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ORIGINAL ARTICLES

Optimizing Injection Parameter of Metal Injection Molding Processes Using the Feedstock of 16 µm Stainless Steel Powder (SS316L), PEG, PMMA and Stearic Acid

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ABSTRACT

Optimization of injection molding parameters isrequired to achieve acceptable strength anddensity of green compact prior to debinding and sintering process in MIM. This study relies on an L_9 orthogonal array of Taguchi method in optimizing parameters ofmetal injection molding process and to study effect of solvent debinding stage. Feedstock in this study consists of stainless steel powder (SS316L) with the powder loading of 64Vol% and binder compositions are polyethelene glycol (PEG-73%wt), polymethyl methacrilate (PMMA-25%wt) and stearic acid (SA-2%). Results show that optimum parameters are: mold temperature 55^0C, injection temperature 145^0C, injection pressure 700 bar and packing time 10 s. From the analysis of variance (ANOVA), packing time give effect achieve 69.57% in order to produce good surface quality and mold temperature 43.40 % for the highest contribution factor to the strength of the green compact. The most suitable immersion time for debinding process is 180 minutes at the immersion temperature of 59^0C.

Key words: Stainless steel, Metal Injection Molding, Taguchi's orthogonal array, analysis of variance, green compact

Introduction

Metal injection molding (MIM) is a near-shape molding process that combines the injection and powder metallurgy procedures (German and Bose, 1997). It had been reported significantly reduce production cost for producing small, complex, precision parts in mass production (Heaney *et al*., 2005). MIM process has several stages: mixing metal powder with binder, injection molding, debinding and sintering (Yea *et al*, 2008). Optimization of injection molding parameters is required in order to produce of high quality of green compact to ensure successfully debinding and sintering processes (German and Bose, 1997). Most of researchers utilize Taguchi method to optimize the injection molding parameter. Ji*et al* (2001) used Taguchi method in characterizing and optimizing the process factors for sintering water-atomized 316L stainless steel. Taguchi method also was used by Zu (1997) to study the effects of debinding factors on the mechanical properties of injection molded tungsten heavy alloys.Karatas*et al* (2008) and Ahn*et al* (2009) note that properties of green compact are dependenton mold temperature, injection temperature, injection pressure. Mold temperature and the packing time have the highest contribution to the surface quality of green compact reported by Jamaludin*et al*. (2009).

Debinding process is the third stage of MIM process which the purpose is to remove the polymer binderusing heating or solvent(Thian*et al*, 2001). The important goal of water debinding process is to remove the binder in the shorter time with the least green impact on the compact. It can becontrolled by immersion time and immersion temperature. The optimum immersion temperature presented by Yulis (2008) is59^0C for the 316L stainless steel powder with composition binder; 73% PEG, 25% PMMA and 2% stearic acid. Beside thatOmar*et al* (2003) reported that no swelling and cracking on specimen when using 316L stainless steel powder and two types binder systemPE/PW/SA and PEG/PMMA which immersion time 4 hours and immersion temperature 60^0C.

In this study, Taguchi Method with an L_9 orthogonal array was used to study effect injection molding parameters on the properties and quality of the green compact. Debinding process was conducted using water for environmentally purpose. The objectives of this paper are to find the optimization value of the injection molding parametersand immersion time for solvent debinding.

Materials And Methods

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The 316L stainless steel powder used in this experimentwas a gas-atomised powderhaving a mean particle size of 16 µm with spherical in the shape as shown Fig.1 and pycnometer density 7.93g/cm^3 which kindly supplied by ANVAL, Sweden.The 316L stainless steel powderwas mixed with 73% weight of polyethylene glycol (PEG 4000), 25% weight of polymethyl methacrylate (PMMA) and 2% weight of stearic acid (SA) as a surfactant using the sigma blade mixer. Acetone was added into the feedstock with the ratio 4ml of acetone for every gram of PMMA will reduce viscosity and high shear rate that improving the mixing result of the feedstock (Ibrahim *et al*, 2008).

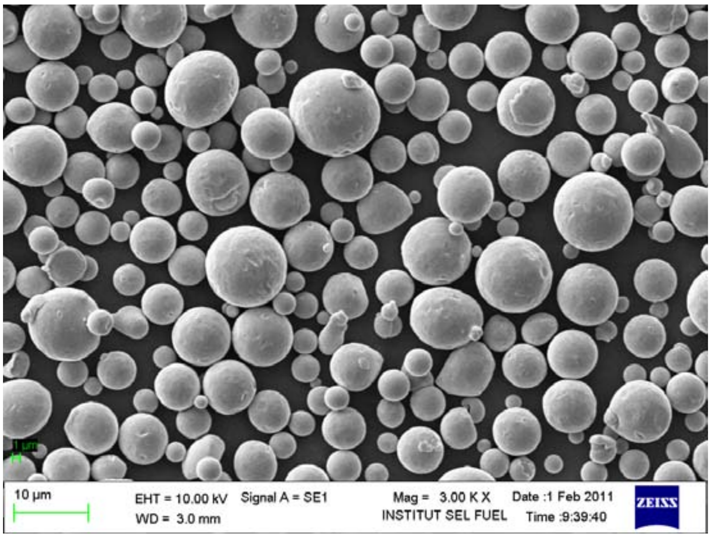


Fig. 1: Scanning electron micrographs of 316L stainless steel powder with mean particle size of 16 µm

Rheology analysis of the feedstock was carried out using the Shimadzu CFT-500D to identify the flow characteristic of the feedstock that appropriate for injection molding process. Battenfeld BA 250 CDC injection molding machine was used with single cavity of standard tensile bar shape of mold based on MPIF 50 Standard. INSTRON Universal Tester 5567 was used to perform the three point bending test in order to find out the strength of specimens. Debinding process was done by immerse injection component with the optimized injection parameter into the distilled water at 59^{0}C. L_9 Taguchi orthogonal array with 9 rows and 4 columns is suitable for these variables, Injection parameters that involved are mold temperature, injection temperature, injection pressure, and packing time.

Table 1 show parameter symbols and experiments level of each parameter. Every defect that will predict occurs in process MIM was made grade of scores such as; Flashing (0.5), separation of debinding material (0.5), weld line (1), flow line (1), bending components (2), silver streaks (2), crack and fracture (3), ejector pin imprint (3), short shot (3).

Table1: Parameter Symbols and Level experiments

Parameters	Symbol	Level		
		1	2	3
Mold Temperature (^{0}C)	A	55	60	65
Injection Temperature (^{0}C)	B	145	150	155
Injection Pressure (bar)	C	600	650	700
Packing Time (s)	D	5	10	15

Result and Discussion

3.1 Rheology Analysis:

Fig. 2shows rheology properties of the feedstocks. Based onFig.2feedstockshave characteristic of pseudo-plastic with the flow index less than 1 where on every temperature 130^{o}C, 140^{o}C and 150^{o}C there are increasing flow index 0.277, 0.433 and 0.451, respectively. The viscosity and the shear rate value are also in the acceptance range of 10 Pa.s to 1000 Pa.s and 10^2 s^{-1} to 10^5 s$^{-1,}$ respectively (German and Bose, 1997). Pseudo-plastic flow is appropriate flow for MIM process where viscosity of flow decreasing due to increasing of shear rate on certain value. Shear rate ($\dot{\gamma}$) and shear stress (τ) can be defined by;

$$\tau = K\dot{\gamma}^n \quad (1)$$

K is a coefficient,*n*is flow behaviour index. Whenn > 1 indicates material is dilatant,where metal powder and binder would separate under high shear rate (Huang *et.al*, 2003).

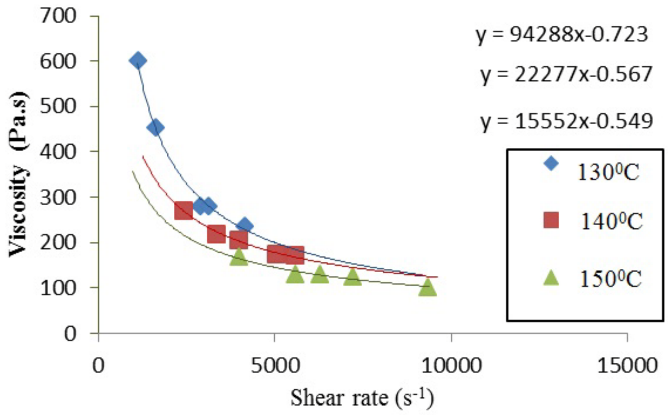


Fig. 2: Viscosity against shear rate at different temperature.

3.2 Optimization of injection molding process parameters:

Based on grade scores that determined previously for each defects will predict on green compact. Table1was used to determine S/N Ratio for surface and strength quality of green compact, criteria that used to find S/N ratio using*the smaller the better*for surface qualityand *the larger the better* for strength quality.Taguchi method for *the smaller the better*was utilized for measuring surface quality of the green compact as the evaluate factors are shown on Fig.3. The optimum injection parameters for surface quality were on the mold temperature 550°C, injection temperature 1500°C, injection pressure 700 bar and packing time of 10 s. While SN Ratio for *larger the better* for determining the optimum injection parameters for strength quality of green compact. Fig.4 shows that optimum injection parameter were achieved on mold temperature 600°C, injection temperature 1450°C, injection pressure 650 bar and packing time of 5 s.

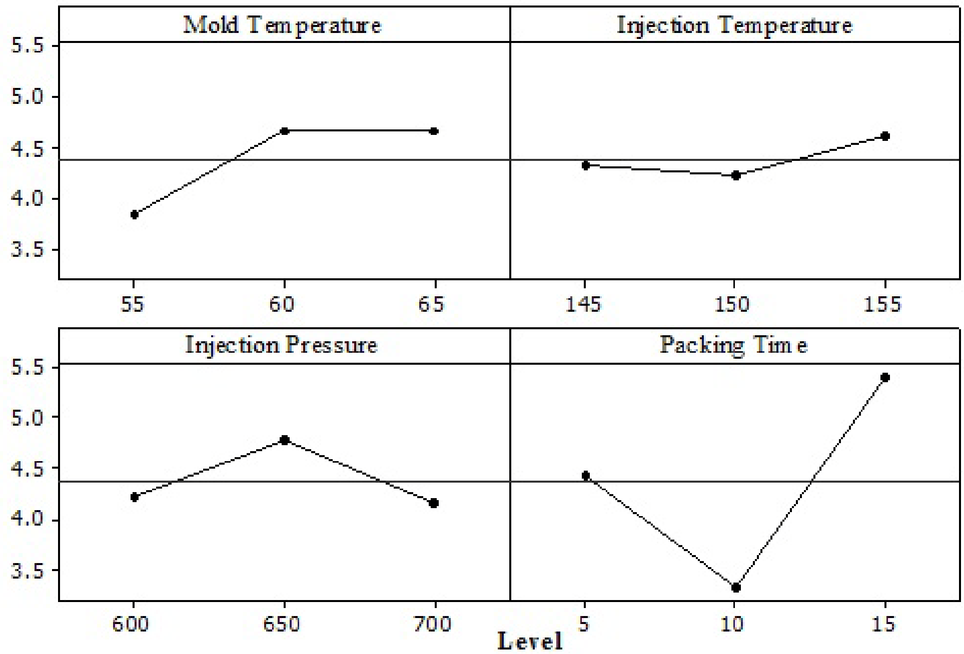


Fig. 3: Mean for surface quality at various level of injection parameters

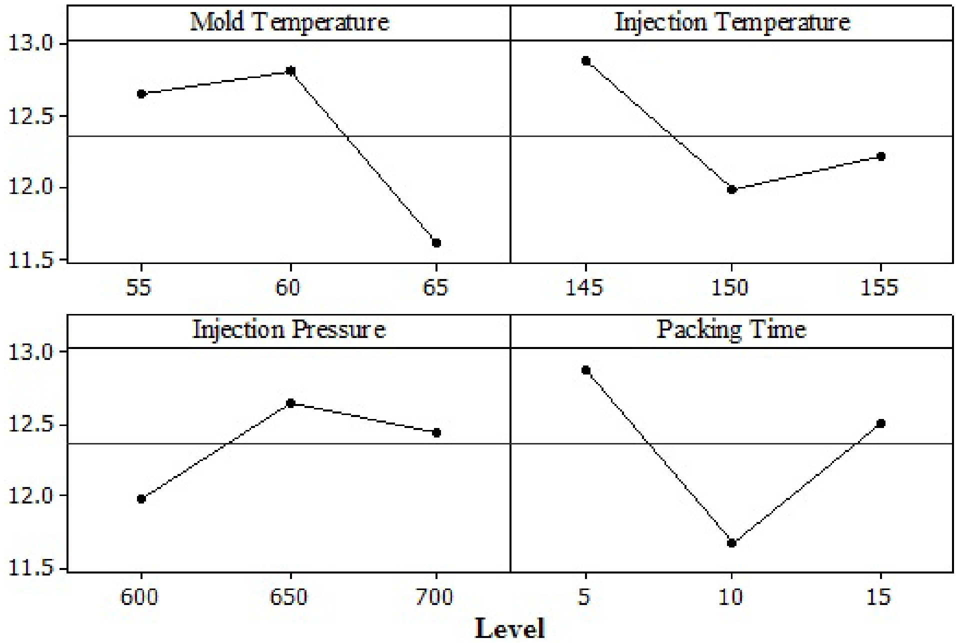


Fig. 4: Mean for strength at various level of injection parameters

Table 2 shows the combination of the optimum parameter of both evaluation criteria. Packing time has highest contribution for surface quality achieve 69.57% and the lower factor that giving contribution was injection pressure only 3.40%. Moreover, highest contribution for strength was contributed by mold temperature and the lower was injection pressure parameter, 43.40% and 14.01%, respectively. The optimum combination injection parameter for surface quality and strength were mold temperature 55^{0}C, injection temperature 145^{0}C, injection pressure 700 bar and packing time of 10 s. The analysis of variance (ANOVA) was also employed to determine the significant contribution factor. The result show that packing time was the most influence parameter to the surface quality of the injected component and mold temperature gives significant effectsto the strength evaluation criteria. This was also same result presented by Berginc *et al*, (2007) that the mold temperature has highest contribution to quality of green compacts.

Figure 5(a) shows the result of the sample injected part that using the optimum injection parameter. Short shot was defect that always occurs in this experiment when low injection temperature and low injection pressure, percentage occurrence of its defect achieve 33%. It was due to loading material cannot fill fully mold cavity as shown Fig5(b). Fig5(c) demonstrates weld line defect on injected part. It was resulted due to high surface tension of feedstock. Itwas resulted by high viscositywhen performed on low temperature.

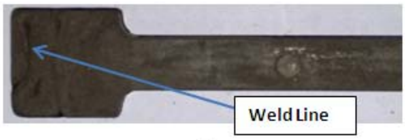
Table 2: Optimum injection parameter and contribution percentage of the factor

Factor	Optimum parameter	Contribution percentage, %	
		Surface quality	Strength
Mold temperature	55^{0}C	22.65	43.40
Injection temperature	145^{0}C	4.37	20.45
Injection pressure	700 bar	3.40	14.01
Packing time	10 s	69.57	22.03
Error		0.01	0.01

3.2 Immersion time:

Fig 6 shows that the percentage of the PEG/PMMA binder system dissolve in the distil water at the 59^{0}C. After 60 minutes, the PEG/PMMA binder system dissolve rate was decreasing gradually due to the low content of PEG/PMMA binder system in the component. PEG/PMMA binder systems completely dissolved in distil water at the 180 minute. Fig.7shows the changing of the surface image of the component before debinding process (Fig.7 (a)),it can be seen binder system fills almost spaces between powder particles and powder particles was distributed in fairly uniform all of surface. On immersion time 120 minute Fig.7 (b) particlepowder was become clear which indicated that PEG has been removingand 180 minute Fig.7(c), stainless steel powder become clearer than immersion time previously.

(a)



(b) (c)

Fig. 5: Injection part samples, Optimum result and various defects on injection parts; (a) optimum result, (b) Short shot and (c) Weld line

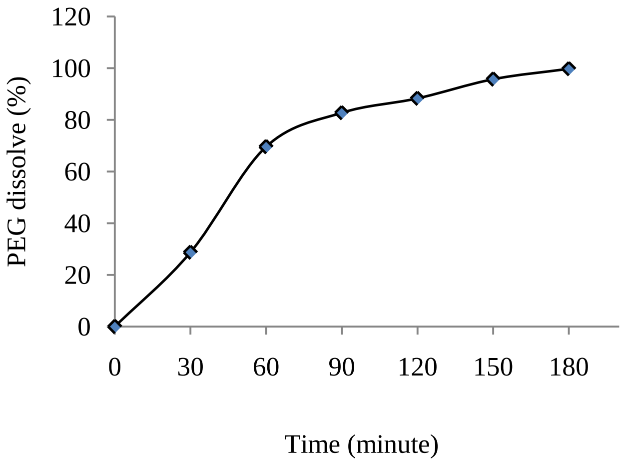
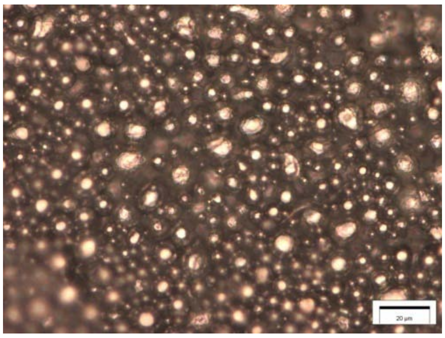
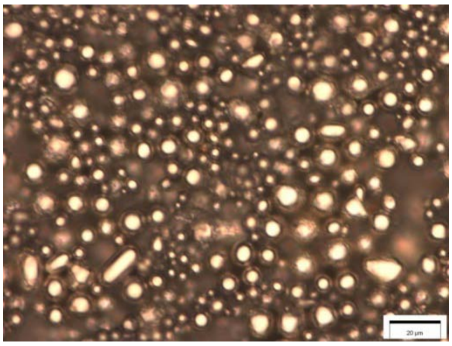
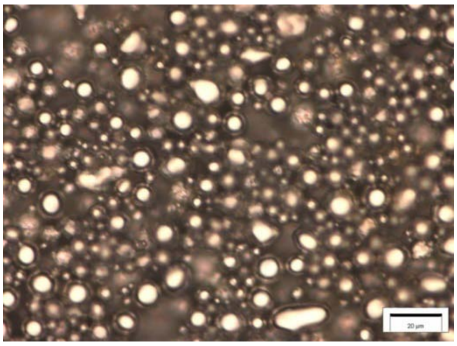


Fig. 6: Percentage PEG dissolved against the immersion time



(a)





(b) (c)

Fig. 7: Microstructure of MIM parts after debinding processes on various immersiontimes. (a) Microstructure before debinding process. (b) Microstructure specimen on 59oC, 120 minute, (g) Microstructure specimen on 59oC, 180 minute

Conclusion:

From the experiments carried out, it was concluded that the feedstock formulation were shown a pseudoplasticflow behaviour,than suitable for MIM processes. Optimization of injection molding parameters is successfully implemented to enhance of surface and strength quality. Moreover,effect of packing time is the most significant factor to obtain the best surface quality of the green compact while the strength of injected component is most influenced by the mold temperature. The combination of the optimum parameters are mold temperature 55^0C, injection temperature 140^0C, injection pressure 700 bar and packing time 10 s.

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