Optimization of Composite MIM Feedstock Rheological Behaviour by Experimental Analysis

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Abstract

The kneading process and formulations of feedstock obviously affect the quality of MIM products. In the present work, the rheological behaviour of the composite MIM feedstock, metal matrix (Cu) with few additions of ceramic powders (Al_2O_3), was measured by a self-designed/manufactured simple capillary rheometer. Experimental results show that the distribution between powders and binder is more uniformly when blending time increased. Though high powder loading will increase the feedstock viscosity, the fluidity reveals relatively stable through the load curves of extrusion. Besides, the temperature-dependence of viscosity of the feedstock approximately follows an Arrhenius equation. Basing on Taguchi's method, the kneading optimization conditions and the rheological model of the feedstock were established, respectively.

Keywords : composite, capillary rheometer, Taguchi's Method

1. Introduction

Metal injection molding (MIM) generally includes four processes: kneading process, injection molding, debinding and sintering. The successful application of MIM systems depends on power characteristics, formulation of binder, good mixing and rheological behaviour, and proper filling of the mold [1,2].

Kneading technique is widely used in industries. The most important rheological property in MIM is viscosity. It is well known that a high viscosity of a feedstock makes molding difficult. [3-5].

Experimental design using orthogonal arrays has thoroughly developed by Taguchi's and is well suited for the kneading problem. Such an approach allows one to obtain the same information as a full factorial experimental design, but with fewer testing trials [6, 7].

In the present work, a self-designed simple capillary rheometer is used to conduct the experiments of measuring feedstock rheology. Basing on Taguchi's method, the kneading optimization conditions and the rheological model of the feedstock were established, respectively.

2. Experimental and Results

The raw materials used in this study include copper powder (Cu), alumina powder (Al_2O_3) and polyethylene (PE). Copper powders were used as metal matrix, its physical properties are shown in Table1. The PE with melting point 109 ^oC (PAXOTHENE, USI Co., Taiwan) and alumina powders with mean particle size of 4.6 um (AM-21, Sumitomo Co., Japan) play as the single componet binder and additives, respectively. In kneading process, both of copper and alumina powders are preheated to remove moisture. Then, the binder is sequentially added and kneaded with the powders at varying rate within the range 36-120 rpm. Samples were loaded into the preheated barrel of the self-designed capillary rheometer at specific temperatures within the range 120-140^{o}C.

Table 1. Physical properties of copper powder used in this experiment*

Apparent density	2.85-3.25(g/cm^3)		
Screen analysis (%)	(Micron)	(U.S.Mesh)	
	+100	+150	0.2%
	-100/+75	-150/+200	13.0%
	-75/ +45	-200/+325	41.0%
	-45	-325	45.8%
Flow rate	28sec/50gms		

*HA795, supplied by Kuo-Tan Co., Taiwan

In general, shear stress of non-Newtonian flow tends to be related to shear rate by a power-law equation. The correction of non-Newtonian flow behaviour is modified by Rabinowitsch correction to calculate true wall shear rate,

$$\dot{\gamma}_t = \frac{3n+1}{4n}\left(\frac{32Q}{\pi D^3}\right) \qquad (1)$$

In Taguchi's method, the kneading factors and factor levels selected in the experiment are shown in Table 2.

Table 2. Factors and factor levels selected in matrix experiment*

Factor	Level		
	1	2	3
A: P/B+ (w/o)	(95/5)/20	<u>(90/10)/20</u>	(80/20)/20
B: time (hr)	0.5	<u>1.0</u>	1.5
C: T (°C)	<u>125</u>	130	135
D: N (rpm)	36	60	<u>120</u>

*Starting levels are underlined; + $(Cu/Al_2O_3)/PE$

Since minimization of external force variances is the goal of optimization, the signal/noise (S/N) ratio can be calculated using the formula

$$S/N = -10\log_{10}\left(\frac{1}{m}\sum_{i=1}^{m} y_i^2\right) \qquad (2)$$

The effect of few additives, alumina powders, on the viscosity of composite feedstocks is investigated and shown in Fig.1. It can be observed that the flow behaviour in the MIM composite feedstock could be characterized as shear-thinning. Besides, the value of flow index of composite feedstocks is lower about 11% than that of without alumina powders. It could be the reason of agglomeration of finer alumina powders in the composite material.

The evolution of MIM feedstocks viscosity with temperature follows an Arrhenius-type law as shown in Fig.2. The value of active energy is also calculated as 1.28 KJ/mole.

The S/N ratio with the largest value for each factor is the optimum level over the range of settings. In Fig.3, the S/N value of the factor A at level 1 is larger than that at others. This indicates that powder loading is the most important factor affects the kneading homogeneity of feedstocks. After determining the optimum conditions, a confirmation experiment has been conducted. The value of flow index and viscosity decreased about 18% and 30% than that of initial settings, respectively. Furthermore, the improvement of the flow stability can also be verified.

3. Summary

Several conclusions can be drawn from this study.

1. The composite MIM feedstocks could be characterized as shear-thinning and the viscosity with temperature also follows an Arrhenius-type law.
2. With an increase of the alumina powders loading, there is an increase in the viscosity.
3. Based on the experimental verification, the optimum settings are A1/B3/C2/D.

Acknowledgements

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4. References

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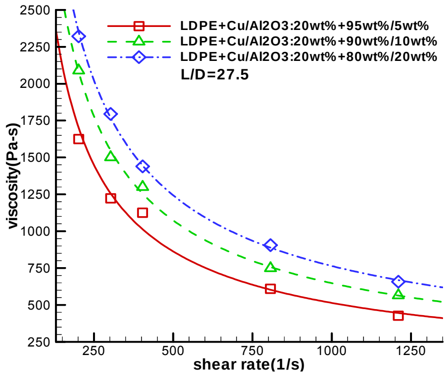

Fig. 1. The graph of viscosity vs. shear rate for composite MIM feedstock at 130°C

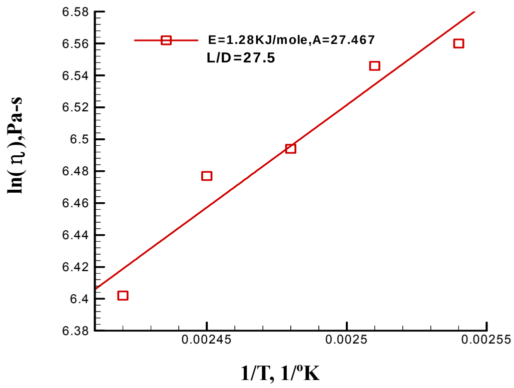

Fig. 2. Ln scale plots for the relationship of the viscosity to temperature

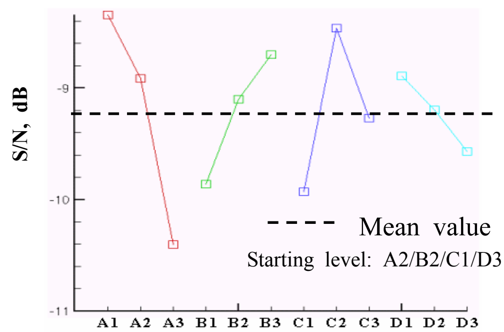

Fig. 3. Plots of factor effects