The International Conference on Advances in Materials and Processing Technologies,
26-28 October 2009
Kuala Lumpur, Malaysia

AN INFLUENCE OF A BINDER SYSTEM TO THE RHEOLOGICAL BEHAVIOR OF THE SS316L METAL INJECTION MOLDING (MIM) FEEDSTOCK

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ABSTRACT

The influence of a binder system to the rheological behavior of a Metal Injection Molding (MIM) feedstock is presented in the paper. Three different types of binder systems are used consist of: a) PEG & PMMA b) Palm stearin & LLDPE and, c) Tapioca starch & LLDPE. The viscosity and shear rate of the feedstocks were measured at various range of temperature and shear rate across the L/D = 10 capillary rheometer. The flow behavior index, n and activation energy, E of each feedstock were measured to show its significance as MIM feedstock. Generally, the result indicates all feedstock exhibits a shear thinning behavior and the binders are suitable as MIM binder. Additionally, the present paper has discovered that the binder system does not have much influence to the activation energy. In order to show the relevance of the rheological behavior to the actual injection molding performance, green parts has been injection molded and the result shows an agreement with the rheological behavior result.

KEYWORDS: Metal Injection Molding (MIM), rheological behavior, binder system, flow behavior index, activation energy

1. INTRODUCTION

Metal injection molding (MIM) is a near-net shaped processing technique that permits manufacturing of complex components. Fabrication starts by compounding a thermoplastic binder and powder metal mixture, referred to as feedstock, followed by injection molding, binder removal and sintering (Suri et al., 2003 [1]). This advanced manufacturing process is a modification of the common injection molding process for plastics where a significant volume fraction of plastic is replaced by a metal powder with a plastic binder to form a paste feedstock and injection molding, a “green” part using the specific feedstock on a conventional thermoplastic molding equipment. The major advantages from this manufacturing process include high product density, a more intricate shape, higher mechanical properties, and a better surface finish over the traditional powder metallurgy products. Moreover, an inherent advantage of MIM is that the molding parts are hard enough to meet any needs for secondary machining (Huang et al., 2003[2]).

The rheological properties are important in the injection molding process, since they involve the flow of the molten feedstock into the mold cavity. Rheological analysis can be made to quantify the stability of the feedstock during molding process (Krauss et al. [3]). This comes from the fact that, the feedstock fed into the injection machine should be injected into a mold at an appropriate temperature and pressure. A low injection temperature results in high flow viscosity and causes die filling problems. On the other hand, a high temperature results in the separation of the powder and the binder, and also causes high shrinkage of the final product. The injection pressure will have similar effects which are: low pressure results in a die filling problem and high pressure results in binder separation. It is important to know the volume percentage of the powder and the binder in the feedstock before putting it into the injection machine. If the volume percentage of the powder is high, the injection process will be difficult. Excessive binders, on the other hand, will result in high shrinkage of the final product.

The present paper describes the rheological investigation of three different type of composite binder which has been mixed with water atomized stainless steel (SS316L) powder. The purpose of the investigation is to understand the influence of binder system to the rheological behavior of the feedstock.

2. METHODOLOGY

A MPIF 50 standard tensile bar is used as a specimen. A 316L stainless steel water-atomized powder with pycnometer density of 7.90 g/cm^3 is used as a metal powder. The morphology and particle size distribution of the water atomised powder is shown in Figure 1 and Table 1 respectively.

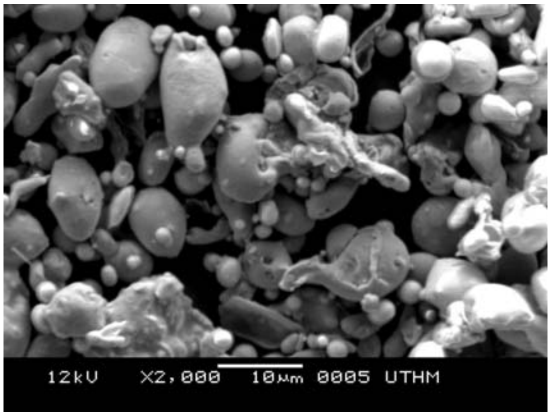

Figure 1 Morphology of the SS316L water-atomised powder

Table 1 SS316L water atomised powder particle size distribution

	Particle size (μm)			Particle distribution slope, S_w	Specific surface area, S (m^2/g)
	D_{10}	D_{50}	D_{90}		
Coarse	4.985	15.052	34.747	3.036	0.573
Fine	3.338	7.157	17.515	3.588	0.978

Prior to the injection moulding, compositions of SS316L and binders are mixed in a sigma blade mixer to obtain the homogenous paste before it formed into granules. Three type of composite binder systems are used in the study: i) Tapioca starch + linear low density polyethylene (LDPE) ii) Palm stearin + linear low density polyethylene (LDPE) and, iii) polyethylene glycol (PEG) + polymethyl methacrylate (PMMA). Due to high viscosity of tapioca starch based binder and wider specific surface area, S of the fine powder, the rheological property of the fine powder feedstock was unable to be tested. Thus, the coarse powder has been introduced to the S+PE based binder, while another type of the binder systems uses fine powder. The abbreviations of the binders are as shown in Table 2.

Table 2 Abbreviations of the composite binder system

Abbreviations	Binder system		
	Backbone	Secondary	Additives
S + PE	Linear low density polyethylene (LLDPE) 28.5 wt. %	Tapioca starch 41.3 wt. %	Glycerol (23.3 wt. %) +citric acid (1.9 wt. %) +stearic acid (5 wt. %)
PS + PE	Linear low density polyethylene (LLDPE) 40 wt. %	Palm stearin 60 wt. %	
PEG + PMMA	polymethyl methacrylate (PMMA) 73 wt. %	polyethylene glycol (PEG) 25 wt. %	stearic acid 2 wt. %

3. RESULTS AND DISCUSSION

The moldability of the MIM feedstock is greatly influenced by the rheological properties. The flow behaviour index, n and the activation energy, E are the significant rheological property that influences the sensitivity of the feedstock materials to shear rate and temperature gradient. As shown in Figure 2, the melt viscosities of the feedstock are influenced by the shear rate and the temperature. The viscosity is declining as the shear rate and melt temperature were increases. This is by the fact that the shear thinning on the feedstock materials when applied to shear stress.

The shear thinning is related with a pseudo plastic behaviour of the feedstock materials. As shown in Figure 2, the viscosity of the S+PE is higher than the PS+PE and PEG+PMMA. At the mean time, the PS+PE and PEG+PMMA demonstrate the same level of viscosity over the wide range of shear rate. This is due to the same particle size owned by the PS+PE and PEG+PMMA feedstock.

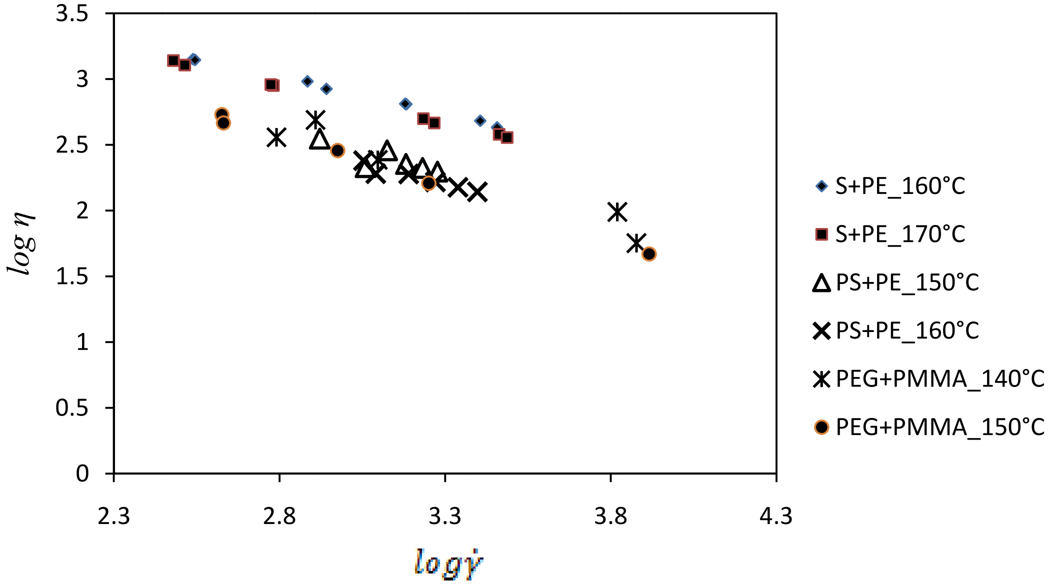

Figure 2 Correlation of viscosity and shear rate.

A regression of the scatter plot shown in Figures 2 can be rewritten as

$$\eta = K\dot{\gamma}^{n-1} \tag{1}$$

where η is the viscosity at shear rate of $\dot{\gamma}$, K is a constant and, n is a flow behavior index. Equation (1) has been widely used to correlate the data of viscosity to shear rate for pseudo plastic and dilatant fluids, which is known as the power-law equation.

The flow behavior index, n of the power-law index indicates the shear sensitivity. Smaller n of feedstock indicates higher shear sensitivity and more pseudo plasticity of the feedstocks. Some molding defects such as jetting are associated with small n, i.e., higher shear sensitivity (Yang et al., 2002 [4]). During the injection molding process, pseudo plastic behavior is desirable and, therefore, a decrease in viscosity with an increase in the shear rate is suitable. This dependent behavior of the viscosity against the shear rate is especially important when producing complex and delicate parts, which are vital products in the Metal Injection Molding (MIM) industry (Agote et al., 2001 [5]; Jamaludin et al. 2008 [6]; Norhamidi et al. 2008 [7]). As shown in Figure 3, the feedstocks demonstrate the pseudoplastic behaviour as the flow behaviour index, n are less than 1. The S+PE shows the lowest shear sensitivity followed by PS+PE, while the PEG+PMMA demonstrated the highest shear sensitivity especially at 150 °C.

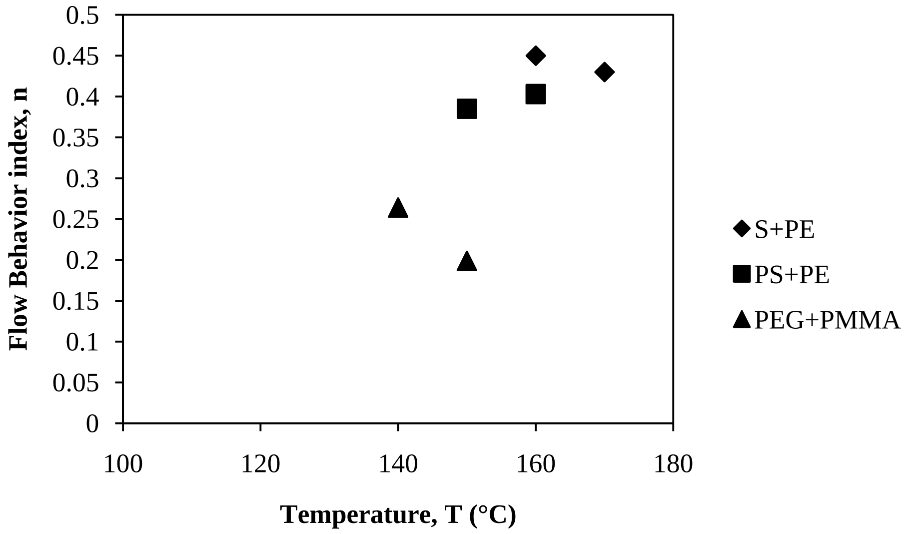

Figure 3 Flow behaviour index, n

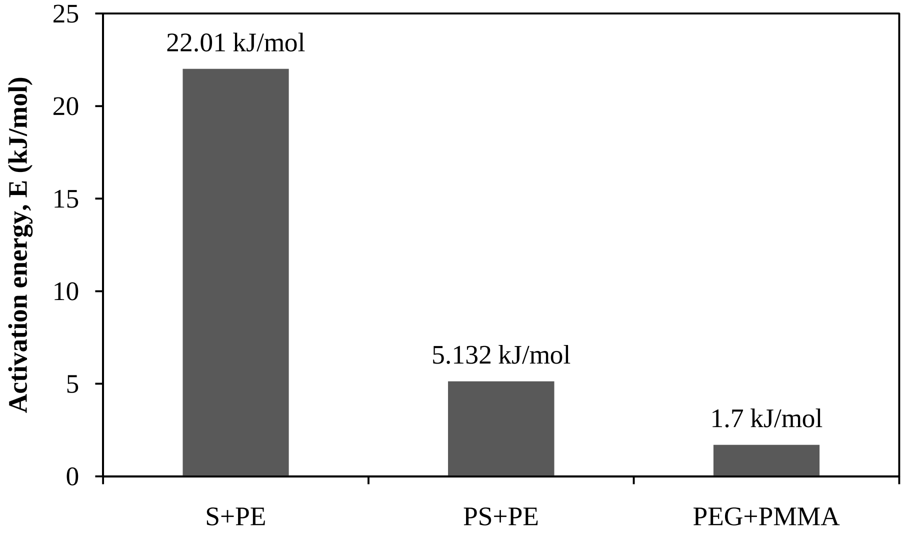

Figure 4 Activation energy

In addition, the controllability of viscosity within an injection molding barrel by controlling the temperature of barrel, nozzle and mold, the temperature dependence of viscosity may have an effect on the response of the material to the sudden non-uniform cooling within a cavity. For example, during the molding stage, the feedstock is forced into the mold where it immediately begins to cool. If the cooling is accompanied by a rapid increase in the viscosity, the result may be incomplete filling of the mold and induces cracking or porosity in the molded parts. Therefore, low temperature dependence is desired to minimize problems arising from fluctuating molding temperatures, thereby minimizing stress concentration, cracks and shape distortions (German and Bose, 1997 [8]; Hausnerova et al., 2006 [9]). The value of flow activation energy, E as shown in Figure 4 represents the influence of temperature on the viscosity of the feedstocks, is an important parameter for injection molding. The relationship of those properties in Figure 4 is as shown in the equation below. The apparent viscosity at a shear rate rate of 1000 s^{-1} which falls in the normal range of shear rates for injection molding of MIM feedstocks,

$$\eta = \eta_0 \exp\left(\frac{E}{RT}\right) \qquad (2)$$

where R is the gas constant, T the temperature and η_o the reference viscosity.

As shown in Figure 4, S+PE exhibits the highest temperature sensitivity followed by PS+PE and PEG+PMMA. This is by the fact that the S+PE feedstock uses coarse powder compared to that of PS+PE and PEG+PMMA. Small variation of the temperature sensitivity between PS+PE and PEG+PMMA shows a little influence of a binder system to the activation energy.

Table 3 Minimum injection parameter

	S+ PE	PS+PE	PEG+PMMA
Injection temperature (°C)	150	140	150
Injection pressure (bar)	900	450	550

In order to evaluate the moldability of the feedstocks, Table 3 shows that the minimum injection temperature and pressure for injection molding the feedstocks. The S+PE feedstock require higher injection pressure compared to other feedstock due to starch sticky property that contributes to higher shear during injection molding. Nevertheless, the PS+PE feedstock require less injection pressure due to natural lubrication provided by the palm stearin has minimizes the injection pressure.

4. CONCLUSIONS

The rheological behaviour of three different MIM binder systems has been evaluated. The study discovered that:

1. The binder systems demonstrated a pseudoplastic behaviour although S+PE demonstrates lower shear sensitivity.
2. Although PS+PE and PEG+PMMA binder system shows better shear sensitivity than of the S+PE binder system, the PS+PE and PEG+PMMA are less sensitive to temperature fluctuation.

3. The equivalent level of viscosity and activation energy owned by the fine powder feedstock (PS+PE and PEG+PMMA) shows that the binder system has less influence to the rheological properties.
4. The rheological properties present in this paper agree with the minimum injection temperature and pressure presented in the paper.

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