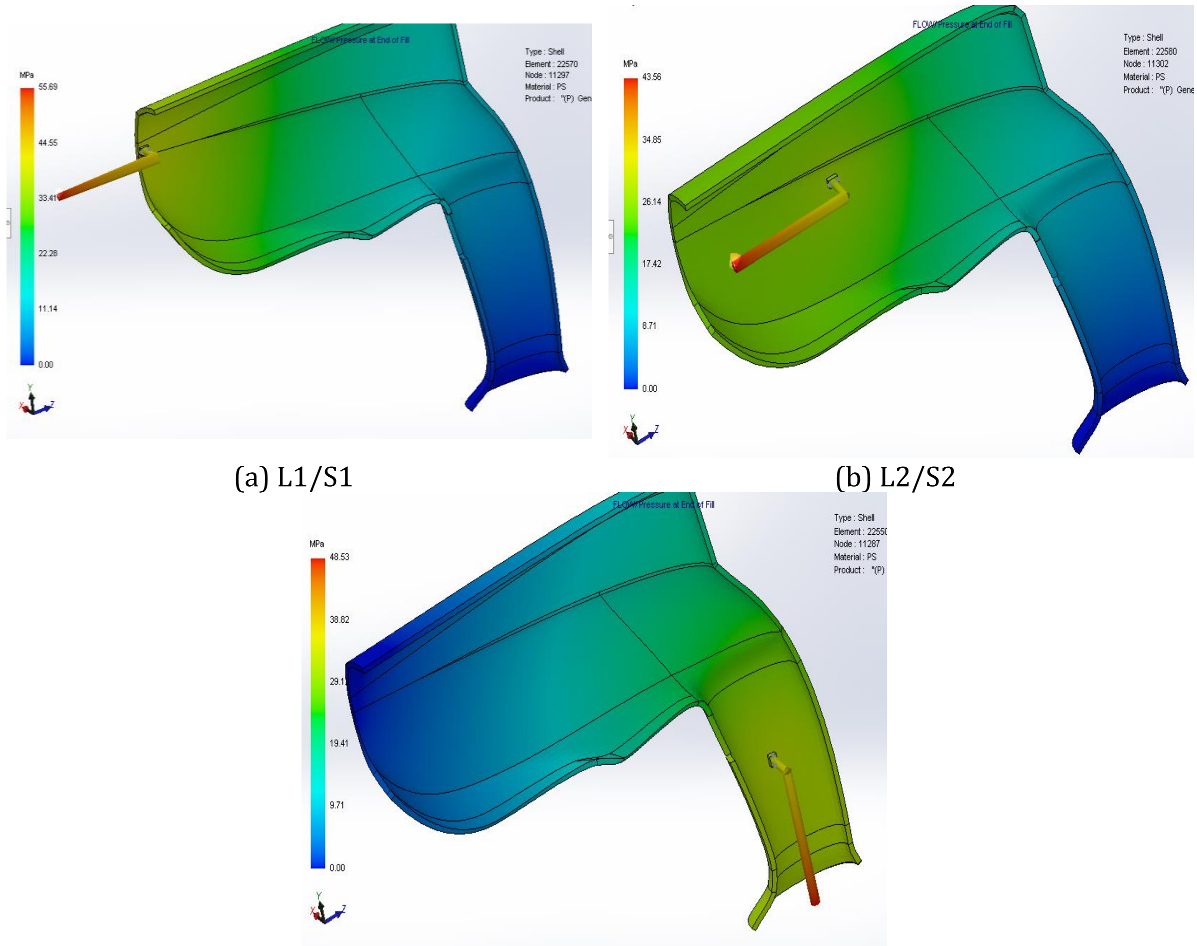


Figure 3: Pressure on runs 1-9.

After the filling analysis, the packing of injection moulding was carried out. The dependent parameters, such as shear stress, pressure and volumetric shrinkage, are investigated in the simulation. The Packing results are summarised in Table 4. The shear stress has slight differences in the value for a similar gate location. Similarly, the pressure and volumetric shrinkage only showed a minor change at a similar location when different sprues were applied. The result revealed that the sprue design insignificantly affects the shear stress, pressure and volumetric shrinkage. However, the apparent variation was spotted in the changes in gate location. For example, sprue design S1 at locations 1,2 and 3 yielded significant shear stress and pressure changes. A minor change was found in volumetric shrinkage during the packing stage. The volumetric shrinkage has a low percentage for each run, with a minimum value of 1.26% to a maximum of 2.80%. In injection moulding, the minimum volumetric shrinkage is desired to obtain a better quality of the injected part. A combination of L3 and S3 resulted in the lowest volumetric shrinkage (1.26%). The contour of volumetric shrinkage for L3/S3 is depicted in Figure 5. Thus, L3/S3 can be considered in the actual injection moulding process of hand drill casing.



(a) L1/S1

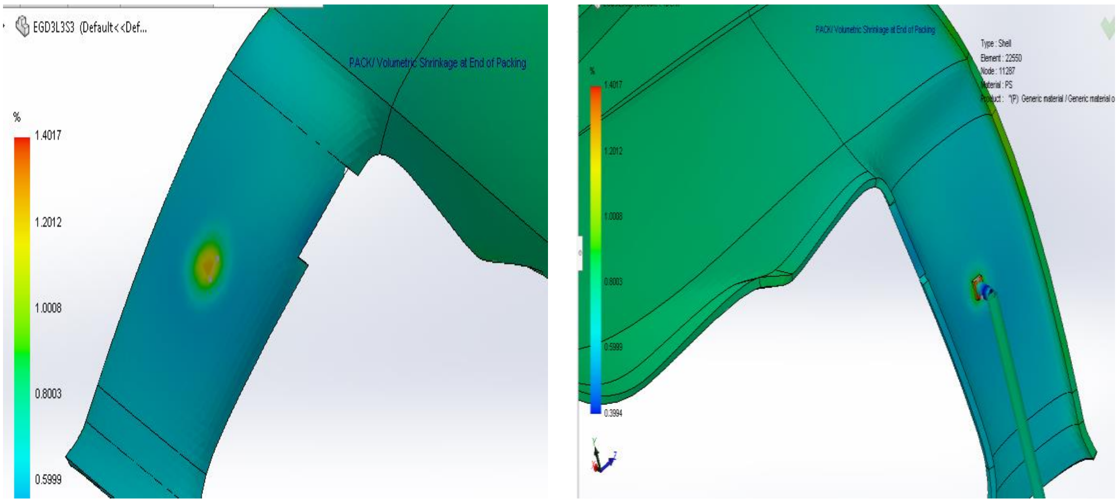
(b) L2/S2

(c) L3/S3

Figure 4: Pressure distribution on the selected simulation run.

Table 4: Edge gate result for Packing analysis.

No of run	Location (L)/Sprue (S)	Shear stress (MPa)	Pressure (MPa)	Volumetric shrinkage (%)
1	L1/S1	0.542	22.27	2.06
2	L1/S2	0.542	22.26	2.04
3	L1/S3	0.429	22.09	1.26
4	L2/S1	0.423	17.42	2.42
5	L2/S2	0.331	17.54	2.80
6	L2/S3	0.401	17.42	1.49
7	L3/S1	0.919	19.57	2.29
8	L3/S2	0.974	19.71	2.16
9	L3/S3	0.962	19.41	1.40



(a) outer side (b) inner side

Figure 5: Volumetric shrinkage of L3/S3 case.

4. CONCLUSION

The effects of the gate location and sprue design on plastic flow behaviour during the filling and packing process were successfully investigated using the simulation technique. With the aid of simulation software, the plastic flow and various dependent parameters were obtained for better understanding during the injection moulding process. The design of the numerical experiment was constructed with the combination of gate location and sprue design. The simulation results revealed that the gate location affects the pressure distribution during the fill analysis. The gate location significantly influenced the shear stress, pressure, and volumetric shrinkage in packing analysis. The sprue design demonstrated a slight effect on all dependent parameters. The application of L3/S3 resulted in the lowest volumetric shrinkage (1.26%) compared to other combinations (1.4%– 2.8%). Thus, this combination can be applied in the injection moulding of hand drill casing. The current results could increase the understanding of a complex injected part during the filling and packing analysis of the injection moulding process.

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