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Influence of Pressure Type on Powder Injection Moulding of Stainless Steel (316L) Powder

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ABSTRACT

In this study, influence of hydrolic pressure or gas pressure on the powder injection molding of 316L stainless steel was investigated. Variations in the microstructure, hardness and density of the porduced samples were discussed in the frame of presure type. In the injection molding applied molding pressure, ratio of powder/binder, binder leacing time, sintering temperature also were examined. Experimental works showed that the gas pressure system was observed to be more effective than hydrolic pressure system for each parameters. Experimental results also showed that the powder ratio in the feedstock and sintering temperature had dominant effect on hardness and microstructure of the samples. The leaching time of Polyethylene Glycol (PEG) 600 binder has been decreased with increasing molding pressure. Increasing hardness and density of samples were achieved by increasing metal powder ratio. The increasing in hardness and density were also observed by increasing sintering temperature.

Keywords:
Powder injection molding; Hydrolic pressure system; Gas pressure system; Debinding times; Sintering temperature; Powder/binder ratio.

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INTRODUCTION

Powder injection molding (PIM) used in the production of small-sized complex machine parts, prostheses and medical device parts is a method of filling metal or ceramic powders into molds with the aid of a binder or carrier[1-4]. Powder and binder mixtures prepared for powder injection molding are called "feedstock". In order to obtain the feedstock, metal and ceramic powders are mixed with thermoplastic binders and other additives. Nowadays water and many inorganic materials are successfully used as the other additives. The amount of binder varies from 15% to 50% in volume [2]. In practice, feedstocks containing numerous binders and similar additives are multifunctional systems. Figure 1 shows flow chart steps of the PIM process. Firstly, the appropriate selected powder/binder is mixed and then granulated. The granular mixture is placed into the injection machine.

The mixture coming to the toothpaste consistency is delivered to the cavity of the mold which is connected to the injection machine with a suitable pressure at given temperature.Thereby the green part is obtained by taking the shape of the mold. In the next step of the process the binder is removed from the green part. The removing process can be carried out in essentially two different ways. The decomposition of the binder is carried out with firstly the solvent and then thermally. After removing the binder from the green part sintering is performed.Sintering should be carried out in a suitable atmosphere to prevent losses of critical elements, such as carbon in the steel, from being degraded by nitrogen or oxygen. At the end of the sintering process, a part is found which is almost completely dense and has a relatively low porosity level. By appropriate separation and sintering it is possible to obtain 90-99% of the theoretical density of the material. Mechanical properties of the fully dense parts are similar to that of the as-cast and/or forged parts[3].

Therefore, the PIM method has important advantages over other methods for the production of advanced parts with complex shapes. The main advantages of PIM are related to lower costs and shorter debinding time. The PIM enables to mold metal/ceramic parts with soft and low cost molds. For the fabrication of samples without cracks and distortion, the rheological behaviour of feedstock is very important [5–7]and it is clearly influenced by powder characteristics and binder

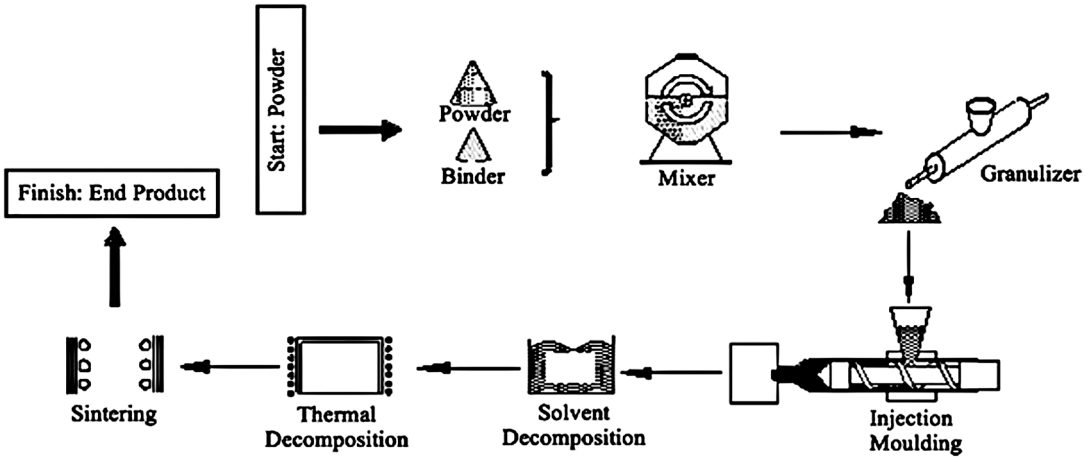


Figure1. Manufacturing process of powder injection moulding [2].

properties. The knowledge of characteristics of powder and binder is essential for successful PIM manufacturing [8]. PIM of stainless steels has been widely investigated[9-11]. In spite of various studies [7-11] on the PIM, a systematic investigation on the effect of processing parameters with gas and/or hydraulic piston pressure have not been reported. Thus, the present work was performed to investigate the effect of applied molding pressure, ratio of powder/binder, binder leacing time, sintering temperature on the density, hardness and microstructureof samples in two different (gas or hydrolic) pressurized molding system

EXPERIMENTAL

In experimental studies 316L stainless steel powder sized with 45 μm produced by water atomization method were used. A water-soluble mixture of 80% PEG 600 and 20% PMMA was used as the binder.The binder and powder mixtures (50%, 52% and %54 of solid volume ratio) were first dried and then mixed in semi-solid state on the heating plate. The prepared binding powder mixtures were injected into the mold of the PIM.In order to injection of the powder materials, two types of molding systems were used as given in Figure 2.During the filling

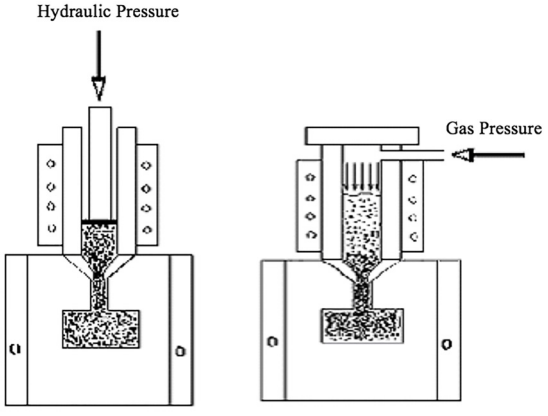


Figure 2. Moulding systems of powder injection moulding machine.

feedstock into the mold in the molding process, the feedstock and the mold temperature were held constant at 160 °C and 60 °C, respectively.Molten feedstock was injected into the mold cavity by means of the hydraulic and/or gas pressureunder 20, 30 and 40 bar.After that the binder (PEG 600) was dissolved in a ceramic pot filled with distilled water at 60 °C for different times (2-6h). Termal removing of binder(PMMA) was carried outin an argon atmosphere controlled furnace at 360 °C for 1.5 hours and then sintering was performed at different temperatures (1250, 1300, 1350 °C).Density measurement was taken before and after sintering in the device with AD-1653 density kit.Microstructural characterization of the investigated samples was carried out by Nicon Epiphot 200 model optical microscopy. In the microscopic examination studies, the samples ground and polished with standard metallographic methods were electrolytically etched in the oxalic acid solution under 1.5 volts for 15 seconds.The hardness measurements were determined using Schimatzu HMV-2 microhardness machine having Vickers indenter under 10 g.load.

RESULTS AND DISCUSSION

Changes in the binder (PEG 600) loss are given in Figure 3 with respect to the water dissolving times and the molding pressure. As seen Figure 3, the loss of the binder in each molding pressure appears to be insoluble after 6 hours.Also it has been determined in Figures 3 that applied the molding pressure is an important factor for PEG 600 weight loss. The PEG 600 loss decreased with increasing the molding pressure in accordance with Ref. [12].

Figure 4 shows SEM images of samples before and after the binder dissolution. It is seen that the 316L stainless steel powders are coated with the binder mixtures

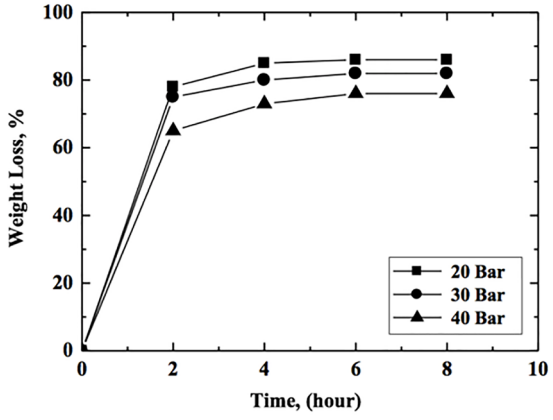


Figure3. PEG loss as a function of leaching time and pressure (solid volume fraction: 50%)

(PEG + PMMA) before the dissolution.Figure 4b shows the formation of voids and channels between powders by dissolution of PEG 600 obtained after 6 hours at 60 °C. During the dissolution, the PMMA remains in the structure and provides the connection of the powder particles with each other.The smilar results were reported by Omar et al. [13,14]. The presence of void and channels between powders helped burning out of the PMMA during thermal dissolution and prevented distortions owing to gas expansion.

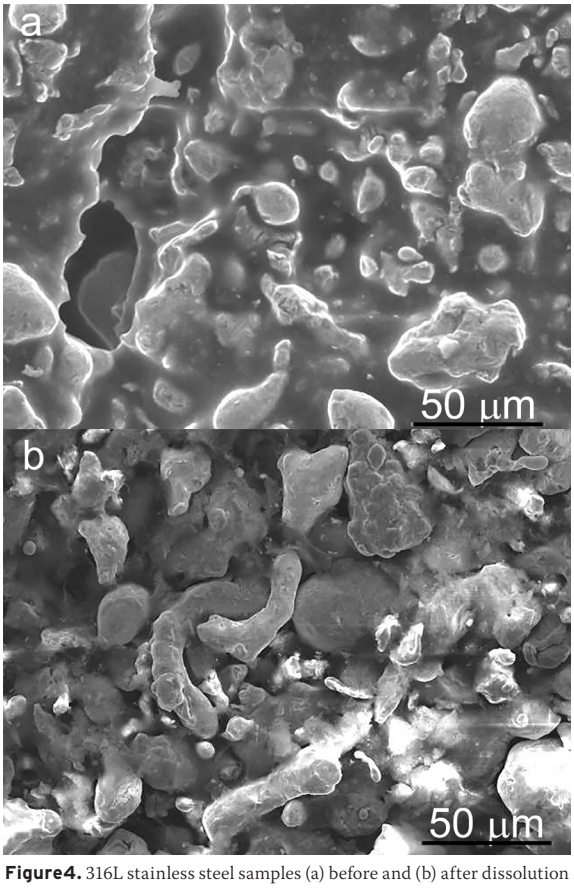
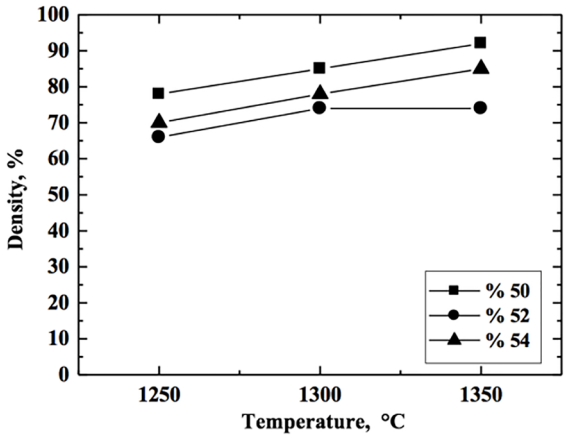
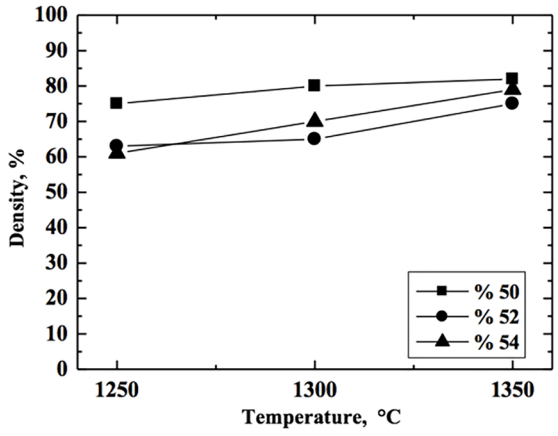


Figure4. 316L stainless steel samples (a) before and (b) after dissolution process (500X).



(a) Method: Gas pressure

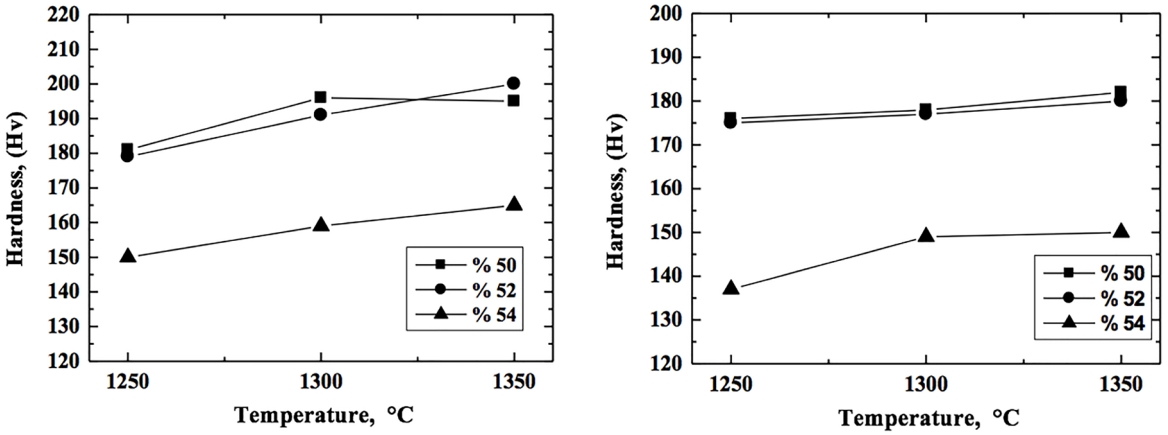


(b) Method: Hydraulic pressure

Figure 5. Density change as a function of sintering temperature.

It is shown in Figure 5 that the density increases with sintering temperature and decreases with solid volume ratio in two different systems. Figure 5 shows that the density of the samples with 50 % solid volume ratio sintered at 1350 °C is 83% for the hydraulic system (Fig 5b) and 92% for the gas system (Fig. 5a). This can be attributed to the closed of the gaps and insufficient binder for packaging by hydrolic pressure. It has also been reported in the literature [14] that when the amount of binder increased from 10% to 25%, the sintering density rised from 92 % to 95%.It is reported that [12] addition of fewer binders caused powder to lock between each other due to insufficient sliding during the flow.

It has been observed in Figure 6 that the hardness increases with sintering temperature and decreases with increasing solid volume ratio in both molding systems. As seen in Figure 6, the hardness of samples produced by gas press is higher at 1350 °C.Omar et al. [14] also indicated that the hardness of the samples would increase due to the better condensation with increasing binder ratio and sintering temperature.



(a) Method: Gas pressure (b) Method: Hydraulic pressure

Figure 6. Hardness change as a function of sintering temperature.

In this study in contrast to the gas pressure system,hydrolic system led to the heterogenus powder distrubution(Figure 7). This can be explained with pushing the binders towards the edge zone of the mold by the effect of the hydraulic pressure and forming too many gaps at the edges after the binders dissolution during sintering.

The sintering applied at 1250 °C led to the very porous microstructure (Figure 8a). As the sintering temperature increased, the pores disappeared and the powder grains bonded to each other better (Figure 8b). When the sintering temperature reached to 1350 °C grain growth was be more significient (Figure 8c). Relaeted to increased sintering temperature the pores decreased and became more spherical. This is supported by the literature [15,16].

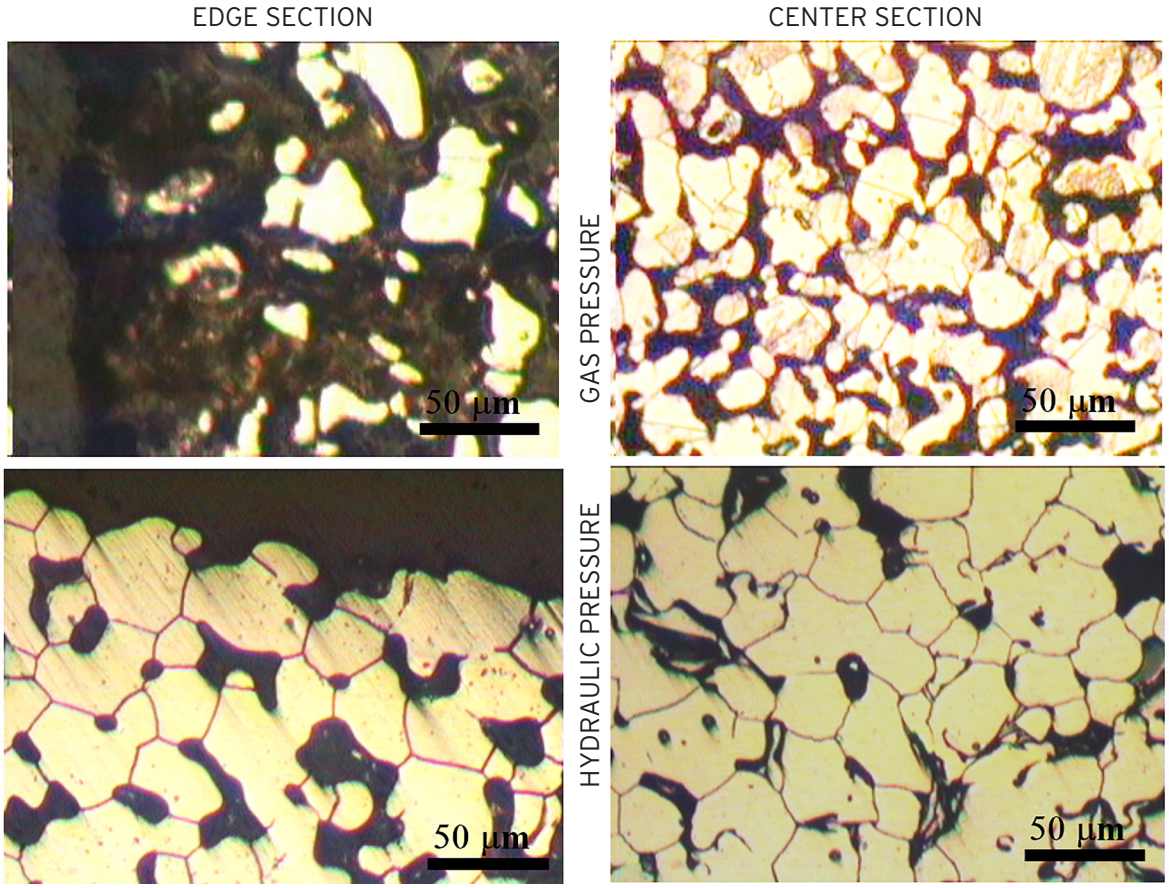
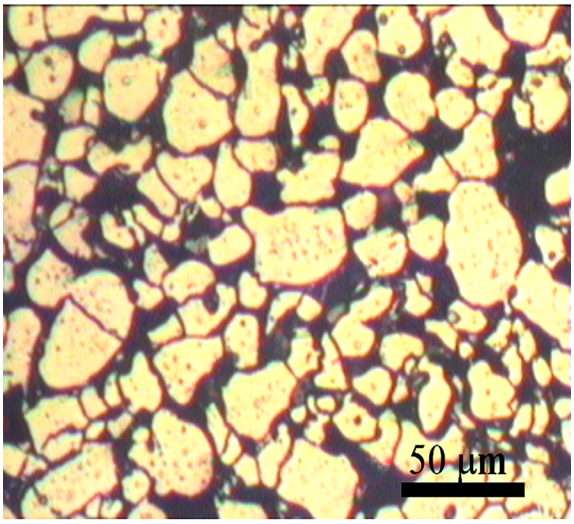
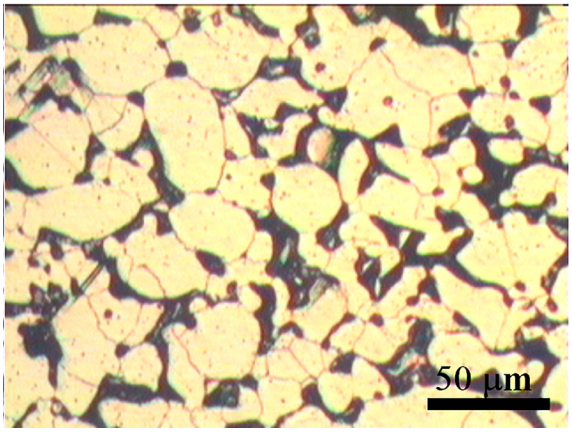


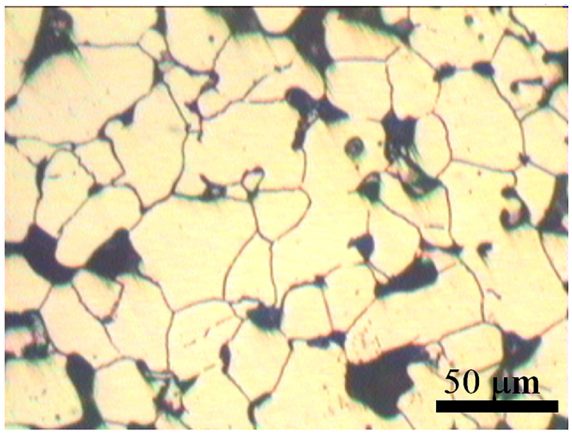
Figure 7. Optical microstructures of the samples with a volume fraction of 50% produced by hydraulic and gas pressure methods.



(a) 1250 °C



(b) 1300 °C



(c) 1350 °C

Figure 8. Optical microstructures of the samples with a volume fraction of 50% sintered at (a) 1250 °C, (b) 1300 °C and (c) 1350 °C for 1 h.

CONCLUSION

The results of the experimental studies can be summarized as follows

1. Experiment results showed that the 6 hours leaching time for both molding systems is sufficient to dissolve the PEG 600 binder.
2. Hydrolic pressure system has pushed the binders towards the edge zone of the mold and formed excessive gaps at the edges after the binders dissolution during sintering.
3. In both molding systems, the hardness and density of the samples increased with sintering temperature and decreased with solid volume ratio.
4. It has been shown that the samples produced by the gas pressure system in the experiments exhibited a homogeneous distribution of the powder in the microstructure compared to the hydraulic pressure system.

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