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Effect of injection moulding parameters in reducing the shrinkage of polypropylene product using Taguchi analysis

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Abstract. Nowadays, manufacturing industry is growing rapidly in any country over the world. Plastic industry is the one of the manufacturing industry that has high demand among consumers. Polypropylene is popular due to its characteristics such as recycle, low cost, chemical resistance, excellent impact strength, food grade availability and so on. The plastic product is normally produced by using an injection molding machine. The quality of the product depends on the injection molding parameters during the processing. Thus, the optimization of the injection molding parameters on processing polypropylene by using design of experiment is the main objective of the study. The best value of injection molding parameters such as melting temperature, injection pressure, injection speed, cooling time, holding time and holding pressure have been obtained and optimized using Taguchi method. From the results obtained, the most significant injection molding parameter on the shrinkage of polypropylene is holding time. The result has been supported by analysis of variance (ANOVA). The optimization of injection molding parameters contributes to the plastic processing such as increasing productivity as well as maintaining the dimension and quality performance of the product.

1. Introduction

Plastic plays an important role in the manufacturing industry today. There are a lot of plastic manufacturing processes available such as blow molding, casting, compression molding, extrusion, fabrication, foaming, injection molding, rotational molding, and thermoforming [1]. Injection molding is a manufacturing process to produce plastic injection molds from both thermoplastic and thermosetting plastic materials. Injection molding is a high rate production process and permits good dimensional units. Hence, injection molding is the most popular process applied in plastic industry. Besides, injection molding machine is capable to produce complex parts and shapes [2]. Design of experiments (DOE) is a useful and systematic approach to control the error in determining the relationship between factor of process and the quality of product [3]. With the help of DOE, the optimization of the process setting can be done.

The Taguchi method is a structured approach in determining the best combination of input or parameter to produce a product or service [4]. This method is based on the orthogonal array experiment providing a set of well-balanced experiment and signal-to-noise (S/N) ratios [5]. Besides, this method helps to optimize the best injection molding parameters with less number of experiments that conducted by using Minitab 17 in producing a good plastic product.



Analysis of variance (ANOVA) test is more a collection of data analysis techniques than a single statistical test. [6] This analysis estimates the importance of one or more factors by analyzing the response variable means at different factor levels. It will help to figure out if need to reject the null hypothesis or accept the alternate hypothesis.

Polypropylene (PP) is a thermoplastic polymer that is widely used in packaging and labeling, textiles, stationery, plastic parts and reusable containers, laboratory equipment, loudspeakers, automotive components and polymer banknotes. PP can be improved towards mechanical properties and thermal resistance, while the chemical resistance is decreased by additionally present methyl group. Several previous studies extensively focused on the effect of composition and processing parameters on PP products [6-10]. In PP production, shrinkage is one of major problem that will affect the dimension and specification of the final product. This shrinkage problem may affect the quality control of the product [10].

A lot of previous findings shows that the optimization of injection moulding parameters are successfully done by Taguchi and ANOVA analysis. G Singh, et al. [5] has optimized the injection molding process parameters such as melt temperature, injection pressure, packing pressure, and packing time, each at three levels towards the tensile strength of plastic. This study used ANOVA method to find the significant parameter. A Wavare et al. [10] optimized the effect of injection parameters on shrinkage and warpage of manufactured PP homopolymer. H P Kale et al. [11] studied the effect of process parameters for injection molding on shrinkage of high density polyethylene (HDPE). Recently, Yitao Zheng et al. [12] investigated the optimization of the composition on mechanical performance of PP based composites using Taguchi and ANOVA techniques. As for A Batwara et al. [13], their used Mold Flow simulation combined with ANOVA analysis on optimization of PP product. Recent works done by D Kusić and A Hančič [14] using PP filled with calcium carbonate focusing on shrinkage and warpage reduction using six molding conditions in their Taguchi analysis.

In this study, six injection molding parameters are investigated on processing PP product using Taguchi and ANOVA analysis. The optimization of the process parameters aims to minimize the shrinkage of the final product during the PP production.

2. Experimental work

2.1. Design of experiment and sample preparation

The injection molding parameters that are investigated in this study such as melting temperature, injection pressure, injection speed, cooling time, holding time and holding pressure. The injection molding parameters were set at three levels. The injection parameters value was referred to the previous finding [5]. The table 1 shows the setting of injection molding parameters used in this study. The L27 (36) orthogonal array was used in this study. The MA23 injection molding machine which was manufactured by Tat Ming technology Co. Ltd from Hong Kong was used to produce the PP product. The raw materials, polypropylene homopolymers was supplied by Lotte Chemical Titan (M) Sdn. Bhd. The specimens were produced according to the parameters as stated in Table 1.

Table 1. Setting of injection molding parameter used in this study.

Injection moulding parameter	Level 1	Level 2	Level 3
Melting temperature (°C) (MT)	200	210	220
Injection pressure (bar) (IP)	70	80	90
Injection speed (rpm) (IS)	20	30	40
Cooling time (s) (CT)	4	5	6
Holding time (s) (HT)	2	4	6
Holding pressure (bar) (HP)	50	60	70

2.2. Experimental testing

The shrinkage of PP product is depending on the resins, moulding conditions, part design, part wall thickness, and direction of flow. The shrinkage, S was calculated by: [10]

$$S = \frac{(V_m - V_p)}{V_m} \times 100 \quad (1)$$

where V_m is the volume of mold; V_p is the volume of specimen and S is the shrinkage of the product.

2.3. Data analysis and validation

Taguchi method was utilized to find the optimum injection molding parameter on processing PP products. Minitab-17 is a statistical software helped to evaluate the best injection molding parameter that produced less shrinkage of PP product. The data analyzed the shrinkage measurement as the response. By setting the options “smaller is better” as S/N ratio for both responses, the graph and table of S/N ratio and means were constructed by Minitab-17.

ANOVA was implemented in this study to validate which injection molding parameter is significant in this study. The confidence level was set up to 95% and type of confidence interval is upper bound. If the significant factor is more than one, the R-squared showed the contribution value to which factor is more significant in this study.

Table 2. Taguchi design data.

No.	MT	IP	IS	CT	HT	HP	Shrinkage
1	1	1	1	1	1	1	5.86
2	1	1	1	1	2	2	3.37
3	1	1	1	1	3	3	0.57
4	1	2	2	2	1	1	5.10
5	1	2	2	2	2	2	2.76
6	1	2	2	2	3	3	1.03
7	1	3	3	3	1	1	6.44
8	1	3	3	3	2	2	3.03
9	1	3	3	3	3	3	0.46
10	2	1	2	3	1	2	5.90
11	2	1	2	3	2	3	3.79
12	2	1	2	3	3	1	1.69
13	2	2	3	1	1	2	6.36
14	2	2	3	1	2	3	3.49
15	2	2	3	1	3	1	1.88
16	2	3	1	2	1	2	6.93
17	2	3	1	2	2	3	3.72
18	2	3	1	2	3	1	1.11
19	3	1	3	2	1	3	7.28
20	3	1	3	2	2	1	3.98
21	3	1	3	2	3	2	2.03
22	3	2	1	3	1	3	6.86
23	3	2	1	3	2	1	4.14
24	3	2	1	3	3	2	2.38
25	3	3	2	1	1	3	6.70
26	3	3	2	1	2	1	3.79
27	3	3	2	1	3	2	2.15

3. Results and discussions

All the experimental data were tabulated with Taguchi L27 (36) orthogonal array that being designed in the Minitab-17 as shown in table 2. The S/N ratios for shrinkage was plotted in figure 1. According to the ranks, the most significant parameter for decreasing shrinkage in sequence were HT, MT, HP, IP, IS and CT.

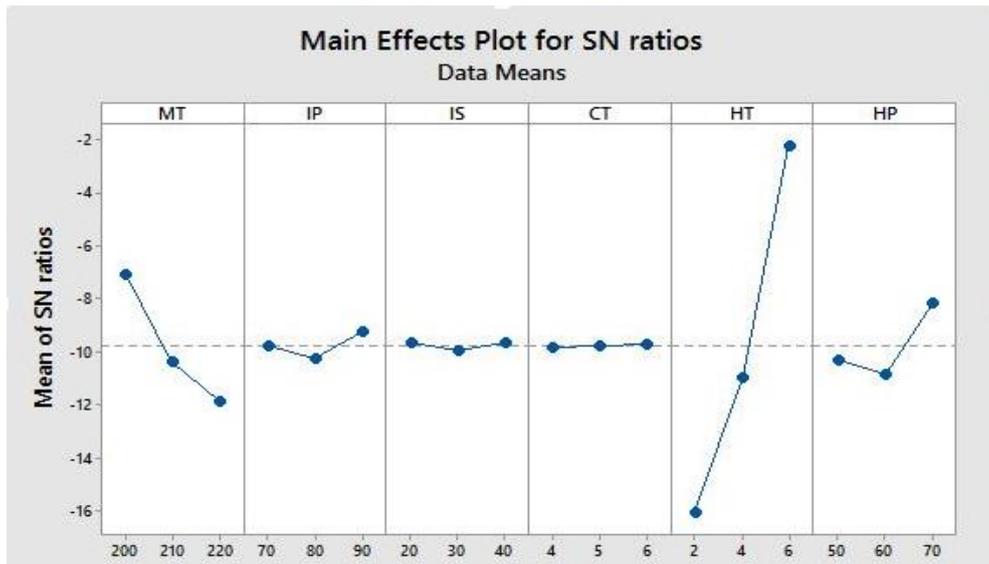


Figure 1. The main effects plot for S/N ratios.

As shrinkage is the ‘Smaller is better’ type quality characteristic, the appropriate set of input parameters was MT1, IP3, IS3, CT3, HT3, and HP3 providing the decrease in shrinkage of PP products. Table 3 shows the optimum injection moulding parameters on processing PP products that have the least shrinkage.

Table 3. Optimum injection moulding parameter on processing PP for shrinkage.

Injection moulding parameter	Values
Melting temperature (°C) (MT)	200
Injection pressure (bar) (IP)	90
Injection speed (rpm) (IS)	40
Cooling time (s) (CT)	6
Holding time (s) (HT)	6
Holding pressure (bar) (HP)	70

As shown in table above, the IP, IS, CT and HP parameter were the highest value that being implemented in this study. However, those parameters were not given a significant change against shrinkage. This statement was further evident by data shown in figure 1. The MT parameter was the lowest value and the HT parameter was the highest value. The figure 1 shows that both parameters influenced in reducing shrinkage on processing PP. In fact, the HT was the most dominant factor compared to the MT. This may due to the large holding pressure that being exerted after the cavity filled up when the mould was started to cool and solidify. Hence, the holding time will affect the shrinkage if the value is being changed drastically. If this happen, the defect issue will occur such as sink mark and warpage.

According to previous work [10], longer CT, lower MT, higher IS and higher HP parameter were recommended to reduce the shrinkage on plastic processing [5]. In fact, only MT influenced in reducing shrinkage on processing PP in this study [10]. A lots of findings found that MT as the dominant factor for reducing shrinkage on processing PP [10-11]. Besides, Altan's findings [15] revealed that the most dominant factor to reduce shrinkage of PP was HP and MT. This was due to the very close packing of the crystalline structure place in the solidifying and cooling phase. On the other hand, CT was found to be the factor with most significant effect on the shrinkage of High Density Polyethylene followed by refilling pressure [16]. In fact, different geometries of mould design may result in different controlling parameters. Thus, the most significant factor may vary in different product mould design and raw materials.

Table 4. Response (rank) for means for shrinkage.

Injection moulding parameter	Rank
Melting temperature (°C) (MT)	2
Injection pressure (bar) (IP)	6
Injection speed (rpm) (IS)	3
Cooling time (s) (CT)	5
Holding time (s) (HT)	1
Holding pressure (bar) (HP)	4

Table 4 shows the response (rank) tables for means of shrinkage. This rank was compared with the percent contribution that can be found in the ANOVA analysis. This table also supports whether the range and the injection molding parameter that being analyze in Taguchi design affecting the shrinkage. Table 5 shows the ANOVA table and result analysis for shrinkage. This table represents the most significant parameter on processing parameter in terms of minimizing the effect of shrinkage in fabrication process. The most significant parameter would affect the results if the setting was changed significantly in processing PP product. The most significant parameter was referring to the P-value and the value must be less than 0.05. If the P-value was more than 0.05, the parameter is considered not significant in this study. The R-squared was used to show the percent contribution value of parameter in this study.

For percent contribution in this study, the holding time (HT) was the highest percent compared to other injection molding parameters on processing PP, which accounts for 94.10% of the total effect. The contribution of other parameters in descending order is melting temperature (MT) (5.53%), injection speed (IS) (0.27%), holding pressure (HP) (0.06%), cooling time (CT) (0.03%), and injection pressure (IP) (0.01%) respectively.

Table 5. Anova result analysis.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	R-sq (%)
MT	2	6.408	3.204	0.69	0.512	5.53
IP	2	0.014	0.00723	0.00	0.999	0.01
IS	2	0.305	0.1527	0.03	0.969	0.27
CT	2	0.031	0.01539	0.00	0.997	0.03
HT	2	109.035	54.5176	142.83	0.000	94.10
HP	2	0.068	0.03414	0.01	0.993	0.06

For percent contribution in this study, the holding time (HT) was the highest percent compared to other injection moulding parameters. By referring to the table 4, it shows that the ANOVA analysis is able to verify the Taguchi design analysis for shrinkage. This shows that the Taguchi design analysis is reliable and acceptable in this study. Based on the results above, it shows that MT and HT were the dominant parameters. This results also reflect and support the Taguchi design where both parameters

were dominant factors in the analysis earlier. Despite only HT was the most significant parameter, but MT still has impact towards processing PP in reducing shrinkage.

The optimum injection parameters support the Taguchi principle and they will help to produce better product quality for mass production. The optimum injection moulding parameters on processing PP were used in fabrication of final PP product. The product as shown in figure 2 is less shrinkage, no warpage and has good image appearance.

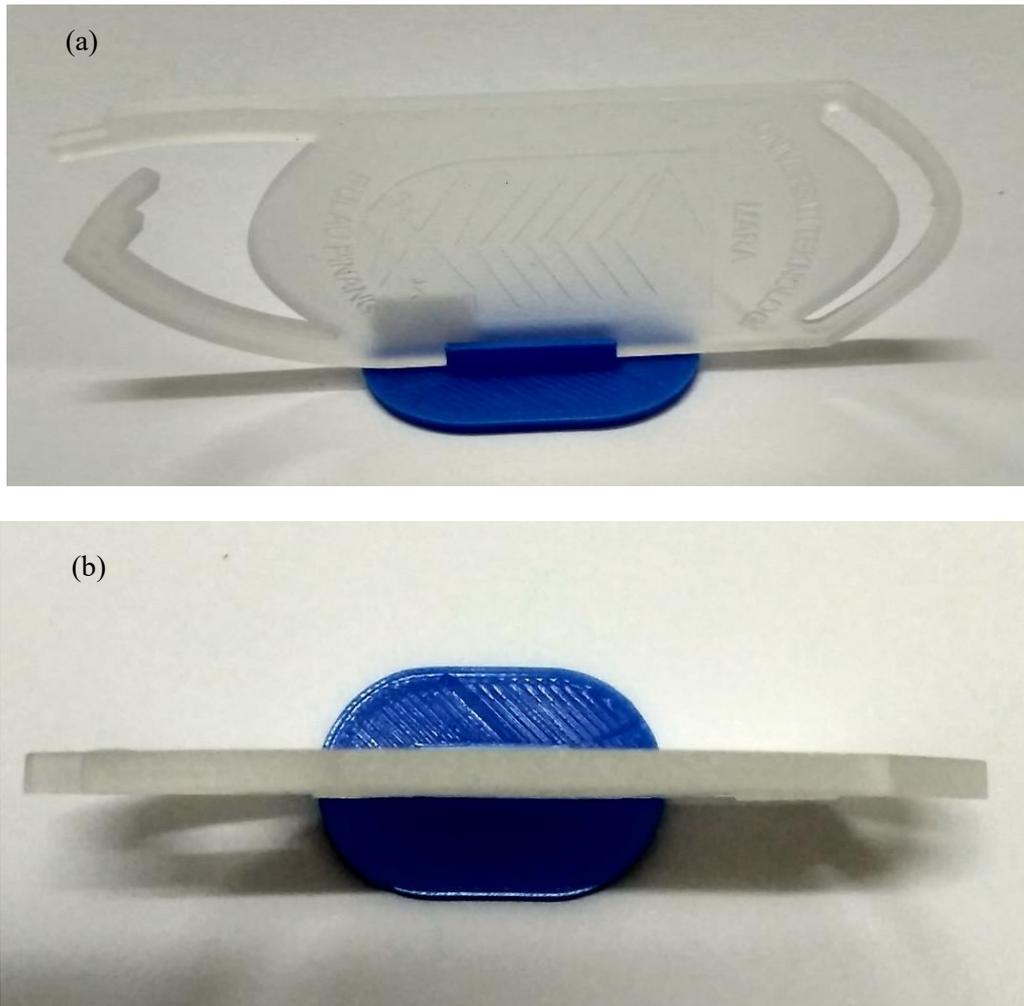


Figure 2. Product fabricated using optimum parameters: (a) front view (b) side view.

4. Conclusions

The Taguchi and ANOVA methods were utilized to study the effect of different injection molding parameters on shrinkage of PP product. With the help from the Taguchi analysis, the optimum set of process parameters were found. The results showed that 200°C of MT, 90 bar of IP, 40 rpm of IS, 6s of CT, 6s of HT and 70 bar of HP were needed in order to get the PP product having the least shrinkage problem. The most dominant parameter was holding time (HT). The ANOVA analysis helped to validate the result of Taguchi analysis for the responses. The ANOVA analysis also found that the HT was the significant injection molding parameter in minimizing the shrinkage. The optimization of injection molding parameter contributes to the plastic processing such as increasing productivity, quality and reliability of the product.

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