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Simulation Study and Analysis of Different Polymer Material in Injection Mould Process of Plastic Gear by Using Moldflow Adviser Software and Taguchi Method

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Abstract: In this study, Moldflow Adviser software was used to explore the injection moulding process ability of polyamide, polyphenylene ether (PPE) and polycarbonate/acrylonitrile butadiene styrene blends (PC/ABS). By altering the process parameters, the impacts of the process conditions for three different polymeric materials were evaluated and compared. To achieve this objective, a plastic gear was designed and used as product part. Mould temperature, melt temperature, and injection pressure is the process parameter that focused in determining the best processing ability for three material. At the end, the cooling quality result of all three gears were actually the same based on the simulation. However, the comparison of sink mark between this products, gear that made from PPE has the lowest value compare to those polyamide and PC/ABS. Result analysis also show that warpage indicator for PPE material in Moldflow®, attained the lowest value which mean at the same time, the volumetric shrinkage also the smallest compare to polyamide and PC/ABS material. Then, Taguchi method was applied in this study to find the main effects, analysis of variance (ANOVA) and single-to-noise ratio (S/N ratio) using the results from simulation. Through this investigation, the optimum process parameters for injection moulding process can be acquired and the primary process parameters that affect the performance of the gear can be determined.

Keywords: Injection Moulding, Different Polymer, Taguchi

1. Introduction

In the era of industry revolution, one of the world's fastest growing sectors is the plastic industry. Plastic materials with chemical and physical characteristics that can be altered definitely make it more possible to manufacture conceivable and functional goods. With high strength and low weight characteristics, plastic products has been used anywhere from household utensils to industrial use (Khairnar et al. 2018). There were thousands types of polymer or thermoplastic material that can be

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used in injection moulding process for engineering applications. It is important to choose the suitable material in manufacturing the product as it can influence the performance of the product in term of functions and ability as each of this material has its own properties and characteristics. So based on the above factors it is important to select the best and right material based on the applications of the product.

In this study, the main approach is to assure the quality of the plastic gear by choosing the right material. The quality and performance of the moulded parts produce may be influenced by various processing parameters in injection moulding simulation. This study mainly focuses on the material selection for producing the plastic gear which it will be manufacture using injection moulding process. There is a few parameter regarding the injection mould process that will be consider to manufacture the plastic gear which is mould temperature, injection pressure and melt temperature. Thus, this study investigate the effects of injection moulding process parameter (mould temperature, melt temperature and injection pressure) on Polyamide, Polyphenylene Ether (PPE) and Polycarbonate/Acrylonitrile Butadiene Styrene Blends (PC/ABS) gear.

2. Materials and Methods

This chapter gives insight into the method/process of doing this case study. The objective of this chapter is to provide clearer guidelines and explanation/discussion for each approach used in this case study, in order to aid in better understanding of the methodologies utilised in this case study.

2.1 Mould Design

In this project, the geometric 3D layout of the plastic gear was drawn using SolidWorks software. Then, the geometric 3D layout was imported into Moldflow software to be set for the simulation. After the mould has been design in the mouldflow which including the designing of parting plane, mould size, injection location, gate, runner and sprue, the Moldflow file is simply duplicate to create another file. Totally, there were three Moldflow files divided for three different type polymer.

2.2 Material Selection

When come to selecting the material, studies in literature and research on the physical and chemical properties of polyamide, polyphenylene Ether (PPE) and blend of polycarbonate with Acrylonitrile Butadiene Styrene (PC/ABS) have been done to obtain the required information about the material characteristics and properties. Their melt temperature and mold temperature required in injection moulding process also be considered as each material need to have similar value of this two properties. This is crucial because in the end of this study, the result obtained in Moldflow for this three material is to be compared. Table 1 show three material that had been selected along with their respective manufacturer and trade name.

Table 1: List of selected material

No.	Material	Manufacturer	Trade Name
1.	Polyamide (PA6)	DSM (Japan)	Novamid-1010G30
2.	Polyphenylene Ether (PPE)	Romira GmbH	Luranyl KR 2403 G4 S
3.	Polycarbonate/Acrylonitrile Butadiene Styrene Blend (PC/ABS)	Daicel Polymer Ltd	Novalloy S 1220

2.3 Taguchi Method Approach

The Taguchi Method combines the Design of Experiments with the optimization of control parameters to produce the best results. In other words, for each simulation, the Taguchi technique generates various combinations of input parameters and their levels. In this study, Minitab software were used to apply Taguchi approach as tools to produce the combination.

This study examined at only three injection moulding parameters which are mould temperature, melting temperature, and injection pressure. These process parameter were chosen to be the same for three different product material (polyamide, PPE and PC/ABS) as the outcome of the injection moulding simulation can be compared evenly and fairly between these gears. These three materials were selected as it has similar melt temperature range and similar mould temperature needed range. Table 2 listed the process parameter and their levels.

Table 2: Injection Moulding Input Parameters and Levels

Parameters	Unit	Level 1	Level 2	Level 3
Mold Temperature	°C	70	90	110
Melt Temperature	°C	235	267.5	300
Injection Pressure	MPa	100	300	500

After the range of input parameter had been decided, the next step is to insert the data into the Minitab. Taguchi L9 orthogonal array (OA) matrix is used to plan trials with three elements at three different levels as listed in Table 2. Table 3 shows the simulation arrangement for injection moulding settings utilizing the L9 OA in Minitab. Each row of this table reflects a simulation with various parameter combinations and levels.

Table 3: Simulation Layout Planning Using L_9 Orthogonal Array Design

	Parameter/Level		
Simulation No.	**Mold Temperature** (°C)	**Melt Temperature (°C)**	**Injection Pressure (MPa)**
1	70	235	100
2	70	267.5	300
3	70	300	500
4	90	235	300
5	90	267.5	500
6	90	300	100
7	110	235	500
8	110	267.5	100
9	110	300	300

3. Results and Discussion

The injection moulding process of plastic gear was studied and analysed using injection moulding simulation, where the Moldflow Adviser 2021 was used. Plastic gear analysis was further divided into three categories: cooling quality, warpage, and sink mark analysis. There were three input process parameter which is mould temperature, melt temperature and injection. Possible combinations of optimum parameters can be estimated using main effect and ANOVA analysis.At the end of this chapter, the final results gained was compared to choose the best product.

3.1 Cooling Quality

Because of its shape and thickness, the cooling quality result of a part shows where the heat prefers to stay. The result depicts how heat will naturally move away from the hot part of the block and towards the block's edges. The cooling time variance and temperature variance results are combined to produce this result. A part with green, yellow, and red patches is graphically depicted in the cooling quality result as shown in Figure 1. The green areas represent good cooling quality, the yellow areas represent a medium cooling quality, and the red areas represent a poor cooling quality. Other than that, Table 4 shows the results of cooling quality criteria for polyamide, PPE and PC/ABS using nine different input parameter combination.

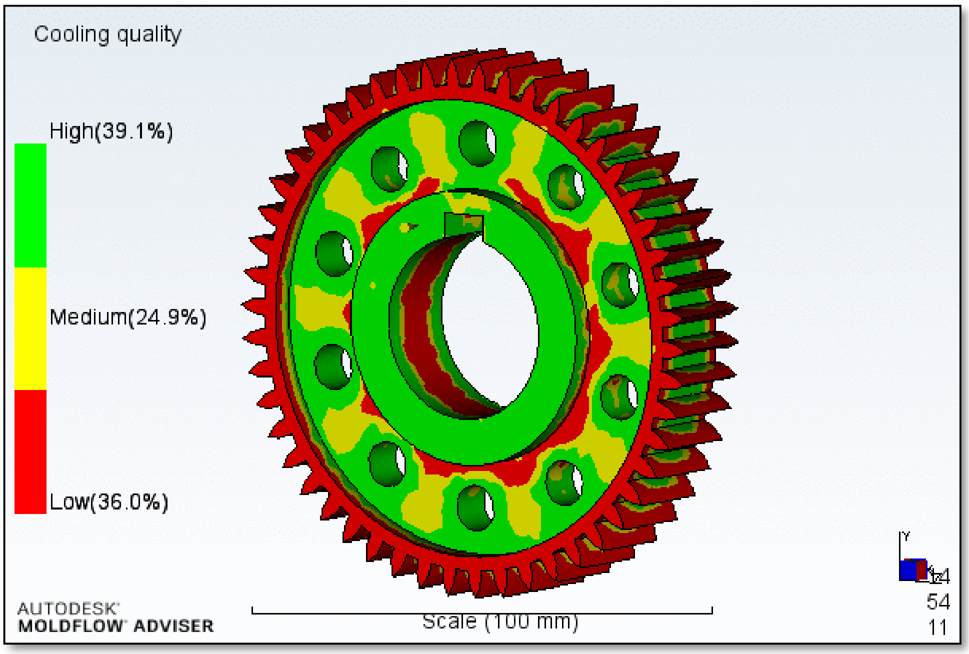

Figure 1: Diagram of Cooling Quality Results of Plastic Gear

Based on Table 4, cooling time variance result, it indicated the difference between the time it takes for polymer to freeze in any section of the part and the average time it takes for the entire part to freeze. Positive value areas take longer to freeze than the average time. The time it takes for areas shown as negative values to freeze is faster than the average time. The average time to freeze is indicated by zero values in this result.

Table 4: Results for Cooling Quality of Polyamide, PPE and PC/ABS

Simulation No.	Max. Temp. Variance (℃)	Min. Temp. Variance (℃)	Max. Cool Time Variance (s)	Min. Cool Time Variance (s)
1	8.2	-6.8	99.25	-42.66
2	8.2	-6.8	99.23	-42.65
3	8.2	-6.8	99.25	-42.69
4	7.5	-6.8	99.25	-42.69
5	7.6	-6.8	97.6	-42.66
6	7.6	-6.8	99.24	-42.67
7	8.2	-6.8	99.2	-42.64
8	8.2	-6.8	98.41	-42.63
9	8.2	-6.8	99.19	-42.65

3.2 Warpage

Table 5 shows the data results of warpage analysis for polyamide, PPE and PC/ABS using nine different input parameter value combination.

Table 5: Warpage Summary Result for Three Materials

Simulation No.	Nominal max. deflection (mm)	Percentage exceeding Nominal Max. Deflection (%)	Percentage Within Nominal Max. Deflection (%)
1	2.58	0	100
2	2.58	0	100
3	2.58	0	100
4	2.58	0	100
5	2.58	0	100
6	2.58	0	100
7	2.58	0	100
8	2.58	0	100
9	2.58	0	100

Table 5 shows that the summary results gained from all nine simulation of warpage analysis for three materials is exactly the same. However there is a significant different that showed in graphical result for Deflection-all effects and Warpage Indicator-all effects. Figure 2 and Figure 3 shows the graphical simulation results of deflection-all effects and warpage indicator for polyamide, PPE and PC/ABS

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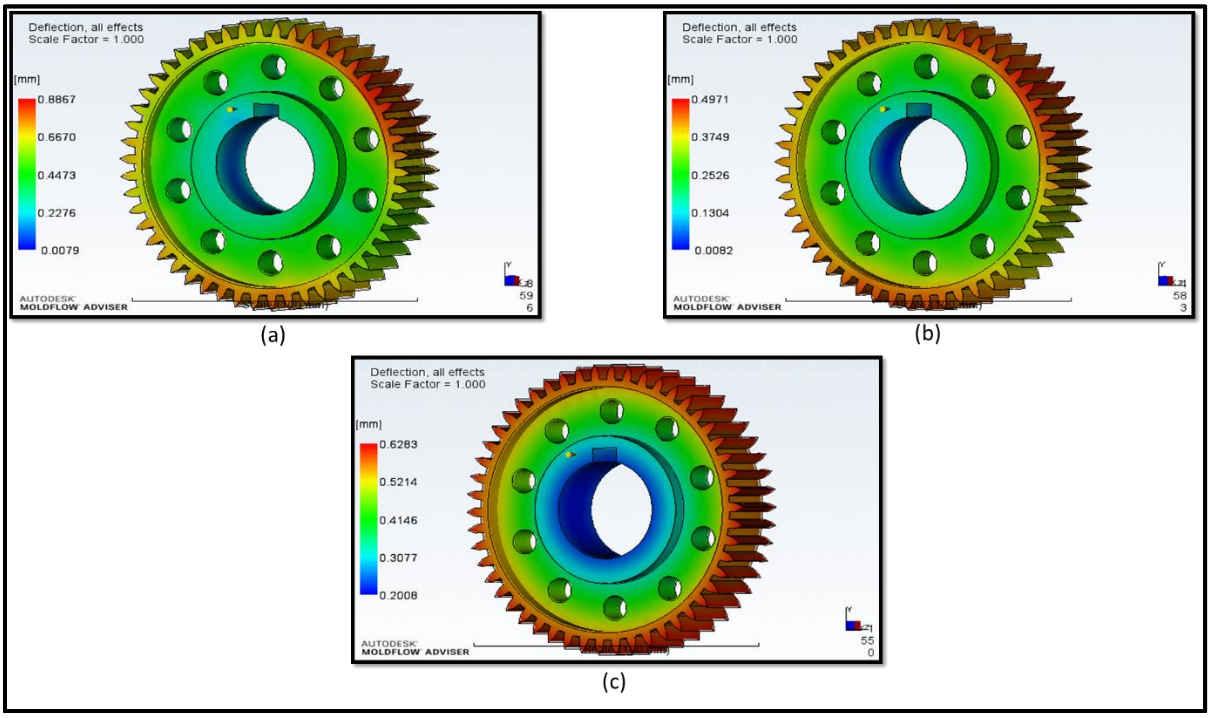

Figure 2: Deflection-All Effects (fifth simulation) Illustrations for (a) Polyamide (b) PPE (c) PC/ABS

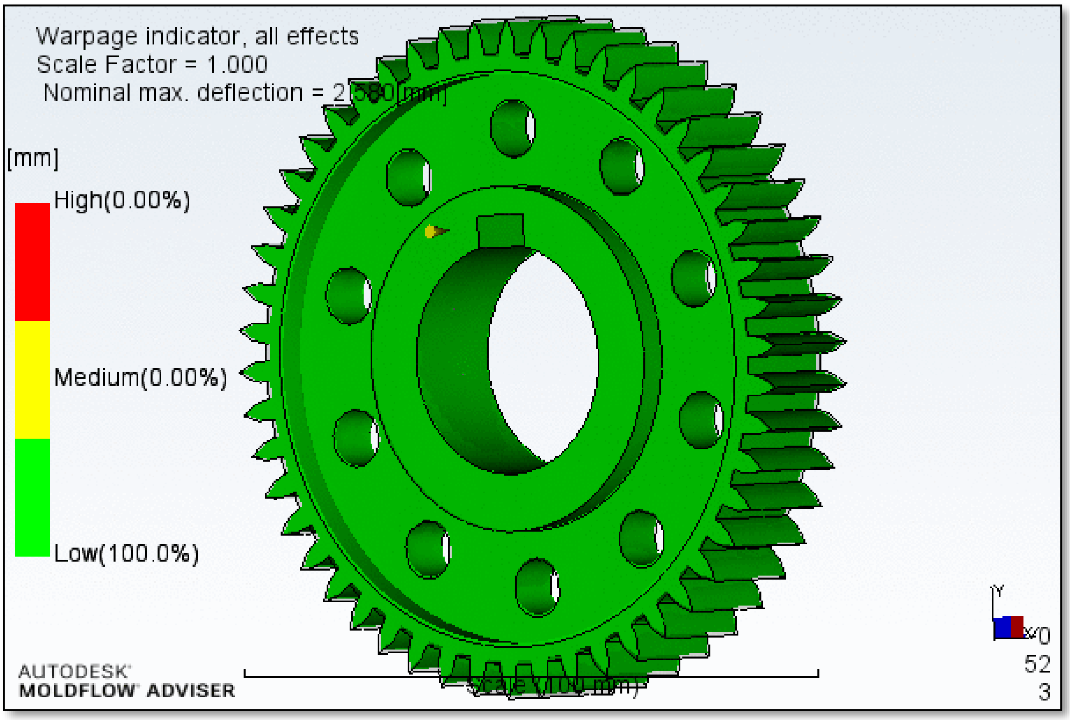

Figure 3: Warpage Indicator Illustration for All Results

3.3 Sink Mark

The position and amount of sink marks that are likely to affect part quality are shown in the sink mark simulation analysis. Blue marked colour area shown the lowest quantity of sink mark while red marked colour area is the highest. The graphical and data analysis of sink mark estimation results for polyamide (PA6) gear, PPE gear, and PC/ABS gear are shown on Figure 4.

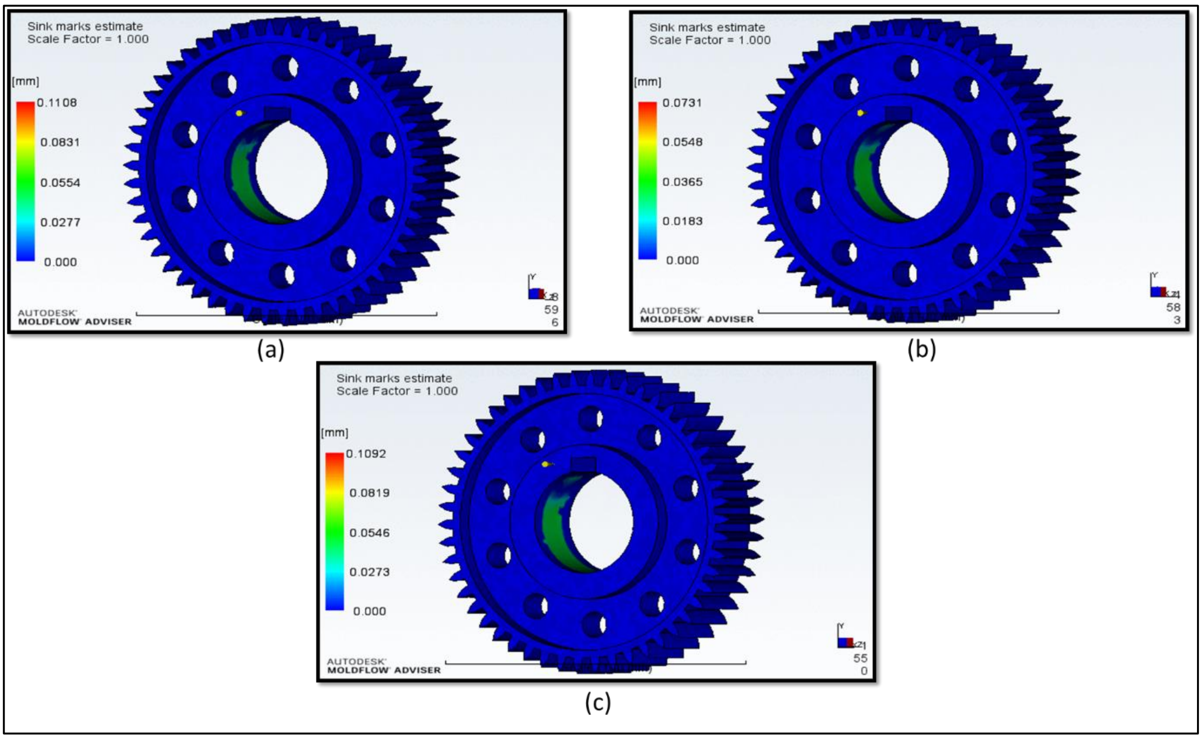

Figure 4: Sink Mark Analysis (fifth simulation) Illustrations for (a) Polyamide (b) PPE (c) PC/ABS

3.4 Minitab Analysis

According to the simulation plan that listed in Table 3 previously, total of 27 simulation have been done with 9 simulation for each three material. The results data were examined using main effects, ANOVA, and signal-to-noise ratio (S/N) analyses in the latter. These three analysis were done by utilizing the Minitab software to gained precise and accurate outcome.

3.4.1 Main Effects

The quality features evaluated in this study were "the-smaller-the-better," due to the fact that the lower the cooling time, sink mark, and deflection of the gear, the better the quality. Figure 5 shows the main effect graph for polyamide, PPE and PC/ABS gear. This graph shows that the combination of parameters and their levels resulted the optimum quality characteristic. It seems that the result of the main effects for all material is actually the same. Thus, the optimal combination of parameters and their levels for achieving minimum average output value is mould temperature at level 2 (90°C), melt temperature at level 2 (267.5°C), and injection pressure at level 3 (500 MPa).

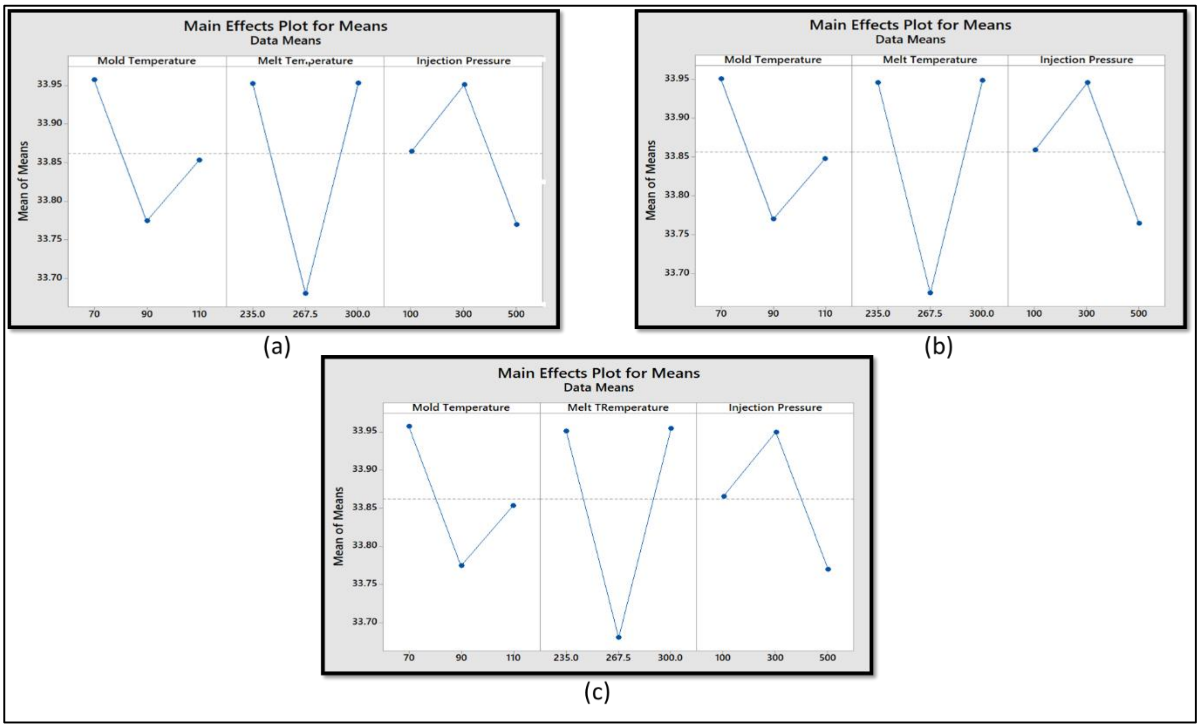

Figure 5: Main Effects Graph for (a) Polyamide (b) PPE (c) PC/ABS

3.4.2 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) was conducted in order to specify which input parameter that effects the average output value the most. The ANOVA findings (automatically generated by Minitab) for the average output value are shown in Table 6, Table 7 and Table 8 for polyamide, PPE and PC/ABS gear respectively.

Table 4.16: ANOVA Table for Polyamide Gear Results

Parameter/Factor	Degree of Freedom	Sum of Squares	Mean Square	F	Contribution (%)
Mould Temperature	2	0.05074	0.02537	1.02	16.98
Melt Temperature	2	0.14882	0.07441	2.98	49.81
Injection Pressure	2	0.04923	0.02462	0.99	16.48
Residual Error	2	0.04997	0.02498		16.73
Total	8	0.29876			100

Table 7: ANOVA Table for PPE Gear Results

Parameter/Factor	Degree of Freedom	Sum of Squares	Mean Square	F	Contribution (%)
Mould Temperature	2	0.04953	o.o2476	1.00	16.68
Melt Temperature	2	0.14883	0.07442	3.02	50.13
Injection Pressure	2	0.04923	0.02462	1.00	16.58
Residual Error	2	0.04931	0.02465		16.61
Total	8	0.29690			100

Table 8: ANOVA Table for PC/ABS Gear Results

Parameter/Factor	Degree of Freedom	Sum of Squares	Mean Square	F	Contribution (%)
Mould Temperature	2	0.05074	0.02537	1.00	16.98
Melt Temperature	2	0.14883	0.07442	2.95	49.82
Injection Pressure	2	0.04866	0.02433	0.96	16.29
Residual Error	2	0.05052	0.02526		16.91
Total	8	0.29876			100

3.4.2 Single to Noise Ratio (S/N Ratio)

The signal-to-noise ratio (S/N) with a higher value identifies control factor settings that reduce the impacts of noise factors. In the case of this simulation study, the signal to noise ratio determines how sensitive the quality characteristic to uncontrollable factors (error) in the simulation. As previously stated, the quality characteristic used in this study was "the-smaller-the-better," which means that he lower the cooling time, sink mark, and deflection of the gear, the better the performance. In this research, main effects plot technique was use for S/N ratio where it show how each factor affects the response characteristic. Figure 9 show the main effects plot for S/N ratio for polyamide, PPE and PC/ABS gear results.

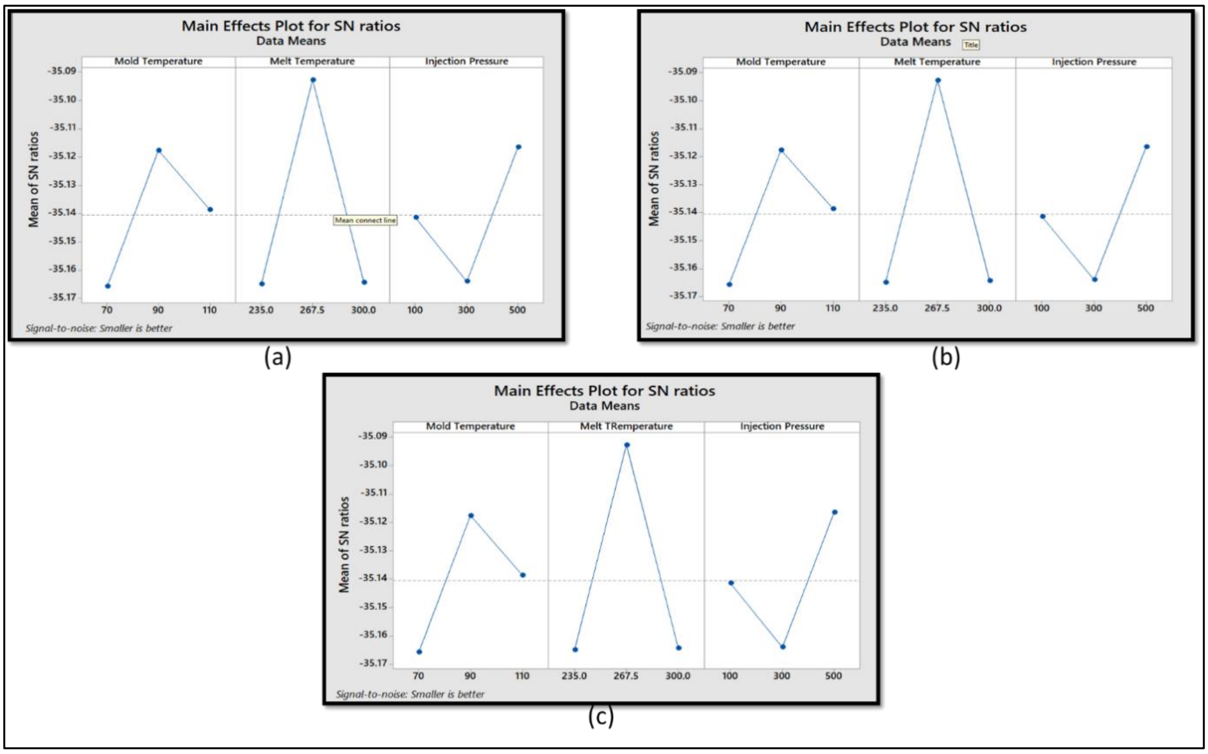

Figure 9: Main Effects Plot for S/N Ratio (a) Polyamide (b) PPE (c) PC/ABS

4. Conclusion

On the basis of the findings of this case study, the conclusions that can be stated is that the mould temperature at 90℃, melt temperature at 267.5℃, and injection pressure of 500 MPa was the combination of parameters and their levels for optimum output value (cooling quality, warpage, and sink mark). Based on analysis of variance (ANOVA) results, for polyamide gear, the contribution of mould temperature, melt temperature and injection pressure to the quality characteristic (average value of maximum cool time variance, average sink mark depth, and nominal maximum deflection) is 16.98%, 649.81%, and 16.48% respectively. Mold temperature has also been the most impacted parameter to the average output value (50.13%) for PPE material, followed by injection pressure (16.68%) and mould temperature (16.68%) (16.58%). Next, as with PC/ABS, melt temperature contributed the most to the average output value (49.82%), followed by mould temperature (16.98%) and injection pressure (16.29%). The optimum parameter combination and their levels appeared to be the same with fifth simulation. Thus, PPE most likely to be choose as it show low value of sink mark estimation and warpage in the result compare to polyamide and PC/ABS.

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References

[1] Khairnar, Yogesh S et al. 2018. “A Review on Design of Plastic Injection Mould.” : 34–38.

[2] Fetecau, Catalin, Daniel Valentin Dobrea, Ion Postolache, and Dobrea Daniel Valentin. 2067. “Overmolding Injection Molding Simulation of Tensile Test Specimen.” International Journal of Modern Manufacturing Technologies ISSN 3604(2).

[3] Fu, Hongbo et al. 2020. “Overview of Injection Molding Technology for Processing Polymers and Their Composites.” ES Materials & Manufacturing: 3–23.

[4] Jozwik, Jerzy, Arkadiusz Tofil, and Andrzej Lukaszewicz. 2019. “Application of Modern Measurement Techniques for Analysis of Injection Moulding Shrinkage.” Engineering for Rural Development 18: 1742–48.

[5] Krause, Beate, Lisa Kroschwald, and Petra Pötschke. 2019. “The Influence of the Blend Ratio in PA6/PA66/MWCNT Blend Composites on the Electrical and Thermal Properties.” Polymers 11(1).

[6] Llewelyn, Gethin, Andrew Rees, Christian Griffiths, and Martin Jacobi. 2020. “A Design of Experiment Approach for Surface Roughness Comparisons of Foam Injection-Moulding Methods.” Materials 13(10).

[7] Park, Hong Seok, and Xuan Phuong Dang. 2017. “Development of a Smart Plastic Injection Mold with Conformal Cooling Channels.” Procedia Manufacturing 10: 48–59.

[8] Da Paz, Renê Anisio et al. 2016. “Mechanical and Thermomechanical Properties of Polyamide 6/Brazilian Organoclay Nanocomposites.” Polimeros 26(1): 52–60.

[9] Satheeskumar, S., and G. Kanagaraj. 2016. “Experimental Investigation on Tribological Behaviours of PA6, PA6-Reinforced Al2O3 and PA6-Reinforced Graphite Polymer Composites.” Bulletin of Materials Science 39(6): 1467–81.

[10] Sin, Lee Tin et al. 2012. “Computer Aided Injection Moulding Process Analysis of Polyvinyl Alcohol-Starch Green Biodegradable Polymer Compound.” Journal of Manufacturing Processes 14(1): 8–19.

[11] Vilas Andhalkar, Vijaykumar, and S. R. Dulange. 2017. “Injection Molding Methods Design, Optimization, Simulation of Plastic Flow Reducer Part by Mold Flow.” International Research Journal of Engineering and Technology (IRJET) 04(6): 1742–46.

[12] Zhang, Shengming et al. 2019. “A Novel Synthetic Strategy for Preparing Polyamide 6 (PA6)-Based Polymer with Transesterification.” Polymers 11(6).

[13] Zink, Béla et al. 2017. “Enhanced Injection Molding Simulation of Advanced Injection Molds.” Polymers 9(2).