OPTIMIZATION OF INJECTION MACHINE PARAMETERS ON HIGH TENSILE STRENGTH OF POLYPROPYLENE/FIBREGLASS

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ABSTRACT: The objective of this study is to investigate the optimum process parameters on the high tensile strength of mechanical properties in the injection machine process. The injection machine parameters selected are melt temperature, holding pressure, injection time and cooling time. Taguchi and ANOVA method were performed for design the experimental matrix and to find the most significant of the parameters. PP having 20% of fibreglass was employed. Injection machine Arburg 420C 800-250 having 80 ton of clamping force has been used to moulded the dumbbell shape test sample according to ASTM D638 standard. The tensile test was performed using the universal testing machine. The result shows that the most significant factors that affected the tensile strength are cooling time, followed by injection time, holding pressure and melt temperature. Cooling time contributes 61.13%, meanwhile, injection time, holding pressure and melt temperature contribute each of them 20.15%, 13.41% and 5.32% respectively. Optimization of cooling time at 10 s, injection time at 0.5 s, holding pressure at 350 MPa and melting temperature at 205 °C shows the highest tensile strength 20.9243 MPa and desirability value is 1. Thus, by using the Taguchi optimization method the optimize parameters of injection machine parameters can be determined with the achievement of the highest tensile strength.

KEYWORDS: *Injection Moulding; Polypropylene; Fibreglass; Tensile Strength; Taguchi Method*

1.0 INTRODUCTION

Mechanical properties of thermoplastic consist of tensile strength, tensile modulus, hardness, etc. In various tests of mechanical strength, tensile test is the most widely performed as the material plastic requires strength in holding stretching force. Plastic materials are rarely used in virgin material, where usually plastic materials are mixed with an additive to enhance the strength of a product. According to Mulle et al. [1] that the virgin polypropylene added with fibreglass increased its tensile strength up to 44% when added with reinforcing agent of 25 wt.% of fibreglass. The enhance of composite material due to fibreglass as reinforcing agents are stiffer and stronger than the polymer matrix where polymer matrix serves as a medium of transfer load from one fibre to other as well enhanced the polymer composite [2-4].

Plastic part can be produced using various polymer manufacturing processes which one of them is using an injection moulding process. Injection moulding is known as the most important process for processing the mass production of a plastic product having a complex shape and long-range of sizes with high precision. Nowadays, the production of injection moulded plastic study has been rapidly increased. This is because the plastic products are relatively easy to mould into complex shapes, low in cost, lightweight and low energy requirement for processing compared to metal [5,6]. However, to produce high tensile strength, the machine parameters need to be studied. According to Hentati et al. [7], the parameters of the injection machine can cause tensile strength to increase if it is properly adjusted. It is because the parameters set in the injection machine affect the quality of the moulded product. In the injection moulding process, namely, the process parameters that affected the quality of injection moulding are injection pressure, injection time, packing pressure, cooling time, packing time, melt temperature, etc. The type of defects that always be found in injection moulding are like warpage [8], surface blemish [9], voids [10], flash jetting [11], flow mark [12] and weld line [13].

In this study, polypropylene (PP) has been selected based on PP material easy to mix with additive materials such as natural fibre [14-16], metal powder [17], ceramic powder [18], polymer plastic material

[19], etc. Furthermore, PP is a thermoplastic polymer resin where melting temperature is range from 190 °C to 210 °C. PP is much preferable compared to other types of plastic material because PP is easy to be processed and consumes less cost. The example of products that have been produced from PP is packaging, household appliances, etc. PP can be categorised under semi-crystalline polymer where it contains percentage crystallinity considerably higher than to other plastic materials. The higher crystallinity due to the structural arrangement changing when molten plastic injected into the mould cavity at hot temperature then cooling process taking place at considerably low temperature. Increasing of crystallinity can cause the strength of the moulded part increased [20]. There are various types of gating system applied in plastic injection mould such as side gate, pin-point gate, tap gate, etc. From the previous study, it was found that the side gate system was suitable for the flat part since the direction of fibres parallel at flow direction [21]. However, the side gate was not suitable for cylinder part which it can affect the flow front end of the meet point as a result weldline can be found on the meet flow front that affected the strength of the part.

Rathi and Salunke [22] stated that the easiest way to do the set-up on the injection moulding machine is based on the trial-and-error method or on the experience of moulding technician and machine set-up operator. The disadvantage of this approach is time-consuming and not cost-effective. Despite this time-consuming approach, there is no assurance that the optimum process parameters can be obtained [23]. Taguchi method one of design of experiment (DOE) technique can be used as optimum process parameter, however other methods of DOE such as factorial design and response surface method (RSM) are also can be implemented. Compared to other DOE technique, Taguchi method only requires minimal experimental runs for process optimization. According to Prasad et al. [24], they found that the time required for conducting experiments using RSM is almost twice that needed for the Taguchi methodology. The advantage of using Taguchi method is efficient and effective experimental approach can reduce the experimental trials and this method is used to determine the optimum level of process parameters [25].

Therefore, this study focuses on the effect of processing injection moulding machine parameters on the tensile strength of polypropylene having twenty per cent of fibreglass. The tensile test sample was injected using the two-plate side gate system. Four injection moulding machine parameters selected were cooling time, injection time, holding pressure and melting temperature. Taguchi method was selected for design the experimental matrix and ANOVA was used to find the most significant of the parameter to the response. Optimization parameter on the maximum of tensile strength was also performed using the desirability function approach to find the optimum set of combination parameters.

2.0 METHODOLOGY

PP having 20% of fibreglass was employed in this experimental study. Type of PP filled with 20% fibreglass was Dynaglass PPG3637. Meanwhile, injection moulding machine ARBURG 420C 800-250 having 80 ton of clamping force has been used to moulded the dumbbell shape test sample according to ASTM D638 standard. Two-plate mould with side gate system was used to mould the dumbbell part. All dumbbell shape test samples were kept at room temperature (25±3) °C for two days and relative humidity (30±2)% before beginning the tensile test. The tensile test was performed using the universal testing machine from Shimadzu Autograph AGS-X with maximum load capacity 20 kN. The pulling speed of the tensile test was set at 50 mm/min. The level process parameters selected are melt temperature (205 °C to 245 °C), holding pressure (350 MPa to 550 MPa), injection time (0.5 s to 0.9 s) and cooling time (10 s to 30 s) as shown in Table 1.

Table 1: Experimental parameters of the injection moulding machine

Level	Melt temperature (°C)	Holding pressure (MPa)	Injection time (s)	Cooling time (s)
Low	205	350	0.5	10
Medium	225	450	0.7	20
High	245	550	0.9	30

The injection moulding machine parameters were obtained from the analysis done using Autodesk Moldflow simulation software from the previous research [26]. Further, for the optimization process, Taguchi method was performed in this study. Taguchi optimization method applied S/N ratio to qualify the quality characteristics deviating from the desired value. Since this study focuses the highest output of the tensile strength, therefore S/N ratio the bigger the better is applied as shown in equation 1 [27].

$$\frac{S}{N}\text{ (Bigger)} = -10\log\left[\sum \frac{\frac{1}{y^2}}{n}\right] \tag{1}$$

where y is total of the tensile strength result and N is the number of the tensile test sample in the experimental run.

3.0 RESULT AND DISCUSSION

3.1 Experimental Result

The value of tensile strength is directly taken from the stress-strain curve. For this study, the final value of tensile strength was obtained through the average tensile strength value of three pieces of the dumbbell shape test sample. As presented in Table 2, the highest value of tensile strength comes from the set of a parameter in the experimental run at number 1.

Table 2: Experimental result of tensile strength and S/N ratio

Run	Melt temperature (°C)	Holding pressure (MPa)	Injection time (s)	Cooling time (s)	Tensile strength (MPa)	S/N ratio
1	205	350	0.5	10	20.9243	26.4130
2	205	450	0.7	20	20.2007	26.1073
3	205	550	0.9	30	20.4583	26.2174
4	225	350	0.7	30	20.4043	26.1944
5	225	450	0.9	10	20.4644	26.2200
6	225	550	0.5	20	20.4155	26.1992
7	245	350	0.9	20	20.2664	26.1355
8	245	450	0.5	30	20.4260	26.2037
9	245	550	0.7	10	20.6125	26.2826

Based on the result, the highest of tensile strength is 20.9243 MPa with the combination of set machine parameters at 205 °C of melt temperature, 350 MPa of holding pressure, 0.5 s for injection time and 10 s of cooling time. From the table, it means that when the cooling time, melt temperature, holding pressure and injection time parameters are respectively set-up at the low level of machine setting parameters, the tensile strength of the polypropylene filled with fibreglass reaches to its highest value. As stated by Yan et al. [4] the reinforcing agent that was fibreglass entanglement with polymer matrix at the lower temperature rather than at high temperature the fibreglass and polymer chain were parallel due to the composites were easily flowed during exit at nozzle injection mould machine.

In this study, the value of tensile strength is translated into a signal to noise ratio. Since, in this study, the aim is to find the highest tensile strength. Therefore, analyse work in Taguchi approach was set to the bigger the better mode. The result in Table 2 shows that the tensile strength result was translated into S/N ratio where the highest S/N ratio was 26.4130 in the experimental run at number 1 and the lowest S/N ratio was 26.1073 in the experimental run at number 2.

Table 3 indicates the response table for a signal to noise ratio of tensile strength. The bigger the better characteristic was used to obtain the best setup of parameter arrangement. The best combination of a parameter was identified by selecting the highest difference value of each factor. In the table, it shows that delta value for cooling time has the higher value meanwhile the lowest value of injection machine parameter is melt temperature. Thus, it shows that the most influenced factor that has been affected the tensile strength is cooling time followed by injection time, holding pressure and melt temperature. Poszwa et al. [28] stated that when the cooling process takes appropriate time, it will increase the internal stresses of the injection moulded component due structure proper arrangement of the polymer chain. Hence, cooling time was the most significant factor affecting the moulded of the plastic part.

Table 3: The response of signal to noise ratio with ranking

Level	Melt temperature (°C)	Holding pressure (MPa)	Injection time (s)	Cooling time (s)
1	26.25	26.25	26.27	26.31
2	26.20	26.18	29.19	26.15
3	26.21	26.23	26.19	26.21
Delta	0.04	0.07	0.08	0.16
Rank	4	3	2	1

The main effect plot for S/N ratio on each factor was transformed to graph means of S/N ratios versus the level of injection machine parameters as shown in Figure 1. The graph in the figure shows that optimum level for all factors reach at a Level 1 for melting temperature at 205 °C, holding pressure at 350 MPa, injection time at 0.5 s and cooling time at 10 s. These value level on each parameter will be used to find the optimum parameters on tensile strength.

3.2 Analysis of Variance (ANOVA)

ANOVA was performed to determine the relative significance of individual factors on tensile strength. The P-value is able to test the significance of each factor on the response factor. The ANOVA computes the quantities such as P-value and R-squares (R-sq) as represented in Table 4. A parameter with P-value greater than 0.05 is considered to be insignificant while parameter with P-value lower than 0.05 is considered to be significant [29]. Based on this statement, the cooling time is considered as the most significant factor meanwhile the other factors with higher P-value than 0.05 are considered to be a less significant factor. R-squares describes the amount of variation observed is explained by the input factors. High R-squares indicate that the input factor is able to predict the response with high accuracy [30]. As shown in the table, the highest R-squares value is in cooling time that has been recorded as 61.13%. This followed by injection time at 20.15%, holding pressure at 13.41% and the lowest R-squares value is 5.32% for melt temperature. Therefore, it shows that cooling time is the most significant factor that affects the tensile strength of polypropylene filled with 20% of fibreglass.

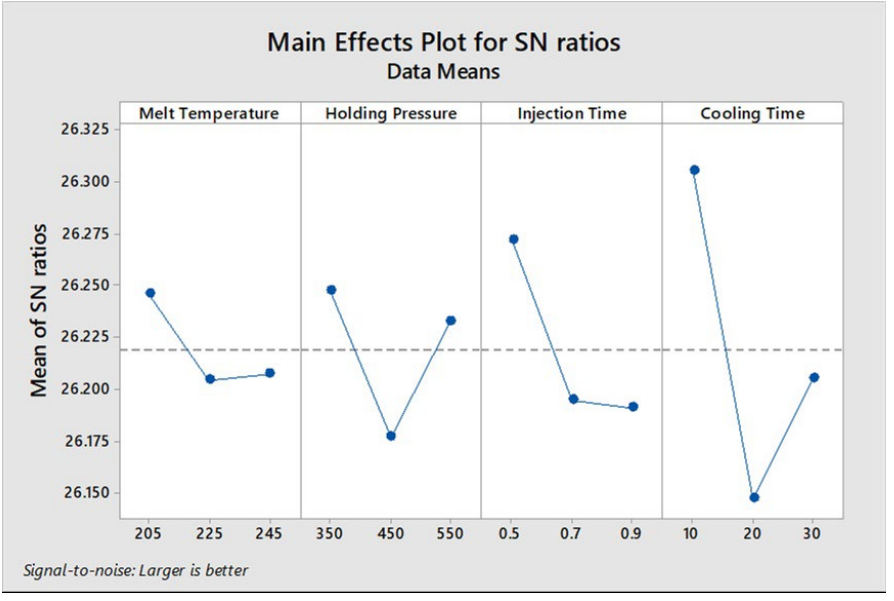

Figure 1: Main effects plot for S/N ratio

3.3 Optimum Parameter using Desirability Function Approach

In order to find the optimum tensile strength for this study, the optimum test was conducted. For the optimum test, the optimum set of a parameter is analysed by using the Minitab software. The purpose is to find that by using an optimum set of parameter, the highest tensile strength value can be found. Based on the optimum level in Figure 1, the combination of an optimum parameter of tensile strength is set at 205 °C for melt temperature at Level 1, 350 MPa for holding pressure at Level 1, 0.5 s for injection time at Level 1 and 10 s for cooling time at Level 1 as shown Table 5. A further process, desirability function approach was done to find the set of parameters that can produce high tensile strength.

Table 4: Ranking contribution for tensile strength

Parameters	P-value	R-sq (%)	Rank
Melt temperature	0.849	5.32	4
Holding pressure	0.649	13.41	3
Injection time	0.509	20.15	2
Cooling time	0.059	61.13	1

Table 5: Best combination of parameters

Factor	Value	Level
Melt Temperature (°C)	205	1
Holding Pressure (MPa)	350	1
Injection Time (s)	0.5	1
Cooling Time (s)	10	1

Table 6 shows the value of desirability after the optimization process parameters by Minitab software. Each experimental run produces a different value of desirability. Desirability function approach assigns number 0 and 1 to the possible value with 0 completely undesirable and 1 represent a completely desirable [31].

Table 6: Desirability value

Run	Tensile Strength (MPa)	Desirability
1	20.9243	1.0
2	20.2007	0
3	20.4583	0.3560
4	20.4043	0.2814
5	20.4644	0.3644
6	20.4155	0.2968
7	20.2664	0.0908
8	20.4260	0.3114
9	20.6125	0.5691

It is found that the combination of an optimum process parameter having desirability value of 1 in the experimental run at number 1 meanwhile the lowest desirability value of 0 in the experimental run at number 2. Therefore, it shows the experimental run at number 1 is the most optimum set-up parameters that produce high tensile strength.

4.0 CONCLUSION

The performance of tensile strength produced by side gate in the injection moulding machine process is investigated based on four injection machine parameters using Taguchi method, ANOVA and desirability function approach. The most significant factor affected tensile strength is cooling time contributed 61.13% followed by 20.15% for injection time, 13.41% for holding pressure and 5.32% for melt temperature. This result shows that longer cooling time increases crystallinity, thus better structure arrangement. Optimization combination parameters found that melting temperature at 205 °C, holding pressure at 350 MPa, injection time at 0.5 s and cooling time at 10 s. These combination parameters show the highest desirability as well as higher tensile strength as compare to other experimental runs.

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