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INJECTION MOLDING OF 316L STAINLESS STEEL POWDER USING PALM OIL BINDER SYSTEM

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ABSTRACT

This paper focuses on the investigation to produce sintered specimen of stainless steel parts produced by vertical injection molding technique. The stainless steel powder was mixed using z-blade mixer with the thermoplastic binder system comprising of polyethylene, paraffin wax, stearic acid, palm stearin and palmitic acid at different volume percent (%). The feedstock then was studied in term of viscosity and shear rate using capillary rheometer. The feedstock was molded using vertical injection molding machine. After molding, the green molded specimen was immersed into the solvent to extract partly of the binder system. The specimens then were sintered under vacuum atmosphere at the temperature of 1360^{o}C. The physical and mechanical properties of the sintered specimen such as density, hardness, porosity, shrinkage, weight loss, ultimate tensile strength and elongation achieved the minimum requirement for the Standard Metal Powder Industries Federation (MPIF) 35. The microstructure of the sintered specimens was also shown the twin structure of stainless steel and also ferrite and pearlite phase.

INTRODUCTION

Powder Injection Molding (PIM) is known as a cost-effective technique for producing small, complex, precision parts in high volume. The PIM process was developed from the traditional shape-making capability of plastic injection molding and materials flexibility of powder metallurgy [1,2].

In PIM process, there are consists of four-(4) main step to produce the final sintered parts: mixing, molding, debinding and sintering. The stainless steel 316L powder that was used in the investigation was mixed with a typical binder system at the volume percent range of 30 to 40%. Binder system is an important key component, which provides the powder with the flowability and formability necessary for molding. In this studies, the binder system that was applied were based on thermo-plastic and palm oil derivative binders such as polyethylene, paraffin wax, stearic acid, palm stearin and palmitic acid was formulated and developed in order to increase the homogeneity of the mixture. Table 1 shows the contents, percentage and melting temperature of palm stearin that was used as a binder system[3,4,5].

Table 1: Contents of Palm Stearin with the Melting Temperature

CONTENTS	PERCENTAGE (%)	MELTING (^{o}C)
Palmitic Acid	54.3	62.0
Oleic Acid	32.5	16.3
Linoleic	7.0	85.0
Stearic Acid	4.7	70.0
Myristic	1.3	54.0
Linolenic	0.1	44.0

The reason of using palm stearin as a binder system is due to the contents of palm stearin itself that can be an advantage during debinding process. The binder has been removed from the part based on the constituent of the impurities present. This is important since the removal of binder must be performed gradually so as to maintain the shape of the debound part or in other word is without losing its shape during slow heating. At different heating temperature, the binder melts leaving different impurities at different melting point. The left impurities also help forming a capillary hole for the removal of the following binder. Finally, all the binder constituents have been removed from the part. The shape of the part is retained. Therefore, the selection of palm stearin as the binder system fulfills the important criteria of binder system in PIM process.

EXPERIMENTAL DETAILS

The morphology of stainless steel 316L powder from ANVAL, Sweden is shown in Figure 1. It shows that the particle shape of the powder is spherical. The mean size of the stainless steel 316L powder was measured using LS Particle Size Analyzer is 15.18 μm. The chemical composition of the powder stainless steel 316L was determined using Induced Couple Plasma (ICP) is shown in Table 2.

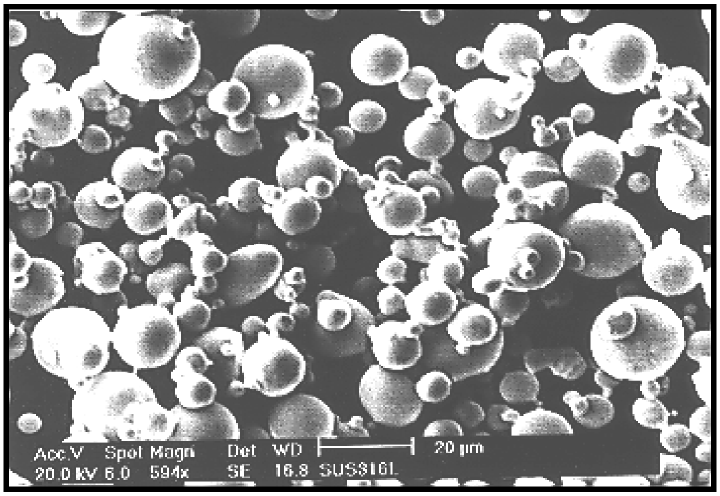


Figure 1: Morphology of the Stainless Steel 316L Powder

Table 2: Stainless Steel (SUS 316L) Powder Chemical Composition and Characteristic

Powder Identification: SUS316L
Powder Source: Anval 316 Stainless Steel, Sweden

Powder Chemistry	***By Manufacturer***	***By ICP***
%C	0.026	-
%Si	0.580	0.36
%Mn	1.430	1.44
%P	0.030	0.01
%S	0.012	-
%Cr	16.40	16.11
%Ni	10.40	9.97
%Mo	2.080	1.92
Tap density, g/cm^3	4.09	
Apparent density, g/cm^3		2.82
Pynometer density, g/cm^3	7.96	

In this studies, three-(3) different composition of binder system was developed and the volume percentage (vol. %) of binder composition of polyethylene (PE), paraffin wax (PW), stearic acid (SA), palm stearin (PS) and palmitic acid (PA) was formulated and namely as system A, B and C is shown in Table 3.

Table 3: Three-(3) Different Composition of Binder Systems

Binder	**System A (vol.%)**	**System B (vol.%)**	**System C (vol.%)**
Polyethylene	35	35	35
Paraffin Wax	55	55	55
Palm Stearin	10	-	-
Palmitic Acid	-	10	-
Stearic Acid	-	-	10

The melting temperature of each of the binders system was measured using Differential Scanning Calorimetry (DSC) is shown in Table 4.

Table 4: Melting Temperature of each Binder System

Binder	Melting Temperature (^{o}C)
Polyethylene	125.86
Paraffin Wax	63.60
Palm Stearin	54.22
Palmitic Acid	64.82
Stearic Acid	57.79

Determination of critical and optimum solid loading of the mixture powder/binder was measured using Brabender Plasti-Corder machine. The weight of stainless steel powder of 218 gram was poured into mixer bowl at different volume percent of oleic acids. Figure 2 show torque value versus solid loading of the mixture between powder and binder. From the results, the critical and optimum solid loading of the powder is 69.58% and 65.00% respectively.

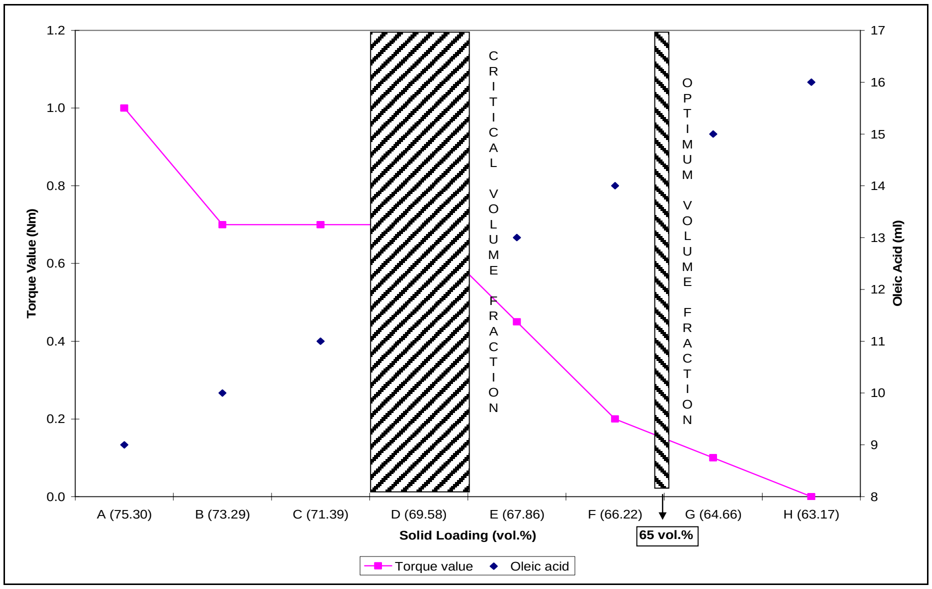


Figure 2: The Torque Value Versus Solid Loading of the Mixture

The rheological study of the compatibility and homogeneity of the mixture was measured in term of torque value, viscosity and shear rate using Brabenda Plastic-Corder and Capillary Rheometer. The mixture of the powder and binder so called as feedstock was mixed using z-blade mixer at the temperature range between 130 to 160^{o}C for 2 hour. The feedstock then was adopted to mold into the tensile test parts using Vertical Injection Molding (VIM) machine. After molding, the binder holds the particle in place. In the debinding process, two-(2) type of debinding method was implemented in order to remove the binder system on the green of the molded parts. In the first debinding process, the green molded parts were subjected to a solvent extraction where around two third of the volume fraction of the binder was removed. The green molded parts were immersed into the heptane for 4 hours at the temperature of 60^{o}C. The next process, the part which is had undergone solvent extraction were subjected to a thermal debinding where all the organic binder were completely removed. The parts were heated up to 440^{o}C at the rate of 1^{o}C/min and maintained at that temperature for 2 hours. The parts then were continued heated at 10^{o}C/min up to 1360^{o}C under vacuum atmosphere with holding time of 2 hours using High Temperature Control Atmosphere Furnace (HTCAF).

The density, hardness and strength of each of the sintered part were measured using Densimeter ED-120T, Vicker Hardness Tester and Instron-Universal Testing Machine respectively. Scanning Electron Micrograph (SEM) was used to investigate the microstructure of the sintered parts.

RESULTS AND DISCUSSION

Rheology study

The homogeneity of the feedstock was determined using Brabender Plastic-Corder and Capillary Rheometer. Figure 3 show the torque value versus time of the feedstock of system A, B and C

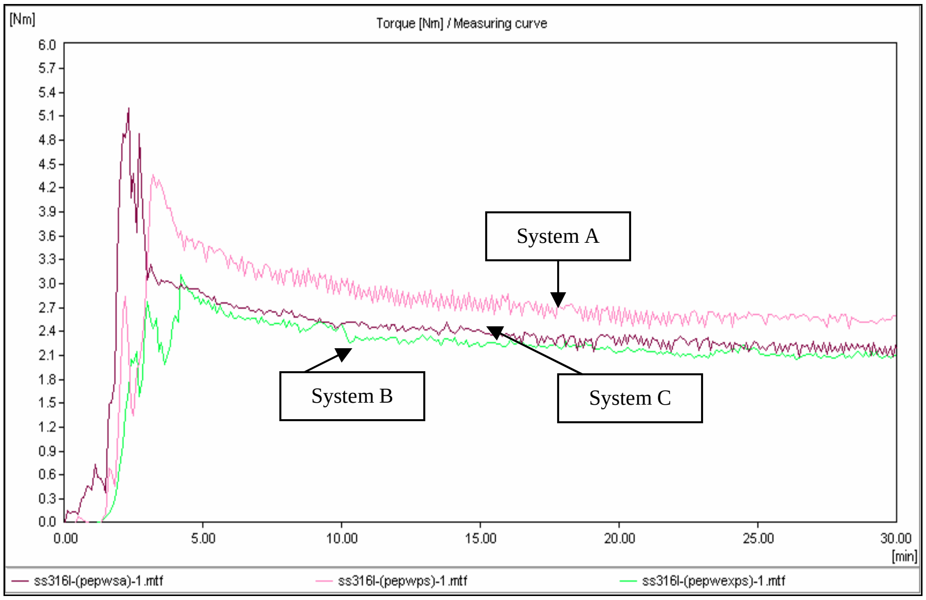
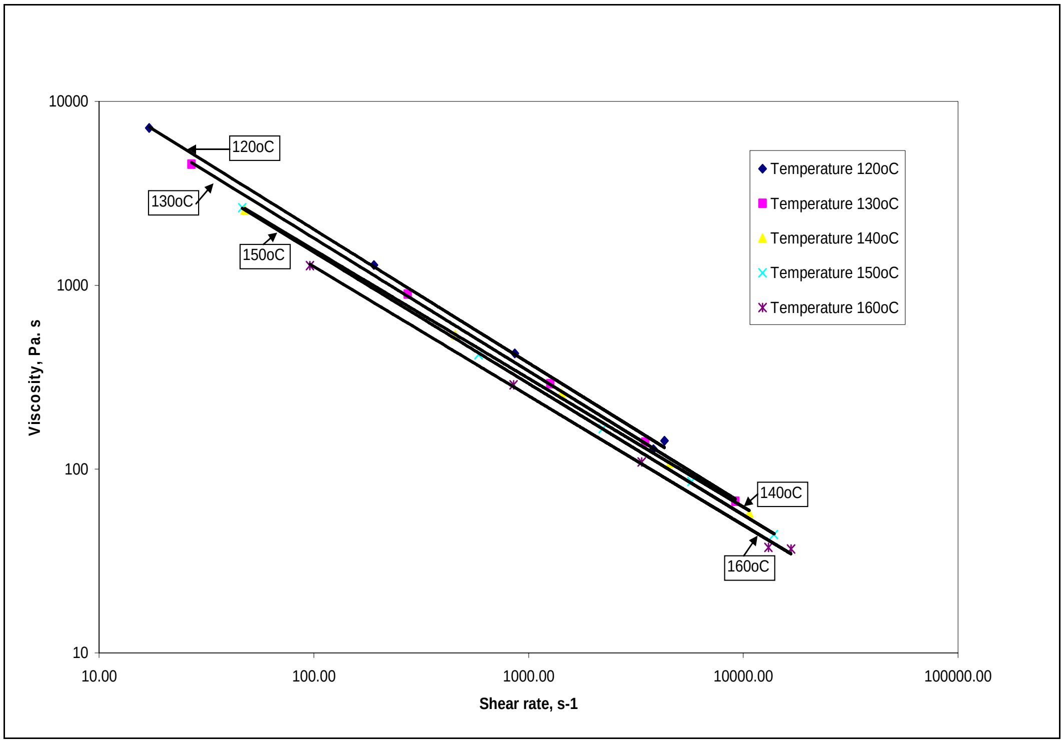
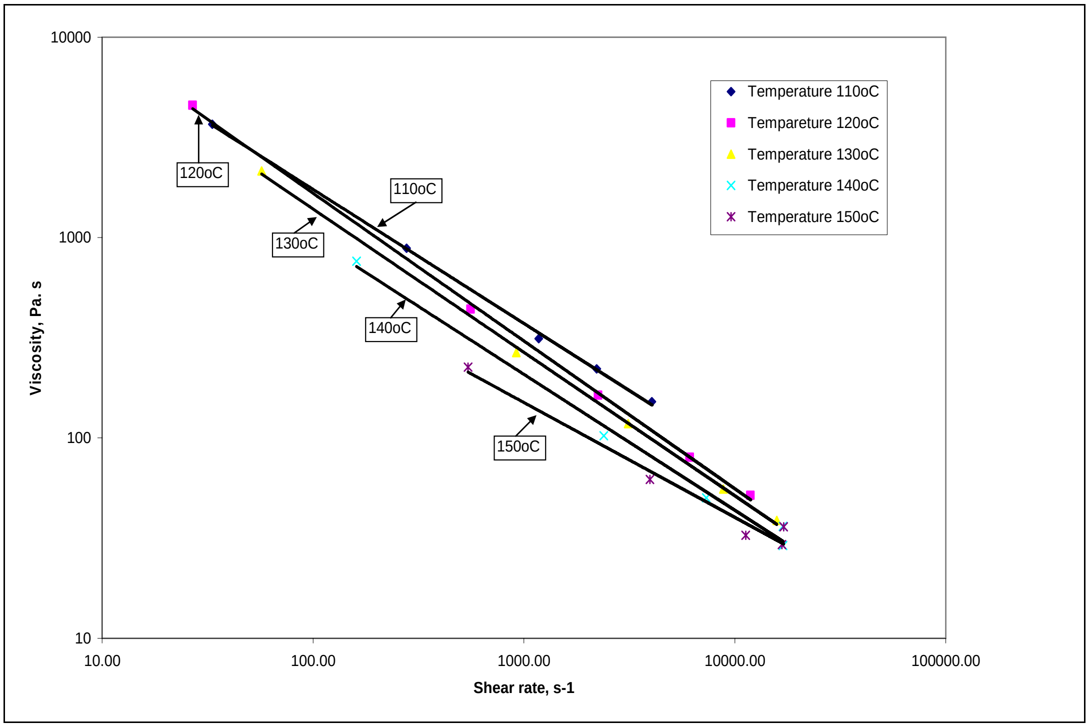


Figure 3: The Torque Value Versus Time of the Feedstock System A, B and C.

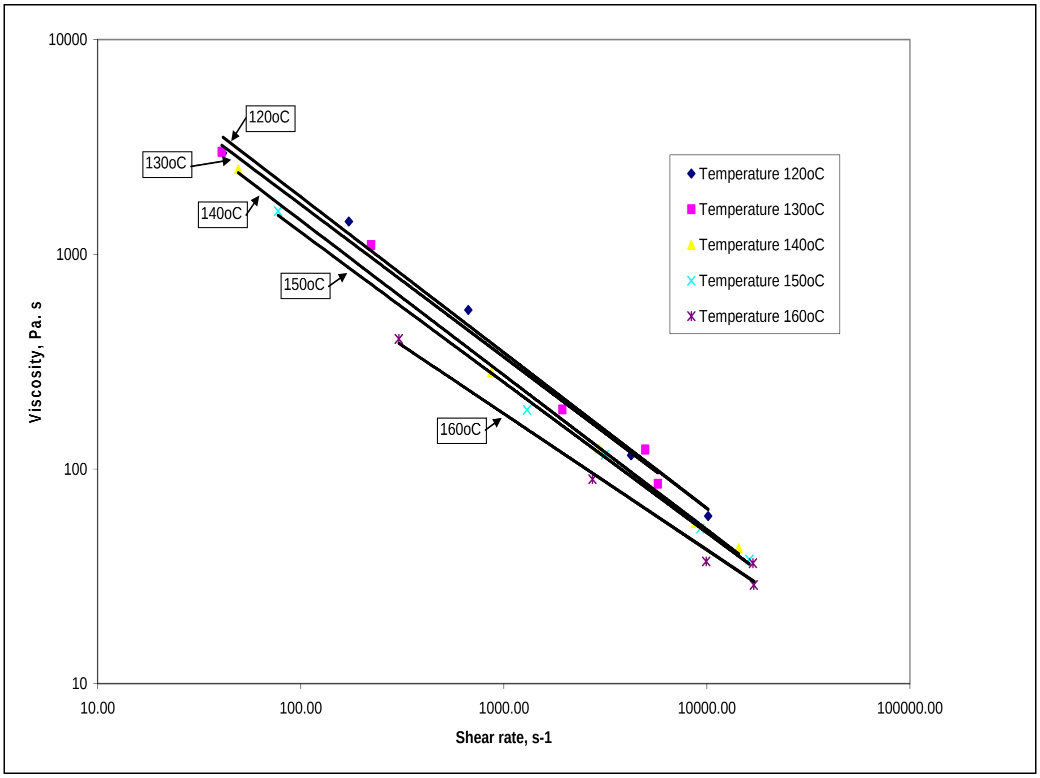
From the results, the feedstock of system B has the best of homogeneity follow by feedstock system C and A. The whole system has the torque value in the range of 2.1 to 2.7 Nm. Figure 4 (a), (b) and (c) show the viscosity versus shear rate of the feedstock system A, B and C using capillary rheometer at different temperature range of 120^{o}C to 160^{o}C. The results show that the viscosity of the feedstock exhibit pseudo-plastic behavior, which is common for PIM feedstock. The variation of viscosity versus shear rate in log-log scale graph is almost linear, which is an indicator of feedstock stability. Besides, as the temperature of feedstock increases, the viscosity decreases. In order to make the feedstock flow nicely into injection molding machine, the shear rate and viscosity should be in the range of 100 s^{-1} to 10000 s^{-1} and 1000 Pas. Table 5 shows the recommended temperature range that can be injected for the feedstock of system A, B and C for the metal injection molding machine.



(a) Binder System A



(b) Binder System B



(c) Binder System C

Figure 4: The Viscosity Versus Shear Rate of the Feedstock System A, B and C using Capillary Rheometer at Different Temperature Range of 120°C to 160°C

Table 5: Temperature Range of the Feedstock System A, B and C

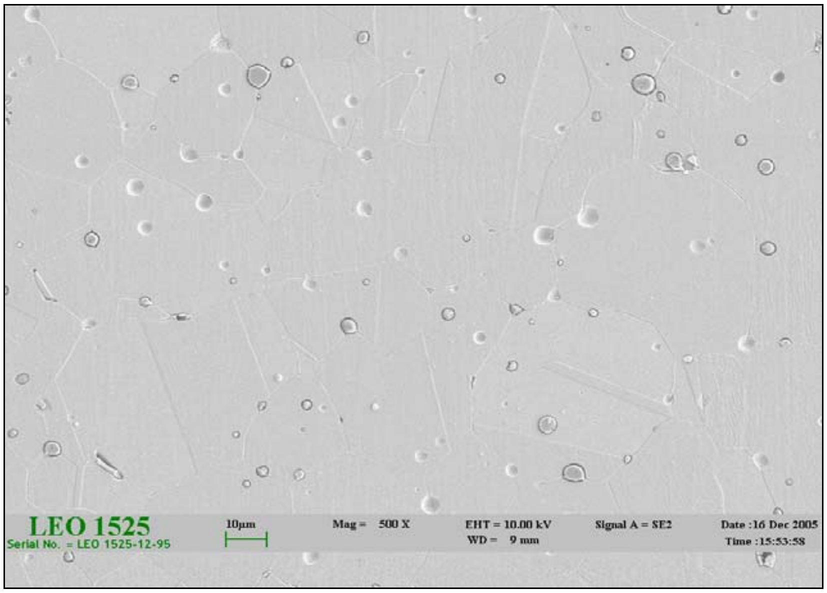
Feedstock System	Temperature range (°C)
A	120 to 160
B	130 to 140
C	130 to 150

Table 6: The Physical and Mechanical Properties of the Sintered Tensile Test Part of System A, B and C

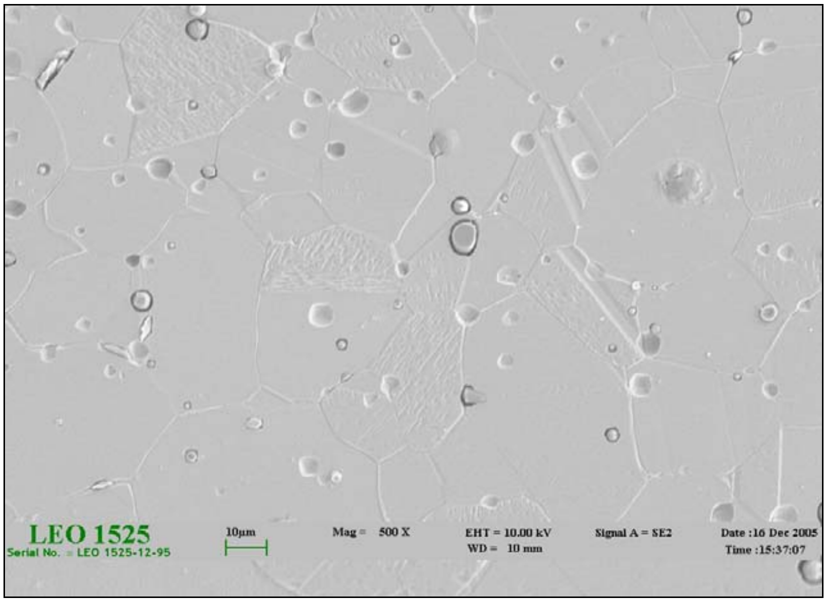
Properties	**System A**	**System B**	**System C**
Density (g/cm^3)	7.845	7.850	7.853
Hardness (Hv)	162.5	158.9	160.1
Shrinkage (%)	14.17	14.55	13.88
Strength (MPa)	511.87	501.41	511.23
Elongation (%)	21.74	21.06	21.63

Physical and Mechanical Properties

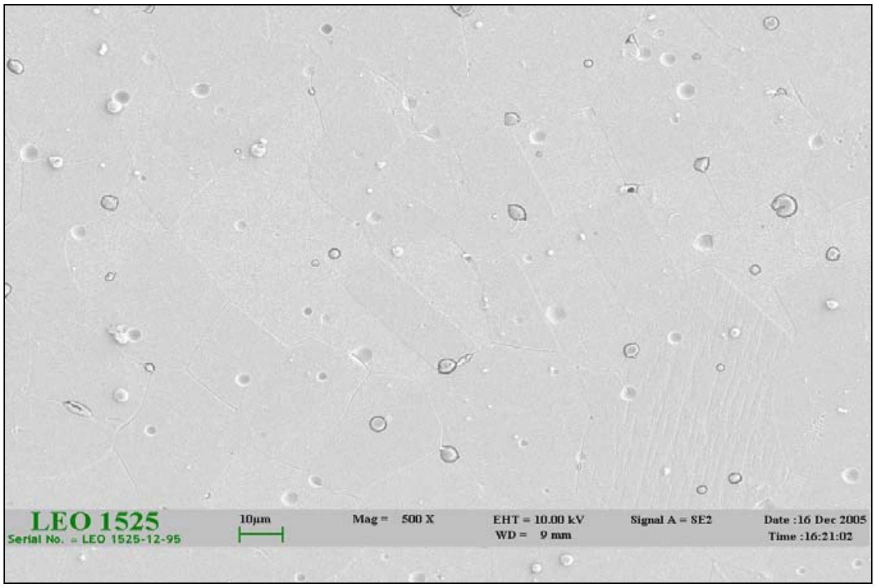
The physical and mechanical properties of the sintered tensile test part were shown in Table 6. The results show that the sintered parts have achieved the minimum requirement for sintered PIM parts compared with Standard Metal Powder Industries Federation (MPIF) 35. Microstructure observation of the system A, B and C clearly show the twin structure of stainless steel and shown in the Figure 5 (a), (b) and (c).



(a) System A



(b) System B



(c) System C

Figure 5: The Microstructure of the System A, B and C.

CONCLUSION

The feedstock of palmitic acid has the best of homogeneity follow by stearic acid and palm stearin. To make the feedstock suitable for injection molding machine, the shear rate and viscosity of the feedstock should be in the range of 100 s^{-1} to 10000 s^{-1} and 1000 Pas. The physical and mechanical properties of the sintered part have achieved the minimum requirement for sintered PIM parts compared with Standard Metal Powder Industries Federation (MPIF) 35. The twin structure of stainless steel has shown clearly on the micrograph.

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