SINTERING PARAMETER OPTIMIZATION WITH QUALITY ENGINEERING TECHNIQUE: BEST FLEXURE STRENGTH

Khairur Rijal Jamaludin[1,2*], Norhamidi Muhamad[2], Mohd Nizam Ab. Rahman[2], Sufizar Ahmad[2,3], Mohd Halim Irwan Ibrahim[2,3], Murtadhahadi[2], Nor Hafiez Mohamad Nor[2,4]

[1] College of Science & Technology
Universiti Teknologi Malaysia
International Campus, 54100 Kuala Lumpur, Malaysia

[2] Faculty of Engineering & Architecture,
National University of Malaysia, 43600 Bangi, Selangor, Malaysia

[3] Department of Mechanical & Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

[4] Faculty of Mechanical Engineering,
Universiti Teknologi MARA, 40450 Shah Alam, Selangor Darul Ehsan, Malaysia

Introduction

Metal injection moulding (MIM) is a net-shape process which combines the versatility of plastic injection moulding with the strength and integrity of machined, pressed or otherwise manufactured small, complex, metal parts. The process combines the design freedom of plastic injection moulding with material properties near that of wrought metals.

Optimisation of the processing parameter is essential to obtain high quality final parts. Rigid final part is essential to maintain an excellent performance of the powder metallurgy products especially for the tough application such as automotive, defence and industrial tools. Many earlier studies about sintering of MIM part are concerning with microstructures, densification, and sintering atmosphere (Li et al. 2003 [2]; Fu et al. 2005 [3]; Koseski et al. 2005 [4]; Suri et al. 2005 [5]; Berginc et al. 2006 [6]). Sintering parameters were optimised by adjusting the sintering variables without using any design of experiment (DOE) methodology. Optimisation of the sintering parameter for the final part densification has been discussed by Ji et al. (2001) [9] and Jamaludin et al. (2009) [10].

Experimental

MPIF 50 standard tensile bar is used as a specimen. Water atomised 316L stainless steel powder with D_{50} of 7.157 µm, pycnometer density of 7.90 g/cm^3 is mixed with 73 % PEG weight of polyethylene glycol (PEG) and 25 % weight of polymethyl methacrylate (PMMA).

The main variables involved in this study are as shown in Table 1, while the orthogonal array used for the experiments is as shown in Table 2. The factor level for each variable shown in Table 1 refers to the maximum and minimum limit that influences the final quality of the specimens.

Table 1 Factor level (variables) in the experiment

	Factor	Level 0	Level 1	Level 2
A	Sintering Temperature (°C)	1340	1360	1380
B	Dwell time (minute)	60	120	240
C	Heating rate (°C/min)	6	8	10
D	Cooling rate (°C/min)	6	8	10

Results

Table 2: Orthogonal array and flexure strength

	Orthogonal array L_9 (3^4)				Replication (flexture strength (MPa))				
Eksperiment	A	B	C	D	1	2	3	4	$\bar{y}$
1	0	0	0	0	892.5	893	892.7	892.7	892.8
2	0	1	1	1	735.8	736	735.88	735.88	735.88
3	0	2	2	2	699	698.50	698.71	698.71	698.71
4	1	0	1	2	662.1	661.00	661.55	661.55	661.55
5	1	1	2	0	781.7	782.00	781.82	781.82	781.82
6	1	2	0	1	704.9	706.00	705.43	705.43	705.43
7	2	0	2	1	753.1	752.00	752.53	752.53	752.53
8	2	1	0	2	714	715.00	714.49	714.49	714.49
9	2	2	1	0	682	680.00	680.65	680.65	680.65
								Ave.	735.98
								Max	892.74
								Min	661.55

Table 3: ANOVA for the flexture strength at α = 0.005

	Degree of freedom, f_n	Sum squared, S_n	Variance, v_n	Variance ratio, F_n	Critical F value	% Contribution, P_n
A	2	28514.35	14257.18	109939.6	$F_{0.005, 2, 27}$=6.4885	18.59
B	2	34041.15	17020.58	131248.6	$F_{0.005, 2, 27}$=6.4885	22.20
C	2	37948.39	18974.19	146313.3	$F_{0.005, 2, 27}$=6.4885	24.75
D	2	52836.86	26418.43	203717.1	$F_{0.005, 2, 27}$=6.4885	34.46
error	27	3.50	0.129682			0.00
Total	35	153344.26				100

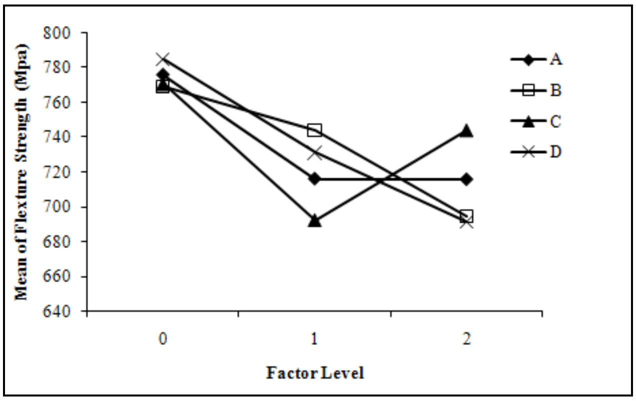

Fig. 1 Response plot for the best flexure strength

Table 4: Optimum sintering parameter for the best flexure strength

Optimum parameter: A0 B0 C0 D0 (Sintering temperature, 1340 °C; Dwell, 60 minit; Heating rate, 6 °C/minit; Cooling rate, 6 °C/minit)					
Optimum performance: 892.74 MPa Confidence interval: ± 0.307 at confidence level of 90 % ($\alpha = 0.1$) Range: 892.43 MPa $< \mu <$ 893.05 MPa					
	Confirmation experiment (MPa)				
Repeat	1	2	3	4	average
(MPa)	892.48	893.00	892.74	892.74	892.74

Conclusions

Sintering variables are highly significant to the flexure strength, at a very high significant level of $\alpha = 0.005$. Cooling rate is the important variable for the best flexure strength, followed by the heating rate, dwell time and sintering temperature. Thus, the results shown in this paper that the diminution of the flexure strength is obvious when the cooling rate is increased.

REFERENCES

[1] Li, S., Huang, B., Li, D., Li, Y. Liang, S. & Zhou, H. Inflence of sintering atmosphere on densification process of injection moulded gas atomised 316L stainless steel. *Powder Metallurgy.* Vol 46 No 3 (2003) 241-245.

[2] Fu, G., Loh, N.H., Tor, S.B., Tay, B.Y., Murakoshi, Y. & Maeda, R. Injection molding, debinding and sintering of 316L stainless steel microstructures. *Applied Physics A: Materials Science and Processing*. Vol 81 (2005) 495-500.

[3] Koseski, R.P., Suri, P., Earhardt, N.B., German, R.M. & Kwon, Y.S. Microstructure evolution of injection molded gas and water atomized 316L stainless steel powder during sintering. *Materials Science and Engineering.* Vol A390 (2005) 171-177.

[4] Suri, P., Koseski, R.P. & German, R.M. Microstructural evolution of injection molded gas and water atomized 316L stainless steel powder during sintering. *Materials Science and Engineering.* Vol A402 (2005) 341-348.

[5]Berginc, B., Kampuš, Z. & Šuštaršič, B. The use of the Taguchi approach to determine the influence of injection-moulding parameters on the properties of green parts. *Journal of Achievements in Materials and Manufacturing Engineering*. Vol 15 No 1-2 (2006) 63-70.

[6] Khairur Rijal Jamaludin, Norhamidi Muhamad, Mohd Nizam Ab. Rahman, Sri Yulis M. Amin, Murtadhahadi. The optimisation of molding parameter for reducing the Metal Injection Molding green part defects (in Malay). *The Journal of The Institution of Engineers, Malaysia*. Vol. 69 No. 2 (2008a) 40-46.

[7] Khairur Rijal Jamaludin, Norhamidi Muhamad, Sri Yulis M. Amin, Mohd Nizam Ab. Rahman, Muhammad Hussain Ismail, Murtadhahadi. Injection Molding Parameter Optimization Using Taguchi Method For Highest Green Strength For Bimodal Powder Mixture with SS316L in PEG, and PMMA. *Advances in Powder Metallurgy and Particulate Materials* (2008b)

[8] Ji, C.H., Loh, N.H., Khor, K.A. & Tor, S.B. Sintering study of 316L stainless steel Metal Injection Molding parts using Taguchi method: final density. *Materials Science and Engineering.* A311 (2001) 74-82.

[9] Jamaludin K. R., Muhamad N., Ab. Rahman M. N., Amin S. Y. M., Ahmad S., Ibrahim M.H.I. Sintering Parameter Optimisation of the SS316L Metal Injection Molding (MIM) Compacts for Final Density Using Taguchi Method. *Proceeding of the 3rd International Symposium, South East Asian Technical University Consortium (SEATUC)*, 2009.

[10] Park, S.H. *Robust design and analysis for quality engineering.*UK: Chapman & Hall (1996)