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Physical Properties and Microstructure Study of 316L SS Fabricated by Metal Injection Moulding Process

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Abstract. Metal injection moulding (MIM) has been practised to process alloy powders to become components with significant physical and mechanical properties. Dissimilar than other methods, MIM focuses on the production of high volume, a small, and complex shape of products. The performance of the compacts depends on the suitable sintering parameters that governs their strengths in the final phase which determines the excellent properties of the sintered compacts. Three different sintering temperatures were utilised; 1100, 1200, and 1300 ˚C with two different soaking times; 1 and 3 hours at 10 ˚C/min heating rate to study their effect on the physical properties and microstructure analysis of 316L SS alloy compacts. The shrinkage measurement, surface roughness, and density measurement had been conducted for physical properties study. Different sintering temperatures give an effect to the physical properties of the sintered compacts. The shrinkage measurement at 1300 ˚C and 3-hour sintering condition demonstrated the highest percentage reading which was 10.1 % compared to the lowest percentage reading of 6.4 % at 1100 ˚C and 1-hour sintering conditions. Whereas, the minimum percentage of density measurement can be found at sintering conditions of 1100 ˚C and 1-hour which is 83.9 % and the highest percentage is at 1300 ˚C and 3-hour sintering condition which is about 89.51 %. Therefore, it has been determined that there could be a significant relationship between sintering temperature and physical properties in which it can be found from the porosity of the compact based on the microstructure studies.

INTRODUCTION

The binder is the principal component in metal injection moulding that provides the metal powders flowability [1] and formability which are significant for moulding [2]. It is an impermanent conveyance for homogeneously filling alloy powder into required shape [3]. It is also a concern for remain in that particular shape before the sintering process [4]. An ideal binder system for MIM must have remarkable specialities; such as flow quality, suitable for powder, debinding and fabrications [5]. The selection of proper binder is beneficial for producing complete integral MIM parts victoriously[6].

When it comes to material aspects, a huge number of alloy systems have been grown in conventional metal injection moulding process, and one of them is 316L stainless steel (316L SS) [7]. It is one of the most used materials for MIM research and industrial applications, because of the superior properties [8] of high oxidation

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resistance, high heat resistance, and excellent weldability [9]. Besides that, 316L SS alloy is also a biocompatible metallic material that had been used in the biomedical application as it shows attractive biocompatibility, mechanical properties, and excellent corrosion resistance [10].

Ideally, in MIM, the removal of the binder would open up pore channels which allow accelerated removal of the higher boiling point compacts. The compacts are sintered following the debinding stage. This stage is crucial to the MIM process as an appropriate sintering temperature and time would ensure pore-free structure which resulted in good mechanical and physical properties. Therefore, sintering temperature and time are one of the important criteria that should be considered [11]. Therefore, the suitable sintering parameters will increase the properties besides reducing the porosity of sintered compacts through microstructure observations. This study is carried out to analyse the effect of the sintering conditions on the physical properties and microstructure of 316L SS alloy fabricated by Metal Injection Moulding process. The compacts were sintered at three different sintering temperatures from 1100, 1200, and 1300℃ at two different sintering time; 1 and 3 hours by using 10℃/min heating rate. The optimal physical properties and microstructure are expected to obtain at higher sintering temperature and time of the compacts.

EXPERIMENTAL

Gas atomised powder 316L SS alloy used in this study was supplied by SANDVIK OSPREY LTD., the UNITED KINGDOM with 22 µm particle size. Powder particles are mostly in spherical shape. The binders used in this study consists of three different components which are: (1) Paraffin wax (PW) as filler, (2) Atactic Polypropylene (APP) as a backbone polymer and (3) Stearic Acid as a surfactant. The binders were chosen based on previous work done by Ahn *et al.* (2009) [12] and referred to research by German and Bose, where he stated that waxes, more than any constituent, are routinely used in PIM binder. They have good wetting and low molecular weight of wax provides a high volatility that aids debinding. Most of the binders are thermoplastic based on the mixture of wax and plastics. Besides, stearic acid which acts as surfactant agent reduces the contact angle during debinding by lowering the surface energy of the binder-powder interface. Accordingly, its usefulness improves as the particle surface area increases. Firstly, the metal powder was fused with the binder components to create a homogeneous feedstock paste. In this experiment, the ratio of metal powder and binder used is 62:38 by volume was chosen based on the preliminary study on 60, 62 and 64 % powder loading. The powder loading 62% showed optimum properties and viscosity. The final step in feedstock preparation is to make the mixture in pellet forms which are easy to be transported to the moulding machine.

Injection moulding was performed using metal injection moulding machine. Here, the pelletized feedstock is injection moulded into the desired shape by heating in the machine and injected under pressure into the tool cavity. Then, after the specimens being moulded, they were let to cool down until firm enough to be taken from the mould. Dog-bone-shaped compacts were moulded. The dimensions of the compact are shown in the following Figure 1.

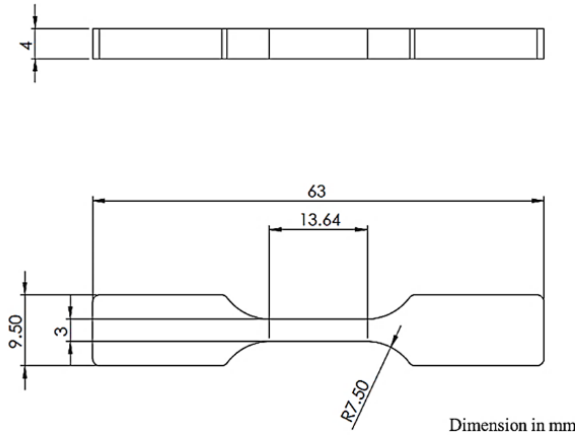


FIGURE 1. Shape and dimension of tensile compact

Debinding was achieved in two-steps debinding process, i.e., solvent debinding to dissolve PW and thermal debinding to remove remaining binders which are APP and SA from the brown compacts. The green compact was

soaked in heptane bath for 2 hours and holding at a temperature of 60 ˚C. For thermal debinding, the brown compact was placed in the furnace tube and surrounded by highly pure argon gas flow atmosphere. The cycle involved heating at a rate of 5 ˚C/min to 500 ˚C followed by soaking for 1 hour. After debinding, the compacts were sintered in a furnace. It is a continuous process step from the thermal debinding process. The conditions of the compacts are as listed in Table 1. Each set of conditions consists of five compacts. These parameters were being selected based on previous work done by previous researchers [13, 14].

The shrinkage was measured using Vernier calliper. The measurement involves length, width and thickness of the compact. The reading average of each measurement will be compared between green compact and sintered compact in order to obtain the percentage of shrinkage. The compact's density was measured by Archimedes principle technique. The weight of the compacts was measured in air and water and the density value was obtained after the density of distilled water was measured. By using MEIJI-MT 7100 optical microscope (OM), the microstructures of the compacts were systematically observed.

TABLE 1. Compacts conditions

Compacts	Sintering Temperature (˚C)	Sintering Time (h)
S01	1100	1
S02	1100	3
S03	1200	1
S04	1200	3
S05	1300	1
S06	1300	3

RESULTS AND DISCUSSION

Shrinkage

The compact shrinkage data is shown in Figure 2. Highest shrinkage of the compact was 10.1 % obtained at the sintering temperature of 1300 ˚C for 3 hours soaking time. The lowest shrinkage occurred at a lower sintering temperature of 1100 ˚C for 1-hour soaking time. At higher sintering temperature and longer time, the powder particle has more time for consolidation process to occur, results in higher shrinkage amount. This finding is consistent with Omar, M.A. and I. Subuki (2012) [13] where they found that the shrinkage for sintered compact has increased when the sintering temperature increases from 1300 until 1360℃. As the sintering temperature increase, it lessens the volume of pore, thus the result shows the raise of the linear shrinkage.

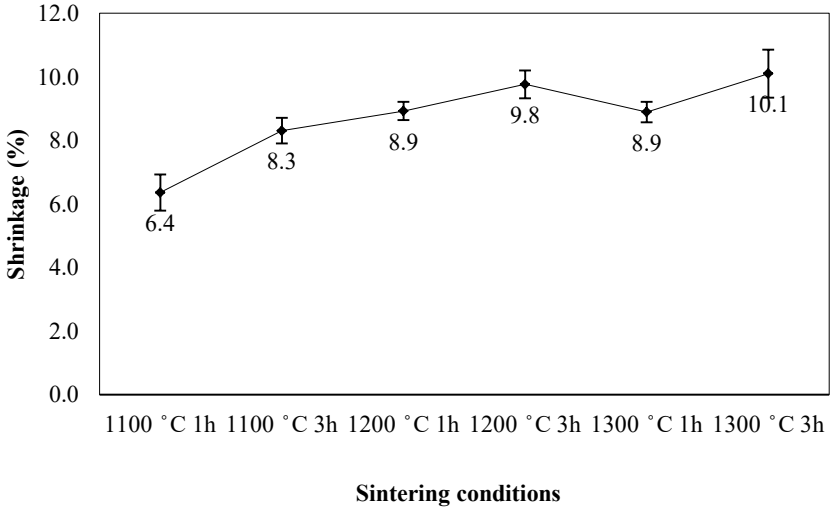


FIGURE 2. Comparison of shrinkage between sintered compact

Relative Density

Figure 3 presents the effects of the relative density of sintered compacts using different sintering time and temperature. For sintering conditions of 1100˚C and 1 hour, the density was 83.9 %, and it was the lowest relative density compared to other sintering conditions. In addition, at sintering temperature of 1300˚C and 3-hour holding time shows highest relative density of 89.51 %. According to the study done by N. Kurgan *et al*., (2010) [15] the maximum sintered density was achieved at 1300 °C with 88% of relative density. So, from this experiment, it has been proven that by applying the sintering temperature of 1300°C, for 3-hour sintering time, better relative density of 316L stainless steels compacts was achieved which is 89.5%. Blain, *et.al* , (2006) [14] mentioned there is a poor blending of metal powder to fuse together when the sintering temperature is low. Meanwhile, G.C. Obasi, (2010) [16] the level of densifications, seems to be better at higher sintered temperature. This result can be supported by the optical micrograph from Table 1, where the number of pores tends to decrease with increasing of sintering temperature and time.

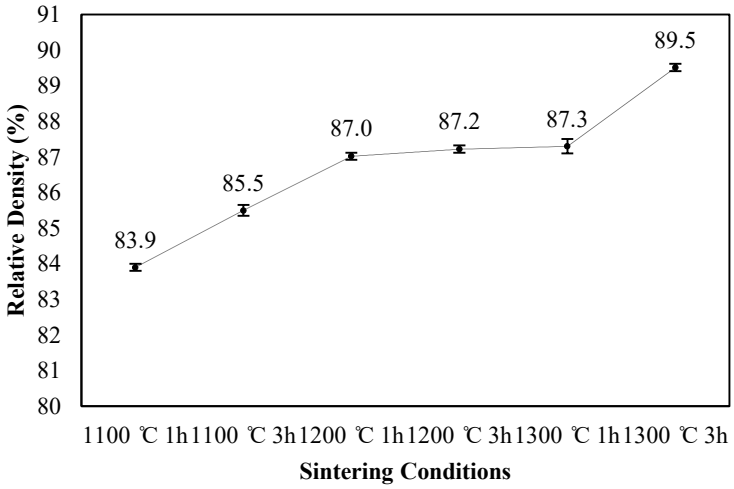
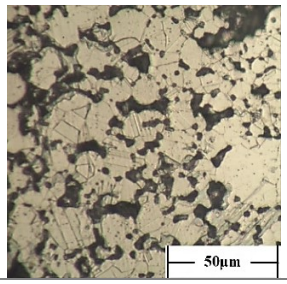
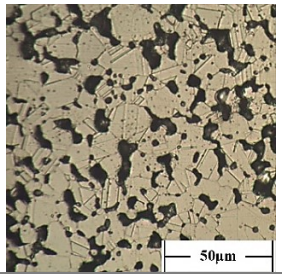
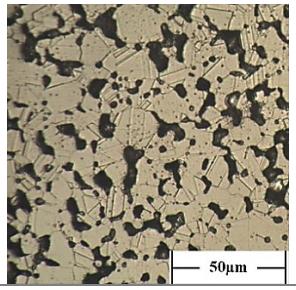
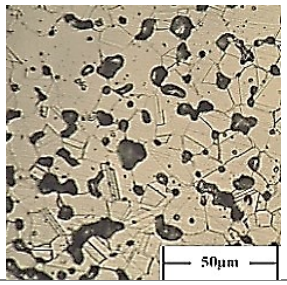
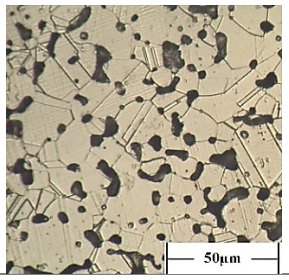
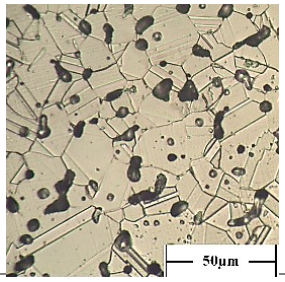


FIGURE 3. The comparison of relative density measurement at different sintering conditions

Microstructure

Results of optical micrograph on the compact condition of before and after etching as well as after sintering are demonstrated in Table 2. At higher sintering temperature and time, the amount of porosity in the sintered compact decreased. During sintering process, the initially loose powder particles has experienced powder consolidation to become a dense. While the higher the sintering temperature, the larger the grain size of the microstructure. It can be evidence from Omar, M.A. and I. Subuki's ,[13] where their finding shows that at different sintering temperatures ranging from 1300 to 1380℃, as the temperature increased, the microstructure starts to coarsen that reduces surface area, increases grain size and compact enhance with consequent changes in the pore size and shape. Thus, it can be proved that, this relation is consistent with the finding, where at higher sintering temperature enhance better properties of the sintered compacts.

TABLE 2. Optical Microscopic images of compact's microstructure at different sintering conditions

Sintering conditions	1-hour	3-hour
1100℃		
1200℃		
1300 ˚C		

CONCLUSIONS

The result at 1300 ˚C sintering temperature and 3-hour soaking time shows highest sintered compact shrinkage of 10.1 % than the sintered compact at 1100 ˚C and 1-hour condition. While the highest sintered compact density can be found at 1300 ˚C and 3 hours which is 89.51 % and the lowest sintered compact density of 83.9 % is at 1100 ˚C and 1-hour. The shrinkage and the density shows a significant relationship with sintering temperature and sintering times. The amount of porosity is higher for the lower sintered compact density while is less at higher compact density. It can be concluded that at higher the sintering temperature and longer sintering time the compact of 316L SS alloy shows better physical properties. In this study, the optimum sintering condition for the 316L SS alloy compact is at 1300℃ and 3-hour which comply with the requirement for Metal Injection Moulded Parts.

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REFERENCES

1. S. M. Jabir, A. Noorsyakirah, O. M. Afian, M. Z. Nurazilah, M. A. Aswad, N. H. M. Afiq and M. Mazlan, Procedia Chemistry **19**, 148-152 (2016).
2. A. Páez-Pavón, A. Jiménez-Morales, T. G. Santos, L. Quintino and J. M. Torralba, Journal of Magnetism and Magnetic Materials **416**, 342-347 (2016).
3. T. Palermo, Metal Powder Report **69** (3), 16-21 (2014).
4. G. Chen, P. Cao, G. Wen and N. Edmonds, Materials Chemistry and Physics **139** (2–3), 557-565 (2013).
5. M. D. Hayat, G. Wen, T. Li and P. Cao, Journal of Materials Processing Technology **224**, 33-39 (2015).
6. T. S. Shivashankar, R. K. Enneti, S.-J. Park, R. M. German and S. V. Atre, Powder Technology **243**, 79-84 (2013).
7. P. Tourneroche, J.-C. Gelin, M. Sahli and T. Barrière, Procedia Engineering **81**, 2530-2536 (2014).
8. P. Wongpanit, S. Khanthsri, S. Puengboonsri and A. Manonukul, Materials Chemistry and Physics **147** (1–2), 238-246 (2014).
9. J. D. B. de Mello, C. Binder, G. Hammes and A. N. Klein, Wear **301** (1–2), 648-655 (2013).
10. A. Arifin, A. B. Sulong, N. Muhamad, J. Syarif and M. I. Ramli, Materials & Design **55**, 165-175 (2014).
11. H. Ye, X. Y. Liu and H. Hong, Materials Letters **62** (19), 3334-3336 (2008).
12. S. Ahn, S. J. Park, S. Lee, S. V. Atre and R. M. German, Powder Technology **193** (2), 162-169 (2009).
13. M. A. Omar and I. Subuki, *Sintering Characteristics of Injection Moulded 316L Component Using Palm-Based Biopolymer Binder*. (INTECH Open Access Publisher, 2012).
14. D. C. Blaine, J. D. Gurosik, S. J. Park, R. M. German and D. F. Heaney, Metallurgical and materials transactions A **37** (3), 715-720 (2006).
15. N. Kurgan and R. Varol, Powder Technology **201** (3), 242-247 (2010).
16. G. C. Obasi, O. M. Ferri, T. Ebel and R. Bormann, Materials Science and Engineering: A **527** (16–17), 3929-3935 (2010).