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Optimization of Thermoplastic Material for Plastic Injection Molding Process by Using Taguchi Method

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Abstract: Plastic injection molding process can produce a large amount of plastic components but can create several formations of defects such as sink marks and warpage. The objectives of this project are to minimize the defects of the final product of the plastic injection molding by optimizing the processing parameters and to compare the formation of defects between two different thermoplastic material which are polyethylene and polycarbonate. Taguchi method with L9 orthogonal array has been used to optimize the processing parameters which are mold temperature, melt temperature, injection pressure, and clamp open time to minimize the defects on both materials by running the simulation on Autodesk Moldflow Adviser software. The results show that the formation of defects can be minimized which is up to 36.2% after optimizing the processing parameters. Up to 76.49% formation of defects can be reduced by using different combination of processing parameters on different materials. Therefore, the new materials and processing parameters can be applied for further study to determine the behavior of the defects on the plastic components.

Keywords: Plastic Injection Molding, Optimization Method, Thermoplastic Materials

1. Introduction

Plastic injection molding process is a mass production process that can produce high number of products with complicated shapes with good dimensional in short cycle times [1]. The plastic industry is the fourth largest manufacturing industry with approximately $321 billion in annual shipments and more that 1.5 million direct employees [2]. Plastic injection molding also has the largest yield, highest efficiency, and highest dimensional accuracy compared to other processing methods [3]. More than 1/3 of all thermoplastic materials have been injection molded and more than half of the polymer are converted into parts by using injection molding [4]. However, the quality of the product can be varied based on several condition which are machine, mold, material, and operator [5]. The possibility of error that can occur in plastic injection molding is high. The range of the defect can be determined by the quality of the injection molding process. There are many parameters that affect the injection molding

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process that will result the defects in the injection molding. Recent study listed more than 200 different parameters that can affect the process directly or indirectly [5]. The good quality product means that there are measures for the product's qualities, and that the product meets or exceeds specified levels for these measurements [6].

However, the plastic injection molding is the process that has been made by human, so, there is always a room of error. This error can be controlled by optimizing the significance processing parameters that affect the formation of defects. The purposes of this study are to minimize the defects for the final product of the plastic injection molding by optimizing the processing parameters and to compare the formation of defects between two different thermoplastic material which are polyethylene and polycarbonate.

2. Materials and Methods

Two thermoplastic materials were used in this study which are polyethylene and polycarbonate. These materials are in different classes which are amorphous and semi-crystalline thermoplastic. Table 3.1 shows the comparison between amorphous and semi-crystalline material.

Table 3.1: Comparison between amorphous and semi-crystalline thermoplastic

Class	Amorphous	Semi-crystalline
Melting and solidification	Exhibit progressive softening over a wide temperature span	Rapidly change from solid melt condition over a quite narrow temperature band
Shrinkage	Display very low shrinkage which is between 0.5% to 1%	Shrink considerably more which is between 1.5% and 5% depends on material

In this project, the main simulation software is Autodesk Moldflow Adviser 2021. The AMA 2021 was used to run the plastic injection molding process simulation. The design of the mold was imported from SolidWorks 2019. The ATV fairing was chosen as design of mold for the simulation process. The processing parameters were optimized by using Minitab 20.3. Structural analysis was done to determine the critical spot of the maximum stress on ATV fairing when forces exerted.

This simulation project consisted of two parts of simulation which are before and after optimization method. Table 3.2 shows the parameters for three level of selected factor on polyethylene and polycarbonate material The L9 orthogonal array was created by using Minitab software to conduct a screening process. The screening process has conducted to obtain the analysis response which are the formation of sink marks and warpage.

Table 3.2: Parameters for three level of selected factor on polyethylene and polycarbonate material

Material	Processing Parameter	Level 1	Level 2	Level 3
Polyethylene	Mold Temperature (˚C)	20	40	60
	Melt Temperature (˚C)	180	220	240
	Injection Pressure (MPa)	180	240	300
	Clamp Open Time (s)	4	5	6
Polycarbonate	Mold Temperature (˚C)	70	95	120
	Melt Temperature (˚C)	260	300	340
	Injection Pressure (MPa)	100	300	500
	Clamp Open Time (s)	4	5	6

The second simulation was conducted by using the new combination of processing parameters that has been optimized by using Taguchi method. The new input was used in AMA 2021 to run the simulation for plastic injection molding process.

3. Results and Discussion

The results and discussion section presents data and analysis of the study. The screening process has been done by using AMA 2021 to obtain the data for analysis response for both material which are polyethylene and polycarbonate. The different number of defects which are sink marks and warpage was obtained by using different combination of the processing parameters. Taguchi method has been applied as the optimization method to obtain the optimal processing parameters to minimize the formation of defects on the materials. The second simulation was done by using the new combination of processing parameters that have been optimized to obtain the new analysis response.

3.1 Analysis response

The screening process was done by conducting nine trials of simulation using L9 orthogonal array. The different value in parameters for three level of selected factor on polyethylene and polycarbonate material produced different combinations of processing parameters. After the simulation was done by using the L9 orthogonal array table, the different value of formation of defects was obtained. Figure 3.1 shows the minimum and maximum value for the formation of sink marks and warpage on polyethylene and polycarbonate material. The maximum value obtained for sink marks on polyethylene material is 11.31mm while the lowest value formed is 9.612mm. The highest value for warpage is 38.55mm, which is higher than the maximum value for sink marks. The minimum value for warpage obtained is 30.67mm. For polycarbonate material, the value for minimum and maximum formation of sink marks are 4.74mm and 6.835mm respectively. The formation of warpage was higher than sink marks which is 16.62mm as the maximum value. The lowest value for warpage on polycarbonate material is 16.62. The result shows that the polycarbonate material produced low formation of sink marks and warpage compared to polyethylene.

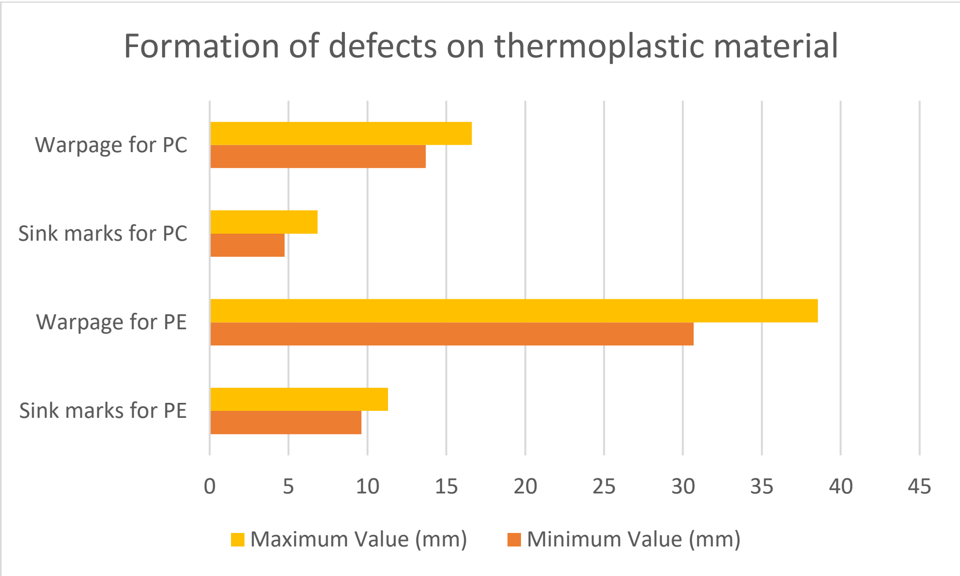

Figure 3.1: Graph for formation of defects on thermoplastic material

3.2 Optimization method

Figure 3.2, Figure 3.3, Figure 3.4, and Figure 3.5 show the graph for S/N ratio for defects on thermoplastic materials. The S/N ratio was set to smaller is better to obtain the smaller value for the formation of the defects. The graphs show the similar patter which is the formation of defects was highly affected by the melt temperature of the materials. The different value of melt temperature will lead to the wide change of the formation of defects on polyethylene and polycarbonate material. Since it has little effect on the production of flaws, the clamp open time is the least important processing parameter in this study.

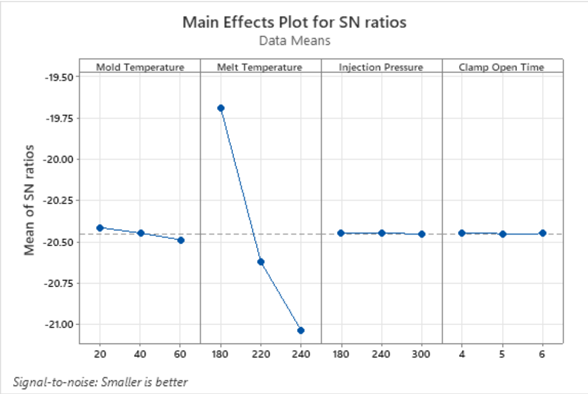

Figure 3.2: Graph for S/N ratio for sink marks for polyethylene material

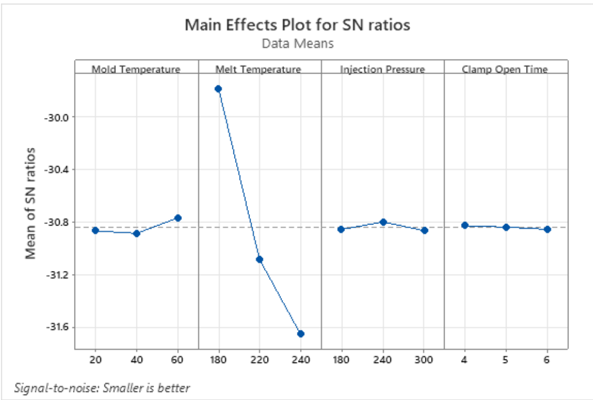

Figure 3.3: Graph for S/N ratio for warpage for polyethylene material

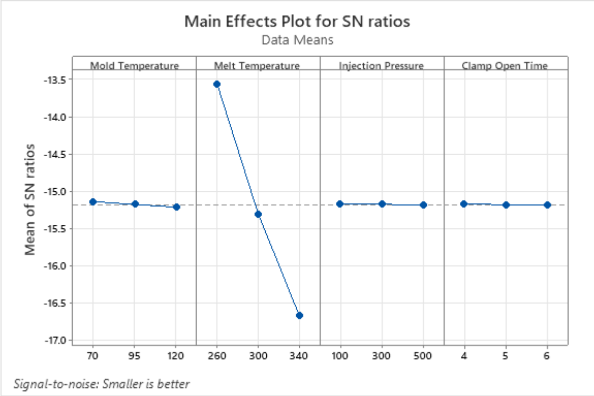

Figure 3.4: Graph for S/N ratio for sink marks for polycarbonate material

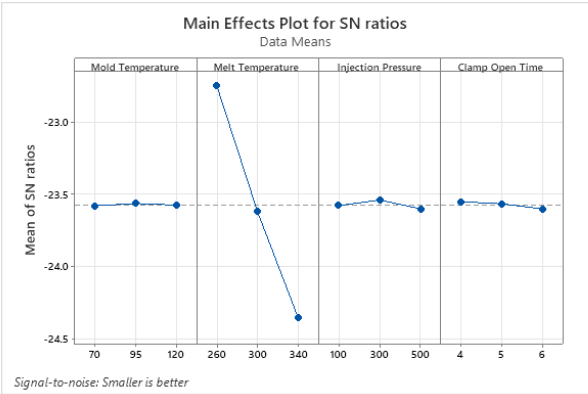

Figure 3.5: Graph for S/N ratio for warpage for polycarbonate material

From the graph obtained, the new combination of processing parameters was determined. Table 3.4 show the optimized processing parameters that have been create by using Taguchi method in Minitab software. The optimized processing parameters for sink marks on polyethylene are 20˚C mould temperature, 180˚C melt temperature, 180MPa injection pressure, and 4s clamp open time. For warpage, the optimized processing parameters are 60˚C mould temperature, 180˚C melt temperature, 240MPa injection pressure, and 4s clamp open time. The optimized parameters for sink marks and warpage on PC material are 70˚C mould temperature, 260˚C melt temperature, 100MPa injection pressure, 4s clamp open time and 95˚C mould temperature, 260˚C melt temperature, 300MPa injection pressure, 4s clamp open time respectively. The results show that for both formation of defects, the value for melt temperature and clamp open time is constant. The optimal melt temperature for polyethylene and polycarbonate are 180˚C and 240˚C. The changes in value of the optimal melt temperature will lead to high formation of defects because the melt temperature is the most significance processing parameters to the formation of defects.

Table 3.4: Optimized processing parameters for polyethylene and polycarbonate material

Material	Processing Parameter	Sink Marks	Warpage
Polyethylene	Mold Temperature (˚C)	20	60
	Melt Temperature (˚C)	180	180
	Injection Pressure (MPa)	180	240
	Clamp Open Time (s)	4	4
Polycarbonate	Mold Temperature (˚C)	70	95
	Melt Temperature (˚C)	260	260
	Injection Pressure (MPa)	100	300
	Clamp Open Time (s)	4	4

3.3 Comparison of value of defects between before and after optimization method on polyethylene and polycarbonate

From table 3.5, the formation of sink marks after the Taguchi method has been applied is lower than the formation of sink marks before the optimization method. The values of the formation of sink marks are 11.31mm and 9.612mm for before and after the optimization method respectively. The percentage difference of formation of sink marks on polyethylene material is 16.23%. The value of formation of warpage on polyethylene material before the optimization method is 38.55mm. It shows that after the optimization process, the formation of warpage decreases to 30.67mm. The percentage difference of formation of warpage on polyethylene material is 22.77%. From the results, the percentage difference of formation of sink marks is lower than the formation of warpage. The optimized processing parameters will minimize the formation of warpage more than the formation of sink marks on polyethylene material.

The values of the formation of sink marks on polycarbonate are 6.835mm and 4.740mm for before and after the optimization method respectively. The percentage difference of formation of sink marks on polycarbonate material is 36.2%. The value of formation of warpage on polycarbonate material before the optimization method is 16.400mm. It shows that after the optimization process, the formation of warpage decreases to 13.700mm. The percentage difference of formation of warpage on polycarbonate material is 17.94%. From the results, the percentage difference of formation of sink marks is higher than the formation of warpage. The optimized processing parameters will minimize the formation of sink marks more than the formation of warpage on polycarbonate material. Based on the simulation processes and results, it shows that the design of experiment is the best method to decrease the number of trials of experiments and obtained enough data.

Table 3.5: Formation of defects on polyethylene and polycarbonate before and after optimization method

Material	Parameter Name	Before optimization	After optimization
Polyethylene	Sink marks (mm)	11.310	9.612
	Warpage (mm)	38.55	30.67
Polycarbonate	Sink marks (mm)	6.835	4.74
	Warpage (mm)	16.62	13.70

3.4 Comparison of formation of defects between polyethylene and polycarbonate after optimization method

Table 3.6 shows the result obtained for the injection moulding process simulation for polyethylene and polycarbonate material The percentage difference for sink marks and warpage between polyethylene and polycarbonate material are 67.89% and 76.49% respectively. The structure of the polyethylene material is semi-crystalline while the structure of the polycarbonate material is amorphous. These two different structures can lead to difference value in formation of defects on the material. From the results, it shows that during the injection moulding process, the formation of defects on polycarbonate material is lower than polyethylene material. Polyethylene is a lightweight thermoplastic material that is not strong and hard compared to the polycarbonate material. Polycarbonate material is more rigid compared to polyethylene material; thus, the formation of defects is less than polyethylene material. The difference in value of the formation of sink marks is less than the difference in formation of warpage between polyethylene and polycarbonate. From these results, it shows that polycarbonate material can produce the low value of defects after the optimization method compared to polyethylene material.

Table 3.6: Formation of defects on polyethylene and polycarbonate after optimization method

Material	Defects	Defects Value (mm)
Polyethylene	Sink marks	9.612
	Warpage	30.67
Polycarbonate	Sink marks	4.74
	Warpage	13.70

4. Conclusion

From the screening process, the conclusion that can be made is that the combination of processing parameters will affect the formation of defects on the thermoplastic materials. The results obtained prove that the formation of defects can be varied based on the selection of combination of the processing parameters. Certain processing parameters can highly affect the formation of defects on the thermoplastic material such as melt temperature. The graphs obtained show that the formation of defects will have a high difference in value if the melt temperature is change. The injection pressure and clamp open time do not affect the formation of defect too much. The second simulation is done by using the combination of processing parameters obtained during the optimization process. The results show the formation of defects can be minimize after the optimization method. The formation of defects for polycarbonate material is lower than the formation of defects for polyethylene material.

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