PARAMETER OPTIMIZATION OF INJECTION MOULDING USING HIGH DENSITY POLYETHYLENE-PINEAPPLE LEAF FIBRE

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ABSTRACT: Recently, the challenging factors among researchers and manufactures are to produce metal components at low cost without gratifying customers' desires. This research aims to determine the significant parameters condition to produce a free defect of High Density Polyethylene (HDPE)-Pineapple Leaf Fibre (PALF), using PALF compositions of 0 wt.%, 10 wt.%, 20 wt.% and 30 wt.%. Therefore, four parameters were included in this research work, moulding temperature (A), moulding speed (B), moulding pressure (C) and cooling time (D) are investigated to optimize the injection moulding, which analysed two responses (hardness and ultimate tensile strength). Thus, Taguchi L9 (34) Orthogonal Array was applied. The percentage contribution to the parameters towards both responses were defined by Analysis of Variance (ANOVA). For hardness, the greatest contributing parameters were A, D, D and B for 0 wt. %, 10 wt. %, 20 wt. % and 30 wt. % of PALF, respectively. Then, the highest contribution parameters were A, D, A and A for 0 wt.%, 10 wt.%, 20 wt.% and 30 wt.% of PALF, respectively. Experimental result was provided with confirmation test for validation to confirm the effectiveness of this method. The research work proved that the applied method was able to optimize the process with minimum trials without gratifying the production of optimal qualities of PIM components.

KEYWORDS: *Injection Moulding; Pineapple Leaf Fibre; Taguchi Method; Hardness; Ultimate Tensile Strength*

1.0 INTRODUCTION

Currently, Powder Injection Moulding (PIM) is greatly applied to fabricate the intricate and complex components while reducing the machining cost. PIM is known as conventional technology exploited by researchers and manufacturers due to its flexibility and ability in producing large amounts of small and complex components [1]. Basically, plastic is known as economical and versatile material to be used in various types of applications. Principally, there are four major stages in PIM technology, including mixing, injection moulding, debinding and sintering [2-4]. It starts by mixing the powders and binders in an appropriate formulation in order to form a desired shape of industrial, and even medical components. Binders are removed in debinding process before sintered, without sacrificing the ability of producing a free distortion debound components (solvent). Finally, the debound component is fired at high temperature to acquire the approximated theoretical densities, so called sintering [5]. Yet, this research work only covers the PIM processes until injection moulding, specifically the optimization step.

In this research, the optimum condition parameters are determined in order to conduct the injection moulding process for producing the injected components formulated by High Density Polyethylene (HDPE) and Pineapple Leaf Fibre (PALF). In order to achieve this, the parameters condition should be optimized before the process is performed. Initially, the production quality is able to be controlled by ensuring that there are no quality issues. In this research, Taguchi Orthogonal Array L_9 (3^4) is applied to analyse the optimum injection moulding condition parameters.

German and Bose state that injection moulding optimization steps are required in order to fabricate the high quality of injected components. Also, it is to ensure the success, and necessarily occurred according to debinding or sintering, although it may have their original defects since the mixing and injection moulding [6-7]. According to that, it is proven that the injection moulding optimization is very critical in PIM while minimizing the manufacturing cost, time and component distortions. The Design of Experiment (DOE) of Taguchi Method is known as an effective tool being implemented by previous researchers in order to optimize a certain condition or process [8-11]. This method is commonly applied to perform an optimization step of injection moulding parameters that are able to analyse the injected component performances, for example density, surface quality, strength and hardness. Besides, the tool is capable to minimize the trial numbers, rather than trial-and-error method [12-17].

In performing the optimization step, there are several parameters involved, mould temperature, moulding temperature, moulding speed, moulding pressure, holding time, cooling time and much more. Previous literature [18] reported some significant parameters which influence the mechanical characteristics of the green components, which involve the MIM of recycled HDPE and virgin HDPE. Previous work optimizes the MIM using several responses, yield optimum tensile, compressive and flexural strength. It was observed that the injection temperature shows the most influential parameters that affect in obtaining optimal responses. Besides, holding pressure is recognized as the most influential parameters in order to produce the free defect of polycarbonate green components [19]. Previous literature of [20] investigated the influence of moulding parameters and weld line towards mechanical characteristics of polypropylene green body. Taguchi Orthogonal Arrays (OA) of L_9 (3^4) and Analysis of Variance (ANOVA) are applied in the previous work. There are four significant injection moulding parameters involved, which are moulding temperature, moulding pressure, packing pressure and cooling time. It is found that the most influential moulding parameter is injection time. The most significant parameters which influence the tensile load are moulding pressure and moulding temperature. Then, the most significant parameters that influence the impact strength are moulding temperature and moulding pressure. Other significant parameters are packing pressure, which is specifically beneficial for producing good weld line qualities of green body [21].

Next, another literature in [22] found the effect of 7 moulding parameters on two responses, weld line width and tensile impact properties. It is noticed that melting temperature is the most significant and contributing towards weld line width, and followed by mould temperature and moulding pressure. For tensile impact characteristic, the most significant parameters are mould temperature, followed by moulding temperature, moulding pressure and cooling time. Accordingly, it is found that the most significant parameters are moulding speed, moulding temperature, moulding pressure, packing pressure and packing time [23], which aims to enhance the injected components of mechanical properties, by employing the Taguchi method, rather than coupling the injected components with additives. Nevertheless, the authors only optimize four vital parameters; moulding temperature (A), moulding pressure (B), moulding speed (C) and cooling time (D). Overall, this research work aims to analyse the optimum injection moulding parameters condition to produce optimal value of hardness and ultimate tensile strength.

2.0 METHODOLOGY

The research started by preparing the MIM components. The natural fibre of Pineapple Leaf Fibre (PALF) was used to produce a free defect green components. By using the formulation of 10 wt. % PALF, 20 wt. % PALF and 30 wt. % PALF, the mixture of HDPE - PALF was preheated at 160℃, and mixed using Plastograph Brabender. Then, the feedstock was crushed into small pellets using Plastic Granulator SLM 50FY (Figure 1). Next, the feedstock was transformed into a desired shape of PIM components, using injection moulding machine, Model of Nissei 21 Horizontal Screw Injection Moulding Machine, as shown in Figure 2. The green components produced in this research work were given by dimensions of 25.40 mm length x 12 mm width x 5 mm height. Using the Design of Experiment (DOE) of Taguchi Orthogonal Arrays (OA) of L_9 (3^4), the optimal injection moulding parameters were optimized by measuring two type of responses, which are hardness and ultimate tensile strength. Taguchi Orthogonal Array L_9 (3^4) involved 9 trials, 4 parameters and 3 levels. The standard of ISO 527-2 is used to conduct ultimate tensile test and ASTM D2240 used to perform hardness test. In analysing the two responses, S/N ratio and Analysis of Variance (ANOVA) were applied to discover the most influential parameters and percentage contribution, respectively.

3.0 RESULTS AND DISCUSSION

The only four parameters were selected, moulding temperature (A), moulding pressure (B), moulding speed (C) and cooling time (D). Therefore, an L_9 orthogonal array with four columns nine rows was appropriate and used in this study. All the parameters are illustrated in Table 1 with their levels and range. Table 2 shows the experimental layout for this optimization stage using Taguchi OA of L_9 (3^4). Each row of this table symbolizes an experiment with different arrangement of parameters and their levels.

Figure 1: Plastic granulator (SLM 50FY)

Figure 2: Nissei 21 horizontal screw injection molding machine

Table 1: Injection molding parameters for measuring the response of hardness and ultimate tensile strength

Parameter	Symbol	Level 1	Level 2	Level 3
Molding temperature (℃)	A	170	180	190
Molding pressure (%)	B	30	35	40
Molding speed (%)	C	30	35	40
Cooling time (s)	D	5	6	7

Unit conversion: 1 % of injection pressure = 1.61 MPa, 1 % of injection speed = 3.50 rpm

Table 2: Experimental plan using taguchi orthogonal array of L_9 (3^4)

Trial no.	Parameter level			
	A	B	C	D
1	170	30	30	5
2	170	35	35	6
3	170	40	40	7
4	180	30	35	7
5	180	35	40	5
6	180	40	30	6
7	190	30	40	6
8	190	35	30	7
9	190	40	45	5

3.1 Analysis of Signal to Noise (S/N Ratio)

The S/N ratio was applied to determine the sensitivity if the quality characteristic towards the uncontrollable parameters (error) in the experiment. The quality characteristic are divided in three categories; namely, the lower the better, the higher the better and the nominal the better. In this case, the larger-the-better was applied, as the components desired optimum hardness and ultimate tensile strength. The S/N ratio can be written as Equation (1) such as

$$\frac{S}{N} = -\log\left(\frac{1}{n}\sum\frac{1}{y_{i^2}}\right) \tag{1}$$

where n is the total number of shot for each trial and y is the amount of score for the quality measured. Table 3 illustrates the S/N ratio of hardness response for 0 wt. % PALF, 10 wt. % PALF, 20 wt. % and 30 wt. % of PALF. The best parameters combination could be described by selecting the widest range value for each parameters. The highest value of S/N ratio is defined as the optimum level parameters. In regard of these tables, it can be found that the optimum levels for each parameter are differ for different PALF compositions.

Table 4 shows the summary of all the optimum combination parameters and levels for all PALF compositions. Hence, it shows that the only 0 wt. % PALF and 10 wt. % PALF showed the same optimum level for each parameter. Besides, at 5 second of cooling time recorded as optimum level for all PALF compositions. This phenomenon shows that the mixture of HDPE and PALF is optimum when using the 5 seconds of cooling time, for achieving an optimal value of hardness. Also, it does not acquire a longest cooling time to achieve an optimal value of hardness.

Table 3: Response table of S/N ratio for 0 wt. % PALF, 10 wt. % PALF, 20 wt. % PALF and 30 wt. % PALF towards hardness response

PALF composition (wt. %)	Level	A (dB)	B (dB)	C (dB)	D (dB)
0	1	35.8941	35.9405	35.9405	35.9868
	2	35.8941	35.9541	35.8941	35.9541
	3	35.9868	35.8941	35.9206	35.9841
	Diff.	0.0927	0.0600	0.0464	0.0327
	Rank	1	2	3	4
10	1	35.9868	35.9405	35.9860	36.0780
	2	36.0317	35.9861	35.9405	36.0324
	3	36.9680	35.7447	36.0317	35.8941
	Diff.	0.9812	0.2414	0.0912	0.1839
	Rank	1	2	4	3
20	1	36.0780	36.0780	36.0780	36.1236
	2	36.1319	36.2319	36.0780	35.9868
	3	36.0780	36.0780	36.1519	36.0780
	Diff.	0.0539	0.1539	0.0739	0.1368
	Rank	4	1	3	2
30	1	36.2314	36.1775	36.2853	36.3314
	2	36.1775	36/2853	36.3221	36.2775
	3	36.3221	36.1775	36.2775	36.2853
	Diff.	0.1446	0.1078	0.0446	0.0539
	Rank	1	2	4	3

Table 4: Optimization parameters and levels for response of hardness

Parameter	PALF composition			
	0 %	10 %	20 %	30 %
A	190	190	180	190
B	35	35	35	35
C	30	30	40	35
D	5	5	5	5

Whereas, Table 5 depicts the response value of S/N ratio for 0 wt. % PALF to 30 wt. % PALF toward the response of ultimate tensile strength. Again, the optimum level of parameters can be obtained by selecting the greatest different value of S/N ratio for each parameters.

The optimum parameter was obtained according to the greatest value of S/N ratio between the levels. Therefore, the best condition parameters and their levels of 0 wt. % PALF to 30 wt. % PALF were acquired. Table 6 summarizes all the optimum condition parameters for all PALF compositions and also shows that the molding pressure of 30 % was being an optimum value for all PALF composition towards the ultimate tensile strength response.

Table 5: Response table of S/N ratio for 0 wt. % PALF, 10 wt. % PALF, 20 wt. % PALF and 30 wt. % PALF towards ultimate tensile strength response

PALF composition (wt. %)	Level	A (dB)	B (dB)	C (dB)	D (dB)
0	1	25.5640	25.7102	26.600	26.3811
	2	26.1461	26.4335	25.9696	26.3045
	3	29.8975	26.1307	26.2448	25.5888
	Diff.	4.3335	0.7233	0.2752	0.7923
	Rank	1	3	4	2
10	1	25.8739	25.9669	25.8729	25.8779
	2	25.9534	25.8511	25.8922	25.8246
	3	25.8929	25.8998	25.9527	26.0153
	Diff.	0.0795	0.1158	0.0798	0.1907
	Rank	4	2	3	1
20	1	26.1218	25.9952	25.9830	26.0530
	2	25.9691	26.0357	25.9992	25.9153
	3	25.8564	25.9164	25.9650	25.9790
	Diff.	0.2654	0.1193	0.0342	0.1377
	Rank	1	3	4	2
30	1	25.8739	25.9669	25.8729	25.8779
	2	25.9534	25.8511	25.8922	25.8246
	3	25.8905	25.8998	25.9527	26.0152
	Diff.	0.0795	0.1158	0.0798	0.1879
	Rank	4	2	3	1

Table 6: Optimization parameters and levels for response of ultimate tensile strength response

Parameter	PALF composition			
	0 %	10 %	20 %	30 %
A	190	190	180	180
B	30	30	30	30
C	40	40	35	40
D	5	5	5	6

3.2 Analysis of Variance (ANOVA)

ANOVA was performed to further determine the significant parameters that affected the quality characteristics. In performing the ANOVA, the degree of freedom (f), sum of squares (SS), variance (V) and the percentage of contribution (P) were calculated. The all quantity characteristics are formulated using Equations (2)-(5) such as

$$f_T = N - 1 \tag{2}$$

where f_T is the total degree of freedom for the data and N is the total number of experiments.

$$S_T = \left(Z_{a1^2} + Z_{a2^2} + .. + z_{aN^2}\right) - \frac{\left(z_{a1} + z_{a2} + .. + z_{aN}\right)^2}{N} \tag{3}$$

where S_T is the total sum of squared deviations, Z_a is the experimental value and N is total number of experiments in the orthogonal array.

$$V = \frac{s_t}{f_A} \tag{4}$$

Percentage contribution is the ratio of the sum of square of the parameter to the total sum of the square of all parameters. Equation (5) indicates the influence of certain parameter in terms of percentage towards the response measured:

$$P_A = \frac{s_A}{s_T} \times 100\% \tag{5}$$

where S_A is the sum of the squared deviations and S_T is the total sum of the squared deviations. Table 7 demonstrates the ANOVA for 0 wt. % PALF, 10 wt. % PALF, 20 wt. % PALF and 30 wt. % PALF toward hardness response. According to ANOVA, it showed that the most contributing parameters towards hardness was injection temperature valued by 40.03 % for 0 wt. % PALF. It was followed by D which contributed by 39.99 %, B and D that contribute 9.99 %. Then, for 10 wt. % PALF, it showed that the most contributing parameter was D, with recorded value of 59.09 %. Also, the most contributing parameter for 20 wt. % PALF was D, valued by 81.26%. Last, for 30 wt. %, PALF was injection pressure, valued by 39.96 %.

For the next responses (ultimate tensile strength), ANOVA data is tabulated in Table 8, showing the all PALF percentage compositions. In that case, the moulding temperature showed a highest contribution towards the response, valued by 41.93 %. It was followed by cooling time and moulding pressure, valued by 33.46 % and 20.99 %, respectively. Next, for 10 wt. % of PALF, cooling time exhibited the highest contribution which valued by 57.48 %, followed by moulding pressure valued by 20.39 %. For the next PALF composition (20 wt. % PALF), moulding temperature showed the highest contribution valued by 54.80 %, followed by moulding speed, valued by 24.53 %. Last, the moulding temperature showed the highest percentage contribution of 46.66 % for 30 wt. % PALF, followed by cooling time, recorded by 18.96 %.

Table 7: ANOVA table for 0 wt. % PALF, 10 wt. % PALF, 20 wt. % PALF and 30 wt. % PALF towards hardness response

PALF composition (wt. %)	Parameters	DOF	S	V	P (%)
0	A	2	0.89	0.4415	40.03
	B	2	0.222	0.1145	9.99
	C	2	0.222	0.111	9.99
	D	2	0.889	0.445	39.99
10	A	2	0.222	0.111	4.54
	B	2	1.555	0.778	31.81
	C	2	0.222	0.111	4.54
	D	2	2.889	1.4445	59.09
20	A	2	0.222	0.111	6.245
	B	2	0.222	0.111	6.245
	C	2	0.222	0.111	6.245
	D	2	2.889	1.445	81.27
30	A	2	0.240	0.12	10.80
	B	2	0.882	0.441	39.96
	C	2	0.882	0.441	36.69
	D	2	0.218	0.109	9.81

Table 8: ANOVA table for 0 wt. % PALF, 10 wt. % PALF, 20 wt. % PALF and 30 wt. % PALF towards ultimate tensile strength

PALF composition (wt. %)	Parameters	DOF	S	V	P (%)
0	A	2	7.738	3.869	41.93
	B	2	3.875	1.9375	20.99
	C	2	0.659	0.3295	3.57
	D	2	6.175	3.0875	33.46
10	A	2	0.051	0.0255	9.90
	B	2	0.105	0.0525	20.39
	C	2	0.053	0.0265	10.29
	D	2	0.296	0.148	57.48
20	A	2	0.525	0.2625	54.80
	B	2	0.235	0.1175	24.53
	C	2	0.103	0.0515	10.75
	D	2	0.095	0.0475	9.92
30	A	2	0.433	0.2165	46.66
	B	2	0.17	0.085	18.31
	C	2	0.1352	0.0676	14.57
	D	2	0.176	0.088	18.96

3.3 Confirmation Experiment Test

The confirmation test was performed to verify the estimated result with the experimental results. This test is not necessary if the optimal combination of parameters and their levels coincidentally match with one of the experiments in the orthogonal array. In this present study, the confirmation test was compulsory. The confident interval is calculated using Equation (6) such as

$$CI = \pm\sqrt{\frac{F_{\alpha}(f_1, f_2) x V_e}{n_e}} \tag{6}$$

where $F\alpha(f_1,f_2)$ is the variance ratio for DOF of f_1 and f_2 at level of significance α. The confidence level is $(1-\alpha)$, f_1 is the DOF of mean (usually equal to 1) and f_2 is the DOF of the error. Variance for error terms is V_e and number of equivalent replication is given as ratio of number of trials (1 + DOF of all factors used in the estimate).

The confident level will indicate the maximum and minimum levels of the optimum performance. The expected result at optimum performance had being calculated and it is tabulated in Table 9 and Table 10 for both responses of hardness and ultimate tensile strength, respectively. It shows the optimum performance (μ) within a theoretical range for all PALF compositions. Confirmation experiments were conducted by running another ten replications at combined setting of "optimum parameter" that was shown in Table 9 and Table 10. It was found that the average S/N ratio obtained from the confirmation experiments fell within the expected result at optimum performance, for both responses of hardness and ultimate tensile strength. Hence, this indicates that the confirmation test was valid since the acceptable S/N ratio was lies in the range of expected result at optimum performance.

Table 9: Confirmation test for hardness

Optimum parameter	HDPE - PALF mixture (%)	Expected result at optimum performance, μ (dB)	S/N ratio (dB)
$A_1B_2C_3D_1$	100-0	$34.98<\mu<35.03$	35.94
$A_1B_2C_3D_1$	90-10	$35.05<\mu<36.15$	36.00
$A_2B_2C_3D_1$	80-20	$36.01<\mu<37.18$	36.09
$A_3B_2C_2D_1$	70-30	$36.11<\mu<36.39$	36.21

Table 10: Confirmation test for ultimate tensile strength

Optimum parameter	HDPE-PALF mixture (%)	Expected result at optimum performance, μ	S/N ratio (dB)
$A_3B_1C_3D_1$	100-0	$25.78<\mu<26.98$	26.12
$A_2B_1C_3D_1$	90-10	$25.89<\mu<27.52$	26.34
$A_2B_1C_2D_1$	80-20	$26.07<\mu<27.86$	26.37
$A_2B_2C_3D_1$	70-30	$26.34<\mu<26.79$	26.43

4.0 CONCLUSION

In this research work, the optimization of injection molding process for mixture of HDPE and the four varied of PALF compositions (0 wt. %, 10 wt. %, 20 wt. % and 30 wt. %) using Taguchi orthogonal array towards both response of hardness and ultimate tensile strength are discussed in this manuscript. From the experiment and analysis, the following conclusions can be drawn. The highest contribute parameters towards hardness for 0 wt. % PALF, 10 wt. % PALF, 20 wt. % PALF and 30 wt. % PALF are moulding temperature (valued by 40.03 %), cooling time (valued by 39.99 %), cooling time (valued by 81.26 %) and moulding speed (valued by 39.96 %), respectively. Meanwhile for the response of ultimate tensile strength, the most contributing parameter is the moulding temperature (valued by 41.93 %), cooling time (valued by 57.48 %), moulding temperature (valued by 54.80 %) and moulding temperature (valued by 46.66 %) using compositions of 0 wt. % PALF, 10 wt. % PALF, 20 wt. % PALF and 30 wt. % PALF, respectively. The optimum variables acquired from ANOVA are acceptable where the range of optimum performance lies within the range of expected result at optimum performance (μ). The results meet the requirement when S/N ratio (as depicts in Table 9 and Table 10) from confirmation experiment is within the range. According to the findings, it can be stated that Taguchi method is a powerful tool for evaluating single response performance in metal injection molding.

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