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Optimization of Injection Moulding Parameters for 68wt% Ti-6Al-7Nb Feedstock Using Taguchi Method

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ABSTRACT

Nowadays, metal injection molding has become among the capabletechnique in powder metallurgy study to produce small-scale complicated part at an effective process and economical cost for bulk production. This study investigates the effect of injection moulding parameterson the density of green part of Ti-6Al-7Nb. The titanium alloy powder of Ti-6Al-7Nb is mixed with binder 40%wt of palm stearin and 60%wt of polyethylene as a binder system. Taguchi Method with L18 orthogonal array have been used to minimize the test run while to optimize the injection parameters and maintaining the quality standard of data measurement. Parameters optimized are the injection temperature, injection pressure, holding time, injection time and mold temperature. Finally, result show that the optimum combination of injection factor that can be produces the best value of green density, which eventually will leads to higher density for sintered parts.

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INTRODUCTION

In current years, metal injection molding (MIM) developed very competitive as a kindof powder metallurgy net-shaping process. Familiarizing the idea of plastic injection molding, the binder is addedinto metal powder particles as the agent of flowability to getmolded parts of the desired shape (Yimin *et al*. 2007).MIM is an advanced technology process consists of several processing stage which are mixing, injection molding, debinding and sintering. The most challenging process in MIM is injecting the feedstock to produce high quality of the green part (Randall and German, 1997).Thus, to ensure the reliability of the product the quality of the green part such as strength and density are great important to be taken during the injection process. The green part with highly compact will produce a superior final density that is very close to the theoretical density. Besides that, the green compact strength is most important in handling process. The stronger green compact is easy to be handling (K.R. Jamaludin *et al*. 2010).

In this study, Taguchi approach technique were used to analyse and considered the best green density by optimizing the injection molding parameters.For successful implementation in design of experiment (DOE), the L18 orthogonal array was chosen to analyze the parameter. The injection parameters that will be used are injection temperature, injection pressure, holding time, injection time and mold temperature.

The main reason to use the Taguchi method in this study is one of anefficient application of design. Furthermore, Taguchi method also can improve product quality and design at initial of experiment. Other than that Taguchi method is has proven to produce high quality product in a short period of time and at low cost and statistically is a robust technique.

Methodology:

Materials:

Fig. 1 shows that titanium niobium powder of average size 50 µm and purchase from MHC Industrial Co. Ltd (China) was irregular in shape. This powder have been milled in a planetary ball mill (Fritsh pulverisette-6) to reduce particle size to 24 µm. Fig. 2 shows the scanning electron microscope of titanium niobium powder after milling process. Hard metal ball and bowl were used to prevent contamination, and ethanol was used as milling medium to avoid agglomeration, minimize temperature rise and oxidation. After wet milling,

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powder was dried in vacuum avon at 100 °C (Abdolali *et al*.,2014).

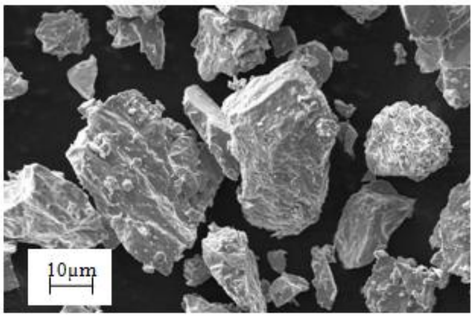

Fig.1 : SEM of Ti-6Al-7Nb

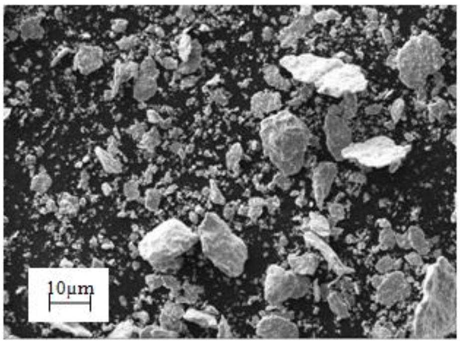

Fig. 2: Scanning electron microscope of Ti-6Al-7Nb powder after ball mill.

This study consist palm stearin as a major components was supplied by Intercontinental Fats Sdn. Bhd. The back bone polymer is low-density polyethylene (LDPE) was purchased from Titan Chemicals Sdn. Bhd. The characteristic of binder system was shown in Table 1.

Table 1: Binder Properties.

Binder	Weigth (%)	Melting Temperature (°C)	Density (gcm^{-3})
Palm Stearin (PS)	40	61	0.891
Polyethylene (PE)	60	127	0.950

Feedstock Preparation:

The feedstock is represents a balance mixture of powder and binder. The success and failure for next subsequence process were determined by ratio of powder and to binder. Nevertheless, the composition where the particles are filled as closely as possible without external pressure and all space between the particles is filled with binder called the critical powder loading(Randall and German, 1997). In this study, the critical powder volume percentage (CPVP) and mixing process wasimplementing by using the Brabender measuring mixture (W50 ETH). The titanium niobium powder was mixed with 60 wt% and 40 wt% LDPE and Palm Stearin, respectively at 150 °C for 90 min. in 68 vol. % powder loading as shown as Fig. 3. To obtain homogeneous feedstock, the mixing temperature were selected depend on the melting point of binder system(Abdolali*et al*.,2014). The injection moulding process was done by using the Micro injection moulding machine –DSM Xplore to get the green part.The green density of the specimen was tested based on Archimedes method with a mass balance.

Design of Experiment:

As shown in Table 2**,** L18 ($2^1 3^7$) orthogonal array (OA) was chosen as the experimental design for this study. The three level designs of experiment (DOE) was selected with five parameters are reflect in the injection moulding process such as mold temperature, injection pressure, injection temperature, injection time and holding time. Firstly, based on screening test all the parameter needs to be knows for example the upper and lower limit value of the successful process. This approach is proved to be highly operativewhich is controlled by more than one factor for measuring performance of a process. The most attractive advantage of this approach is that is does not always involve great number of test.

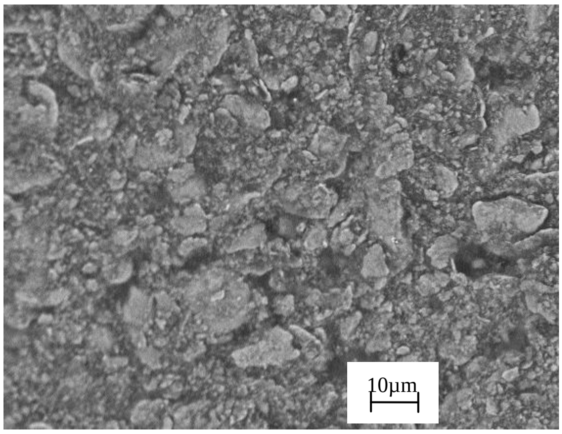

Fig. 3: Morphology of 68%wt feedstock.

Table 2: Control parameter and its value.

No	Parameter/level	Symbol	Level 1	Level 2	Level 3
1	Injection Temp. (°C)	A	145	150	155
2	Injection Pressure (bar)	B	9	10	11
3	Mold Temp.(°C)	C	80	85	90
4	Injection Time(s)	D	6	7	8
5	Holding Time(s)	E	6	7	8

Table 3: Orthogonal Array L18($2^1 3^7$).

Exp. No	Parameters								Green Density (g/cm³)				
	1 e	2 A	3 B	4 C	5 D	6 E	7 e	8 e	Repeat 1	Repeat 2	Repeat 3	Mean (µ)	S/N (dB)
1	1	1	1	1	1	1	1	1	3.340	3.337	3.340	3.339	10.4723
2	1	1	2	2	2	2	2	2	3.326	3.315	3.315	3.319	10.4192
3	1	1	3	3	3	3	3	3	3.227	3.324	3.297	3.283	10.3225
4	1	2	1	1	2	2	3	3	3.262	3.258	3.302	3.274	10.3011
5	1	2	2	2	3	3	1	1	3.323	3.267	3.323	3.304	10.3808
6	1	2	3	3	1	1	2	2	3.331	3.322	3.295	3.316	10.4120
7	1	3	1	2	1	3	2	3	3.312	3.267	3.322	3.300	10.3705
8	1	3	2	3	2	1	3	1	3.326	3.331	3.331	3.329	10.4471
9	1	3	3	1	3	2	1	2	3.294	3.291	3.321	3.302	10.3753
10	2	1	1	3	3	2	2	1	3.305	3.327	3.317	3.316	10.4131
11	2	1	2	1	1	3	3	2	3.388	3.549	3.325	3.421	10.6725
12	2	1	3	2	2	1	1	3	3.300	3.336	3.305	3.314	10.4059
13	2	2	1	2	3	1	3	2	3.283	3.317	3.284	3.295	10.3559
14	2	2	2	3	1	2	1	3	3.328	3.291	3.335	3.318	10.4171
15	2	2	3	1	2	3	2	1	3.275	3.282	3.246	3.268	10.2845
16	2	3	1	3	2	3	1	2	3.289	3.243	3.316	3.283	10.3234
17	2	3	2	1	3	1	2	3	3.301	3.227	3.274	3.267	10.2827
18	2	3	3	2	1	2	3	1	3.316	3.303	3.318	3.312	10.4026

RESULTS AND DISCUSSIONS

In design of experiment (DOE) the term Quality Characteristic (QC) is used to represent the objective and in this study was referred the QC=B: bigger is better with the specimens densities as a response, which is the higher magnitude of calculation will be chosen over smaller ones. Hence, based on theoretical, there is no upper limit on the result but some upper limit is needed for numerical correctness in practice. The average performance can be considered as the target value to achieve stability.

Signal-to-Noise (S/N) Ratio:

In this work the result have a variation; several samples under same conditions have been tested. There are 3 samples at each condition were tested. There are total 18 conditions meaning 54 separate experiments were conducted.In this study, the quality characteristic for density is a “bigger is better”.The S/N ratio for that type of response was used as given below:

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

Where;

Yij= the amount of score for the green density

n = is the total number of shots for eachtrial

Table 3lists the measured specimen green densities with 3 repetition of measurement together with S/N ratio result.

Analysis of Variance (ANOVA):

The purpose of ANOVA is to calculate the important of the process parameters to the green density. Table 4 shows the ANOVA result consist the degrees of freedom, the sum of squares, , mean square, F ratio, pure sum of squares and the percentage contribution of the parameters studied.Factor D (injection time) indicated the greatestacute parameter for the best green density characteristic, followed by factor A(injection temperature) and factor B (injection pressure). Referring from the table result, the factors arenot significant affecting for the high green density is factor E (holding time) and C (mold temperature). The injection time is the most significant factor with 57.2% of contribution followed by injection temperature of 12.2 % and injection pressure 6.7 % While, the holding time and mold temperature less significant whichmust not be neglected to produce the green part with highquality.

Table 4: The calculated ANOVA showing the percentage contribution of the parameters.

Factors	Sum of squared, *Sn*	Degree of Freedom, *fn*	Variance (Mean Square, *MS*)	Variance Ratio, *Fn*	Percent Contribution , *Pn* (%)
A	0.01433	2	0.00717	13.67354	12.20744
B	0.00833	2	0.00416	7.94467	6.68926
C	0.00023	2	0.00011	0.21801	-0.75323

D	0.06328	2	0.03164	60.38014	57.19629
E	0.00011	2	0.00005	0.10181	-0.86515
Error	0.023	43	0.00052	1	25.5254
Total	0.109	53	0.04366		100

In order to achieve complete filling into the tiniest cavities in the mould; temperatures and pressures of melt flow is usually adjusted (Attia and Alcock, 2011). Based on calculated S/N ratio using equation (1)the interaction plot for the mean ratio shown in Fig. 4 were plotted. The optimum parameters for 68% powder loading were summarized in Table5. Where the injection temperature is 145°C, injection pressure at 10 bars, mould temperature is 80°C, injection time and holding time is 6 s respectively.

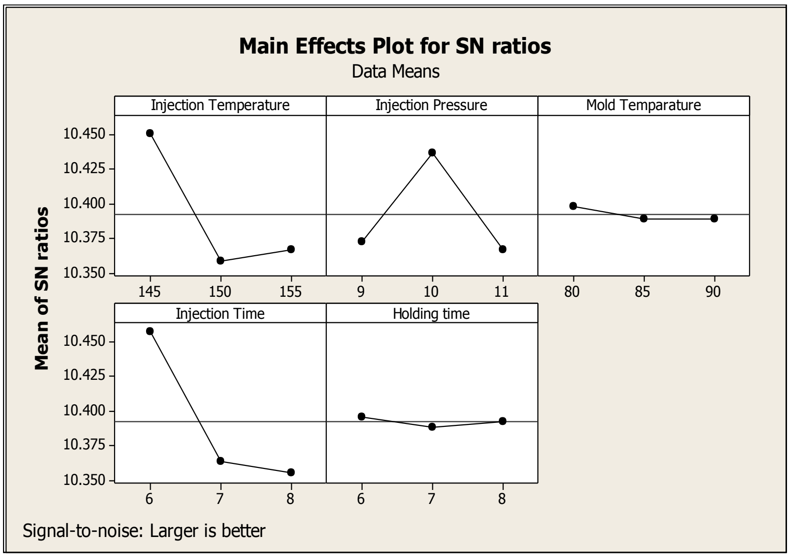

Fig. 4: Main effects plot for S/N ratios.

Table 5: Optimum parameter for 68% powder loading.

Factors	Level	Optimum Parameter
Injection Temperature	1	145°C
Injection Pressure	2	10 bar
Mould Temperature	1	80°C
Injection Time	1	6 s
Holding Time	1	6 s

Conclusion:

From the previous study, approved that Taguchi Method were successfully investigated for optimizing parameters in injection molding process for Ti-6Al-7Nb. Taguchi's Method is targeted to increase the quality of products and processes. However, analysis of variance (ANOVA) had difference point of view, startsthat the relation significance to the individual factors and the interactionmethod.

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