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A Study of Injection Moulding Optimum Parameters to Control Shrinkage and Warpage of Polypropylene-Nanoclay Hinges Samples

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Abstract. Injection moulding is one of the most efficient processes in mass production that can easily attain up to complex geometry product within a very short cycle time. To choose a suitable setting of parameter was very crucial, in controlling the quality of product with regard to their function. The main propose of this research is to optimize the injection moulding parameter for controlling the shrinkage and warpage of thermoplastics sample through practical injection moulding. The additional study for this project is to investigate the effect of nanoclay contents towards the parameter setting. In this experiment, the selected parameters were packing pressure; melt temperature, screw speed and filling time. The material that was selected for this project was a mixture of polypropylene and nanoclay with the addition of polypropylene-grafted-maleic anhydride as the compatibilizer. Three formulations were chosen, which was 0 wt%, 3 wt% and 5 wt% of Nanoclay. Each formulation was added with 15 wt% of compatibilizer. The experiment design for this project shall adopt the $L_9 4^3$ Orthogonal Array of Taguchi Method. By using the Signal to Noise Ratio responses, the optimum parameter for each formulation has been obtained. The findings of this experiment shall be useful for future manufacturing process in order to control shrinkage and warpage specifically for products made from polypropylene-nanoclay.

Introduction

The quality of the injected moulded parts depends on the material, part / mould designs, and the processing parameters that were required to manufacture these products. Warpage and shrinkage were among the most highly occurred defects for thin-shell plastic parts [1]. Upon this statement, this project was carried out to optimize the injection moulding parameters towards the processing of manufactured samples, and to investigate the effect of nanoclay contents towards the parameter setting.

The selection of parameter settings were made based on the findings from several researchers. By referring to [2], pressure and temperature were the most affecting parameters that shall fully specify the quality of injection moulded part. According to [3], the most important factor that affects warpage was packing pressure. The main function of packing pressure of the process is to maintain the plastic pressure inside the cavity until the gate has frozen off that is then acts as a barrier to any further pressure loss in the cavity. The amount of packing pressure needs to be high enough and maintain during packing time to prevent any loss of pressure or discharge of plastic resin back out of the gate. Reference [4] had stated that shrinkage was influenced by a number of factors, and the most important factor was packing pressure. If the packing pressure is high, more material is forced into the mould cavity and then the shrinkage is reduced.

Polypropylene (PP) was chosen as the main material, because of its good mechanical properties and wide range of applications with well balanced properties, and the most important is it has a very good heat resistance [5]. To make this project more interesting, the addition of nanoclay was taken into place. Nanoclay (NC) is one of the most suitable materials that have successful results in polymers. It is famous since it can enhance the properties of polypropylene and many more. It also has good availability, relatively easy surface modification possibilities and low price among several nanofillers, as compared with carbon nanotubes for instance [6].

Taguchi Method was chosen as the tools for design of experiment, based on a comprehensive review which had provided more than enough information about past research which relates to this design of experiment approach [7]. In terms of parameter setting studies, the author had carried out several researches with different type of samples, material and responses. The findings from these researches were used as guidance for this project [8–10]. One of the latest researches had been successfully achieved by optimising the test sample made from polypropylene and clay, without using any compatibilizer [11]. Therefore, this project was performed as the extended version of previous research conducted by the author.

Research Methodology

Fig. 1 shows the research process flow explaining about the experiment conducted for this project. This research started from the mixing process using Brabender Plastograph and palletizing. The second step is to perform practical injection moulding by using the Nissei NP-7F injection moulding machine (Fig.2). The sample (Fig. 3) which was produced and measured the shrinkage and warpage was a hinge test sample. Three different formulations were chosen which were which were 0 wt%, 3 wt% and 5 wt% of Nanoclay (NC). Each formulation was added with 15 wt% of compatibilizer which was a polypropylene-grafted-maleic anhydride (PP-g –MA). The part qualities (shrinkage and warpage) that had been selected will be optimized by choosing the right factor and level by using Taguchi Method Orthogonal Array (Table 1).

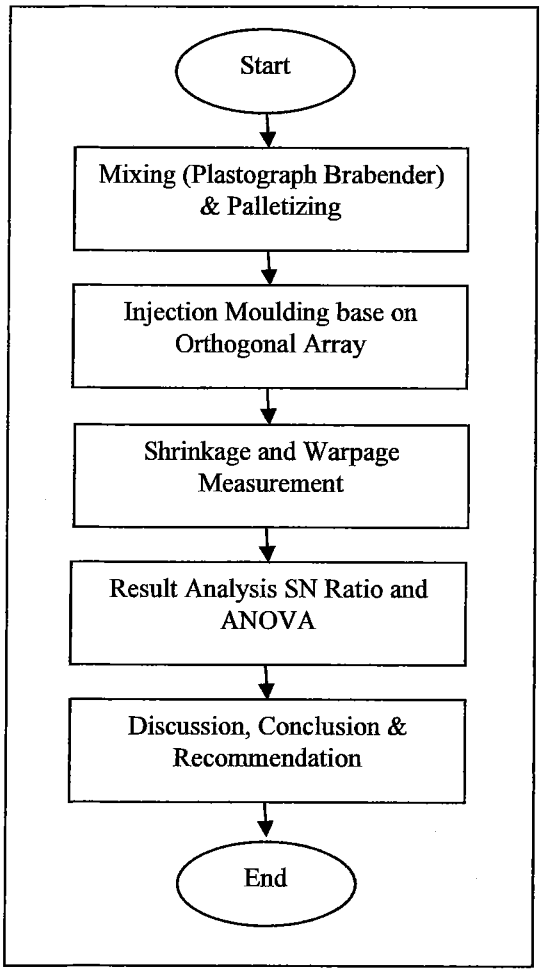

Fig. 1 : Research Process Flow

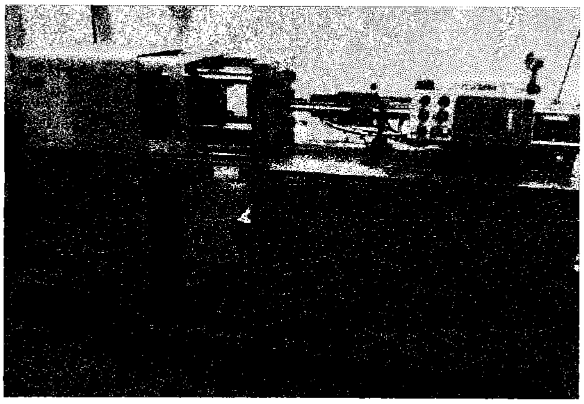

Fig. 2 : Injection Moulding Machine

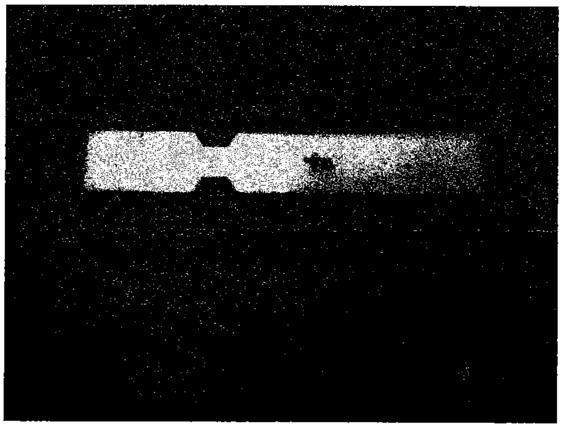

Fig. 3: Test Sample

The selected parameters that were taken into consideration are melt temperature (MT), packing pressure (PP), screw speed (SS), and filling time (FT). Experiments of injection moulding were conducted at Polymer and Ceramic Laboratory in Universiti Tun Hussein Onn Malaysia (UTHM). The value of Signal to Noise (S/N) ratio was calculated in order to get the best combination of parameters that optimize the part of qualities.

Table 1: Values of Orthogonal Array ($L_9 4^3$) with Results based on formulation.

Trial	MT (°C)	PP (%)	SS (%)	FT (s)	Average Value of Shrinkage (%)			Average Value of Warpage (mm)		
					0%	3%	5%	0%	3%	5%
1	170	20	20	1	0.0215	0.0181	0.0164	0.093	0.049	0.029
2	170	30	30	2	0.0204	0.0148	0.0107	0.065	0.032	0.012
3	170	40	40	3	0.0198	0.0032	0.0037	0.059	0.041	0.031
4	180	20	30	3	0.0202	0.0142	0.0127	0.072	0.067	0.053
5	180	30	40	1	0.0202	0.0072	0.0033	0.093	0.056	0.029
6	180	40	20	2	0.0207	0.0166	0.0146	0.035	0.033	0.027
7	190	20	40	2	0.0195	0.0009	0.0036	0.039	0.035	0.025
8	190	30	20	3	0.0201	0.0157	0.0150	0.067	0.049	0.035
9	190	40	30	1	0.0207	0.0182	0.0165	0.062	0.056	0.047

Result and Discussion

This part focuses on the result of experimental data and analysis of defect control (warpage and shrinkage) in relation with the parameter setting. To obtain the best combination parameter in order to produce minimum defects, S/N ratio has been calculated by using Minitab 16 Statistical Software, based on the average value obtained from Table 1. Fig. 4, Fig, 5 and Fig. 6 show the Signal to Noise Ratio Responses for shrinkage with different percent of Nanoclay. Fig. 7, Fig, 8 and Fig. 9 show the same type of result for warpage.

According to the results of warpage and shrinkage obtained from Table 1, it was found that the lowest value of shrinkage was obtained from trial no 7 for the mixture of 0% NC and 3% NC. In the other hand, the shrinkage value of 0.0033% was gained for 5% NC, from trial no 5. As for warpage, the value of 0.035 mm has been achieved for pure Polypropylene, and the value dropped to 0.0032 mm and 0.012 mm for 3% NC and 5% NC respectively.

Table 2 shows the optimum parameter setting for different percentage of Nanoclay. These values were obtained by choosing the peak value of signal to noise ratio responses generated from Fig. 3 to Fig. 9. It was found that for controlling shrinkage, there was no change for screw speed setting, and for warpage there was no change for filling time. In terms of packing pressure the value seems to be reducing with the additional of nanoclay, for both shrinkage and warpage cases.

Results from Table 2 also rectified that by adding more Nanoclay, the shrinkage and warpage shall decrease. This condition had met the agreement with the findings in reference [5] and [11], whereby according to Reference [5], the nanocomposites produced from PP and NC are said to be resistant to heat and have a low tendency to wrap. In this research, for instance, pure polypropylene has produced 0.0201% of shrinkage, and the value decreased to 0.0036 mm by adding 5% of NC. This result also have verified the fact from [2] that melt temperature and packing pressure were important to be monitored, whereby there were slight changes upon the addition of nanoclay content. With this excellent result, based on statement in [5], these nanocomposites can be used in the manufacturer of interior and exterior of automobiles.

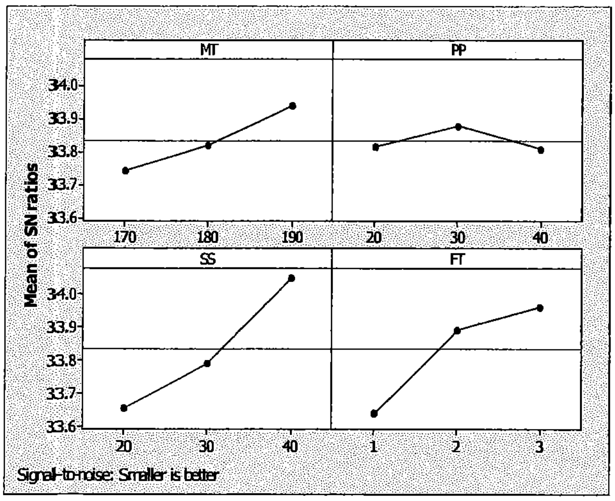

Fig. 4: S/N Ratio of Shrinkage for 0 wt% NC

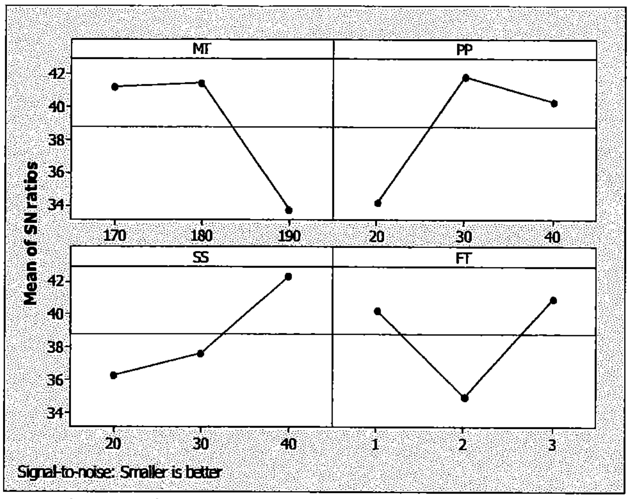

Fig. 5: S/N Ratio of Shrinkage for 3 wt% NC

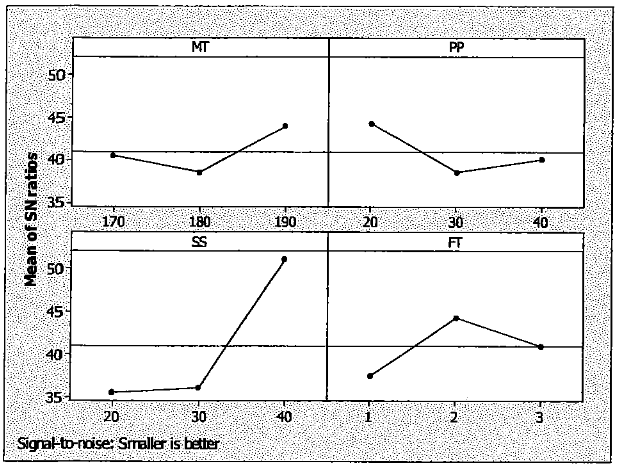

Fig. 6: S/N Ratio of Shrinkage for 5 wt% NC

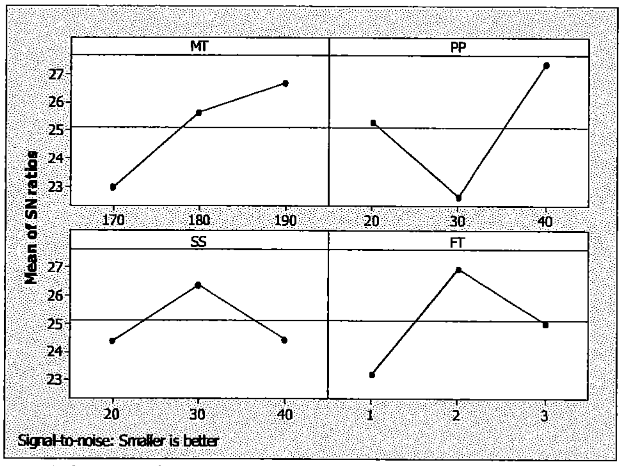

Fig. 7: S/N Ratio of Warpage for 0 wt% NC

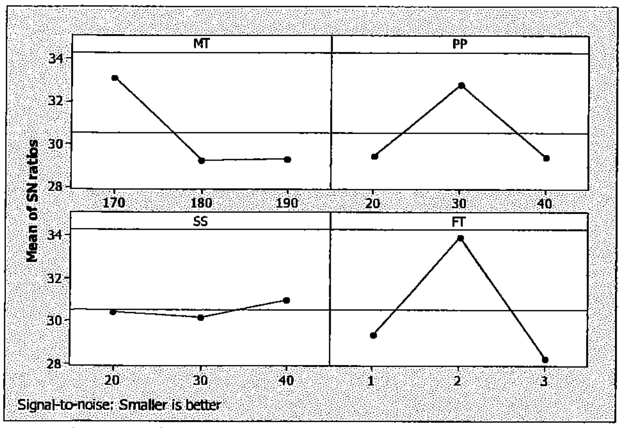

Fig. 8: S/N Ratio of Warpage for 3 wt% NC

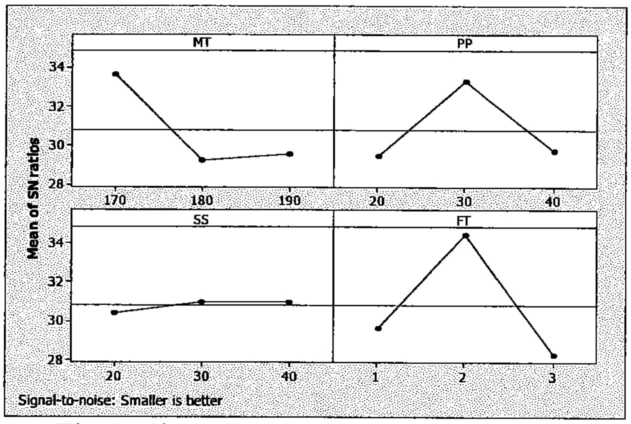

Fig. 9: S/N Ratio of Warpage for 5 wt% NC

Conclusion

Based on the results, the optimized parameters setting for each formulation have been rectified. Comparison has been made within the pure polypropylene and the mixture of polypropylene-nanoclay nanocomposites. The parameter setting was found to be slightly changed with the presence of nanoclay. The defects such as warpage and shrinkage were been able to reduce by choosing the right parameter setting, as well as with the additional of nanoclay. The findings of this experiment shall be useful for future manufacturing process in order to control shrinkage and warpage specifically for products made from polypropylene-nanoclay.

Table 2: The Optimum Parameter Setting for different percent of Nanoclay

NC %	Shrinkage					Warpage				
	MT	PP	SS	FT	Result	MT	PP	SS	FT	Result
0	190	30	40	3	0.0201	180	40	30	2	0.035
3%	180	30	40	3	0.0072	170	30	40	2	0.032
5%	190	20	40	2	0.0036	170	30	30	2	0.012

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