Jurnal Teknologi

Full paper

Optimization of 67% Powder Loading Co-30Cr-6Mo μMIM Part by Taguchi Method

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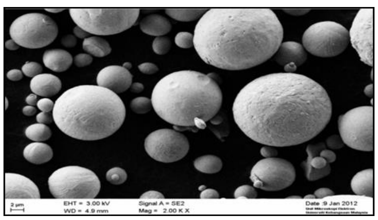
Article history

Received :29 July 2013
Received in revised form :
31 January 2014
Accepted :3 February 2014

Graphical abstract



Abstract

This research studies the effect of injection moulding parameters on the density of green body of Cobalt-30Chromium-6Molybdenum (Co-30Cr-6Mo) for powder injection moulding (PIM) feedstock. In this paper 20 micron Co-Cr-Mo powder was mixed with a palm stearin and polyethylene binder system. L18 orthogonal array by Taguchi Method was used to optimize and predict the future performance. Several injection parameters were optimized such as injection temperature, holding pressure, injection temperature, and mould temperature and injection time. The result shows that the optimum combination of these parameters will produce higher density micro parts. The optimum parameters for 67% powder loading of 20μm Co-30Cr-6Mo powder is 180°C injection temperature, while injection pressure, mold temperature, packing time and injection time are 10 bar, 100°C, 5 s and 7 s respectively.

Keywords: Taguchi method; optimization; injection moulding; green density

Abstrak

Penyelidikan ini mengkaji kesan parameter pengacuanan suntikan terhadap ketumpatan jasad hijau Kobalt-30Kromium-6Molibdenum(Co-30Cr-6Mo) bagi proses pengacuanan suntikan serbuk. Kajian ini menggunakan Co-30Cr-6Mo bersaiz 20 mikron dan bahan pengikat stearin sawit dan polietilena. Kaedah Taguchi L18 digunakan untuk mengoptimumkan parameter suntikan dan meramal prestasi jasad hijau yang akan dihasilkan. Beberapa parameter suntikan telah dioptimumkan seperti suhu suntikan, tekanan pegangan, suhu suntikan, suhu acuan dan masa suntikan. Keputusan analisis menunjukkan bahawa kombinasi parameter yang optimum akan menghasilkan ketumpatan jasad hijau yang tertinggi dan terbaik. Parameter optimum yang diperolehi bagi 67% pembebanan serbuk Co-30Cr-6Mo bersaiz 20 micron adalah 180°C suhu suntikan, manakala tekanan suntikan, suhu acuan, masa padatan and masa suntikan adalah 10bar, 100°C, 5 s and 7 s masing-masing.

Kata kunci: Kaedah Taguchi; pengoptimuman; pengacuanan suntikan; ketumpatan jasad hijau

1.0 INTRODUCTION

Metal injection moulding is favourable in producing small intricate part and cost effective for mass production [1]. The high quality injected part is a must for achieving high quality final sintered part. However, there are few factors that need to be optimized in achieving good quality of injected part such as the density, strength, defect and etc. One of challenges in micro injection molding is the ability to completely fill in the micro-scale cavity [2].

Therefore to minimize cost, defect and time, DOE techniques has been applied. Taguchi method is one of well known optimization tool among researchers. For example, Ji et. al. [3] studied on the sintering of 316L stainless steel metal injection moulding parts and Ahmad *et al*. [4] determined the optimised sintering parameters of titanium alloy foam by Taguchi method. Besides optimization, Taguchi focuses on determining the effects of the control factors on the process parameters [5].

Nevertheless, this study is focused on the optimization of injection moulding parameters such as injection pressure, injection temperature, mould temperature, packing time and injection time of Co-30Cr-6Mo to produce high density green part. Powder with 67% powder loading were chosen based Critical Powder volume percentage (CPVP) done previously..

2.0 METHODOLOGY

The feedstock consists of Co-Cr-Mo powder with palm stearin (PS) and Polyethylene (PE) binder. The characteristic of powder (Co-30Cr-6Mo) is shown in Table 1 and the morphology of the powder under 2000 magnification is shown in Figure 1.

Table 1 Co-30Cr-6Mo characteristics

Characteristic	Details
Tap density, g/cm^3	5.20
Pycnometer density, g/cm^3	6.44
Powder size, µm	20

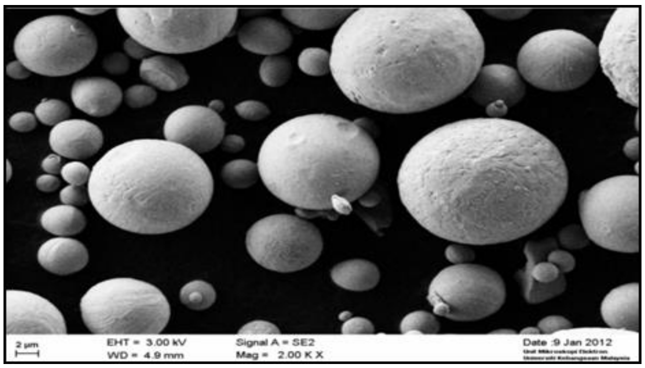


Figure 1 Spherical shape of Co-30Cr-6Mo powder

The densities of the parts were determined based on Archimedes method according to *MPIF Standard 42*. The densities were measured by using a mass balance Sartorius model BSA224S-CW Three level designs of experiment with 5 parameters are consider in the injection moulding where basically all of them were chosen based on screening test. The screening test or injection is done prior to find the upper and lower value for injection parameters. From screening test, low temperature and pressure will lead to short shot. The sampels were successfully injected when the injection temperature, mould temperature and pressure were 160^{o}C, 100^{o}C dan 9 MPa respectively. Thus, this parameters is set as lower limit. In this work, design of experiment (DOE) method is necessary to minimize the number of experiments to be performed. The parameters that involved in the design were injection pressure, injection temperature, mould temperature, injection time and holding time. Table 2 shows the orthogonal array which allocates the level of each parameter. Three levels for each parameter refer to maximum and minimum limit that influence the density result. The densities data were analyzed by using Minitab software according to L18 Taguchi method.

Table 2 Injection parameters for three level Taguchi designs

Level	Injection Temp. (°c) A	Injection Pressure (bar) B	Mold Temp. (°c) C	Injection Time (s) D	Holding Time (s) E
0	160	9	100	6	6
1	170	10	110	7	7
2	180	11	120	8	8

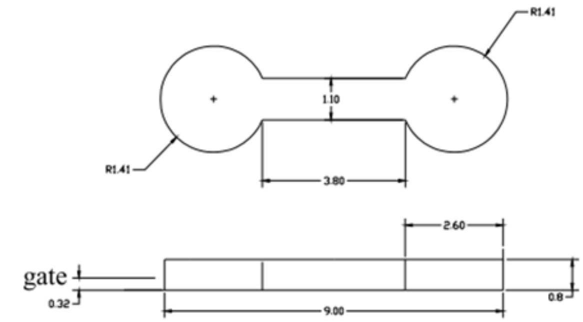


Figure 2 Schematic diagram of the mould cavity (mm)

The schematic diagram of the mould cavity (micro dumbbell) is shown in Figure 2.

3.0 RESULTS AND DISCUSSION

The optimization of control parameters to obtain best results is achieved by the Taguchi Method. Orthogonal arrays (OA) provide a set of well balanced (minimum) experiments and signal to noise ratio (S/N), which are log functions of desired output by data analysis and prediction of optimum result. The known or targeted density value of Co-30Cr-6Mo density is 8.28 g/cm^3. Thus in this work, the characteristics needed are the 'nominal the best', in order to optimize the density:

$$S/N = 10 \text{ Log } \{y/ (\sigma n\text{-}1)2\} \qquad (2)$$

Where y is value of mean density and n is number of replication, while:

$$(\sigma_{n-1})^2 = \sum_1^n \frac{(y_i - \bar{y})^2}{n-1} \qquad (1)$$

Table 3 shows the results of experiment analyzed by Taguchi L18 orthogonal array. The density results were repeated for three times.

Table 3 Design of experiment based on Taguchi L_{18} method

Exp. No.	Parameters 1 e	2 A	3 B	4 C	5 D	6 E	7 e	8 e	Green Density (g/cm^3) Repeat 1	Repeat 2	Repeat 3	S/N (dB)
1	1	1	1	1	1	1	1	1	5.146	4.856	5.509	11.1998
2	1	1	2	2	2	2	2	2	4.864	5.002	5.490	11.4441
3	1	1	3	3	3	3	3	3	4.817	5.127	4.817	14.1828
4	1	2	1	1	2	2	3	3	4.492	4.730	5.156	9.1112
5	1	2	2	2	3	3	1	1	4.891	4.515	5.104	12.4140
6	1	2	3	3	1	1	2	2	4.946	4.336	4.944	11.2739
7	1	3	1	2	1	3	2	3	5.169	5.235	5.546	10.8540
8	1	3	2	3	2	1	3	1	4.944	4.961	5.065	19.3533
9	1	3	3	1	3	2	1	2	4.876	4.908	4.889	26.8546
10	2	1	1	3	3	2	2	1	4.917	4.915	3.874	8.7203
11	2	1	2	1	1	3	3	2	5.035	5.044	5.210	16.2328
12	2	1	3	2	2	1	1	3	4.592	4.592	4.907	11.8735
13	2	2	1	2	3	1	3	2	4.684	5.179	5.072	7.3809
14	2	2	2	3	1	2	1	3	5.085	5.069	4.739	10.8445
15	2	2	3	1	2	3	2	1	4.681	5.246	5.095	14.5736
16	2	3	1	3	2	3	1	2	5.276	4.644	4.739	11.2721
17	2	3	2	1	3	1	2	3	5.244	5.06	5.233	27.5925
18	2	3	3	2	1	2	3	1	4.714	4.866	5.227	18.1974 ∑ 253.3753 T 14.0764

Table 4 ANOVA table showing the percentage contribution of the parameters studied

Factors		Degree of Freedom (f_n)	Sum squared, (S_n)	Variance	Ratio (F_n)	Contribution (P_n,) (%)
A	Injection Temperature	2	112.7144	56.3572	1.4263	20.3734
B	Injection Pressure	2	84.0298	42.0149	1.0633	15.1886
C	Mould Temperature	2	56.1892	28.0946	0.7110	10.1563
D	Packing Time	2	20.1625	10.0812	0.2551	3.6444
E	Injection Time	2	3.5472	1.7736	0.0449	0.6412
Error, e		7	276.5997	39.51424		49.9961
Total		17	553.2429	177.8357		100

Table 4 shows the ANOVA table showing the degrees of freedom, the sum of squares, Mean square, F ratio and the percentage contribution of the parameters studied of green density. Injection temperature (A) is found shall have the greatest influence on the green density followed by injection pressure (B), mold temperature (C), packing time (D) and injection time (E). Based on calculated S/N ratio using Equation (1), the main effects plot is developed as shown in Figure 3. Figure 3 shows the main effects plot for S/N ratio from the density result.

It is also shown in Table 4 that the injection temperature is also the main factor that influenced the density result with 20.37% contribution. This is due to the high composition of polyethylene binder which is 60%. Polyethylene is known to have high viscosity compared to palm stearin. Therefore, high temperature is needed to inject the feedstock. According to German & Bose [1], the viscosity of the feedstock reduced when the pressure increased. This phenomenon is due to increasing feedstock shear stress that facilitates metal powder into the mould cavity to produce the part. Thus, high density part can be achieved at high pressure. However, powder binder separation can occur at very high pressure. Meanwhile, packing time and injection time are not significant for the highest sintered body.

Experiment done by Khairur Rijal (2009) found that the mold temperature has a great influence on the retention of green body dimensions. Optimum mold temperature will reduce the gradient of the temperature drop to feed the material and enter the mold cavity from the nozzle injector. Injection pressure is the third factor that affected the strength of green body. Injection pressure will compressed the feedstock and let it fill the mould cavity before the binder cools at the nozzle.

The optimum parameters were summarized in Table 5. The optimum temperature for injection is 180˚C while injection pressure, mold temperature, packing time and injection time were 10 bar, 100˚C, 5 s and 7 s respectively. Based on the optimized result, the injection process need the highest injection temperature which is 180˚C in order to achieved the nominal density. According to Attia and Alcock, in order to achieve complete filling into the tiniest cavities in the mould; temperatures and pressures of melt flow is usually adjusted [6]. While according to Najman *et al*., the high shear rate at high temperatures facilitate the binder flow ability and make it fill the spaces between the particles in the mold cavity. Therefore, the high-density sintered part will be produced [7].

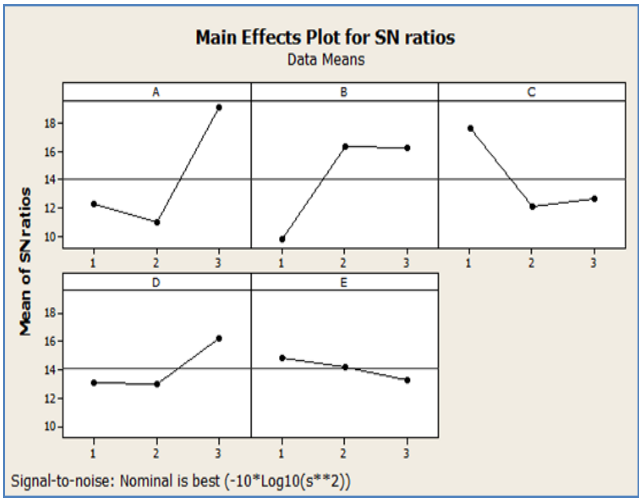


Figure 3 Main effects plot for S/N ratios

Table 5 Optimum parameter for 67% powder loading Co-Cr-Mo

Factors	Level	Optimmum Parameter
Injection temperature	3	180ºC
Injection Pressure	2	10 bar
Mould Temperature	1	100ºC
Packing Time	3	7 s
Injection Time	1	5 s

Confirmation experiments were done for optimum results. Optimum performance calculation is based from significant parameter A, B, C, D and E. The highest S/N ratio for those parameter are used to estimate the range of optimum performance.

Table 6 Estimate the performance as the optimum design (Characteristics Nominal the Best)

Optimum Performance Calculation:
T + (A3-T) + (B2-T) + (C1-T) + (D3-T) + (E1-T)

Current grand average performance = 27.6231
Confident interval at the 90% confidence level = ±0.20714
Expected result at optimum performance, µ dB **27.41596 < µ < 27.8304 dB**

Table 7 below shows green strength of the green part molded by using the optimum injection parameter which is A3, B3, C1, D3 and E1. The results from Table 7 are acceptable as the S/N ratio just 0.02 dB above the minimum level.

Table 7 Confirmation experiment

REP 1	REP 2	REP 3	REP 4	REP 5	S/N : Nominal The Best
5.313	5.222	5.450	5.397	5.297	**27.46**

4.0 CONCLUSION

Based on the Taguchi result, the optimum injection molding parameter that fulfils the optimum green part density is A3 B2 C1 D3 E1. The most important factor that needs to be taken into consideration is injection temperature, followed by injection pressure and the green density. The packing time and injection time which is significant can be reduced to decrease the manufacturing time, and increase the parts production.

Acknowledgement

The author would like to thank the Ministry of Education (KPT) and Universiti Kebangsaan Malaysia (UKM-AP-NBT-11-2009) for their support in the research grant for this project.

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