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Dynamic Response Optimization for Cemented Carbide Injection Molding

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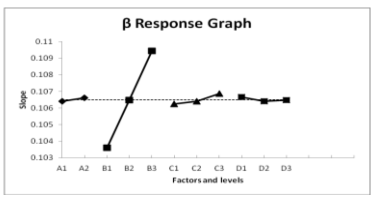
Graphical abstract



Abstract

The need to optimize the injection molding parameters for producing cemented carbide parts via Metal Injection Molding process is crucial to ensure the system's robustness towards manufacturer and customer's satisfactions. Defect free product with best density can be produced while reducing time and cost in manufacturing. In this work, the feedstock consisting of WC-Co powders, mixed with palm stearin and polyethylene binder system was injection molded to produce green parts. Several processing variables, namely powder loading, injection temperature, holding pressure and flowrate, were optimized towards the density of the green body, as the response factor. By considering humidity level at morning and evening conditions as the noise factor, the results show the optimum combination of injection molding parameters that produces best green density. The green part exhibited best density by following this optimum processing parameters, A2B3C1D1, that are flowrate at 20 ccm/s, powder loading at 63% vol., injection temperature at 140°C, and holding pressure at 1700 bar.

Keywords: Cemented carbide; metal injection molding; optimization

Abstrak

Keperluan untuk mengoptimumkan parameter pengacuanan suntikan dalam menghasilkan komponen karbida terekat melalui proses pengacuanan suntikan logam adalah sangat penting demi memastikan kebolehtahanan sistem terhadap nilai kepuasan pihak pembuat dan pelanggan. Ini berikutan produk yang bebas kecacatan beserta dengan ketumpatan yang terbaik dapat dihasilkan dalam masa yang singkat dan kos yang kurang semasa proses pembuatannya. Melalui kajian ini, bahan suapan terdiri daripada serbuk WC-Co yang dicampur dengan bahan pengikat berasaskan stearin sawit dan polietina disuntik untuk menghasilkan jasad hijau. Beberapa pemboleh ubah proses iaitu pembebanan serbuk, suhu penyuntikan, tekanan pegang dan kadar alir telah dioptimumkan terhadap faktor respons, iaitu ketumpatan jasad hijau. Dengan mengambil kira tahap kelembapan pada waktu pagi dan petang sebagai faktor hingar, keputusan akhir menunjukkan gabungan parameter pengacuanan suntikan yang optimum dalam menghasilkan ketumpatan jasad hijau yang terbaik. Melalui gabungan parameter optimum ini, A2B3C1D1 iaitu pada kadar alir 20 ccm/s, pembebanan serbuk 63% isipadu, suhu penyuntikan 140°C dan tekanan pegang 1700 bar, jasad hijau dengan ketumpatan yang terbaik dapat dihasilkan dengan jayanya.

Kata kunci: Karbida terekat; pengacuanan suntikan logam; pengoptimuman

■1.0 INTRODUCTION

Cemented carbide injection molding has been widely accepted as a promising technology in producing small and complex shape with high performance and good surface finish in mass production [1, 2]. The process consists of four sequential steps – mixing, injection molding, debinding and sintering – all of each step has an effect on the characteristic of the final parts. A homogeneus feedstock from deagglomerated powders produced from the mixing step was injection molded to produce green parts, followed by removing the binder system by undergoing the debinding step and finally, sintering the brown parts to produce final parts with high sintered density. The handling of specimen between the interval times of processing step must be made in full caution since the specimen is fragile and any mishandling can lead to the broken parts easily. Thus, a part with high density, which reflects its strength, is required to ensure the successful production for the whole system.

Some important parameters of injection molding step that ensures the production of defect free and high density parts are powder loading, injection rate, holding pressure and injection temperature. Powder loading is the volumetric ratio between metal powder used towards the binder system and usually denoted in % vol. Higher powder loading would be beneficial since the compactness of the feedstock is increased while reducing the voidage between powder particles. Injection rate, which reflects its injection speed, is the velocity of the advancing screw, the axial screw speed and only effective during the injection stage. It has an important effect since it controls pressure transmission during holding pressure stage [3]. In terms of economy (energy savings) and part quality, injection speed should be selected as high as practical. Meanwhile, holding pressure is the pressure exerted on a molded part during a secondary pressure stage. Increasing holding pressure means better compensation of volumetric shrinkage during cooling stage, besides giving better compression of the melt [3]. Injection temperature which effects the melt temperature, has an simultaneous change toward the thermodynamic properties of the molten feedstock, such as viscosity, enthalphy and specific volume [3]. Control of injection temperature is important to ensure volume quantity of the melt and pressure transmission during injection stage is optimized.

Recently, several researchers have done optimization process for the injection molding step for various feedstock. Focusing on Taguchi Method, the optimum injection molding parameters have been found for stainless steel SS 316L [4, 5], and titanium [6] powders. Each of them uses classical approach of static experimental design, without considering the power input signal into their consideration. Thus, to overcome this research gap, the aim of this study is to optimize injection molding parameters for WC-Co feedstock with dynamic response approach. This work is done by varying the power input, which can stimulate the energy transformation to the output function based on its ideal function. The best green density produced is expected to give best properties in the final sintered parts.

2.0 EXPERIMENTAL

2.1 Materials and sample preparation methods

WC (D50 of 8.6 µm) and Co (D50 of 1.6 µm) powders used in this study were supplied by Eurotungstene. com and Inframat Advanced Materials, LLC., respectively. The WC-9Co alloy was then formed by wet milling the elemental powders in ethanol media. Then, the powder was mixed with palm stearin and polyethylene binder system with the ratio of 60:40. The mixing process is conducted by using sigma blade mixer at a speed of 40 rpm and at temperature of 150 oC for 1.5 hours. The powder loading is varied at 59, 61 and 63% vol.

The feedstock was then injection-molded into a tensile shape part by using a Battenfeld 250 CDC injection molding machine with various injection molding parameters. Table 1 summarizes all the control factors and their levels, noise factor and the response factor for the injection molding step.

Table 1 Factors and levels for analysis

Factor / Level			1	2	3
Control factors	A	Injection rate (ccm/s)	10	20	--
	B	Powder loading (%vol)	59	61	63
	C	Injection temperature (°C)	140	150	160
	D	Holding pressure (bar)	700	1800	1900
Noise factor	E	Humidity level	Morning	Evening	--
Response factor	y	Green density	Level on operating condition		
Energy input	M	Injection pressure (bar)	1400	1500	1600

Then, the density of the tensile shape of the green part was tested based on the Archimedes Method, according to MPIF 42 Standard.

2.2 Taguchi Methods

Based on Table 1, L18 orthogonal array was used in this study. Figure 1 represents the P diagram for the system, associated with its ideal function. Appendix A shows the complete experimental setup including the orthogonal array of inner and outer array.

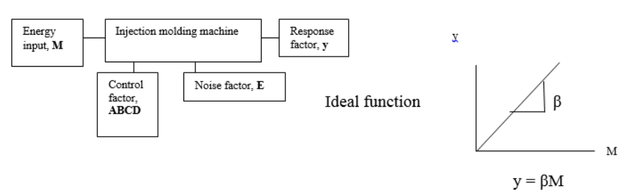
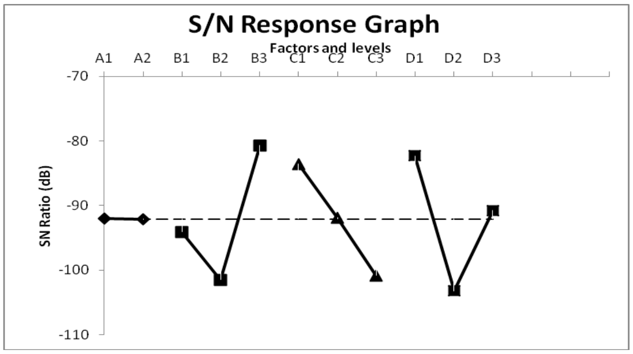


Figure 1 P diagram and ideal function

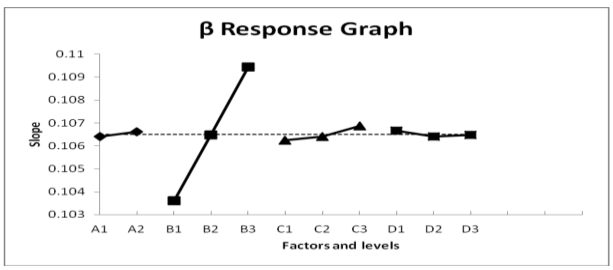
3.0 RESULTS AND DISCUSSION

Figure 2 represents the S/N and β response graph for the system. Based on the two step optimization method, for higher efficiency, higher sensitivity is desirable [7]. Once higher efficiency is established, the opportunities to reduce cost, size and weight of the subsystem will exist [8].

The first step is to maximize S/N. According to Figure 2(a), the maximum point lies at point B3C1D1, while for point A, the line is quite horizontal and significantly hard to determine the maximum point. Thus, the second step is to adjust the β slope, to see which A point gives more significant effect. From Figure 2(b), the maximum point for signal line lies at point A2, making the overall optimum combination for injection molding step became A2B3C1D1.



(a)



(b)

Figure 2 (a) S/N and (b) β Response Graph

The following Table 2 represents the optimum condition associated with their actual values for each processing parameters. Next, is to see the significance of each variables to the performance of response function, which is green density. This step involves creating Response Tables for S/N and β slope (sensitivity), as can be seen from Table 3.

Table 2 The optimum 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

Table 3 Respons table for S/N values

	A	B	C	D
	-92.04	-94.08	-83.56	-82.27
	-92.15	-101.5	-91.87	-103.23
		-80.70	-100.85	-90.78
Δ	0.11	20.81	17.29	20.96
Rank	4	2	3	1

As seen in Table 3, the significance for each factor is determined by looking at the rank Δ numbered accordingly. The difference (Δ) is detected between the highest and lowest point for S/N values. 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. Holding pressure makes density uniformity in the cavity, whereas if the holding pressure is not enough sufficiently, slumps can occur on the surface [9]. On the other hand, if too high holding pressure is applied, sticking of the molded part to the cavity could happen. Thus, a moderate 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 [10]. Hence, the density of the green parts increases. This finding is quite similar with work [4], 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 [10]. 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 4 Prediction values for S/N and *B*

Predictions	S/N (dB)	*β* (dB)
Initial	-75.68	0.103
Optimum	-62.39	0.109
Gain	13.28	5.84

According to the prediction values for S/N and β as seen in Table 4, it shows the positive increment of 13.28 dB for the S/N value and 5.84% gain for β value, between the initial condition (before optimization) and optimum condition (after optimization). The positive increment proves the significance or successful optimization done on the process. Next, a confirmation run is needed in prder to validate the prediction values made beforehand. The confirmation result is shown in the following Table 5.

Table 5 Comparison of S/N and B Values between Predictions and Confirmation Runs

	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 5, it can be seen that there is a positive increment at the S/N values as much as 4.55 dB and 4.95% gain for β value for confirmation run. Although there is a difference between the predictions and confirmation values, but it can still be accepted since there exist positive increment for the S/N value and lies within ±0.5% for the β value. The major reason behind the difference probably due to the noise factor selection factor, which believed to be less suitable and hence to be resyntehesis. However, the optimized system is proven to be better, and more robust to the surrounding, despite having best green density amongst all.

4.0 CONCLUSION

Taguchi method, with dynamic response optimization has been carried out to develop optimum processing parameter for injection molding cemented carbide parts. Based on the two step optimization result, it has been demonstrated that the most influencing factor to the green density is holding pressure, followed by powder loading, injection temperature and lastly injection rate, which is very less significant and can be neglected. The green part exhibited best density by following this optimum processing parameters, A2B3C1D1, that are flowrate 20 ccm/s, powder loading at 63% vol., injection temperature at 140 oC, and holding pressure at 1700 bar. Based on the confirmation run, it is proven that the increment has a gain as much as 4.95%, compared to the initial design. Thus, the result is acceptable and believed to be robust to the ambient's humidity level at all energy input variations (injection pressure). Future efforts will involve debinding and sintering of green parts with this optimum condition to get the best sintered parts with desired properties.

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