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The Influence of Injection Molding Parameter on Properties of Thermally Conductive Plastic

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Abstract. Thermally conductive plastic is the composite between metal-plastic material that is becoming popular because if it special characteristic. Injection moulding was regarded as the best process for mass manufacturing of the plastic composite due to its low production cost. The objective of this research is to find the best combination of the injection parameter setting and to find the most significant factor that effect the strength and thermal conductivity of the composite. Several parameter such as the volume percentage of copper powder, nozzle temperature and injection pressure of injection moulding machine were investigated. The analysis was done using Design Expert Software by implementing design of experiment method. From the analysis, the significant effects were determined and mathematical models of only significant effect were established. In order to ensure the validity of the model, confirmation run was done and percentage errors were calculated. It was found that the best combination parameter setting to maximize the value of tensile strength is volume percentage of copper powder of 3.00%, the nozzle temperature of 195°C and the injection pressure of 65%, and the best combination parameter settings to maximize the value of thermal conductivity is volume percentage of copper powder of 7.00%, the nozzle temperature of 195°C and the injection pressure of 65% as recommended.

1. Introduction

Plastic material currently used in industries such as automotive, manufacturing and aerospace. Increase demand for light weight and easy to shape of the component is main selected criteria to reduce energy consumption, lower manufacturing cost and time. Therefore, the best of material for suitable to be used to meet these criteria is plastic. Thermoplastic is a main types of plastic. This

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plastic can be reused after re-melting and the chemical structure remain unchanged during heating and shaping process. The example for thermoplastic is acrylic, ABS (acrylonitrile butadiene styrene), nylon, and PP (polypropylene). There are some of the noteworthy properties of thermoplastic is have high strength, are lightweight, good chemical and stress cracking resistant, excellent high temperature stability, heat resistance and have relatively low processing cost [1].

But the use of thermoplastic is limited to certain application due to its low thermal conductivity and heat resistant. Thermal conductivity of thermoplastic was reported around 0.2 W/mK (Watts/meter-°Kelvin), considerably lower than most thermally conductive plastic compounds that typically have 10 to 50 time higher conductivity (1-10 W/mK) [2]. Therefore, plastic modification is a way to improve their thermal conductivity and strength through the use of additive or filler [3, 4]. There are several kind of additive that usually used which include metal, ceramic and polymer [5]. Injection molding, extrusion, and compression molding are the methods that is normally implemented to produce thermoplastic composites with additive material [4].

2. Methodology

Copper powder, ABS and surfactant agent are the materials used in this conductive plastic fabrication. ABS considered as an environment friendly material as they are completely recyclable. The properties of material are; ABS material: density of 1.03 g/cm^3 and melting point of 230℃; copper powder: purity of 99%, particles size distribution of 17 μm – 50 μm, melting temperature of 1080 ℃ and the density of 9.84 g/cm^3. The percentage of volume distribution for the copper powder, ABS and paraffin wax is shown in Table 1

Table 1: Percentage of volume distribution for the copper powder, ABS and paraffin wax.

No	**Composition volume, %**			**Density , g/cm^3**
	Copper	**ABS**	**Paraffin wax**	
1	3	96	1	1.27
2	7	90	3	1.58

In this experiment, the actual weight of compounding was determined and calculated by the following equation:

$$Wc = Wcop + W\ ABS / (1 - Ws\ \%) \quad (1)$$

Where;
W_c = weight of composite material in grams
W_{copper} = weight of copper powder in grams
W_{ABS} = weight of ABS in grams
W_S% = weight percentage (wt %) of surfactant

Table 2 shows the calculated elemental and total weight of ABS-Cu composite.

Table 2: Total weight of ABS-Cu composite

No	**Weight, g**			**Total weight, g**
	Cooper, g	**ABS, g**	**Paraffin wax, g**	
1	21.19	78.11	0.71	100.00
2	39.66	58.2	1.71	100.00

ABS material was crushed and sieved into approximately 1mm-5mm particles size purposely to eliminate the impurities content. In order to achieve a homogeneous condition, the powder was mixed with the surfactant agent. The process was carried out by Brabender Plastograph mixer, type W50 at 185℃ with the speed of 20 rpm for 30 minutes. Next, the prepared feedstock was crushed by granulator machine to produce pallets with similar size. The injection process of the pallets was done by horizontal NPF-1F molding machine to produce the sample for tensile strength and thermal conductivity analysis.

The injection machine specification are; screw diameter of 19 mm, injection capacity of 14 cm^3, injection rate 20% and injection pressure of 60% to 65%. In order to prevent the melt from sticking at the screw, the barrel temperature was started from low to high temperature. Figure 1 and Figure 2 show, the injection molding machine and the zone temperature in injection molding machine respectively. The machine barrel temperatures that consist of five temperature zone were set as follow; the nozzle temperature was in the range of 195 ℃ to 220℃, front and middle were set in the range of 190 ℃ to 215℃ and 180℃ to 205℃ respectively, rear 2 and rear 1 were in the range of 170 ℃ to 180 ℃ and 175 ℃ to 200 ℃ respectively. The feeding temperature was set as constant at 50℃ with the cooling time of 5 second.

Figure 1: Injection molding machine

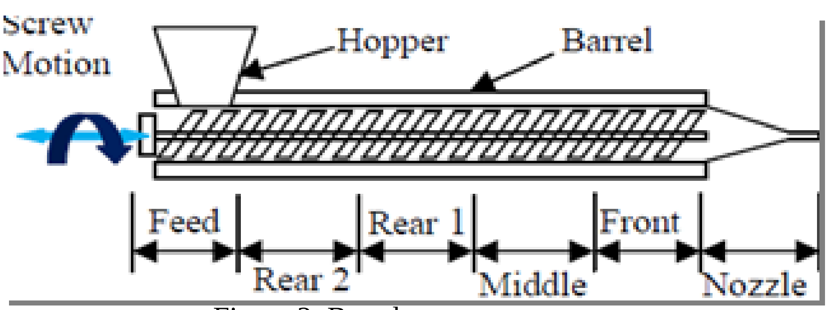

Figure 2: Barrel temperature zone

The influence of composition ratio of volume Cu, nozzle temperature and injection pressure were investigated in this research. Table 3 shows the parameter setting used in this investigation.

Table 3: Investigate Parameter

Factor	**Parameter label**	**Low Level (-1)**	**Middle**	**High Level (+1)**
Composition ratio volume Cu,%	A	3	5	7
Nozzle temperature,℃	B	195	208	220
Injection pressure, %	C	60	62.5	65

DOE method of two-level full factorial with 4 centre points was implemented to develop the mathematical model for performance predicted of the process. Thus, the research was designed with two-level full factorial where a centre point was assigned for each individual factor to evaluate the curvature trend of the response equations. The investigated responses are tensile strength and thermal conductivity. Standard test specimens were conducted based on DIN EN ISO 527-2 for tensile test and Fourier's Law experimental method for thermal conductivity.

Figure 3 shows the schematic of the experimental set-up for the conductivity test as refer to Sia C.K. et al [6]. The results were calculated using equation 2 with the assumption that all specimens were subjected to the same atmosphere of measurement.

$$Q = - kA\ (T_1\text{-}T_2/L) \tag{2}$$

Where ;

K= thermal conductivity, w/mk
A=cross sectional area, m
T_1-T_2= temperature different, ℃
L=thickness,m
Q=rate of heat transfer,joule

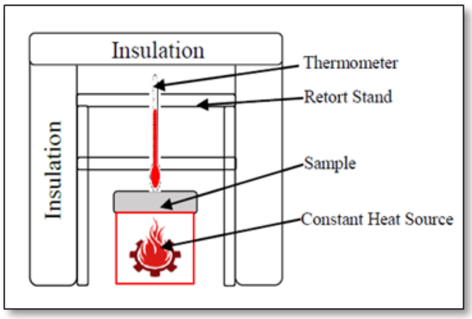

Figure 3: Experimental set-up for thermal conductivity [6]

3. Result and Discussion

All response were statistically analysed through Analysis of Variance (ANOVA) to determine the significant factors including single and the interaction. Total number of 20 experiments were implemented in this research. The revised ANOVA for tensile strength as shown in Figure 4 revealed that the significant single factor are composition of copper, nozzle temperature and injection pressure and the significant interaction factor is the interaction between Cu composition and injection pressure, as indicated by the probability value (p-value) of lower than 0.05.

For Figure 4, the revised ANOVA for thermal conductivity found that the significant single factor is the composition volume ratio of Cu and nozzle temperature while the significant interaction factor is the interaction of Cu composition and nozzle temperature.

ANOVA for selected factorial model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	248.78	6	41.46	28.30	< 0.0001	significant
A-composition ratio volume Cu	*5.82*	*1*	*5.82*	*3.98*	*0.0676*	
B-nozzel temperature	*37.61*	*1*	*37.61*	*25.67*	*0.0002*	
C-injection pressure	*48.66*	*1*	*48.66*	*33.21*	*< 0.0001*	
AB	*41.31*	*1*	*41.31*	*28.19*	*0.0001*	
AC	*108.27*	*1*	*108.27*	*73.89*	*< 0.0001*	
BC	*7.09*	*1*	*7.09*	*4.84*	*0.0465*	
Residual	19.05	13	1.47			
Lack of Fit	*6.51*	*2*	*3.25*	*2.85*	*0.1003*	*not significant*
Pure Error	*12.54*	*11*	*1.14*			
Cor Total	267.83	19				

Figure 4: ANOVA tensile strength

ANOVA for selected factorial model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3.443E-004	3	1.148E-004	8.70	0.0012	significant
A-composition ratio volume Cu	*2.560E-004*	*1*	*2.560E-004*	*19.42*	*0.0004*	
B-nozzel temperature	*1.600E-005*	*1*	*1.600E-005*	*1.21*	*0.2869*	
AB	*7.225E-005*	*1*	*7.225E-005*	*5.48*	*0.0325*	
Residual	2.109E-004	16	1.318E-005			
Lack of Fit	*1.029E-004*	*5*	*2.059E-005*	*2.10*	*0.1422*	*not significant*
Pure Error	*1.080E-004*	*11*	*9.818E-006*			
Cor Total	5.552E-004	19				

Figure 5: ANOVA thermal conductivity

The R square value has also been observed for the source of variation analysis as shown in Figure 6 and Figure 7. R value was found in between 0.6 and 1 indicate that all significant factors were considered in the developed model.

Std. Dev.	1.21	R-Squared	0.9289
Mean	45.98	Adj R-Squared	0.8961
C.V. %	2.63	Pred R-Squared	0.8327
PRESS	44.82	Adeq Precision	20.905

Figure 6: Source of variation analysis for tensile strength

Std. Dev.	3.631E-003	R-Squared	0.6200
Mean	0.11	Adj R-Squared	0.5488
C.V. %	3.25	Pred R-Squared	0.4525
PRESS	3.040E-004	Adeq Precision	7.544

Figure 7: Source of variation analysis for thermal conductivity

Three dimensional surfaces were obtained to illustrate the parameter-response relationship. Figure 8 shows the surface plot graph for tensile strength. It can be seen that the higher the volume of Cu, the lower is the tensile strength which found similar to as found by Mamunya et al. [7]. The optimisation analysis indicated that the low level of Cu composition, low level of nozzle temperature and high level of injection pressure is needed to be used to maximise the tensile strength.

Figure 9 shows the surface plot graph for thermal conductivity. The increasing in the composition of Cu increases the thermal conductivity of the composite material. Although different in parameter range, the response behaviour was found similar as reference [8]. For the thermal conductivity, high level of composition of Cu, low level of nozzle temperature and high level for injection pressure will optimise the response.

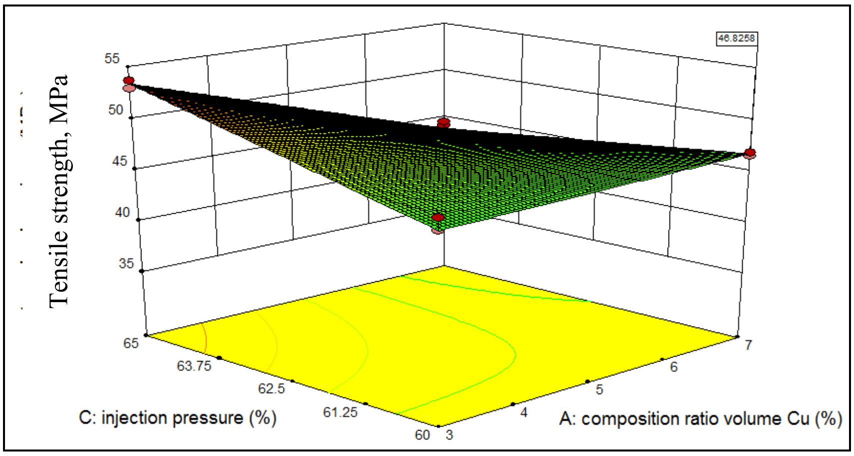

Figure 8: Surface plot graph for tensile strength (σ)

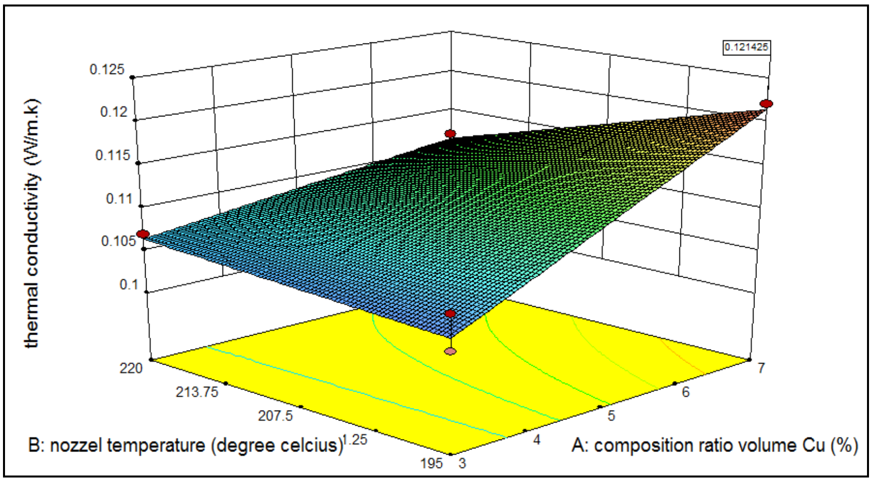

Figure 9: Surface plot graph for thermal conductivity (k)

Mathematical model for each response were developed with 95% confident interval. The predictive model for tensile strenght and thermal conductivity were given by :

Tensile strenght = 209.72566 + 18.87844(A) - 1.77554(B) - 1.12161(C) + 0.064275(AB) - 0.52027(AC) + 0.021304(BC) (3)

Thermal conductivity, k = 0.030213 + 0.019637(A) + 3.45000E-4(B) - 8.50000E-5(AB) (4)

The validity of the developed model was proved through confirmation run. As shows in Table 4, 3 parameter combinations were tested. The result were tabulated (Table 5) and the percentage errors were calculated (Table 6). Results demonstrated that developed model reasonably accurate for the response prediction.

Table 4: Parameter of the confirmation Test

Run	**Composition ratio volume Cu,%**	**Nozzle temperature, ℃**	**Injection pressure, %**
1	4	201.25	61.25
2	4	210	63
3	6	215	64

Table 5: Predicted and Actual responses

Run	**Predicted, σ MPa**	**Predicted, (k) W/mk**	**Actual, σ MPa**	**Actual, (k) W/mk**
1	46.0938	0.109769	46.043	0.103
2	46.4496	0.109813	46.606	0.107
3	45.7457	0.112563	45.775	0.111

Table 6: Residual and Error in Prediction

Run	**Residual of σ, MPa**	**Residual of k, W/mk**	**Error Response 1 (%)**	**Error Response 2 (%)**
1	-.0.0508	-0.006769	0.1	0.6
2	0.1564	-0.002813	0.33	2
3	0.0293	0.0015	0.6	1.35

4. Conclusion

In this research, the relationship between injection molding parameter and the responses were determine experimentally. The mechanical properties of the composite is influenced by certain parameter investigated In this research, the composition ratio volume of Cu is the most significant factor that influence of the mechanical properties of the plastic composite. The best combination parameter setting to maximize the value of tensile strength is the combination of volume percentage of copper powder of 3.00%, the nozzle temperature of 195 ^oC and the injection pressure of 65%, while the best combination parameter settings to maximize the value of thermal conductivity is the combination of volume percentage of copper powder of 7.00%, the nozzle temperature of 195 ^oC and the injection pressure of 65%. In overall, the statistical analysis was provided clear understanding on the influence of injection parameter setting through the validated mathematical models.

References

[1] William F. Smith & Javad Hashemi, Ph.D (2011). “Foundation of Material Science and Engineering” Fifth edition (McGraw-Hill), pages 515-517.

[2] R.P. Kusy , in *Metal-Filled Polymers*, edited by S.K. Battacharya (Dekker, New York, 1986)

[3] Raut, S. V, & Khande, R. B. (n.d.). Investigation of the Effect of Mechanical Properties on the Copper filled Acrylonitrile Butadiene Styrene (ABS-Cu Composites).

[4] Sa’de, N.,Masood, S.H., Nikzad, M., Ibrahim, M.H.I. (2013) “International Journal of Engineering Research and Apllication (IJERA) Dynamic Mechanical Properties of Copper-ABS Composite for FDM Feedstock”, pp.1257-1263.

[5] M. Nikzard, S, H. Masood, I, Sbarski, Thermo Mechanical Properties of a highly filled Polymeric Composites for fused Deposition Modeling, *Material and Design*, 32, 2011, 3448-3456

[6] Sia, C. K., et al. "Optimum preparation and thermal conductivity of novel glossy paint prepared from waste of palm oil fly ash composite." *International Journal of Automotive & Mechanical Engineering* 12 (2015).

[7] Mamunya, Y.P., Davydenko, V.V., Pissis, P. and Lebedev, E.V. (2002). Electrical and Thermal Conductivity of Polymers Filled with Metal Powders, European Polymer Journal, 38(9): 1887–1897.

[8] Mamunya, Ye P., et al. "Electrical and thermal conductivity of polymers filled with metal powders." European polymer journal 38.9 (2002): 1887-1897.