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Research paper

Influences of Injection Pressure and Flow Rate to the Green Properties

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Abstract

Injection moulding is one of the essential processes in Metal injection moulding (MIM). The injection pressure and flow rate are the key factors that influence the quality of the MIM parts. In the present study, experimental work has been performed to identify the influence of injection pressure and flow rate to the surface defects, density and the strength of the green parts. Feedstocks used were water atomised stainless steel powder with a solid loading of 62 %vol and the multicomponent binder consisting PEG, PMMA and strearic acid. Tensile specimens were injection moulded by varying injection pressure from 550 bar to 750 bar and flow rate from 10 cm^3/s to 20 cm^3/s. All feedstocks prepared exhibits a shear thinning behaviour. The results show that the green density and green strength decreases as injection pressure increased. The flow rate is directly proportional to the green strength while the green density is unable to correlate with the flow rate. Excess flashing and severe binder separations were observed when the specimens were injection moulded at injection pressure 750 bar and flow rate 20 cm^3/s.

Keywords: *Metal injection moulding; injection pressure; flow rate; green density; green strength*

1. Introduction

Metal injection moulding (MIM) is a manufacturing technology which can produce very small and complexes parts [1, 9, 19]. It is competitive against other conventional techniques such as machining due to its capability to produce the parts in large quantity at low cost. Generally, MIM composes of four main steps namely a mixing, injection moulding, debinding and sintering. A small portion of polymer binder is initially mixed with the metal powder to form homogenous feedstocks. The feedstocks are feed into the injection machine to shape the part before undergoing the debinding process. The part is then sintered in a furnace to obtain the higher mechanical properties.

In MIM, injection moulding is one of the vital steps affecting the success of the MIM. A good manage of moulding process can reduce the manufacturing lead time. Pressure and flow rate control are two crucial parameters for the success of the moulding process. Flashing, short shot and jetting are some of the common defects that associate with injection pressure and flow rate. The typical values of injection pressure are between 15 and 30 MPa [9, 11,14]. Low injection pressure may cause short shot [12] whereas high injection pressure will cause the feedstocks to flash out from the parting line [4, 13]. The binder becomes less viscous when the injection temperature and pressure are high, and it causes binder separate out from feedstocks. The best moulding condition has adjusted the viscosity of binder 10 Pa.s and feedstocks viscosity between 10 Pa.s and 1000Pa.s [3, 9, 11, 16, 17]. Furthermore, high injection pressure may also cause distortion to happen in the gate region. The moderate flow rate is normally required in MIM because high flow rate can cause jetting and low flow rate result in the uneven mould filling [9, 15].

The moulding parts are called green parts. The mechanical properties of MIM parts purely depend on sintering density and microstructure. However, the significances of green density and green strength must not be neglected. The green parts are brittle; therefore they must have enough strength to attain the shape during debinding. Low green density indicates a high portion of a void in the parts and may cause others defects to occur during debinding. In some previous research, the injection pressure is found to be proportional and has a small effect, less significant to the green density [8, 11]. However, some recent studies show the opposite observation [19-20]. In general, high injection pressure and flow rate will increase the number of the particles involved during the moulding process. Khairur Rijal Jamaludin et al. [18] have conducted ANOVA analysis to study the influences of injection pressure and injection temperature to green strength. The experiment concluded that high temperature increases the green strength. Accordingly, higher moulding pressure is expected to increase the green strength since more particles will involve the infilling process. Ibrahim et al. [20] Mustafa et al. [19] also found that injection pressure is the best effect of the variable in determines the highest green strength. In the parameter optimisation work done by Wahi et al. [12], they noticed that the flow rate is a significant factor affecting the green strength.

From the previous work done [8, 11, 12, 18-20], it can be concluded that there is no definite best value of injection pressure and flow rate in the MIM process. These parameters are varied according to the selection of feedstocks and their characteristic. Thus, it is essential to determine the optimal moulding condition
of each of the feedstock used in the moulding process. The study aims to identify the influences of injection pressure and flow rate to the green parts. The green parts were examined from their surface appearances, densities and strength.

2. Experimental procedures

In this study, water atomised 316L stainless steel powder with particle size D_{50} = 10µm and spherical in shape were used. The binder used is multiple binder systems consisted of Polyethylene glycol (PEG) (73% wt), Polymethyl methacrylate (PMMA) (25% wt) and stearic acid (2% wt). The details of the solid loading of feedstock are shown in Table 1. The mixing was carried out in a Z blade mixer for 1 hour at 70°C. The mixture is then granulated into feedstock in a milling machine. Since the study was intended to investigate the influence of injection pressure and injection speed, the remaining parameter must keep constant. Feedstock's rheological behaviour and the preliminary experiment determined the moulding conditions. Once other moulding parameters were decided, the standardised tensile-test specimen was injection moulded with different level of injection pressure and injection speed using a Battenfeld BA 250 CDC injection moulding machine. The density of compacts was determined by Archimedes immersion method according to MPIF standard 42 while the green strength was determined by three-point bend test using INSTRON 5567 according to the MPIF standard 15.

Table 1: Solid loading of feedstocks

Component		(%V)	(%wt)	(%wt)
Powder	Water atomised SS316L	62	91.64	100
	PEG		6.1	73
Binder	PMMA	38	2.09	25
	Stearic Acid		0.17	2

3. Results and discussion

3.1. Rheological behaviours and preliminary run

Viscous material is characterised by flow behaviour index, n. In MIM, a feedstock with shear thinning behaviour and small flow activation energy, *E* is desirable [3, 16, 17]. The *E* value of the feedstock can be calculated from the ln (viscosity) versus 1/temperature plot at shear rate 1000 s^{-1}. The *E* value of the feedstock prepared is 1.244 kJ/mol, and it is comparable with the result obtained by previous works [3, 21]. Table 2 shows the flow behaviour index, *n* of the feedstocks at the different temperature. All the feedstock exhibits shear thinning or pseudo-plastic behaviour. The lower the value "*n*" value, the more viscosity dependence to the shear rate or showing the greater pseudo-plasticity behaviours of the feedstocks [3, 16, 17]. However, low "*n*" value associated with some undesirable moulding defects such as jetting [16]. Preliminary run showed injection moulding at 130°C caused some specimens experienced defect of the short shot. Therefore, 140°C is the suitable injection temperature since the "*n*" value at this temperature is higher than 150°C. The moulding condition for injection moulded specimen as illustrated in Table 3.

Table 2: Flow behaviour index at different temperature

Temperature (°C)	flow behaviour index, *n*
130	0.3235
140	0.2641
150	0.1988

Table 3: Moulding Condition

Parameter	Condition
Injection Temperature	140 °C
Mould Temperature	60°C
Holding pressure	1000 bar
Holding Time	15 s
Cooling Time	10 s

3.2. Green defects at varying injection pressures and flow rate

The injection was carried out with the pressure in the range between 550 bar to 750 bar and flow rate between 10 cm^3/s to 20 cm^3/s. All inject moulded specimens were found without the short shot. Table 4 summarises the results. From Table 4, it is shown that low flow rate cause cracks in the sample. The cracks are mainly due to the feedstock flow unevenly at a low flow rate. In the moulding process, flow rate controls the time and amount of feedstocks to fill up uniformly into the die cavity [13]. The cracks were found lesser with increasing of the flow rate. Although a high flow rate can eliminate cracks, it results in another defect, binder separations as shown in Figure 1. Table 4 shows binder separation occurred when parts were injection moulded at high injection pressure. This defect was observed in Run 7, Run 8 and Run 9. Injection at 750 bar causes the shear rate increases and lower the viscosity of the binder. Thus, the binders were less viscous and separated out from the feedstock. As can be seen in Figure 1, binder separation is found occurring at near the gate region. The result is consistent with the study conducted by Murtadhahadi [14] and Norhamidi et al. [15]. The binder separation occurs be-cause both metal powders and binders have different flow behaviour when passing a narrow point in the mould. The powder with a higher viscosity will collect near gates while the binders were pushed to far corners of the part [7]. Also, high injection pressures and high flow rates also resulted in flashing as shown in Figure 2. The excessive material is squeezing out of the mould when the part is injection moulded with high pressure or high flow rate [6, 12]. Run 6 with the minimal defect is the best condition to be injected moulded.

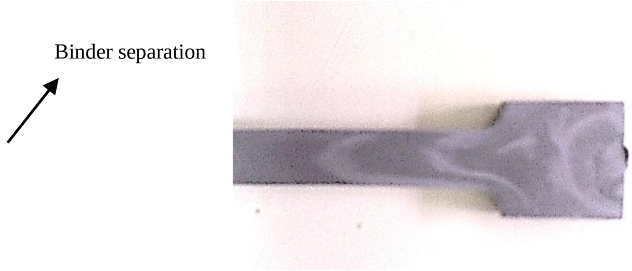

Fig. 1: Binder separation

Fig. 2: Flashing

Table 4: Surface defects at varying pressure and speed

Run	Injection pressure (bar)	Flow Rate (cm^3/s)	Observation
1	550	10	cracks
2	550	15	a bit cracks, a bit binder separation
3	550	20	a bit cracks, binder separation
4	650	10	a bit cracks
5	650	15	a bit cracks, a bit flashing
6	650	20	a bit flashing
7	750	10	binder separation, a bit flashing
8	750	15	binder separation, flashing
9	750	20	binder separation, excess flashing

3.3. Green density and green strength

The mean green density of the specimen is fall in the range between 4.96 g/cm^3 to 5.23 g/cm^3, agree with the theoretical green density. Figure 3 shows that the flow rate was uncorrelated to the green density. Wahi et al. [12] and Amin et al. [13] have demonstrated the flow rate is less significant to the green density. The fluctuant in the mean green density shows flow rate has an interaction with injection pressure. However, the injection pressure is found proportional to the green density. Increased of the injection pressure resulted in a slight reduction in the green density. As can be seen in Figure 3, injection at the pressure of 750 bar show the part obtained the lowest green density. This is mainly due to the green defect, binder separation. The observation obtained in good agreement with studies done by Muhammad Hussain [11] and Murtadhahadi [14]. The powder-binder separation will cause void formation in the part which lowering the density. Therefore, the 550 bar is the best condition to get higher density.

For the effect of green strength, it is generally observed that the green strength is proportional to both flow rate and injection pressure. Wahi et al. [12] concluded the flow rate gives the highest impact on the part strength. Figure 4 shows the green strength of the specimens which injection moulded at 650 bar and 750 bar increases with the increased of the flow rate. Flow rate increased causing the feedstocks flows evenly and increases the number of powder particles filling the die. Therefore, the green strength increases. However, the flow rate behaves differently to the green strength when the part was injection moulded at 550 bar and 20 cm^3/s. The difference is due to the binder separation and cracks occurring. The influence of injection pressure on green strength is found similar to the green density. As injection pressure increased, the green strength decreased. This result is supported by the studies conducted by Mustafa [1]. Indeed, low part density due to the binder separation indicates voids and air trapped in the parts which will decrease the green strength. The best moulding condition to obtain a high green strength are 650 bar and 20 cm^3/s.

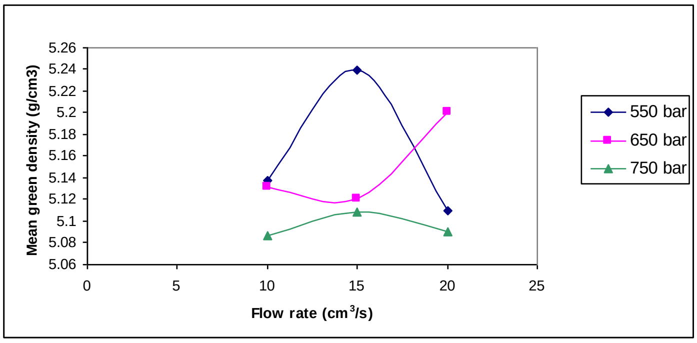

Fig. 3: The mean green density as a function of flow rate

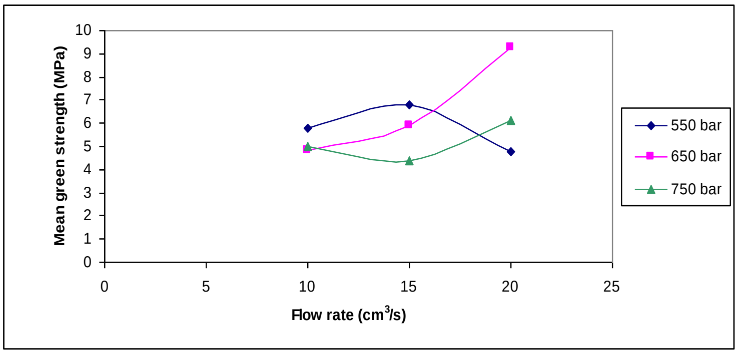

Fig. 4: The mean green strength as a function of flow rate

4. Conclusion

The study concludes the following:

a) Binder separation, flashing and cracks are the defects associated with injection pressure and flow rate.
b) Injection pressure is inversely proportional to green density and green strength. The inverse relation is due to the severe green defects occurring at the pressure above 550 bar.
c) Flow rate was found uncorrelated to the density, but it was directly proportional to green strength. Increased injection flow rate will increase the green strength.
d) Moulding condition of 650 bar and 20 cm^3/s with the minimal surface defects; high density and highest green strength are deemed to be the best condition for the feedstock to be injection moulded.

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References

[1] Mustafa N., Ibrahim MHI, Asmawi R, Aimin AM & Masrol SR (2015), Green Strength Optimization in Metal Injection Molding Applicable with a Taguchi Method L9 $(3)^4$. *Applied Mechanics and Materials* 773-774, 115-17.
[2] Khakbiz M, Simchi A & Bagheri R (2005), Analysis of the Rheological Behavior and Stability of 316L Stainless Steel- TiC Powder Injection Moulding feedstock. *Materials Science and Engineering A* 407, 105–113.
[3] Barriere T, Liu B & Gelin JC (2003), Determination of the optimal process parameter in metal injection molding from experiment and numerical modeling. *Journal of Materials Processing Technology* 143-144, 636-644.
[4] Shahbudin SNA, Othman MH, Aimin SYM & Ibrahim MHI (2017), A Review of Metal Injection Molding- Process, Optimization, Defects and Microwave Sintering on WC-Co Cemented Carbide. *Materials Science and Engineering* 226 012162, DOI: 10.1088/1757-899X/226/1/012162.
[5] Md Radzi MKF, Sulong AB, Muhamad N & Razak Z (2016), Optimization of injection molding parameters for Kenaf/PP composite using Taguchi method. *Advanced Processes and Systems in Manufacturing An International Conference 2016*, 121–122.
[6] Koffi A, Koffi D, Aimin & Toubal L (2016), Injection Molding Parameters Influence on PE Composites Parts. *International Journal of Engineering Research and Development* 12(10), 29–39.
[7] Sebastian Engström, *Metal Injection Molding: A review of the MIM process and its optimization*. Arcada UAS, (2017).
[8] Khairur Rijal Jamaludin, Norhamidi Muhamad, Mohd Nizam Ab. Rahman, SriYulis M. Amin, Shahrir Abdullah & Muhammad Hussain Ismail (2007), Influence of Temperature to the Injection Moulding of Bimodal Powder Mixture. *World Engineering Congress 2007*, 202-210.
[9] German RM & Bose A, *Injection Molding of Metals and Ceramics*. MPIF, (1997).
[10] Mohd Afian Omar, *Injection molding of 316L stainless steel and NiCrSiB alloy powders using a PEG/PMMA binder*, University of Sheffield, (1999).
[11] Muhammad Hussain Ismail, *Powder Loading Influence to the Processing Phenomena in Metal Injection Moulding,* The National University of Malaysia, (2002).
[12] Wahi A, Muhamad N, Jamaludin KR, Rajabi J & Madraky A (2012), Optimization of Injection Molding Parameters by Data Mining Method in PIM Process. *Jurnal Teknologi* 59, 227-232.
[13] Amin SYM, Muhamad N & Jamaludin KR (2013), Optimization of Injection Molding Parameters for WC-Co Feedstocks. *Jurnal Teknologi* 63(1), 227-232.
[14] Murtadhahadi, *Injection Parameter for Metal Injection Moulding (MIM) process to make use of feedstock of SS 316L, PEG, PMMA and Stearic Acid,* The National University of Malaysia, (2007).
[15] Norhamidi Muhamad, Muhammad Hussain Ismail, Ahmad Kamal Arifin Mohd Ihsan & Jaafar Sahari. (1999), Processing Parameter of Metal Injection Moulding. *Proceeding of Research & Development, Department of Mechanical & Material Engineering, National University of Malaysia*, 1999, 143-148.
[16] Tatt Tan Koon, Muhamad Norhamidi, Muchtar Andanastuti, Sulong Abu Bakar & Yunn Heng Shye (2012), Rheological behavior of novel feedstock for manufacturing porous stainless steel via (MIM)-PSH," *Jurnal Teknologi (Sciences and Engineering)* 59(SUPPL.2), 187–191.
[17] Machaka R, Ndlangamandla P & Seerane M (2018), Capillary rheological studies of 17-4 PH MIM feedstocks prepared using a custom CSIR binder system. *Powder Technology* 326, 37-43.
[18] Khairur Rijal Jamaludin, Norhamidi Muhamad, Mohd Nizam Ab. Rahman, Sri Yulis M. Amin, Sufizar Ahmad, Mohd Halim Irwan Ibrahim, Murtadhahadi & Nor Hafiez Mohamad Nor (2008). Influence of Injection Pressure, Injection Temperature, Powder Loading to Green Density: Analysis of Variance. *Conference I - AMReG 08*, 2008, pp:83-91.
[19] Amin AM, Ibrahim MHI, Hashim MY, Marwah OMF, Othman M H, Johar MA & Ng CH (2017), Green density optimization of stainless steel powder via metal injection molding by Taguchi method. *8th International Conference on Mechanical and Manufacturing Engineering 2017 (ICME'17),* DOI: https://doi.org/10.1051/matecconf/201713500038.
[20] Ibrahim MHI, Muhamad N, Sulong AB, Jamaludin KR, Ahmad S & Nor NHM. (2010). Single Performance Optimization of Micro Metal Injection Molding for the Highest Green Strength by Using Taguchi Method. *International Journal of Integrated Engineering (Issue on Mechanical, Materials and Manufacturing Engineering* 2010 35-34.
[21] Sotomayor ME, Várez A & Levenfeld B (2010), Influence of powder particle size distribution on rheological properties of 316L powder injection moulding feedstocks. *Powder Technology* 32200(1-2) 30-36.