Polypropylene-Nanoclay Nanocomposites: The Optimisation Of Parameter Settings Towards Quality Of Snap Fit Samples.

M.H. Othman, S.Hasan, M.H.I Ibrahim, N.M.Main, S.R.Masrol, M.F.Esa
Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia
86400 Parit Raja, Batu Pahat, Johor, Malaysia
hilmi@uthm.edu.my, sulaiman@uthm.edu.my,

Abstract*—The objective of this research is to optimise the injection moulding parameter to control shrinkage and warpage of snap fit product throughout Taguchi Method in practical injection moulding. In this practice, the selected parameters were barrel temperature, holding pressure, injection velocity and injection holding. The material that was selected for this project was a mixture of polypropylene and nanoclay with the addition of 15 wt.% of Polypropylene Grafted Maleic-Anhydride as the compatibilizer. Two formulations were chosen, which was 0 wt% and 4 wt% of nanoclay loading. The design of experiment for this project had used the $L_9 4^3$ Orthogonal Array. By using the Signal to Noise Ratio responses, the optimum parameter for each formulation has been obtained. Analysis of Variance was used to define the most influential factor that contributes towards the quality of samples. Based on the results, the optimum parameters to control warpage and shrinkage have been rectified. The most influential factor that affecting warpage is injection holding with 37.30% of the contribution. As for shrinkage, this factor need to be closely monitored as well, whereby it contributes 68.54% towards shrinkage .The findings of this experiment shall be useful for future manufacturing process which was related to this sample and material.

Keywords*—*Parameter setting, Polypropylene-Nanoclay, snap fit, Taguchi Method, injection moulding.

I. INTRODUCTION

In plastics manufacturing progression, injection molding is one of the most exploited industrial processes. In terms of injection moulding quality control, shrinkage and warpage behavior of a molded plastic part plays an important role in determining final dimensions of the part. However, several processes parameters such as barrel temperature, mould temperature, holding pressure, injection velocity, injection time, and cooling time need to be monitored due to the potential effects towards the quality of injection moulded plastic artefacts. Thus, choosing suitable parameters that concurrently satisfied part qualities are imperative to produce good quality product. Usually, these parameter settings were obtained either based on statically experimental methods, computer aided simulations or operator's experiences [1, 2].

The task becomes more difficult when the product used for this process involving intricate parts like a snap fit sample. Therefore, the objective of project was design to optimise the injection moulding parameter setting, towards the quality of a snap fit product made from polypropylene.

II. LITERATURE REVIEW

A. Optimisation in injection moulding

Taguchi Method was chosen as the optimisation method, based on a comprehensive review regarding the applications of this method in quality control and design optimization of plastic products. This review has provided more than enough information about past research which relates to this design of experiment approach. It was concluded that Taguchi method is very suitable to solve the quality problem in injection moulding of thermoplastic parts [3].

Several researches have successfully achieved good control in reducing defects by using Taguchi optimisation method. For instance, Ozcelik [4] had used this method to study the influence of injection parameters and weld line on the mechanical properties of polypropylene during plastic injection. In his research, he had found that in general the mechanical tests were increased under optimum conditions.

As for another example, Oktem et al. [5] have applied the Taguchi optimization technique to reduce warpage problem which were related to shrinkage variation that were depended on process parameters. This project was focused on producing good samples of thin-shell plastic components for orthose part. The S/N and ANOVA are used to find the optimum levels and to indicate the impact of the process parameters on warpage and shrinkage. The results show that warpage and shrinkage are improved by about 2.17% and 0.7%. Meanwhile, Urzurumlu et al.[6] have minimized warpage and sink index by controlling the process parameters of the plastic parts with different rib cross-section types, and rib layout angle by using Taguchi optimization method. This method was used by exploiting mould analyses to find optimal levels and the effect of process parameters on warpage and sink index. Another researchers, Mehat et al.[7] have studied the mechanical properties of product made from recycled plastic by utilizing the Taguchi optimization method. The results reveal that the product made of 25% recycled polypropylene (PP) and 75% virgin PP exhibits a better flexural modulus compared to the virgin form. The same products exhibits a 3.4% decrease in flexural strength.

In terms of shrinkage and warpage studies, more researchers have come out with several findings which are good to be reffered. As for an example, a research has been carried out by Chang and Tsaur [8] by applying an integrated theory and computer program for producing a simulation of shrinkage, warpage, and sink marks of crystalline polymer injection moulded parts. Both the qualitative results for the theoretical prediction correlated sufficiently with the experimental data. Prashanta et al. [9] have focuses on the effect of multi-walled carbon nanotube addition on shrinkage and warpage properties of polypropylene injection moulding products before and after annealing, while Huang and Tai [10] have determined the effective factors in the warpage problem of an injection-moulded part with a thin shell feature. Kramschuster et al. [11] have investigated the effects of processing conditions on the shrinkage and warpage behaviour of a box-shaped, polypropylene part using conventional and microcellular injection moulding,whereby the result shows that the supercritical fluid content and the injection speed affect the shrinkage and warpage of microcellular injection moulded parts the most, whereas pack/hold pressure and pack/hold time have the most significant effect on these defects [11].

Therefore based on these previous findings, the needs of optimising the parameter settings in injection moulding is vital and important for futher research towards various selection of materials and products. In this project, a snap fit product made from Polypropylene-Nanoclay was the chosen condition.

B. Polypropylene-Nanoclay nanocomposites

Polypropylene (PP) was chosen as the matrix material for this experiment, because of its good mechanical properties and wide range of applications in the market of polymer. Besides that, Polypropylene is also one of the high applied general thermoplastic since its well balanced properties, and the most important is it has a very good heat resistance [12]. By adding fillers such as Nanoclays (NC), these advance composites shall give several advantages such as good modulus and barrier properties. NC's are nano particles of layered mineral silicates. These organoclays comes with potential uses in polymer nanocomposites, as rheological modifiers, gas absorbents and drug delivery carriers. In addition, nanoclay is one of the most suitable fillers that have successful results in combination with polypropylene. Besides that, it is good availability, relatively easy surface modification possibilities and low price among several nanofillers, as compared with carbon nanotubes or other expensive fillers [13].

The author also has carried out several researches about injection moulding processing conditions by utilizing injection moulding simulation with different type of samples, material and responses. The inputs from these projects were used as guidance for this project. An attempt also has been made by optimising the test sample made from polypropylene and clay, without using any compatibilizer [14]–[17]. Therefore, this project was conducted as the extensive version of previous research conducted by the author.

III. Research Methodology

A. Equipment, Cavity shape and Materials

This research started from the mixing process using Brabender Plastograph with melt temperature setting of 165 ºC, speed at 200 rev/min and 10 minutes of mixing time. The mixtures then have been crushed and turns into pellets before performing the injection moulding process.The cavity shape selected in this study was a snap fit product, as displayed in Fig. 1. The base and the cover should be able to snap and fit together as a product. This sample will be used to investigate the effects of injection moulding parameters toward the quality of this sample through practical injection moulding. The injection moulding machine used in this project was JSW 75 Tonne E11 Plastic Injection Moulding Machine (Fig.2), located at Material Processing Lab, School of Mechanical and Aerospace, Nanyang Technical University, Singapore. The material used in this research was copolymer Polypropylene (PP) from TitanPro. The nanoclay used for this project was Nanoclay-Cloisite 20A, gained from the courtesy of Wilbur-Ellis Company, Connell Bros. Company (Malaysia) Sdn. Bhd.

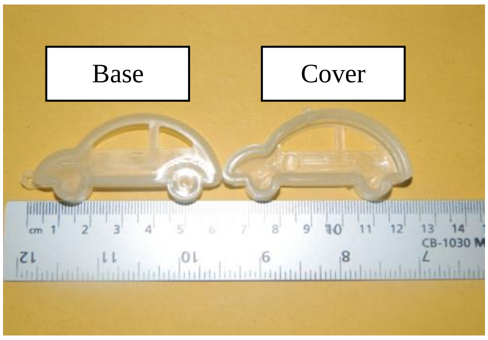

Fig. 1: Snap fit samples for injection moulding.

Fig. 2: JSW E11 75 tonne injection moulding machine.

B. Factor and Level selection.

Based on the Taguchi optimization method, four most significant factors that affect part quality were selected. Three levels of each parameter had been chosen for analysis, as stated in Table I. Based on the value in Table I, 'Level 1' indicate the lowest value of parameter, 'Level 2' means medium value and 'Level 3' means the highest value of parameter selected. In this research, the ($L_9 3^4$) orthogonal was chosen as an orthogonal array because it is suitable for three levels and four factors. The value for the barrel temperature, holding pressure, injection velocity and injection holding was obtained based on the previous studies [15]. Table II shows the detail orthogonal array for this experiment.

TABLE I. SELECTION OF FACTORS AND LEVELS

Factor	Label	Level 1	Level 2	Level 3
Barrel Temperature (ºC)	BT	230	240	250
Holding Pressure (%)	HP	10	15	20
Injection Velocity (%)	IV	5	10	15
Injection Holding (s)	IH	5	7	9

TABLE II. ORTHOGONAL ARRAY WITH RESULTS

Trial	BT(ºC)	HP(%)	IV(%)	IH (s)	Z (mm)	S (%)
1	230	10	5	5	0.1900	4.1337
2	230	15	10	7	0.2367	3.7782
3	230	20	15	9	0.2250	3.5943
4	240	10	10	9	0.2183	3.4503
5	240	15	15	5	0.2650	4.4830
6	240	20	5	7	0.3617	4.3911
7	250	10	15	7	0.3133	4.2471
8	250	15	5	9	0.2400	3.7659
9	250	20	10	5	0.2950	4.3942

C. Measuring Warpage

In this research, after ejection of plastic part from the mould, the flashing and runner were removed. The thickness of specimen was measure at 10 different places with equal length by using micrometre. The readings and average thickness of specimen were recorded by using dial gauge. Fig. 3 illustrated the definition for symbols h, t_a and Z.

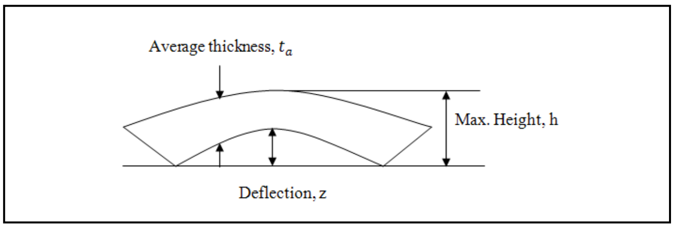

Fig. 3: Warpage measurement

Warpage was calculated by using formula [18]:

$$Z = h - t_a \quad (1)$$

Where Z = Warpage/ deflection of the plate (mm)
h = Maximum height of the plate (mm)
t_a = Average plate thickness (mm)

D. Measuring Shrinkage

Shrinkage is a reduction in linear size that occurs when a polymer is cooling down to room temperature after being inject at moulding temperature. Shrinkage of specimen for each trial or experiment in this research was found by using the following simple equations. The actual mould cavity length L_c is [18]:

$$L_c = L[1+\alpha(T_{mould} - T_{ambient})] \quad (2)$$

Where: α = Coefficient of thermal expansion for steel mould (6.45×10^{-6} 1/°F)
T_{mould} = Mould temperature in °F
$T_{ambient}$ = Ambient temperature in °F

Thus, the shrinkage for the polymer S is:

$$S = \frac{Lc - Lave}{Lc}\ x\ 100\% \quad (3)$$

Where: L_c = actual mould cavity length (mm)
L_{ave} = average of actual sample length (mm)

E. Signal to Noise ratios.

Signal to noise (S/N) ratio for mechanical properties will obtained and optimum levels of the injection parameters will determine through S/N values to achieve maximum mechanical result. In this study, the smaller the better quality characteristic is chosen to solve warpage and shrinkage. The S/N values shall be calculated by using statistical software which was Minitab 16. The response graphs shall be generated through this software, and the peak value for each factor shall be chosen as the optimum setting to control the defects.

F. Analysis of Variance (ANOVA)

In this research, the aim of using the Analysis of Variance (ANOVA) is to determine the significance of process parameters on warpage and shrinkage. The most significant parameter was determined by calculating the percentages of pure sum. From the analysis results, the higher percentages pure sum of factor will contribute more affects from these factors to the samples or product. The ANOVA was calculated by using statistical software which was Minitab 16.

IV. RESULTS AND DISCUSSIONS

After the experiments have been carried out based on the selected parameter setting in the orthogonal array, values of average warpage and shrinkage was gained, as stated in Table II. These data were measured as the average value for both base and cover of the samples. Before the measurement took place, a snap and fit test shall be conducted to ensure that the samples were in good condition. The lowest value obtained from this experiment was 0.1900 mm for warpage and 3.4503 % for shrinkage.

A. Results of Signal to Noise Ratios

Fig.4 shows the main effect plots for S/N ratios, specifically for warpage case. From this figure, the optimum value of parameter setting that should be able to reduce warpage is stated in Table III. By using this setting, a validation test has been carried out and the value of warpage was 0.1539 mm.

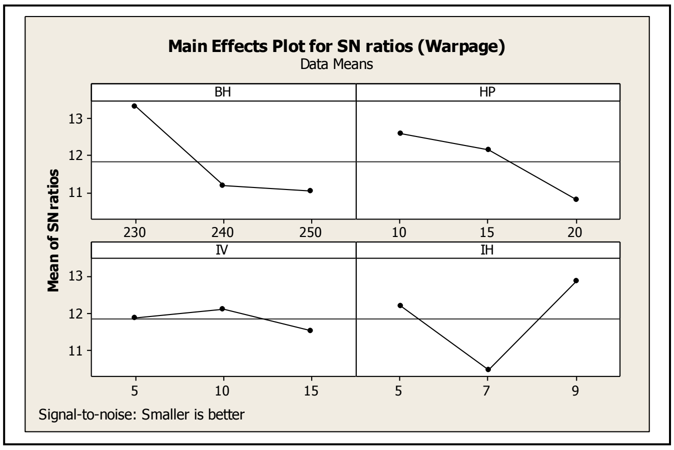

Fig. 4: Main Effect Plot for SN Ratio (Warpage)

TABLE III. THE OPTIMUM PARAMETER FOR WARPAGE

Factor	BT(°C)	HP(%)	IV(%)	IH (s)	Z (mm)
Value	230	10	10	9	0.1539
Level	1	1	2	3	

Fig.5 shows the Main Effect Plots for S/N ratios, specifically for shrinkage. The optimum value to control shrinkage was displayed in Table IV. The shrinkage value obtained from using this optimum setting was 3.1776 %.

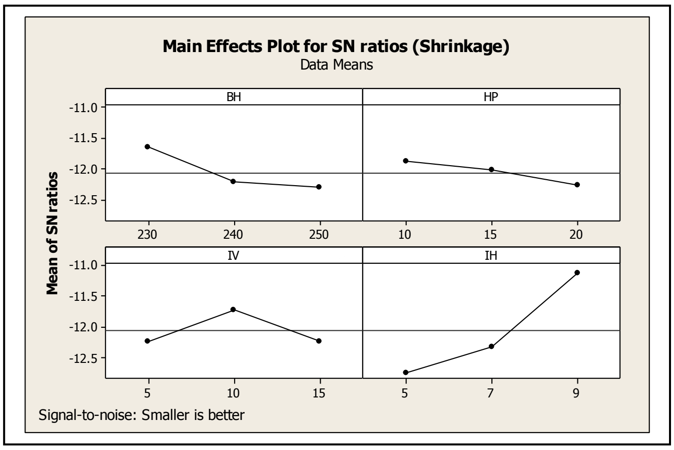

Fig. 5: Main Effect Plot for SN Ratio (Shrinkage)

TABLE IV. THE OPTIMUM PARAMETER FOR SHRINKAGE

Factor	BT	HP	IV	IH	S (%)
Value	230	10	10	9	3.1776
Level	1	1	2	3	

B. Findings of ANOVA

The ANOVA test was applied to determine the influence of each parameter in the designed experimental study. The P (%) value or the pure summary value percentage for each data was monitored. The result for ANOVA for the snap fit samples can be summarized in the Table V for warpage and Table VI for shrinkage. Based on the results of ANOVA in Table V, The most influential factor that affecting warpage is injection holding with 37.30% of the contribution. As for shrinkage, this factor need to be closely monitored as well, whereby it contributes 68.54% towards shrinkage. For warpage, injection velocity was pooled. Meanwhile for shrinkage, the pooled factor was holding pressure. These factors were pooled because it has less significant impact toward responses.

TABLE V. ANOVA FOR WARPAGE

Factor	f	S	V	F	S'	P (%)
BT(ºC	2	0.0085	0.0042	16.1272	0.0079	34.1224
HP(%)	2	0.0051	0.0025	9.6678	0.0045	19.5520
IV(%)	Pooled					
IH (s)	2	0.0092	0.0046	17.5371	0.0087	37.3027
Pooled error	2	0.0005				9.0228
Total	8					100.0000

TABLE VI. ANOVA FOR SHRINKAGE

Factor	f	S	V	F	S'	P (%)
BT(ºC	2	0.1653	0.0827	3.2100	0.1138	9.6062
HP(%)	Pooled					
IV(%)	2	0.1044	0.0522	2.0276	0.0529	4.4666
IH (s)	2	0.8637	0.4319	16.7687	0.8122	68.5407
Pooled error	2	0.05151				17.3865
Total	8					100.0000

The findings of this experiment was quite contradict with [5] and [10]. Based on the finding of [5], injection holding had most significant parameters on shrinkage, and it was the same results achieved from this project. However, they found that it is apparent that holding pressure was most important parameter on warpage which is contradict with the findings of this experiment. According to [10] the results of their research showed that the holding pressure had the greatest influence on the warpage, followed by mould temperature, barrel temperature, and injection holding. The warpage was only slightly controlled by injection holding in thin shell injection moulding. In the other hand, the author aggred with [5] and [10], whereby, applying the experimental design of Taguchi method is a quite effective method to deduce the optimum set of effective factors in injection moulding to produce plastic parts with minimum warpage and shrinkage.

Barrel temperature was found to be the second influential factor to control warpage. The control of temperature was very important, because based on [19], as the temperature increases, the viscosity decreases and the shear rate required to break the clay aggregate may reduced. In the same time the diffusion can be improved whereas a better polymer intercalation and migration of exfoliated platelets shall achieved. The bad point of high temperature was it may cause degradation of clay surfactants, collapsing the inter layers galleries and leading to a loss of clay efficiency, thus resulting to a dispersion of unintercalated tactoid particles [19]. However, with regards to the effects of barrel temperature, this parameter cannot be considered independently of another factor such as injection holding and injection velocity[10].

V. CONCLUSION

To summarize the findings, the optimum setting that should be followed to control shrinkage and warpage in producing a snap fit samples have been achieved. The most influential factor, that affecting warpage is holding pressure with 33.68% of the contribution, followed by injection holding (IH) with 25.71% of P value. In the other hand, injection holding with the contribution of 44.25% need to be closely monitored if we want to reduce shrinkage and then followed by holding pressure. The findings of this project shall be good enough to be used as reference in producing similar product in future.

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