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# Optimization of Injection Molding Parameters for WC-Co Feedstocks

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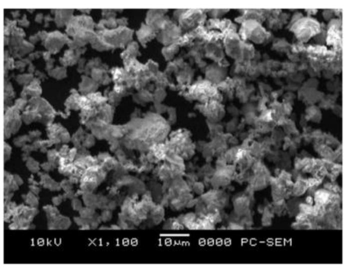
**Graphical abstract**




**Abstract**

This study investigates the effect of injection molding parameters on the density of green body of cemented carbide (WC-Co) – based powder injection molding (PIM) feedstock. Experiments were conducted with ball-milled WC-Co powder mixed with a palm stearin and polyethylene binder system. To minimize the test run while maintaining the quality standard of data measurement, design of experiment approach, particularly Taguchi Method with $L_{18}$ orthogonal array was used in the present study. Several parameters were considered, namely, powder loading, injection temperature, holding pressure and injection rate, while density of the green body as the response factor. The results show the optimum combination of injection factor that produces the best green density value, which eventually will leads to higher density for sintered parts.

*Keywords*: Taguchi method; optimization; injection molding; green density

**Abstrak**

Kajian ini mengkaji kesan parameter proses pengacuanan suntikan terhadap jasad hijau bagi bahan suapan karbida terekat (WC-Co) untuk proses pengacuanan suntikan serbuk (PIM). Ujikaji dilakukan menggunakan serbuk WC-Co yang telah dikisar bebola, dan dicampur dengan sistem bahan pengikat yang terdiri daripada stearin sawit dan polietilena. Bagi mengurangkan jumlah larian di samping mengekalkan standard kualiti bagi pengiraan data, sebuah pendekatan reka bentuk ujikaji, iaitu Kaedah Taguchi dengan $L_{18}$ tatasusunan ortogon digunakan dalam kajian ini. Beberapa parameter diambil kira, iaitu pembebanan serbuk, suhu suntikan, tekanan pegangan dan kadar alir, sementara faktor respons adalah ketumpatan jasad hijau. Keputusan kajian menunjukkan gabungan faktor pengacuanan suntikan yang optimum dan menghasilkan ketumpatan hijau yang terbaik, yang seterusnya akan menghasilkan ketumpatan jasad sinter yang lebih tinggi.

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



## ■1.0 INTRODUCTION

Powder injection molding (PIM), is a kind of net-shape powder metallurgy forming process that is derived from plastic injection molding. The products prepared by PIM are expected to have better mechanical properties and more homogeneus microstructure since the hydraulic pressure applied during injection molding will make the uniform filling of mold cavity and subsequently retarded any density gradient [1]. Other than that, by reducing secondary post treatment unlike machining process and recycling use of PIM feedstock, these could eliminate the fabrication cost. Thus, PIM has become a well established and promising technology for the production of small, complex and near net shape products in mass production with a relatively low processing cost. Recently, the PIM process has gained numerous attractions in producing cemented carbide components due to the advantages.

## ■2.0 MATERIALS AND METHODS

### 2.1 Feedstock and Sample Preparation

The feedstock comprises of ball-milled WC-Co powders with palm stearin (PS) and polyethylene (PE) binder system. Some characteristics of the metal powders and binder components used are as shown in Table 1 and 2 respectively.

**Table 1** Some properties of metal powder

| Powder | Formation method | Average particle size, $D_{50}$ (μm) | Pycnometer density (g/cm$^3$) | Critical powder loading (%) |
|---|---|---|---|---|
| WC-9Co | Wet milled in heptanes | 4.35 | 10.66 | 65 |

**Table 2** Some properties of binder components

| Type | Percentage (%) | Density (g/cm$^3$) | Melting point (ºC) | Decomposition temp. (ºC) |
|---|---|---|---|---|
| PS | 70 | 0.891 | 54.3 | 398.5 – 598.8 |
| PE | 30 | 0.95 | 127 | 389.6 – 501.6 |

The powder particles exhibits irregular shape and have some agglomeration as seen in Figure 1. These agglomerates have been broken into smaller pieces since the powders have been milled in ethanol media for 90 minutes [5]. The powder and the binder components are mixed in sigma blade mixer at the speed of 40 rpm and temperature of 150 ºC, at the powder loadings lower than the critical value of 65%, which are 59, 61 and 63% vol.

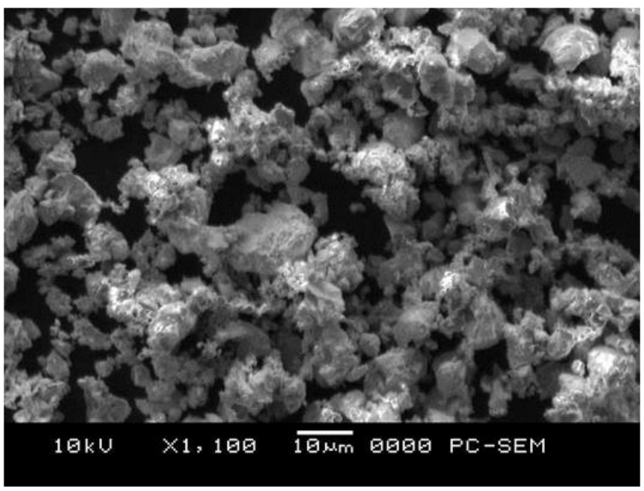



**Figure 1** Morphology of the ball-milled WC-Co powder

After mixing process, the feedstock was injection molded in a Battenfeld 250 CDC injection molding machine. The control processing parameters varied at 3 levels for the injection molding step is listed in Table 3.

**Table 3** Control parameters for injection-molding step

| Factors (unit) | | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Injection rate (ccm/s) | A | 10 | 20 | - |
| Powder loading (% vol) | B | 59 | 61 | 63 |
| Injection temperature (ºC) | C | 140 | 150 | 160 |
| Holding pressure (bar) | D | 1700 | 1800 | 1900 |

The density measurement for the tensile shape green part was done based on the Archimedes Method, according to MPIF 42 Standard.

## 2.2 Taguchi Methods

$L_{18}$ orthogonal array (OA) was chosen as the experimental design for this study. The OA is sufficient enough since the system has 1 control factor with 2 level, and another 3 control factors with 3 levels (refer Table 3), and because all the control factors are orthogonal, so interactions effects are not studied [6]. The energy input is injection pressure while the noise factors are ambient's humidity level at morning and evening condition. The output response is the green density, because not only it reflects the green strength of the part, but also the best green density could lead to the best sintered density of the final part. The P-diagram and the ideal function are shown in Figure 2.

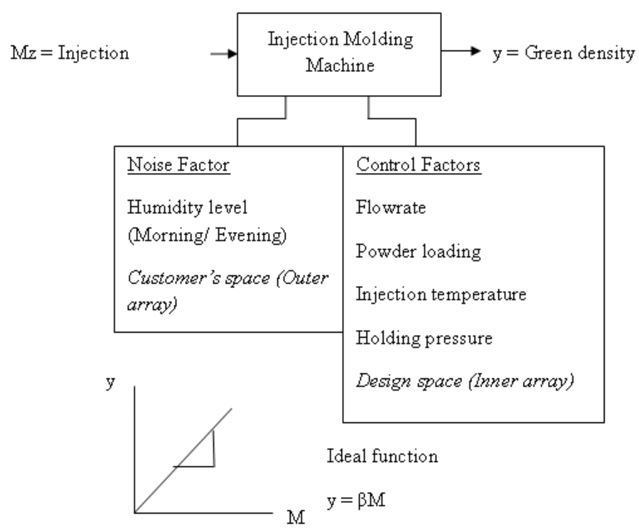
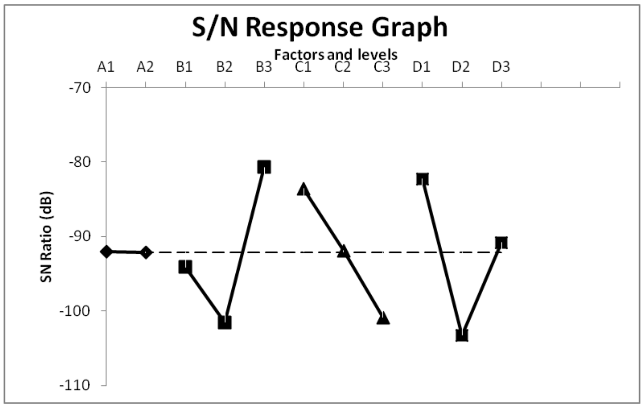


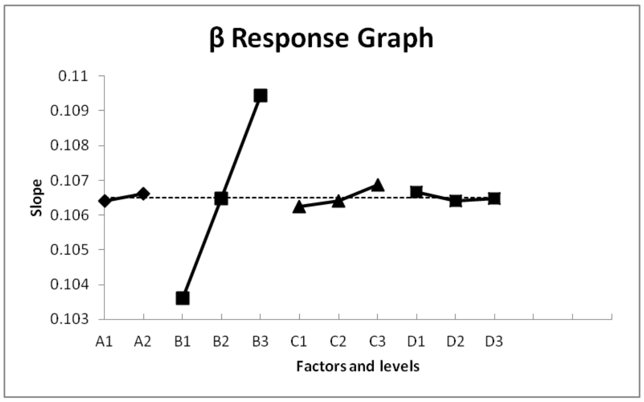

**Figure 2** P-Diagram and ideal function

# 3.0 RESULTS AND DISCUSSIONS

Figure 3 represents the response plot for both signal-to-noise graph and β response graph. Based on the two-step optimization method, higher sensitivity is desirable for higher efficiency [6]. Since higher efficiency is established, the opportunity to reduce cost and loss for the system will occur [7]. Thus, the first step is to maximize S/N. Referring to Figure 3 (a), the maximum S/N lies on the point B3C1D1, while for point A the response line is significantly horizontal. The second step is to adjust slope at Figure 3 (b), the optimum value for point A is A2, thus making the overall optimum combination for the system as A2B3C1D1.




(a)




(b)

**Figure 3** Response graph for (a) S/N and (b) *β*

The following Table 4 presents the optimum set of combination together with their actual value for each control factor.

**Table 4** The optimal condition for injection-molding step

| Factor | | Parameter |
|---|---|---|
| Injection rate | A2 | 20 ccm/s |
| Powder loading | B3 | 63% vol. |
| Injection temperature | C1 | 140 ºC |
| Holding pressure | D1 | 1700 bar |

To see the significance of each factor to the green density, the sensivity is measured based on the difference (Δ) detected between highest and lowest point for each S/N values for all the factors, as seen in Table 5.

**Table 5** Response table for S/N values (Average = -92.09 dB)

| | A | B | C | D |
|---|---|---|---|---|
| | -92.04 | -94.08 | -83.56 | -82.27 |
| | -92.15 | -101.50 | -91.87 | -103.23 |
| | | -80.70 | -100.85 | -90.78 |
| Δ | 0.11 | 20.81 | 17.29 | 20.96 |
| Rank | 4 | 2 | 3 | 1 |

According to the rank numbered for each factor, the largest contribution is factor D (holding pressure). This is by the fact that the holding pressure compresses the melt and fills the cavity, and has an effect until the gate solidifies. If the holding pressure is not enough sufficiently, slumps can occur on the surface [2]. Thus, the highest holding pressure could lead to the highest density of the green part. The second largest contribution is factor B (powder loading). The higher the powder loading, the bonding between powder particles increased within the feedstock and make the green part to pack more densely due to the less voidage created [8]. Hence, the density of the green parts increases. This finding is quite similar with work [9], which also got powder loading as the second most influencing factor after optimization process done on stainless steel based feedstock. Injection temperature (factor C) is still important since the temperature of materials has an effect on the viscosity of the melt, and consequently on the ability of the melt to fill up the cavity [2]. The parts will be unfilled if the viscosity of the melt is too high. Meanwhile for factor A (injection injection rate), the significance is too low and the effect can be neglected. This is because the injection injection rate only controls the time and amount of melt to fill up uniformly into the die cavity.

**Table 6** Predictions values for S/N and β

| Predictions | S/N | β |
|---|---|---|
| Initial | -75.68 | 0.103 |
| Optimum | -62.39 | 0.109 |
| Gain | 13.28 dB | 5.84% |

Table 6 summarizes the predictions made for both S/N and β values between the initial condition (before optimization) and the optimum one (after optimization). The initial conditions refer to the first level for each control factor. From the table, it can be seen that the optimum condition gains increment as much as 13.28 dB for the S/N values, while 5.84% increment for β values, if compared to the initial condition. The positive increment values show the significance of doing optimization process for the system. Next, in order to validate the results, a confirmation run is needed and the result is shown in Table 7.

**Table 7** Summary of S/N and β values between prediction and confirmation run

| | Predictions | | Confirmation | |
|---|---|---|---|---|
| | S/N | *β* | S/N | *β* |
| Initial design | -75.6679 | 0.103403 | -75.6679 | 0.103403 |
| Optimum design | -62.3888 | 0.109443 | -71.115 | 0.108521 |
| Gain | 13.28 dB | 5.84 % | 4.55 dB | 4.95 % |

From Table 7, it can be said that it is confirmed that there is 4.55 dB gains in S/N ratio and the β value increased up to 4.95%, if compared to the initial design. Although there is a bit difference between the prediction and confirmation values, but the value is still significance since it shows positive increments (for S/N value) and lies within the ±0.5 interval (for β value). Thus, the optimized design is proven to be cheaper, more reliable to the surroundings despite having the best green density amongst all.

## ■4.0 CONCLUSIONS

From the study carried out, several conclusions can be drawn out:

(1) Taguchi method, particularly dynamic response analysis is proven as an effective optimization tools for injection-molding step to produce WC-Co part via PIM method.

(2) In order to achieve highest green density, the optimum combination of parameters achieved was A2B3C1D1, that is flowrate at 20 ccm, powder loading at 63% vol., injection temperature at 140 ºC and holding pressure at 1700 bar.

(3) The most influencing factor to the green density is holding pressure, followed by powder loading, then injection temperature and lastly injection rate is very less significant and can be neglected.

(4) From the confirmation run, it was confirmed that the gain had an increment as much as 4.95% compared to the initial design. Thus, the result is acceptable and believed could make the optimized design become better than before (initial design), in term of robustness to surroundings factors at all energy input variations (injection pressure).

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