Preparation of SS316L MIM feedstock with biopolymer as a binder

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Abstract. This paper focus on feedstock preparation for SS316L metal injection molding (MIM) part. The primary step of feedstock preparation, critical powder loading determined by two method; maximum filled volume calculation model and torque analysis. The critical powder loading determined by calculation was 70 vol% to 77 vol% while for experimental approaches shows the value of 75 vol%. The feedstock was prepared by mixing SS316L powder and polymer binder with ratio 70:30 at 175 °C with speed of 50 rpm. The feedstock was analyzed by thermogravimetric analysis (TGA) and Scanning electron microscope (SEM). The composition for the feedstock after preparation step was confirmed by TGA. It was found that the prepared feedstock component was compatible to each other and composition is maintain along the mixing step.

1. Introduction
Metal injection molding (MIM) is an economics and environmental friendly metal working process. The advantages of MIM such as high volume of production and able to produce intricate shape with minimum finishing process [1]. This process consist of four main step. The first step is feedstock preparation; the metal powder mixed with polymer binder. The second step is injection molding followed by debinding. The final step of MIM is sintering, in this step the debind part known as brown part is densified. Each step parameter and condition needs to consider in detail due to failure chaining from one-step to another. The first step of MIM is considered as crucial part. Numbers of studied done on the preparation of MIM feedstock determine the optimum binder composition[2], to improve the bonding between metal powder and binder[3-4], to increase the dispersion of powder and binder in the feedstock[5], and the best metal powder characteristics to ensure free defect part produced[6]. Various paper reported on the optimum composition of feedstock in MIM. Petroleum based polymer has been widely accepted as the binder for MIM feedstock and it is found that bio based polymer can reduced the debinding process of MIM part. Polyhydroxyalkanoates (PHA) is one of bio based polymer that recently been studied by researcher. By replacing petroleum based polymer with bio based polymer, the processing time of MIM part will reduced.

In this paper, MIM feedstock consist of SS316L and (PHA) were investigated concerning the critical powder loading determined by two method and the feedstock properties.
2. Experimental procedures
The SS 316L was supplied by CNPC Powder with density of 7.92g/cm\(^3\). The shape and the particle size distribution of the powder were determined by field emission scanning electron microscope (FESEM JEOL JSM-7000F) analysis and laser particle size analyzer, respectively. The critical powder loading was calculated by the ratio of tap density to pycnometer density relation and measured by mix the powder with oleic acid gradually 1ml for every 3 minutes with speed of 50rpm. The feedstock was prepared with powder loading 5vol% less than critical powder loading determined and binder composition 55, 40, and 5 vol% of paraffin wax (PW), polyhydroxyalkanoates (PHA) and steric acid (SA) respectively. The feedstock was mixed in Barbender internal mixer with 50 rpm at 180\(^\circ\)C. The feedstock was analyzed using TGA and FESEM. The composition of the binder in the prepared feedstock confirmed by TGA and supported by SEM analysis.

3. Results and Discussion
The theoretical value of critical powder loading for SS316L is determined by maximum filled volume calculation model. The tap density to the pycnometer density ratio show the maximum packing state of the powder [7]. It is widely accepted that the critical powder loading will be 10% to 20% more than the tap density; pycnometer density value [8]. Based on the pycnometer density and tap density 7.92 g/cm\(^3\) and 5.1 g/cm\(^3\) respectively, the critical powder loading calculated is in range of 70 vol% to 75 vol%. However, this method is not accurate as the result from calculation is commonly much lower compared to the experimental result [9]. Hence, torque analysis was done to support the theoretical finds. Mixing torque between SS316L and oleic acid is illustrated in Figure 1. The critical powder loading for SS316L was identified at the highest torque value, which is at 75 vol% of powder loading. At this point, the space between the powder particles was fully filled by the binder. As the volume of oleic acid keep increasing, the mixing torque decrease as the liquid be the major constituent and act as lubricant. This critical powder loading value is much higher for the similar average size of powder found by other researcher [10-11]. This is due to the difference in the particle size distribution as indicated in Figure 2. The SS316L powder has wide distribution for size less than D\(_{50}\) and the pore between the large particle filled results in high powder loading.
Figure 1  Mixing torque between SS316L and oleic acid

Table 1: Critical and possible optimum powder loading range for different determination methods

| Method                        | Critical powder loading | Optimum powder loading |
|-------------------------------|-------------------------|------------------------|
| Maximum filled volume calculation | 70 – 75vol%            | 65- 73vol%            |
| Mixing torque analysis        | 75vol %                 | 70-73vol%             |
Figure 2: Particle size distribution of SS316L powder

Figure 3 shows the morphology of the feedstock before (a) and after (b) been analyzed under TGA at 450°C. From figure 3(a), shows that the feedstock dispersion between the powder and binder is homogenous after been prepared with the set parameter and condition. The binder has completely removed and some binding particle melted forming physical bonding between the large powder particles as shown in figure 3(b). This phenomenon provide mechanical support to the brown part produce after thermal debinding which may reduce the brittleness of the part. It is confirmed that this temperature is the lower point temperature range for the debinding temperature.

Figure 3 Morphology of MIM feedstock under SEM (a) dispersion of powder and binder are homogenous at 100 vol% (b) feedstock after TGA test done, binder has fully removed from the feedstock and small particle difused into the large particle increace the strength of the brown part.
4. Conclusion
The paper summarised the primary step in feedstock preparation of SS316L with critical powder loading of 75 vol% determined by mixing torque analysis and 70 vol% to 77 vol% by theoretical approach. The preparation process gives no effect to the composition of the feedstock. A maximum powder loading for MIM feedstock is important to reduce the shrinkage factor and defect caused by excessive amount of binder.

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