INJECTION MOLDING PARAMETER OPTIMIZATION OF TITANIUM ALLOY POWDER MIX WITH PALM STEARIN AND POLYETHYLENE FOR GREEN DEFECTS USING TAGUCHI METHOD

N. H. Mohamad Nor[a], N. Muhamad[b], M. H. Ismail[a], K. R. Jamaludin[c], S. Ahmad[b], &M. H. I. Ibrahim[b]

[a]Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

[b]Department of Mechanical & Materials Engineering, Faculty of Engineering & Built Environment, National University of Malaysia, 43600 Bangi, Selangor Darul Ehsan, Malaysia

[c]College of Science & Technology, Universiti Teknologi Malaysia, Int. Campus, 54100 Jalan Semarak Kuala Lumpur

Introduction

Metal injection Molding (MIM) comprises of several processing stage which are mixing, injection molding, debinding and sintering [1]. Palm stearin (PS) which is started developed by Iriany [2] was found to be a binder and successfully prepared the homogeneous feedstock. This paper attempts to inject the molded part of Ti-6Al-4V powders mix with PS and polyethylene (PE) besides how to obtain defects-free part. Defects that almost occur in MIM during injection process are weld line, flashing, jetting and binder separation [3]. For this strong reason, optimization of the processing parameters is essential. Design Of Experiment (DOE) in Taguchi was used in this study to optimized the injection parameters and the experimental results are then transformed into a signal-to-noise (S/N) ratio. Analysis of variance (ANOVA) also can be used to determine the contribution factors which influence the quality characteristics[4]. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtain from the parameter design.

Experimental

Sample Preparation

MPIF 50 standard tensile bar was used as a specimen. The titanium alloy powder (Ti-6Al-4V) was mixed with 60wt% of PS and 40wt% of PE. The feedstock was then injected using Battenfeld, BA 250 CDC injection molding machine.

Design of Experiment

From Table 1, based on three-level design of experiments and interactions between three important parameters such as injection pressure, injection temperature, and powder loading, Taguchi's orthogonal array (OA) of L_{27} is the most suitable for the DOE.

Table 1: Injection parameters for three levels Taguchi design

Parameter	Factor	Level		
		0	1	2
Injection Pressure (bar)	A	350	450	550
Injection Temperature (^oC)	B	130	140	150
Powder Loading (vol%)	C	63	65	67
Mold Temperature (^oC)	D	40	45	50
Holding Pressure (bar)	E	500	600	700
Injection Rate (ccm/s)	F	10	15	20

Result and Discussion

Table 2 shows the classification of rating for the defects of green part [4].

Table 2: Rating for defects[4]

Defects	Rating
Weld lines	1
Incomplete filling	3
Binder separation	0.5
Binder burn out	0.5
Green broken during mold opening	3
Slumps	3
Deflection	3
Chipping at gate	2
Flashing	0.5
Green broken during ejection	3

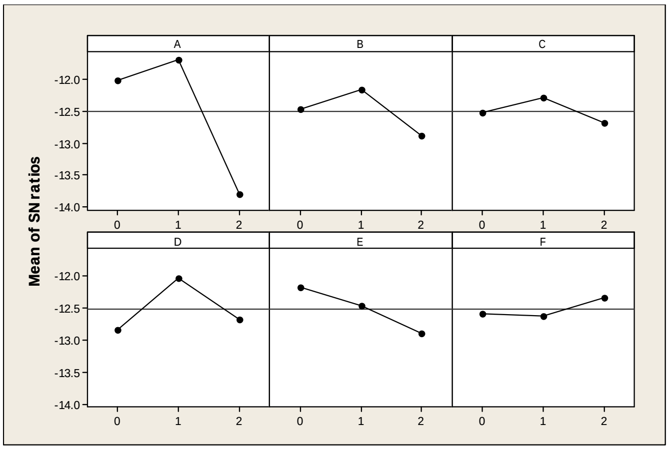

Fig. 1: The Response Plot of S/N Ratio

Analysis of the S/N Ratio

The S/N ratio of the lower-the-better quality characteristic for defects should be taken for obtaining optimal performance of the green parts which is defined as:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} Y_{ij}^2\right) \quad (1)$$

Without considering any interaction the result as shown in Fig.1 is a combination of A1, B1, C1, D1, E0 and F2 as the best set of factors.

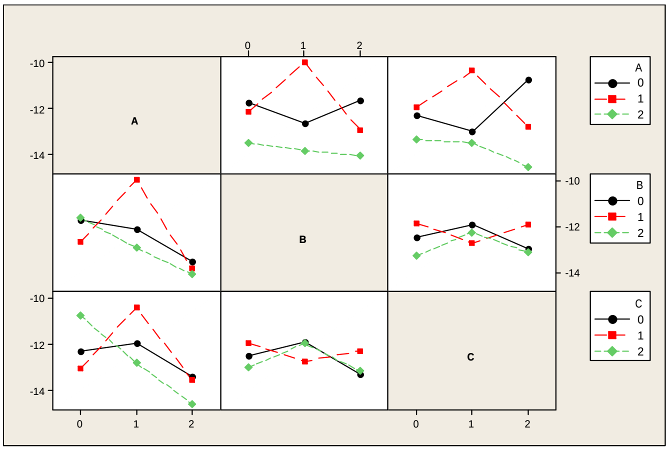

Fig. 2: Interaction Plot of S/N Ratio

Fig.2 shows the interaction plot for the mean ratios. The interaction plot indicates that A1B1, A1C1 and B1C0 have the highest mean S/N ratio at -10.00dB, -10.35dB and -11.85dB respectively. Since the A1C1 has a higher value than B1C0, thus after interaction the combination of the optimum factor remains the same(A1, B1, C1, D1, E0 and F2).

Table 3: ANOVA of green defects after pooling

COLUMNS	FACTORS	DF	SS	V	F	% P
1	A	2	23.4832	11.7416	13.30	30.69
2	B	2		Pooled		
3	AXB	4	13.9882	3.4970	3.96	14.78
5	C	2		Pooled		
6	AXC	4	19.1575	4.7894	5.42	22.08
8	BXC	4		Pooled		
9	D	2		Pooled		
12	E	2		Pooled		
13	F	2		Pooled		
	Error	16	14.1256	0.8828		32.44
	Total	26	70.7544			100

Analysis of Variance (ANOVA)

Table 3 shows the factor A, interaction AXB, and interaction AXC has significantly affect the green defects at contribution of 30.69%, 14.78% and 22.08% respectively. Injection pressure and interaction AXB have significant at 97.5% while interaction AXC at 99% significance level. Table 4 shows the optimum performance, current grand average performance and confident interval which is calculated using equation (2)[5]:

$$CI = \pm\sqrt{\frac{F_{\alpha}(f_1, f_2) \times V_e}{N_e}} \quad (2)$$

Table 5 shows the results and it was found that the average density obtained from the confirmation experiment fell within the prediction 90% confident interval

Table 4: Optimum defect parameter, Optimum performance

A1B1C1		
Optimum performance calculation: $\bar{T} + (\bar{A1} - \bar{T}) + ((\overline{A1XB1}) - \bar{T}) + ((\overline{A1XC1}) - \bar{T})$ -12.5066+(-11.6889+12.5066)+(-9.9954+12.5066)+(-10.3535+12.5066) = -7.0246 dB		
Current grand average performance	:	-12.5066
Confident interval at 90% confidence level	:	±1.0470
Expected result at optimum performance, μ	:	-13.5536<μ<-11.4596

Table 5: Confirmation Experiment

Replication	Parameter Measurement
1	3.5
2	5.5
3	3.5
4	4.5
5	6.5
6	4.5
7	4.0
8	5.5
9	5.0
10	2.0
S/N Ratio	**-13.1299**

Conclusions

In this article, effect and optimization of process parameters in injection molding of Ti-4V-6Al powder and binders of PS and PE to produce free-defects of green part were investigated through Taguchi Method. The optimum injection parameter were found to be 450 bar of injection pressure, 140°C of injection temperature, 65%vol.of powder loading, 45°C of mold temperature, 500 bar of holding pressure, and 20ccm/s of the injection rate (A1, B1, C1, D1, E0 and F2). Regarding on response of green defects injection pressure (Factor A) is the most significant effect which shows a contribution of 30.69%, followed by the interaction of injection pressure-powder loading (AXC) at 22.08% and interaction of injection pressure-injection temperature (AXB) at 14.78%. The predicted range of the S/N ratio for optimum green defect of injection molding is -13.5536<μ<-11.4596.

References

1. German, R.M. & Bose, A. 1997. Injection Molding of Metals and Ceramics. MPIF. New Jersey.
2. Iriany, Muhamad, N., Sahari, J. and Arifin, A.K. 2001. Stability of metal injection molding feedstock containing palm oil. Journal of the Institute of Materials Malaysia, Volume 2, pp.71-83.
3. Bilolov, V.V., Kowalski, L., Duszcyk, J., Katgerman, L. 2006. The effect of constitutive description of PIM feedstock viscosity in numerical analysis of the powder injection molding process. Journal of Materials Processing Technology. Volume 178, pp. 194-199.
4. Jamaludin, K.R., Muhamad, N., Ab.Rahman, M.N., Amin S.Y.M. and Murtadhahadi. 2008. Analysis of variance on the metal injection molding parameters using a bimodal particle size distribution feedstock. Proc. Of Int. Conf. on Mech & Manuf. Eng (ICME2008).
5. Roy, R.K. 1990. A Primer on Taguchi Method, Van Nostrand Reinhold, New York.