Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 11 (10): 1833-1838, 2011
ISSN 1812-5654 / DOI: 10.3923/jas.2011.1833.1838

Injection Molding Parameter Optimization of Titanium Alloy Powder Mix with Palm Stearin and Polyethylene for Multiple Performance Using Grey Relational Analysis

[1,2]N.H. Mohamad Nor, [1]N. Muhamad, [1]A.K. Ariffin, [1]M. Ruzi, [3]K.R. Jamaludin and [4]A. Sufizar
[1]Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[2]Department of Mechanical and Material Engineering, Faculty of Engineering and Built Environment,
Universiti of Kebangsaan, 43600 Bangi, Selangor, Malaysia
[3]Department of Mechanical Engineering, College of Science and Technology,
Universiti of Teknologi, City Campus, 54100 Kuala Lumpur, Malaysia
[4]Department of Mechanical and Manufacturing, Universiti Tun Hussein Onn Malaysia,
86400 Batu Pahat, Johor, Malaysia

Abstract: This paper outlines the optimization the process of injection molding parameters for feedstock of titanium alloy powder and palm stearin binder using grey relational analysis method. A Grey Relational Grade (GRG) obtained from the Grey Relational Analysis (GRA) is used to solve the injection molding operations with the multiple performance characteristic. The L^{27} (3^{13}) of orthogonal array of Taguchi method were performed. Defects, strength and density are important characteristics in determine the quality of the green part. Using these characteristics, the injection pressure, injection temperature, powder loading, mold temperature, holding pressure and injection speed are optimized in the study. From the analysis of variance (ANOVA), the injection temperature has the highest contribution to the quality of green part followed by injection pressure, powder loading, mold temperature, injection rate and holding pressure.

Key words: Metal injection molding, palm stearin, titanium powder, grey relational analysis, taguchi method, green part

INTRODUCTION

Successful production of parts by the Metal Injection Molding (MIM) process is closely related to the formulation of the binder for use the powders. Selection a palm stearin as a binder system was started by Iriany (Iriany *et al*., 2001) and it is believed that can be replace the conventional binder system which mainly comprise of three to four components. Research on palm stearin in MIM is still new and most of researchers mixing with stainless steel powder (Iriany *et al*., 2001; Istikamah *et al*., 2006). Characterization and rheological procedures have been done previously to show that palm stearin binder can be successfully mixed with titanium alloy to produce a homogeneous feedstock (Mohamad Nor *et al*., 2009).

After selection of powder-binder system, mixing process and preparing the homogeneous feedstock, the most crucial process in MIM is injecting the feedstock to produce high quality of the green part (German and Bose, 1997). Work by other authors (Thomas and Evans, 1988; Loh *et al*., 2001) found that the defects which appeared in debinding or sintering were not necessary due to debinding or sintering but may have their origins in injection molding itself. Thus, during injection, controlling the quality of green part is of great importance to ensure the reliability of the products.

For example, defects in green part such as cracks are very difficult to detect immediately after molding and they become apparent only after debinding and sintering (Miura *et al*., 1995). Besides that, the determination highest density of green compact plays an important role. Molded parts may appear to be intact and free of visible defects, but the density gradient in them may cause dimensional variation of distortion during sintering. By verifying the molding parameters, molding defects can be overcome and green parts quality will increase (Loh *et al*., 2001).

This paper reported the use of Taguchi method and grey relational analysis to optimize the injection molding operation for feedstock of titanium alloy and palm stearin with multiple performance characteristic of green part including defects, strength and density. Taguchi method is a systematic application of design and analysis for experiments. It has proved to be an effective approach to

Corresponding Author: N.H. Mohamad Nor, Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

produce high quality products at a relatively low cost. However, the original Taguchi method has been designed to optimize a single performance characteristic. Zu and Lin (1997) optimized the mechanical properties of injection molded W-4.9%Ni-2%Fe in debinding. Ji *et al.* (2001) sintered the stainless steel metal injection molding parts using Taguchi method for final density. Jamaludin *et al.* (2009) optimized the injection parameter of water atomized SS316 L powder with design of experiment method for best sintered density. Vlachos and Chang (2009) optimized the metal powder-mixing parameters for chemical homogeneity and agglomeration. All the above methods cannot be applied to directly solve the operation of optimization problem with multiple performance characteristics. For injection molding process operations, defects are lower-the-better performance characteristic. However, strength and density of green part is a higher-the-better performance characteristic. As a result, improvement of one performance characteristic may lead to a degradation of another performance characteristic. In this paper, the Grey Relational Analysis (GRA) is used to investigate the multiple performance characteristic in the injection molding process of MIM.

Grey relational analysis (GRA): Deng (1989) and Tsao (2009) proposed the GRA to fulfill the crucial mathematical criteria for dealing with a poor, incomplete, and an uncertain system in order to improve the flexibility and the ability of the Taguchi method. Through the GRA, a Grey Relational Grade (GRG) is obtained to evaluate the characteristics of the multiple performances. As a result, the optimization of the complicated multiple response can be converted into the optimization of a single GRG. The Grey-Taguchi method was established for combining both the GRA and the Taguchi method and this method has been successfully applied to optimize the multiple responses of complicated problems in the manufacturing processes. The GRG is obtained from the average of the Grey Relational Coefficient (GRC) of the normalized response (Tsao, 2009; Kopac and Krajnik, 2007). If the expected data sequence is of the form where the-higher-the-better, then the original sequence can be normalized as:

$$x_i^*(k) = \frac{x_i^o(k) - \min x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \qquad (1)$$

where, x^0_i (k) is the original sequence, x^*_i (k) is the sequence after the data preprocessing, max x^0_i (k) the largest value of x^0_i (k) and min x^0_i (k) implies the smallest value of x^0_i (k). The larger normalized results correspond to a better performance and the best-normalized result should equal to 1 (Deng, 1989).

When the form the-smaller-the-better becomes the expected value of the data sequence, the original sequence can be normalized as:

$$x_i^*(k) = \frac{\max x_i^o(k) - x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \qquad (2)$$

The GRCs are calculated to express the relationship between the ideal (best) and the actual results of the experiment. The GRC ζ_i (k) can be expressed as:

$$\zeta_i(k) = \frac{\Delta\min + \xi\Delta\max}{\Delta_{oi}(k) + \xi\Delta\max} \qquad (3)$$

where, Δ_{0i} is the deviation sequence of the reference sequence (x_o) and the comparability sequence (x_i), i.e. $\Delta_{0i} = \|x^*_0(k) - x^*_i(k)\|$, where $x_0(k)$ is the ideal result (=1) and ζ is the distinguishing coefficient set between zero and unity; in this study, it was set to $\zeta = 0.9$ (Kopac and Krajnik, 2007). Δmax being the largest value of Δ_{0i} and the Δmin as the smallest value of Δ_{0i}. Next, GRG of $\xi(x_o, x_i)$ is computed by averaging the GRC corresponding to each quality characteristic is defined as:

$$\xi(x_o, x_i) = \frac{1}{n}\sum_1^n \xi_i(k) \qquad (4)$$

where, n is the number of quality performance. The GRG shows the correlation between the reference sequence and the comparability sequence. The evaluated GRG fluctuates from 0-1 and equals to 1 if these two sequences are identically coincidental.

The GRG is ranked for each experiment. The higher the GRG, it implies that the corresponding experimental result is closer to the ideal normalized value. In other words, the larger the GRG, the better will be the characteristic of the multiple performance.

MATERIALS AND METHODS

Feedstock preparation: The particle of titanium alloy (Ti-6Al-4V) in spherical shape with pycnometer density 4.38 g cm^{-3} was mixed with 60 wt% of PS and 40 wt% of Polyethylene (PE). The mixing process was done in a sigma blade at 150°C for 1 h. The feedstock was then injected using Battenfeld, BA 250 CDC injection molding machine. Figure 1 illustrates schematic diagram of the tensile bar cavity.

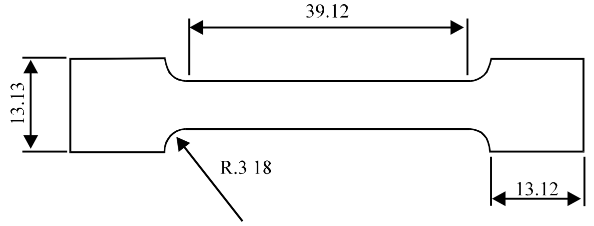

Fig. 1: Dimension (mm) of Tensile bar cavity with thickness of 3.17 mm

Design of Experiment (DOE): In this paper, six injection molding process parameters were investigated i.e., injection pressure, injection temperature, powder loading, mold temperature, holding temperature and injection rate. Other significant effects such as the interaction between three parameters of injection pressure, injection temperature, powder loading were also investigated. The selection injection molding parameters along with their levels are given in Table 1. After injection molding process, three quality objectives of the green part are chosen including the defects, strength and density. Typically, lowest value of defects whilst on the other hand the highest value of strength and density are desirable. Amount of score for defects obtained from Table 2.

RESULTS AND DISCUSSION

Best experimental run: The experiment results for the defects, strength and density are listed in Table 3. The GRG for each experiment of the L_{27} orthogonal array was listed by applying Eq. 3 and 4.

In this study, a linear data preprocessing method for the green defects is the-smaller-the-better and is expressed as Eq. 2 whilst on the other hand green strength and density is the-higher-the better and is expressed as Eq. 1. According to performed experiment design, it is clearly observed that the injection molding parameters setting of the experiment no. 14 has the highest GRG. Thus, the fourteenth experiment gives the best multi-performance characteristics among the 27 experiments.

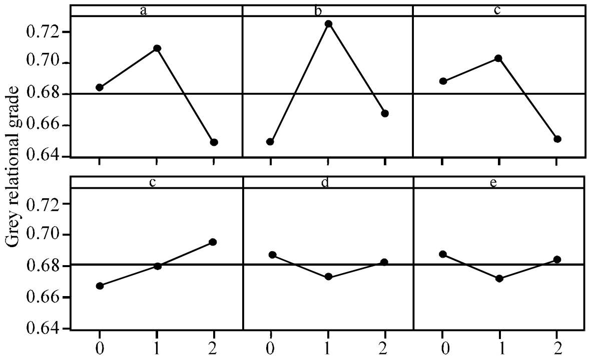

Fig. 2: Response graph of GRG

Table 1: Injection molding parameters for three levels taguchi design

Parameter	Symbol	Level 0	Level 1	Level 2
Injection pressure (bar)	A	350	450	550
Injection temperature (°C)	B	130	140	150
Powder Loading (vol%)	C	63	65	67
Mold Temperature (°C)	D	40	45	50
Holding Pressure (bar)	E	500	600	700
Injection Rate (ccm s-1)	F	10	15	20

Table 2: Rating for defects

Defects	Rating
Weld lines	1.0
Incomplete filling	3.0
Binder separation	0.5
Binder burn out	0.5
Green broken during mold opening	3.0
Slumps	3.0
Deflection	3.0
Chipping at gate	2.0
Flashing	0.5
Green broken during ejection	3.0

Most influence factor: Using the same method, calculations were performed for each factor level and response table was generated, as shown in Table 4. Since the GRG represented the level of correlation between the reference and the comparability sequences, the larger GRG means the comparability sequence exhibits a stronger correlation with the reference sequence. Therefore, the comparability sequence has a larger value of GRG for the green defects, strength and density. Based on this premise, this study selects the level that provides the largest average response.

Figure 2 shows the response graph of the GRG of each injection parameter at a different level respectively. It is clearly shown that the optimum combination of the injection molding parameter to fulfill the requirement of the quality of the green part is A1 B1 C1 D2 E0 F0. This means that the injection pressure at 450 bar; injection temperature, 140°C; powder loading, 65 vol.%; mold temperature, 50°C; holding pressure, 500 bar and the injection rate at 10 ccm/s are the optimum level.

The influence of each injection molding parameter can be more clearly presented by means of the GRG graph. When the last column of Table 4 was compared, it is observed that the difference between the maximum and minimum value of the GRG for factor B is bigger among other factors. This indicates that the injection temperature has stronger effect on the multi-performance characteristics of green part followed by injection pressure, powder loading, mold temperature injection rate

Table 3: Taguchis L27 (313) Orthogonal Array (OA) demonstrate the quality characteristic

	Parameter													Measured parameter				
	1	2	3	4	5	6	7	8	9	10	11	12	13					
Run	A	B	A X B	A X B	C	A X C	A X C	B X C	D	e	B X C	E	F	Defects	Strength (MPa)	Density (g/cm^3)	GRG ξ (x_o,x_i)	Rank
1	0	0	0	0	0	0	0	0	0	0	0	0	0	3.9	2.66	1.4520	0.6299355	21
2	0	0	0	0	1	1	1	1	1	1	1	1	1	3.9	2.44	1.4600	0.6238726	23
3	0	0	0	0	2	2	2	2	2	2	2	2	2	3.5	2.59	1.4604	0.6758208	16
4	0	1	1	1	0	0	0	1	1	1	2	2	2	4.0	2.51	1.4694	0.6731573	17
5	0	1	1	1	1	1	1	2	2	2	0	0	0	4.5	3.06	1.4592	0.7148967	8
6	0	1	1	1	2	2	2	0	0	0	1	1	1	3.6	2.72	1.4570	0.6769080	15
7	0	2	2	2	0	0	0	2	2	2	1	1	1	3.5	3.01	1.4517	0.7391489	5
8	0	2	2	2	1	1	1	0	0	0	2	2	2	4.0	2.85	1.4581	0.6798102	14
9	0	2	2	2	2	2	2	1	1	1	0	0	0	2.8	2.61	1.4581	0.7425636	4
10	1	0	1	2	0	1	2	0	1	2	0	1	2	3.4	2.33	1.4697	0.6965468	12
11	1	0	1	2	1	2	0	1	2	0	1	2	0	3.3	2.97	1.4601	0.7716392	3
12	1	0	1	2	2	0	1	2	0	1	2	0	1	4.8	2.62	1.4578	0.5955167	24
13	1	1	2	0	0	1	2	1	2	0	2	0	1	3.0	2.60	1.4715	0.7841734	2
14	1	1	2	0	1	2	0	2	0	1	0	1	2	2.8	2.99	1.4574	0.8218413	1
15	1	1	2	0	2	0	1	0	1	2	1	2	0	3.1	2.49	1.4633	0.7110038	9
16	1	2	0	1	0	1	2	2	0	1	1	2	0	5.2	2.90	1.4721	0.7088586	10
17	1	2	0	1	1	2	0	0	1	2	2	0	1	3.2	2.58	1.4610	0.7025694	11
18	1	2	0	1	2	0	1	1	2	0	0	1	2	4.6	2.54	1.4582	0.5930708	25
19	2	0	2	1	0	2	1	0	2	1	0	2	1	4.7	2.39	1.4698	0.6246303	22
20	2	0	2	1	1	0	2	1	0	2	1	0	2	4.1	2.64	1.4608	0.6441842	19
21	2	0	2	1	2	1	0	2	1	0	2	1	0	4.9	2.49	1.4606	0.5829687	26
22	2	1	0	2	0	2	1	1	0	2	2	1	0	4.5	2.70	1.4712	0.6882306	13
23	2	1	0	2	1	0	2	2	1	0	0	2	1	4.9	2.57	1.4808	0.7390398	6
24	2	1	0	2	2	1	0	0	2	1	1	0	2	4.5	2.57	1.4776	0.7204189	7
25	2	2	1	0	0	2	1	2	1	0	1	0	2	4.2	1.94	1.4754	0.6485097	18
26	2	2	1	0	1	0	2	0	2	1	2	1	0	4.5	2.83	1.4531	0.6333274	20
27	2	2	1	0	2	1	0	1	0	2	0	2	1	5.6	2.47	1.4618	0.5603989	27
																Σ	0.6809	

Table 4: Response table for GRG

Level	A	B	C	D	E	F
0	0.684	0.6495	0.6881	0.6673	0.687	0.687
1	0.7095	0.7255	0.7035	0.68	0.6729	0.6718
2	0.6491	0.6676	0.651	0.6952	0.6827	0.6837
min-max	0.0604	0.0761	0.0525	0.0279	0.0141	0.0152
Rank	2	1	3	4	6	5

and holding pressure. If the number of injection molding parameters increases, the importance of the controllable factors on the multi-performance characteristics will be determined by ordering max–min grade relational values.

Additionally, Table 5 gives the results of the analysis of variance (ANOVA) for the multi performance characteristic using the calculated value from GRG. According to ANOVA, the factor B, the injection temperature with 26.37% of contribution is the most significant controlled parameters for the injection molding process, the injection pressure with 15.33% contribution, the powder loading with 12.14%, and the mold temperature with 3.20% of contribution. The contribution of holding pressure and injection rate are very small. However, the interaction between the injection pressure and powder loading (factor AXC) shows a contribution of 18.43% followed by interaction between injection pressure and injection temperature (factor AXB) with contribution of 17.64% and the interaction between injection temperature and powder loading (factor BXC) with contribution of 4.08% which are in fact, the most important factors that cannot be neglected.

Furthermore, since all factors have a confident level greater than 90% thus all factors were used to calculate the optimum performance of GRG. This is shown in Table 6 where the optimum performance is at 0.7878 compared to the current grand average performance of 0.6809 (Table 3).

The confident interval is calculated with Eq. 5 (Roy, 2001):

$$CI = \pm\sqrt{\frac{F_a(f_1,f_2)xV_e}{n_e}} \tag{5}$$

where, $F_\alpha(f_1,f_2)$ is the variance ratio for DOF of f_1 and f_2 at level of significance α. The confidence level is (1-α), f_1 is the DOF of mean (usually equal to 1) and f_2 is the DOF of the error. Variance for error terms is V_e and number of equivalent replication is given as ratio of number of trials (1+DOF of all factors used in the estimate). The confident interval will indicate the maximum and minimum levels of the optimum performance and it is shown as the expected result as optimum performance in Table 6.

Table 5: ANOVA results

Columns	Factors	Parameters	DF	Sum squared	Variance	F	Contribution (%)
1	A	Injection Pressure	2	0.016546	0.008273	194.6600	15.33
2	B	Injection Temperature	2	0.028411	0.014206	334.2471	26.37
3	AXB	Interaction 1x2	4	0.019112	0.004778	112.4235	17.64
5	C	Powder Loading	2	0.013119	0.006560	154.3412	12.14
6	AXC	Interaction 1x5	4	0.019967	0.004992	117.45290	18.43
8	BXC	Interaction 2x5	4	0.004549	0.001137	26.75882	4.08
9	D	Mold Temperature	2	0.003522	0.001761	41.43529	3.20
12	E	Holding Pressure	2	0.000940	0.000470	11.05882	0.80
13	F	Injection Rate	2	0.001155	0.000578	13.58824	1.00
	Error		2	0.000085	0.0000425		1.03
	Total		26	0.107407			100.00

Table 6: Estimation of performance as the optimum design

A1B1C1D2E0F0

Optimum performance calculation:

$$\overline{T}+(\overline{A1}-\overline{T})+(\overline{B1}-\overline{T})+(\overline{C1}-\overline{T})+(\overline{D2}-\overline{T})+(\overline{E0}-\overline{T})+(\overline{F0}-\overline{T})$$

0.6809+(0.7095-0.6809)+(0.7255-0.6809)+(0.6881-0.6809)+(0.6952-0.6809)+(0.6870-0.6809)+(0.6870-0.6809) = 0.7878

Current grand average performance	:	0.6809
Confident interval at 95% confidence level	:	±0.01321
Expected result at optimum performance, μ	:	$0.7446<\mu<0.8010$

Table 7: Confirmation test

	Experiment			GRC			
Run	Defects	Strength (MPa)	Density (g/cm^3)	Defects	Strength (MPa)	Density (g/cm^3)	GRG
1	3.2	2.92	1.46	0.863014	0.889	0.571	0.775
2	4.1	2.89	1.47	0.659686	0.858	0.707	0.742
3	3.4	3.01	1.45	0.807692	0.957	0.459	0.741
4	3.4	2.99	1.47	0.807692	0.939	0.707	0.818
5	3.7	3.05	1.48	0.736842	0.995	0.969	0.900
6	2.9	3.04	1.45	0.961832	0.985	0.459	0.802
7	3.3	2.96	1.45	0.834437	0.913	0.474	0.740
8	3.2	2.99	1.48	0.863014	0.939	0.969	0.924
9	3.0	2.77	1.46	0.926471	0.778	0.535	0.747
10	3.1	2.82	1.47	0.893617	0.810	0.702	0.802
Average GRG = 0.799							

Confirmation experiments were conducted by running another ten replications at combined setting of A1, B1, C1, D2, E0 and F0. Table 7 shows the results and it was found that the average green strength obtained from the confirmation experiment fell within the prediction 90% confident interval.

CONCLUSION

Effect and optimization of process parameters in injection molding of Ti-4V-6Al powder and binders of palm stearin and polyethylene to produce the quality of green part were successfully investigated through Taguchi Method and GRA. The optimum injection parameter were found to be A1, B1, C1, D2, E0 and F0 corresponding to 450 bar of injection pressure, 140°C of injection temperature, 65% vol.of powder loading, 50°C of mold temperature, 500 bar of holding pressure, and 10ccm/s of the injection rate. Through ANOVA, the injection temperature is the most significant factor with 26.37% of contribution. The Interaction of factors between injection pressure and powder loading has shown a contribution rate of 18.43%, which must not be neglected to produce the green part with high quality.

ACKNOWLEDGMENTS

The authors would like to thank Universiti Teknologi MARA for the research grant, 600-IRDC/ST/FRGS 5/3/1300 and Ministry of Higher Education, Malaysia and Universiti Kebangsaan Malaysia for the PhD scholarship.

REFERENCES

Deng, J.L., 1989. Introduction of grey system. J. Grey Syst., 1: 1-24.

German, R.M. and A. Bose, 1997. Injection Molding of Metals and Ceramics. Princeton, Metal Powder Industries Fedration, New Jersey.

Iriany, N.M., J. Sahari and A.K. Arifin, 2001. Stability of metal injection molding feedstock containing palm oil. J. Inst. Mater. Malaysia, 2: 71-83.

Istikamah, S., M.O. Afian, M.I. Hussain and H. Zahurin, 2006. Development of composite binder for metal injection moulding process by using palm sterin and polyethylene binder system. Proceedings of the 6th National Polymer Symposium, Kuala Lumpur.

Jamaludin, K.R., N. Muhamad, M.N.A. Rahman, S. Ahmad, M.H.I. Ibrahim and N.H. Mohamad Nor, 2009. Optimizing the injection parameter of water atomized SS316L powder with design of experiment method for the best sintered density. Chiang Mai J. Sci., 36: 349-358.

Ji, C.H., N.H. Loh, K.A. Khor and S.B. Tor, 2001. Sintering study of 316L stainless steel metal injection moulding parts using taguchi method: Final density. Mater. Sci. Eng. A, 311: 74-82.

Kopac, J. and P. Krajnik, 2007. Robust design of flank milling parameters based on Grey-Taguchi method. J. Mater. Process. Technol., 191: 400-403.

Loh, N.H., S.B. Tor and K.A. Khor, 2001. Production of metal matrix composite part by powder injection molding. J. Mater. Process. Technol., 108: 398-407.

Miura, R., Y. Endo, H. Madarame and S. Takamori, 1995. On the occurrence and the prevention of a molding defects in metal injection molding. Adv. Powder Metallurgy Particulate Mater., 2: 147-168.

Mohamad Nor, N.H., N. Muhamad, K.R. Jamaludin, S. Ahmad and M.H.I. Ibrahim, 2009. Characterisation of titanium alloy feedstock for metal injection moulding using palm stearin binder system. Proceedings ot the International Conference on Advance in Materials and Processing Technologies, Kuala Lumpur.

Roy, R.K., 2001. Design of experiments using the taguchi approach. John Willey and Sons, New York.

Thomas, M.S. and J.R.G. Evans, 1988. Non-uniform shrinkage in ceramic injection-molding. Br. Ceram. Tarns. J., 87: 22-26.

Tsao, C.C., 2009. Grey-taguchi method to optimize the milling parameters of aluminum alloy. Int. J. Adv. Manuf. Technol., 40: 41-48.

Vlachos, N. and I.T.H. Chang, 2009. Optimization of metal powder-mixing parameters for chemical homogeneity and agglomeration. Int. J. Powder Metallurgy, 45: 19-28.

Zu, Y.S. and S.T. Lin, 1997. Optimizing the mechanical properties of injection molded W-4.9%Ni-2%Fe in debinding. J. Mater. Process. Technol., 71: 337-342.