Effect of Binders on Physical and Mechanical Properties of Stainless Steel 316L Alloy Fabricated by Metal Injection Moulding Process

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Abstract— Metal injection moulding (MIM) is a well-known process that provides advantages when making small parts with high density. MIM process can cut down the production costs due to its net-shape fabrication advantages, acceptable for manufacturing small parts, and combining great part complexity with high production quantities. This study compares the effects of two binders and sintering parameters on the mechanical properties of 316L stainless steel (SS) MIM compact. The 316L SS compacts have been fabricated by metal injection moulding (MIM) process using two different binders, known as Binder A, and B. Sintering was carried out under high purity argon atmosphere between 1100˚C and 1300˚C for 1 and 3 hours. The physical properties were determined from surface roughness testing, and mechanical properties were evaluated by tensile testing. Compacts with binder B recorded greater surface roughness compared to the compacts utilised binder A. Good agreement between the sintering curve and mechanical properties has been found. Compacts that sintered at 1300 ˚C for 3-hour exhibit highest tensile strength compared to others compacts. By increasing the sintering temperature and sintering time, 316L SS sintered compact recorded better mechanical properties.

Keywords—metal injection moulding; stainless steel 316L; physical properties; mechanical properties;

1. INTRODUCTION

MIM is a near-net shape fabrication method presently used in various industries and applications that brings together the diversity of plastic injection moulding and conventional powder metallurgy (P/M). The process is drawing much attention as a promising technique that leads to a large-scale production of metal working with precision and complex in shape. Metal such as 316L SS are commonly used in MIM process [1-3]. It also is a well-established P/M technique and a viable alternative to investment casting and machining. This process has capabilities in fabricating small, highly complex shapes in large amounts that are difficult to fabricate by using conventional production method [4, 5]. It involves four processing stages which are: i)

mixing of organic binders and metal powders to produce feedstock, ii) injection moulding of the feedstock to form a green compact, iii) solvent and thermal debinding process to remove the binder and produce a brown compact, and iv) sintering to near full density by solid state diffusion [6-8].

Among the four preparing steps, the sintering process is the most essential since it influences the final condition of the parts. Previous studies have shown that the significant parameters of the sintering cycle are: heating rate, sintering time, sintering temperature and sintering atmosphere. These parameters should be carefully controlled to avoid compositional inhomogeneity of final compact and also can affect the microstructure, pore size and shape, and final density [9, 10]. The feedstock is also crucial to MIM; in particular, the binders strongly determine the quality of MIM parts. They produce adhesion between powdered particles and enhance the mechanical properties of feedstock and avoid separation phenomena between binders and powders [11, 12]. Common binders in MIM are wax-based binder systems, and the typical backbone polymers are polypropylene. Various waxes and acids are also added to the binder to lower down the viscosity and increase the wettability and miscibility. The wax-based binder system performed the lowest viscosity and lowest heat capacity, and greater pseudo-plasticity compare to another binder systems [13].

The main issue of the present study is to compare the effects of two different binders and sintering parameters on the physical and mechanical properties of 316L SS MIM compact. Three different sintering temperature and two different sintering time were used.

2. EXPERIMENTAL PROCEDURE

A. Metal Powder

Gas atomised 316L SS supplied by Osprey Co, UK was utilised in this work. The particle size distribution is d_{10} = 4.0 μm, d_{50} = 11.4 μm and d_{90} = 25.9 μm. The chemical composition of the powder is shown in Table 1.

Table 1: Chemical composition of gas atomised 316L SS

Element	Wt.%
Cr	16.7 %
Ni	10.3 %
Mo	2.2 %
Mn	0.99 %
Si	0.69 %
P	0.02 %
C	0.01 %
S	0.05

B. Feedstock Preparation and Injection Moulding

A formulation of 62 vol% powder loading of feedstock was prepared. Two different binder systems consist of paraffin wax (PW), polypropylene (PP), carnauba wax (CW) and stearic acid (SA) utilised to prepare the feedstock. The composition of two difference binder systems is shown in Table 2. The feedstock was mixed in the twin blade type mixer at a rotational speed of 60 rpm at 150 °C for 90 min. Injection moulding was carried out on a Nissei NS20-2A injection moulding machine to fabricate tensile shape compact. The compacts were produced by injection moulding at 150 ◦C, and no cracks were observed throughout green compacts.

C. Binder Removal and Sintering

The debinding process consists of two phases; (1) solvent debinding and followed by (2) thermal debinding. In the solvent debinding process, the green compact was kept in 60˚C solvent bath of the vapourised heptane for 2h. For the thermal debinding phase, the process was carried out in a high-temperature tube furnace with a heating rate of 5˚C/min from room temperature to 500 ◦C and holding at 500 ◦C for one 1 h. At this stage, the residual binders were evaporated into gaseous before blew out by the pressure from flowing argon gas. In sintering stage, the process also will be conducted by using high-temperature tube furnace under argon atmosphere. The compacts were sintered at 1100, 1200, and 1300 ◦C for 1 and 3-hours soaking time. Different sintering parameters were used for groups of compacts as presented in Table 3.

D. Physical and Mechanical Testing

The surface roughness of sintered compacts was determined using a MarSurf PS1 surface roughness tester. Three compacts from each sintering condition were measured five times. The results are presented as mean values. Tensile tests were performed using Instron 5900 Universal testing machine equipped with a 50 kN load cell. The tensile tests were carried out at room temperature at a constant crosshead of 1 mm/min. Three sintered compacts were tested for each condition, and the tensile strength and elongation were determined.

Table 2: Binder system for 316L SS

Binder Type	Components	Composition (%)
Binder A	Paraffin wax (PW)	70
	Polypropylene (PP)	25
	Stearic acid (SA)	5
Binder B	Paraffin wax (PW)	69
	Polypropylene (PP)	20
	Carnauba wax (CW)	10
	Stearic acid (SA)	1

Table 3: Process parameter for sintering

Sintering Condition	Sample group					
	1100 ˚C 1h	1100 ˚C 3h	1200 ˚C 1h	1100 ˚C 3h	1300 ˚C 1h	1300 ˚C 3h
Sintering temperature (˚C)	1100	1100	1200	1200	1300	1300
Sintering time (h)	1	3	1	3	1	3

3. RESULT AND DISCUSSION

A. Influence of sintering parameters on physical properties

Table 4 shows the average results for shrinkage and surface roughness of sintered compact for six different sintering parameters. of sinterd compacts. Fig. 2 revealed the shrinkage and surface roughness in dependence on sintering parameters. As predicted the shrinkage increased with increasing sintering temperature and time. At that, increasing the sintering time by 2h showed a bigger effect to the shrinkage result than increasing the sintering temperature.

Table 4: Average result for shrinkage and surface roughness

Condition	Shrinkage (%)		Surface roughness (µm)	
	Binder A	Binder B	Binder A	Binder B
1100 ˚C 1h	6.1	6.0	1.41	1.96
1100 ˚C 3h	7.9	8.0	1.55	1.64
1200 ˚C 1h	8.5	8.9	1.70	1.86
1200 ˚C 3h	9.4	9.4	1.40	1.77
1300 ˚C 1h	9.1	9.3	1.26	2.04
1300 ˚C 3h	10.1	9.9	1.22	2.07

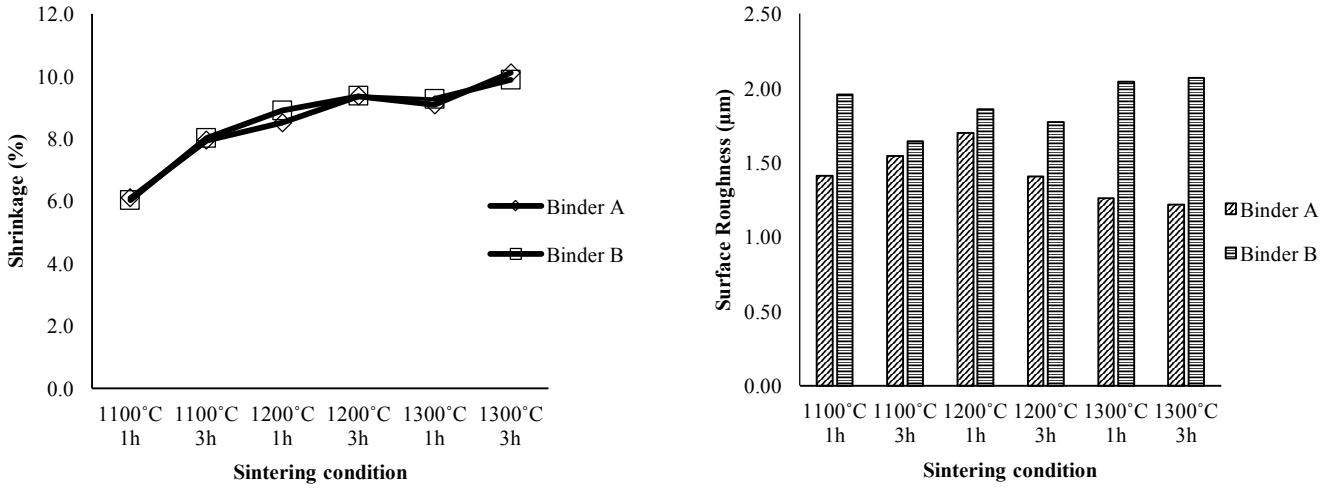

Figure 2: Dependence of shrinkage and surface roughness for binder A and binder B on MIM processing parameters

For surface roughness, in general, compacts from binder B obtained higher surface roughness compared to the compacts from binder A. This is due to the higher content of binder were removed during thermal debinding process for binder B. The present of carnauba wax in binder B cannot being removed by solvent debinding due to its high melting point. Carnauba wax have a capability to retaining the compact shape in late debinding and at early stage of sintering process [1]. During thermal debinding, more binder was removed in binder B and the binder keep push the surface outward and cause the surface of the compacts become rough.

B. Influence of sintering parameters on mechanical properties

Table 4 shows the tensile strength and the elongation of the compacts for binder A and binder B. Also, it can be conclude that an increase in the sintering temperature and time shows a significant effect on ductility and strength characteristics of sintered compacts. However, no major difference has been recorded on the strength and elongation properties between both binder systems. Sintering temperature and time show a stronger effect on both tensile strength and the elongation. Both binder components recorded tensile strength between 222 MPa – 393 MPa. The compact that sintered at 1300 ˚C for 3-hour exhibit highest tensile strength compared to other compacts conditions. Fig. 3 display the graphic representation of tensile strength and elongation based on the processing parameters. The increase in tensile strength is should be due to the better densification at higher sintering temperature where it reduces the pore volume [2, 3].

Table 4: Tensile strength and elongation of the compacts for binder A and binder B

Condition	Tensile strength (MPa)		Elongation (%)	
	Binder A	Binder B	Binder A	Binder B
1100 ˚C 1h	228	222	11.9	10.6
1100 ˚C 3h	276	279	14.5	17.1
1200 ˚C 1h	277	303	17.2	17.4
1200 ˚C 3h	319	332	18.0	21.6
1300 ˚C 1h	351	362	23.6	23.6
1300 ˚C 3h	393	373	21.8	20.5

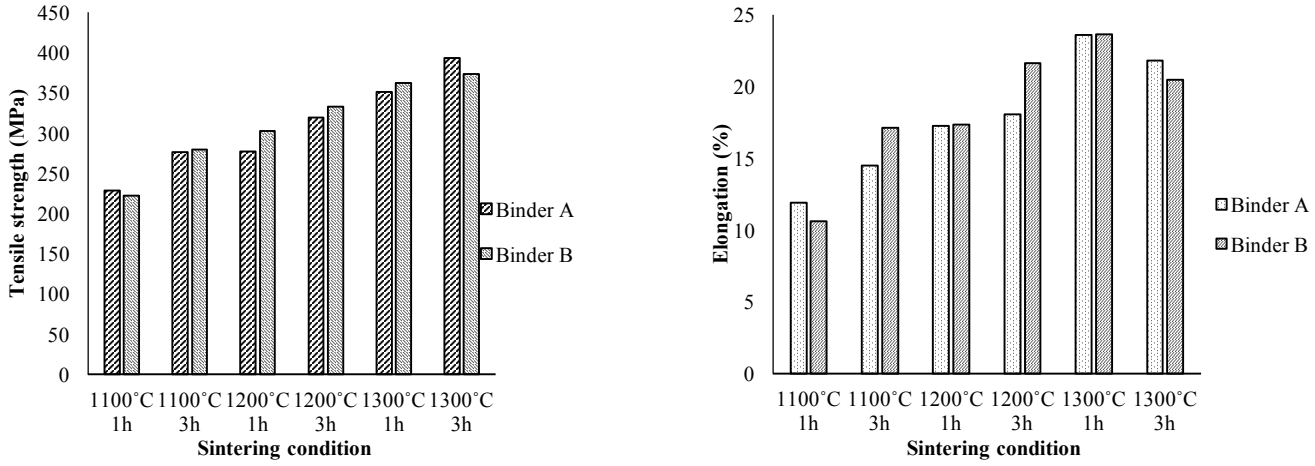

Figure 3: Tensile strength and elongation for binder A and binder B

4. CONCLUSION

Based on the experimental result, this work concludes the following;

- The sintered 316L SS test compacts developed from 62 vol.% powder loading, sintered at 1100˚C, 1200˚C and 1300˚C with two different sintering time showed tensile strength ranges from 222 to 393 MPa and elongation ranges from 10.6 to 23.6%.
- While the present of carnauba wax in binder B give a significant effect on the surface roughness result, no major impact has been recorded on the mechanical properties of the compacts.

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