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HOMOGENEITY CHARACTERISATION OF STAINLESS STEEL 316L FEEDSTOCK FOR WASTE POLYSTYRENE BINDER SYSTEM

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ABSTRACT

The paper describes the homogeneity characterisation of a newly developed binder system based on waste polystyrene (PS) and palm kernel oil (PKO) to produce feedstock for metal injection molding (MIM). It is one of a critical step that must be performed in MIM process in order to have a feedstock that is homogeneous and moldable. In this study, water atomised Stainless Steel powder supplied by Epson Atmix Japan was mixed with a new binder system consisting of waste polystyrene and palm kernel oil in a Brabender Plastograph EC rotary mixer. Several tests were performed to assess the homogeneity of the feedstock that was produced at 60 vol.% powder loadings. The 60 vol.% was chosen because the Critical Powder Volume Concentration (CPVC) of the Powder was found to be 64.8 vol.%. The tests conducted were feedstock density, binder burn-out, rheology and SEM morphology observation. From all the tests conducted, it was found that the feedstock shows good homogeneity and suitable for subsequent processing steps in MIM.

Keywords: metal injection molding, homogeneity, mixing, 316L stainless steel.

INTRODUCTION

People have been trying to keep the environment clean by implementing the sustainability development and conserve the environment. Polymer recycling is a way to reduce environmental problems caused by polymeric waste accumulation generated from daily applications of polymer materials such as packaging and construction material. It is associated with increasing awareness of environmental issues and the desire to save resources since most of these polymer materials are made from oil and gas. Currently, one of the waste plastic that widely used is expanded polystyrene. It is produced massively in order to fulfil the needs and requirement of packing industry (Aminudin *et al*. 2011). The total amount of plastics that ends up in waste stream is increasing parallel with the demand of this polymeric product. It is a great threat to the environment because most plastics are not biodegradable and their disposal in landfills is limited due to space limitation and its incineration is also costly. Therefore in order to address this problem, waste polystyrene could be recycled and used for the manufacturing of different valuable products to maintain the sustainability of the environment. Methods of polystyrene recycling include: Mechanical recycling which usually requires energy consumption, chemical recycling that usually requires depolymerisation and thermal catalytic recycling. The present study is aimed at recycling polystyrene to act as a backbone binder in metal injection molding process.

Metal injection molding process is a manufacturing process intended to produce large amounts of small and complex metal parts. It combines the versatility and high productivity of the metal injection molding with the powder metallurgy technique of sintering. The key points in MIM turned out to be how to make the metal flow into the mold and how to retain the shape of the molded part until it begins the sintering. This problem is commonly solved by dispersing the metal powder into a binder to form a paste that flows at high temperature and becomes solid at room temperature. Consequently, the molded part retains its shape after injection molding and may be handled and processed safely.

The homogeneity of a feedstock refers to how well the particulate solid is distributed in the binder matrix. Feedstock homogeneity promotes dimensional consistency of injected parts and helps preventing such defects as binder separation and powder segregation (Supati *et al*. 2000). An inhomogeneous feedstock can result in density gradients within the molded part and cause distortion (Supati *et al*. 2000). To measure the homogeneity of a feedstock several methods are available including density measurements (Supati *et al.* 2000), binder burnt-out (Liu *et al*. 2005), capillary and torque rheometry (Thomas-Vielma *et al*. 2008), and also scanning electron microscope (SEM) with back-scattered electron (BSE) imaging observation (Liu *et al*. 2005).

Development of new binders has always been a focal interest among researchers since it led to cost and environmental issues reduction. Extensive research has been done by using natural resources binder such as Beeswax (Tam *et al*. 1997), Carnauba Wax (Karatas *et al*. 2004) but none of them focused in waste material. The issue to be highlighted here is to evaluate the potential of using waste polystyrene as a backbone binder in MIM. The fact that the earth has tons of polystyrene disposed every day leads researcher to believe that such waste can be converted into more useful products. However the main limitations are the wettability and particle bonding between metal powder and waste polystyrene. Moreover, the moldability performance, compatibility issue and polystyrene diffusion during thermal degradation are major problems as they contain hydrocarbon chain with a phenyl group attached to every other carbon atom. Therefore this study is intended to understand the feasibility of waste polystyrene (PS) as sustainable binder to produce part through metal injection Molding.

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EXPERIMENTAL

Powder and binder characteristic

Water atomized stainless steel 316L powder having irregular shape with mean size d50 6 µm supplied by Epson Atmix Japan was used in this study as the metal powder. SEM micrograph of the Stainless steel powder (Figure-1) confirms the irregular shape of the metal powder. The Critical Powder Volume Concentration (CPVC) was found to be 64.8% (Figure-2). The characteristics of the metal powder are shown in Table-1, while Table-2 shows the binder system properties.

Table-1. Water atomised stainless steel (316L) powder characteristics.

Powder size and density					
Powder	**Size**	**D_{10}**	**D_{50}**	**D_{90}**	**Density**
SS316L Epson Atmix Corp	6.0 µm	2.87 µm	5.9 µm	10.65 µm	8.0471 g/cm^3

Table-2. Binder properties.

Binder	Density (gcm^{-3})	Melting temperature (^{o}C)	Binder ratio (weight %)
Waste PS	1.05	185.4	60
Palm kernel oil	0.9087	30	40

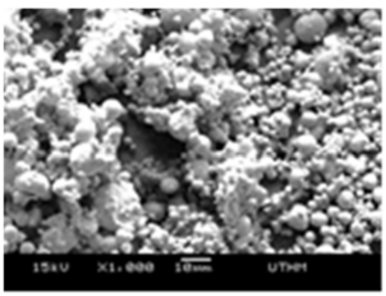

Figure-1. SEM micrograph of SS316L (PF-10F) at 1000x.

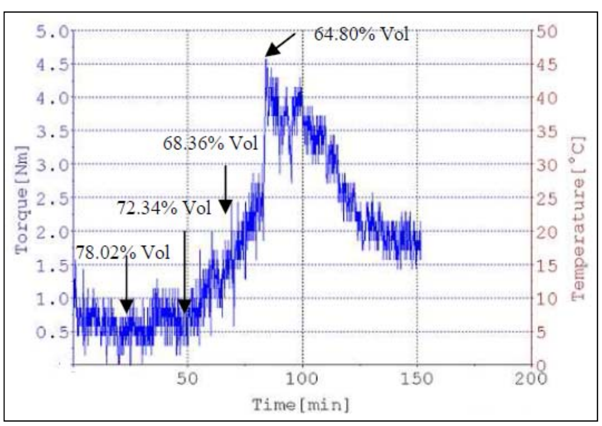

Figure-2. Critical powder volume concentration for SS 316L(PF-10F).

Polystyrene and palm kernel oil

Degradation temperature of Waste PS (Figure-3) and palm kernel oil (Figure-4) were measured by TGA/DTA Linesis Thermo balance. It was found that the highest degradation temperature is 363.4 °C and the lowest is 324.3 °C. This indicates that the mixing conditions must be below the degradation temperature of both binder constituents. Meanwhile, Figure-5 shows the melting temperature of waste polystyrene (185.4 °C).

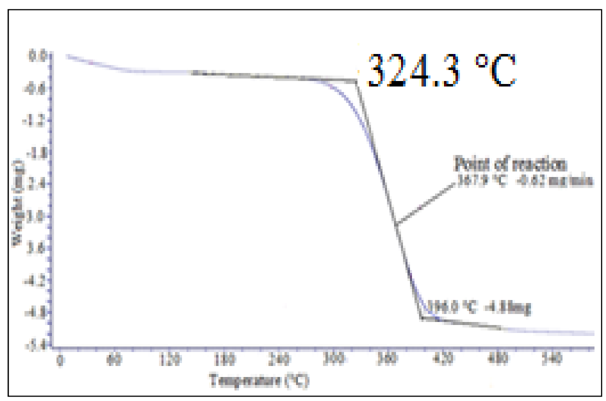

Figure-3. Thermogravimetric curve of waste polystyrene.

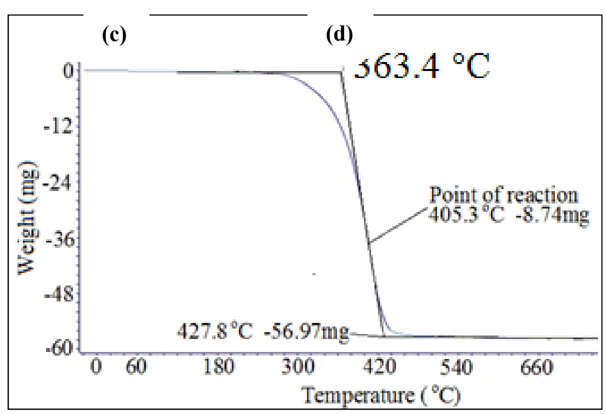

Figure-4. Thermogravimetric curve of palm kernel oil.

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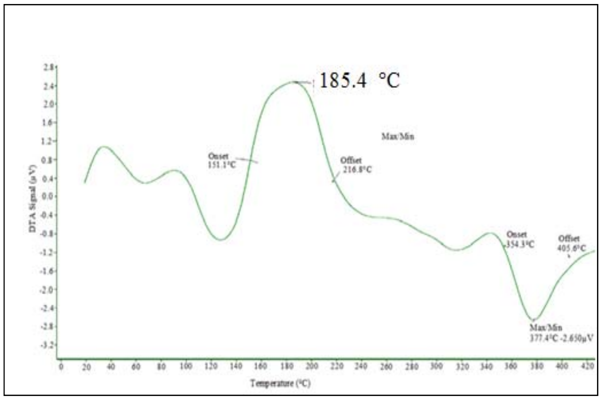

Figure-5. DTA curve of waste polystyrene.

MIXING PROCESS

There are many factors that need to be considered in order to produce homogeneous feedstock such as time, temperature, powder size and shape, formulation of binder, shear rate, and powder loading (Supati *et al*. 2000). However, in this study, only mixing temperature, mixing speed and mixing time were chosen to establish a suitable mixing condition. The mixing was performed by using a rotary mixer (Brabender Plastograph EC) with rotational speed of 30 rpm. The mixing temperature was set at 190 °C, which is within the highest melting temperature (185.4 °C) and the lowest degradation temperature of the binder system (324.3 °C). This allowed complete melting of waste PS and PKO and prevented binder degradation. The polystyrene waste (PS) was fed in first followed by the addition of powder in small consecutive loadings until all the metal powder mixed evenly with melted PS. Afterward, palm kernel oil (PKO) was added into the mixer and blended with the rest of the compositions for about 60 minutes. Lastly, the blended feedstock was taken out from the mixer and left to cool at room temperature before being crushed into small pallet. Table-3 shows the calculation to produce 200 gm feedstock at 60 vol % powder loading.

Table-3. Feedstock calculation.

Powder loading	Powder (gm)	Binder (gm)	PS (gm)	PKO (gm)
60 vol %	186.100	13.900	8.340	5.560

HOMOGENEITY CHARACTERISATION

Homogeneity of the feedstock was analysed by means of density measurement (Supati *et al*. 2000), using the Archimedes water immersion method according to MPIF Standard 42, binder burn-out test using TGA(TGA/DTA Linesis Thermo balance (Liu *et al*. 2005), rheology Test using capillary rheometry (Shimadzu CFT-500D (Thomas-Vielma *et al*. 2008) and scanning electron microscope (SEM)(JSM 6380LA) with back scattered electron imaging (Liu *et al*. 2005).

RESULTS AND DISCUSSIONS

The results of the density measurement for feedstock of five different samples are shown in Figure-6. It is observed that there is slight difference of density value. It is due to difficulty to produce a homogenously perfect feedstock. In the binder burn-out test, the homogeneity of the feedstock was assessed by comparing the weight loss of each binder. The weight loss percentage of binder in the feedstock can be found through Thermogravimetric curves that represent the percentage of the binder in the feedstock. The results for five different samples showed the corresponding thermo gravimetric curves are better replicated and the mass change for PKO and waste PS are almost the same for each loss except slight difference which is consider minimal as shown in Figure-7.

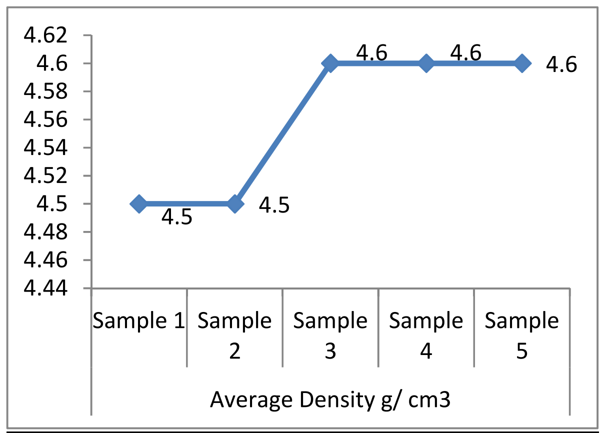

Figure-6. Average density (g/ cm^3) of various samples.

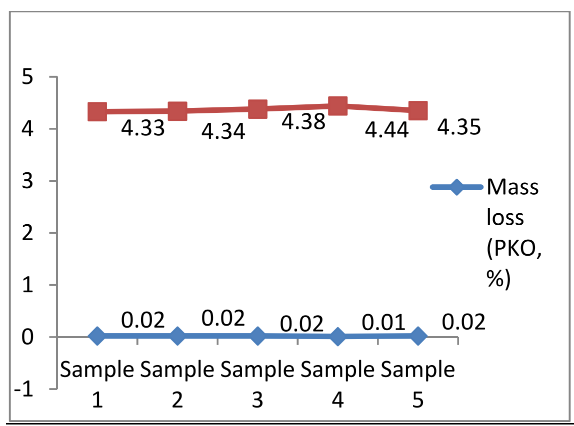

Figure-7. Percentage of mass loss of binder for various sample.

The scanning electron micrograph of the feedstock is shown in Figure-8 below. Stainless steel and binder system could be distinguished as a result of various contrast levels. Stainless steel appears brighter than the binder system due to more back-scattered electrons released because of its higher atomic number. It is

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observed the powder particles disperse homogeneously into the matrix and are surrounded by the binder.

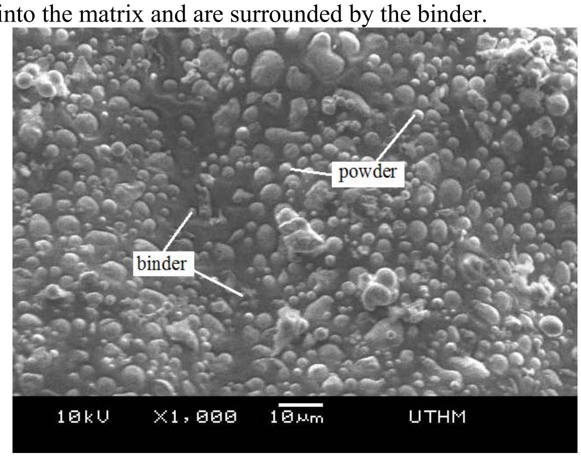

Figure-8. SEM micrograph of feedstock at 1000x.

In the rheological characteristics test, three different temperatures of 150 ˚C, 170 ˚C and 190 ˚C were used. Figure-7 shows the rheological characteristics of the feedstock. It is clear that the viscosity of the feedstock decreases with an increasing shear rate. The results indicate that the feedstock possess pseudo-plastic rheological behaviour. No dilatant behavior, that is viscosity increasing with shear rate, is observed in the figure, indicating no powder-binder separation.

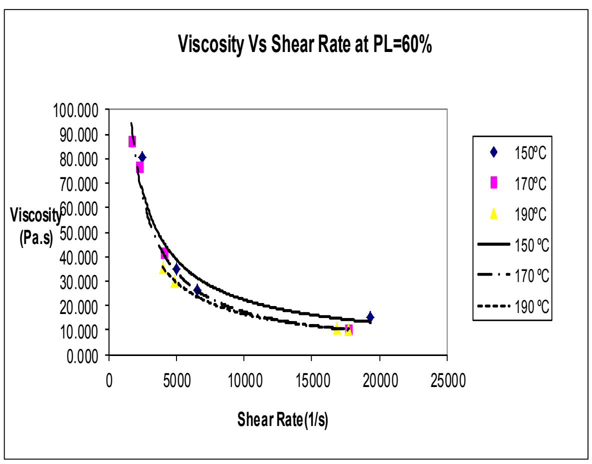

Figure-9. Rheological test of feedstock at various temperatures.

CONCLUSIONS

From the results of different homogeneity analysis techniques, it is inferred that the composite binder, composed of waste polystyrene and palm kernel oil can be used to produce homogenous feedstock for MIM process. It is verified by density measurement test of feedstock, where the density values are almost the same for various samples of the feedstock. Binder burn-out test of five different samples using TGA/DTA method also revealed the feedstock is homogenously mixed. Moreover the SEM micrograph observation also shows the powder particles dispersed homogeneously into the matrix. Rheological characterization of the feedstock also show the feedstock possess pseudo-plastic behavior indicating no powder-binder separation. Experiments in this study confirm that waste polystyrene has the potential to be used as a binder in MIM process.

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