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# Composition and Type of a Binder Effects on the Stainless Steel Foam Microstructure Prepared by Sponge Replication Method

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**Abstract:** Biomaterials with a porous structure are beneficial for a wide range of medical engineering applications such as filtration, bone replacement and implant development. Stainless Steel 316L (SS316L) foam has been fabricated by foam replication method at different SS316L powder composition which is 60 wt%, 65 wt%, and 70 wt%. The binders used were Polyethylene Glycol (PEG), Carboxymethyl Cellulose (CMC) and Polyvinyl Alcohol (PVA), while distilled water was used as a solvent. The effects of using different composition of SS36L powder, binders and sintering time to the SS316L foam properties was studied. The materials were mixed by using a mechanical stirrer at 250 rpm for 1 hour. Polyurethane foam (PU) which was used as a sacrificial template was dipped into the SS316L slurry until fully coated. The coated samples were then dried in a drying oven within 24 hours before being sintered in an argon gas environment at 1200°C. The samples were characterized to observe the microstructure of the SS316L foam produced. As expected, the viscosity of the SS316L slurry was increased as the SS316L composition increases. The viscosity of SS316L slurry prepared by using PVA as a binder is higher than the SS316L slurry prepared with CMC and PEG as binder. The SS316L foam produced consisted of a large volume of open and interconnected pores especially at higher SS316L composition.

**Keywords:** SS316L powder, SS316L foam, medical engineering, stainless steel, PVA

## 1. Introduction

Metal foams with open and interconnected pores are very attractive for a wide range of application. For example, like a catalytic converter in the automotive industry, heat insulator for industrial furnace and in biomedical as a bone implant [1]. Metal foam with an open pore structure could be produced by using several fabrication methods including of space holder method, replication method, combustion synthesis, vapour deposition and rapid prototyping [2][3]. Among all the methods, sponge replication method has been proved capable to produce foam with an open and interconnected pore that is similar to the cancellous bone structure [4].

The fabrication of stainless steel foams from the stainless steel slurry is not straightforward. There are many parameters involved during the slurry preparation including the materials' composition, the mixing methods, types of binders and types of solvents used that affects the slurry's viscosity. It is essential to produce a stainless slurry with appropriate stability and viscosity especially when using sponge replication method to fabricate the foam. Only at certain slurry viscosity, complete impregnation of the stainless steel slurry onto the PU foam template could be achieved. It is very challenging to produce stainless steel slurry with low viscosity at high solid content. Slurry with

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low viscosity is required to allow the slurry easily penetrate into the PU foam pores, while high solid content is needed to improve the mechanical stability during the sintering [5].

PEG, CMC and PVA are among the most used binder to prepare metal and ceramic slurries. This binder is preferred because it is cheaper, environmentally friendly, and also has a better solubility [6]. M. Tange et al. [7] used three different compositions of PVA as a binder which were 1 wt.%, 1.5 wt.% and 2 wt.% to produce titanium foam by sponge replication method. They found that the optimum PVA composition was 1.5 wt.%. In other work, Titanium scaffold has been produced by a group of researcher from the National Engineering Research Center for Biomaterials, Sichuan University, China [4] using the same fabrication method and 5 wt% PVA. Titanium scaffolds with open and interconnected porous structure were obtained after optimizing several processing parameters including the viscosities of Titanium slurries. In this work, the composition of binder is based on the author's previous work [8] since porous SS316L was successfully fabricated using sponge replication method with 5wt.% PEG/CMC. Therefore, this work is conducted to study the potential of PVA as a binder compared to the CMC/PEG in the fabrication of stainless steel foam.

## 2. Experimental procedure

The stainless steel powder, binders and solvent were mixed by using a mechanical stirrer for 1 hour at 250 rpm speed. The composition of the stainless steel powder was varied from 55 wt% to 75 wt%, while the binder's composition was remaining at 5 wt%, and the balance is the distilled water. The slurry viscosity was measured by using Vibro-viscometer. After that, PU foam was immersed in the prepared stainless steel slurry for about 10 minutes. The coated PU foam was then manually pressed to remove the excessive slurry. The immersion and removal steps were repeated three times to ensure that the PU foam was fully coated with the stainless steel slurry. The coated PU foam was dried in the drying oven within 24 hours at 80°C before sintered at temperature of 1200°C in argon gas environment. The microstructure and pore size of the stainless steel foam produced was observed by using optical microscope.

## 3. Result and discussion

Figure 1 shows the average viscosity of the stainless steel slurry with five different compositions of stainless steel using a different type of binder. The viscosity directly increases as the stainless steel composition is increased for both type of binders. Stainless steel slurry with 75 wt. % stainless steel composition show the highest viscosity which are 10076 mPa.s and 5420 mPa.s for samples prepared with PEG/CMC and PVA as binder respectively. The viscosity of the stainless steel slurry produced by using PVA as a binder is significantly higher than the slurry prepared with PEG/CMC as a binder. With the same binder and stainless steel composition, the slurry with PVA binder presents the highest viscosity. It has been reported that the differences in viscosity resulted from the different densities and viscosities of binders [9][10]. The density of PEG, CMC and PVA are 1.08 g·cm-3, 0.51 g·cm-3 and 1.21 g·cm-3, respectively.

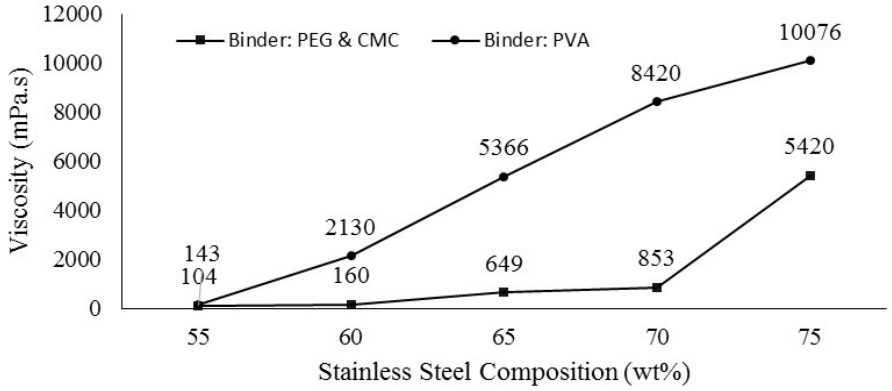


**Fig.1 - The slurry viscosity against stainless steel composition using the different binder**

Figure 2 shows the microstructure of the stainless steel foam produced after sintering process and captured at 10X magnifications by using an optical microscope. All binder materials and PU foam template were removed and burnt out during the pyrolysis stage in the sintering process. Generally, the microstructure of the stainless foam produced by using sponge replication method consisted of open pores and closed pores. Open pores with certain pore size is required for application as biomedical implant.

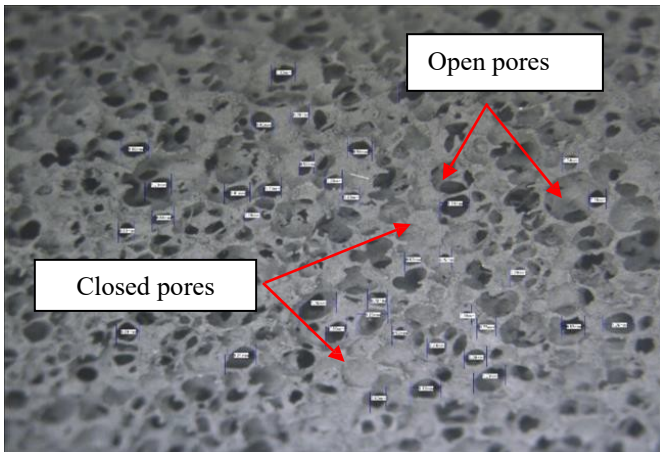


**Fig. 2- Microstructure of stainless steel foam produced by the sponge replication method**

The effect of using a different type of binder on the average pore sizes of the stainless steel foam is shown in Figure 3. The result shows that the pore size is not only affected by the type of binder used but also depends on the stainless steel composition [11]. Using the PVA as a binder has led to the formation of larger pore size compared to PEG/CMC. The pore size of the stainless steel foam prepared by using PEG/CMC as a binder is in the range of 164.16 to 310.34 micronmeters, whereas for stainless steel foam prepared by using PVA as a binder, the pore size is in the range of 516.19 to 733.26 micronmeters. The pore size is increased as the stainless steel composition increase. This is because, as the stainless steel composition increase, the slurry viscosity also increases. Therefore, the amount of the slurry stays adhered onto the PU foam template also increase and produce thicker struts. These struts will not easily collapse during the pyrolysis and sintering process. As a result, the stainless steel foam produced will have larger pore size. The pore size, pore shape and pore distribution are very important since the mechanical properties, corrosion resistance and biological properties of the foam is highly depends on the pore characteristics [12][13][14]. Certain pore size is also required for application such as for biomedical implant. The optimum pore size for biomedical implant is in the range of 100 to 500 micronmeters [13][15]. While the pores interconnection is crucial for blood and nutrition transportation within the bone structure and to allow for bone ingrowth [16].

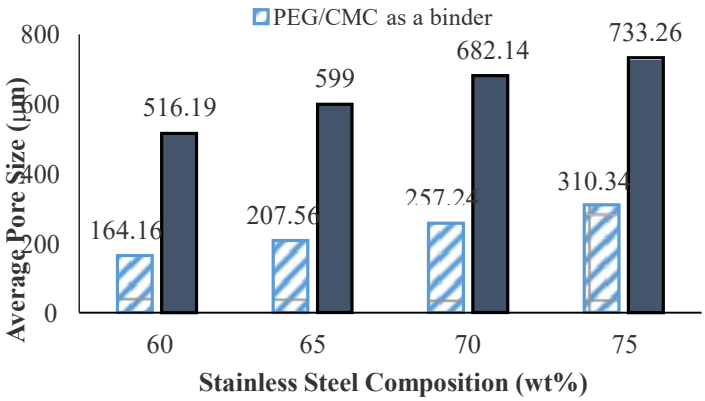


**Fig. 3 - The average pore size of stainless steel foam prepared by using a different type of binder and stainless steel composition**

The effect of using different type of binder on the stainless foam microstructure can be seen clearly in Figure 4. Figure 4 (a), (b), (c) and (d) show the microstructure of SS316L foam with PEG/CMC as a binder with 60 wt. %, 65 wt. %, 70 wt. %, and 75 wt. % stainless steel respectively. Whereas Figure 4 (e), (f), (g) and (h) show the microstructure of SS316L foam with PVA as a binder with 60 wt. %, 65 wt. %, 70 wt. %, and 75 wt. % stainless steel respectively. It can be seen obviously that the microstructure of the stainless steel foam prepared by using PEG/CMC as a binder consist of more open pores compared to stainless steel foam prepared by using PVA as a binder. The stainless steel foam with PVA binder mostly consisted of closed pores. This is due to the viscosity of stainless steel slurry prepared by using PVA as a binder is significantly higher than the stainless steel slurry prepared with PEG/CMC as a binder. The slurry viscosity is very essential in order to obtain a consistent thickness and coating layers on the PU foam template [9].

Generally, it is difficult to completely remove the excess slurry if the slurry viscosity is too high. In fact, it can lead to the blockage of the foam pores which can be seen clearly in Figure 4(h) [3]. The optical images also show that the pore distribution of the stainless steel foam prepared with using PEG/CMC as binder is more homogenous than the pore distribution of the stainless steel foam prepared by using PVA as a binder. Based on the microstructure, the best stainless steel compositions are 60 wt.% and 65 wt.% for stainless steel foam prepared by using PEG/CMC as a binder, and 60 wt.% for stainless steel foam prepared by using PVA as a binder. This is because, these samples highly consisted of open and interconnected pores with homogenous pore distribution.

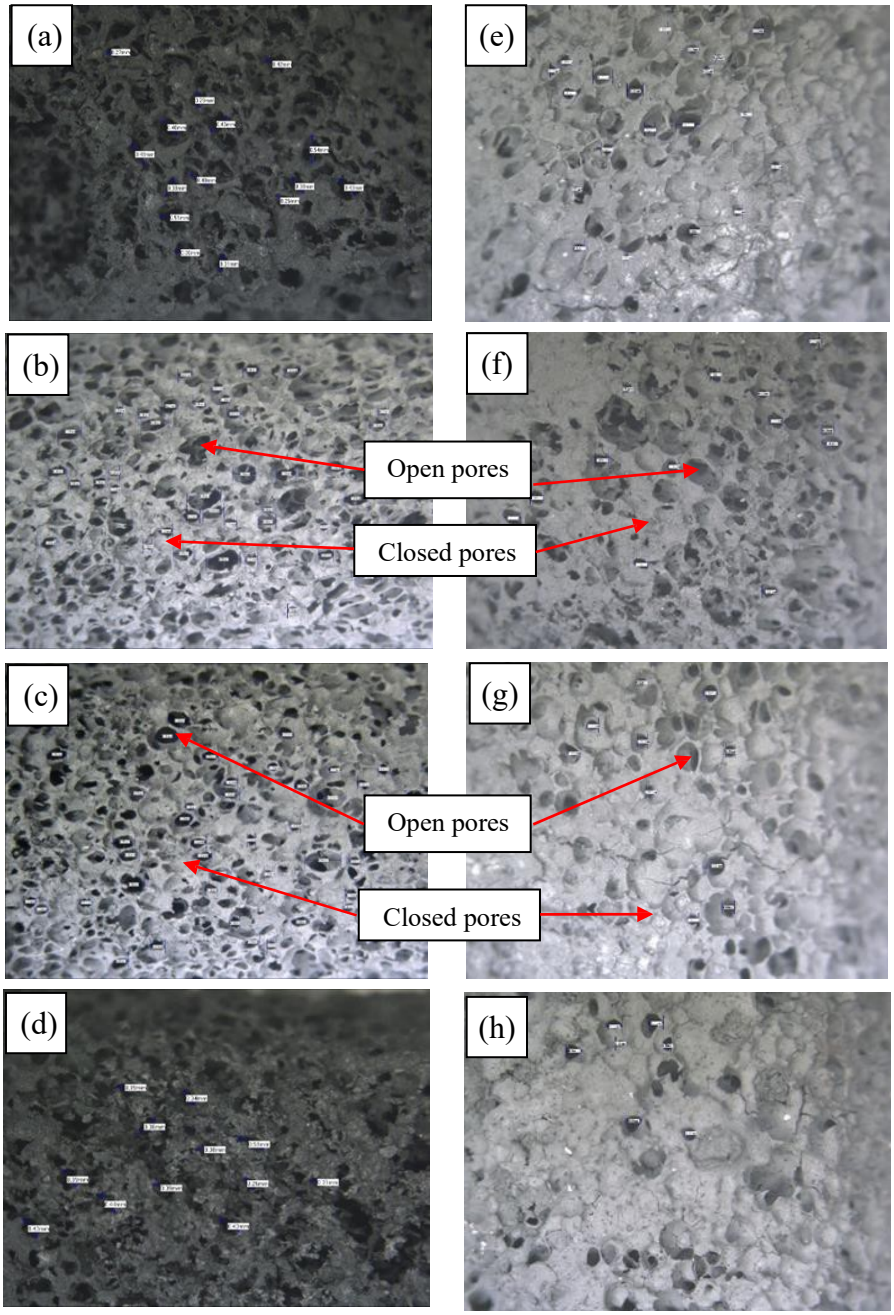


**Fig. 4 - Optical images of the stainless steel foam prepared by using PEG/CMC as a binder at different stainless steel composition of (a) 55 wt%, (b) 60 wt%, (c) 65 wt.%, (d) 70 wt. %, while for stainless steel foam prepared by using PVA as a binder at different stainless steel composition of (e) 55 wt%, (f) 60 wt%, (g) 65 wt.%, (h) 70 wt. %.**

## 4. Conclusion

The results have shown that the addition of 5wt.% PVA as a binder did not give beneficial effects on the stainless steel foam microstructure. The slurry viscosity increase significantly as the PVA was added as a binder. The amount of

open pores also reduced for stainless steel foam produced with PVA as a binder. Therefore, PEG/CMC works better as a binder for the stainless steel slurry preparation especially if the stainless steel composition is in the range of 60 wt.% to 65 wt.%. The pore size of stainless steel foam prepared with PVA as a binder is larger than stainless steel prepared with PEG/CMC as a binder. However, the slurry viscosity maybe reduced if the composition of the PVA added into the slurry is lower than 5 wt%. Therefore, in the future work, it is recommended that the PVA composition could be reduced below than 5 wt%.

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