

## Palm Stearin as Alternative Binder for MIM: A Review

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### ABSTRACT

Palm stearin is one of the fractionation process results from palm oil that is the largest commodities in the world. It has potentially as an alternative of binder in metal injection molding based on researches that conducted in Malaysia. Palm stearin can be combined with other binder to be a binder system with the function as lubricant and surfactant in a binder system. Based on experiments showed Palm stearin has fulfilled requirement as binder in MIM such as pseudoplastic behavior from rheological test and homogeneity of the feedstock. Palm stearin can replace conventional binders that commonly used in industry.

**KEY WORDS:** *Palm Stearin; Natural Binder; MIM; Palm Oil.*

### NOMENCLATURE

MIM     *Metal Injection Molding*  
PS       *Palm Stearin*  
PE       *Polyethylene*

### 1.0 INTRODUCTION

Production of palm oil has been increasing significantly in the recent decades. Palm Oil has successfully become one of the largest traded commodities in the world. This trend has encouraged some countries to establish research institute or organization for palm oil such as Malaysia as palm oil producing

countries.

Metal Injection Molding can be categorized by net-shape process which combines injection molding and powder metallurgy [1]. MIM has advantage for produce small part with complex shape in high volume [2, 3]. MIM is comprised of several stages that should follow. Firstly is started on mixing stage, injection molding stage, debinding stage and sintering stage as shown on Fig.1. In mixing stage, metal or ceramic powder will be mixed with binder before injection process.

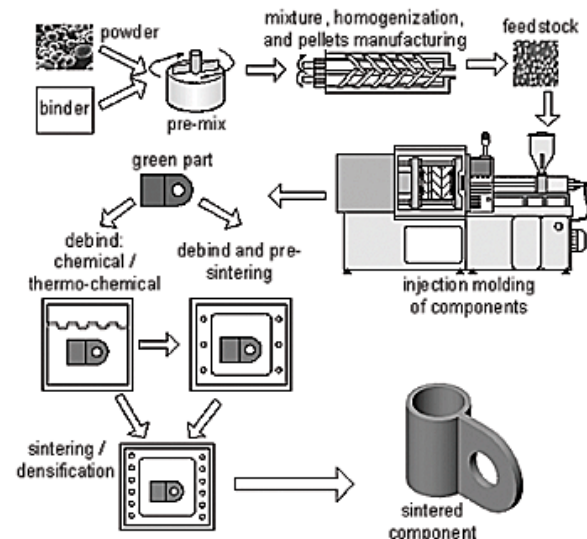


Figure 1: Metal Injection Molding process [4].

Binder has function as a vehicle for homogeneously packing of powder and keeps shape of green body after injection [5]. The selection of exact binder system for certain powder becomes critical thing to determine final product in MIM process. Other consideration that plays important in manufacturing industry is

saving cost. Using Palm Stearin as a natural binder is one of the way to reduce production costs due to Palm Stearin available in considerable amounts especially in Indonesia and Malaysia as the largest producer in the world. In this paper, the following are described with regard to Palm Stearin as alternative binder in

Metal Injection Molding especially in Malaysia.

Oil palm thrives in tropical conditions with position about 5 degrees north and south along the equator line [6]. Oil palm is widely grown in several countries but the largest producers of oil Palm Indonesia and Malaysia as shown on Table 1.

Table 1: Palm Oil: World Supply and Distribution (thousand metric tons) [7]

	2008/09	2009/10	2010/11	2011/12	Mar 2012/13	Apr 2012/13
<b>Production</b>						
Indonesia	20,500	22,000	23,600	26,200	28,000	28,500
Malaysia	17,259	17,763	18,211	18,202	19,000	19,000
Thailand	1,540	1,345	1,288	1,546	1,700	1,700
Colombia	795	770	750	915	960	960
Nigeria	850	850	850	850	850	850
Other	3,074	3,145	3,224	3,286	3,317	3,312
<b>Total</b>	<b>44,018</b>	<b>45,873</b>	<b>47,923</b>	<b>50,999</b>	<b>53,827</b>	<b>54,322</b>

## 2.0 PALM STEARIN

Palm stearin is fraction of palm oil thorough fractionation process of palm oil. Fractionation is process to separated component in palm oil based on differences of melting point [8-10] as shown on the Fig 2. Fractionation process result of crude oil, generally consist of palm olein in liquid fraction and palm stearin in solid fraction which consist of three main groups of triglycerides. trisaturated triglycerides (*palmitate-palmitate-palmitate*); triglycerides (*palmitate-oleate-palmitate*); and polyunsaturated triglycerides (*palmitate-oleate-oleate*)[11].

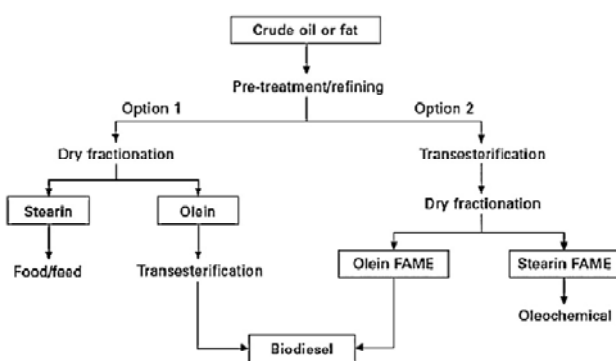


Figure 2: Fractionation of palm oil [12]

## 3.0 BINDER SYSTEM IN METAL INJECTION MOLDING

Binder system play critical position to determined subsequently stage in MIM, failure in one stage in MIM cannot be corrected by next stage, each stage should achieve optimal results and as small

as possible to minimize the defects that occurs. Binder systems constituents for injection molding application can be divide two categorize [13]:

- Low molecular weight polymer; which has low temperature decomposition.
- High molecular weight polymer ; which has relatively high temperature decomposition

Binder system also gives strong effect to determine parameters properties of a feedstock [14]. Generally, removing binder process consists of two stages, comprising of solvent debinding and thermal debinding. A good binder system should have easy to remove in initial removal stage which usually performed using solvent [15], for example distilled water and heptanes. Remaining binder can be removed using next secondary debinding processes, which involve thermal debinding. In this stage, binder as backbone of specimen is removed. After going through a stage of debinding, specimen has behavior very fragile and circumspection is required for handling.

Ideal binder for MIM has decomposition temperature above molding and mixing temperature but has decomposition temperature before sintering temperature [5]. Palm stearin has ideal decomposition temperature as binder, starting around 200°C until around 500°C as shown on the Fig. 3.

Binder system in MIM process is designed based on functions as backbone, filler phase, surfactant and lubricant. Fatty acid in palm stearin is playing important role as surface active agent which required for binder system [17]. Palm stearin in binder system can be used as surfactant and lubricant. Good lubrication is required when release specimen from mold and a surfactant is necessary to connect binder and powder. A simple binder system

comprised of polyethylene and palm stearin has showed satisfactory result [17-22]. Ibrahim, *et al.* 2007, has been compared two binder system which Stearic acid was substituted by palm stearin. Palm stearin has shown good in performance that close to stearic acid value as shown on the Fig 4.

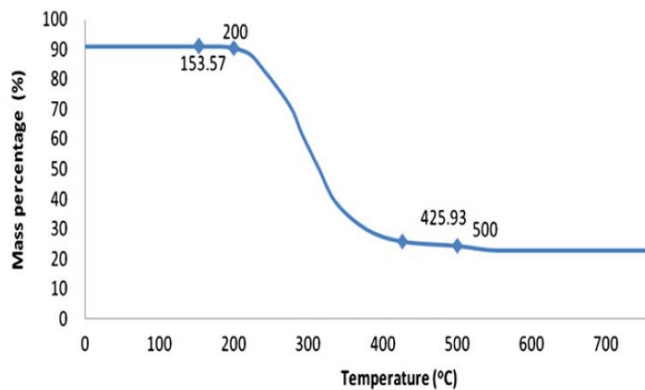


Figure 3: Thermogravimetric curve of Palm stearin [16]

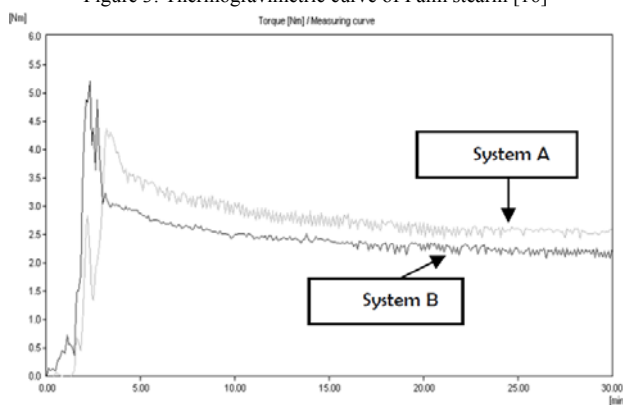


Figure 4: Comparison 2 type of Binder System: System A; polyethylene, paraffin wax and has palm stearin, System B; Polyethylene, paraffin wax, stearic acid [23].

In Biomedical material such as 316L stainless steel, Titanium alloy, palm stearin has been used as binder [20, 23-25]. Abdullah *et al* has reported that palm stearin has successful to use as binder for 316L stainless steel, feedstock 316L stainless steel exhibited homogeneity as shown on the Fig 3. System A and B has consist of Palm Stearin 10 vol%, stearic acid 10vol%, respectively. Both of system has similar composition that consists of Polyethylene 35 vol%, Paraffin wax 55vol%. Ibrahim *et al*, has used binder system with composition binder Polyethylene 40% and Palm Stearin 60% (weight percentage) for mixing with Inconel718 powder for aerospace application. Other researchers also choose 60% Palm Stearin (PS) and 40% of polyethylene (PE) as binder system composition [17, 19, 24].

Palm Stearin has shown pseudo plastic flow behavior with shear sensitivity value less than 0.5 which indicating sensitive with shear rate[22]. Rheological behavior of ZK60 Magnesium

Alloy with binder 60wt.% Palm Stearin (PS) + 40wt.% polyethylene was conduct by M.R. Harun *et al.* also tend to showed pseudo-plastic fluids feedstock [21].

Percentage of palm stearin in binder system has played important role to determine viscosity and sensitivity of feedstock [24,26]. Moreover, Palm Stearin binder system has ability to coated all surface of particle and make hold tightly of particle powder as shown on Fig 5.

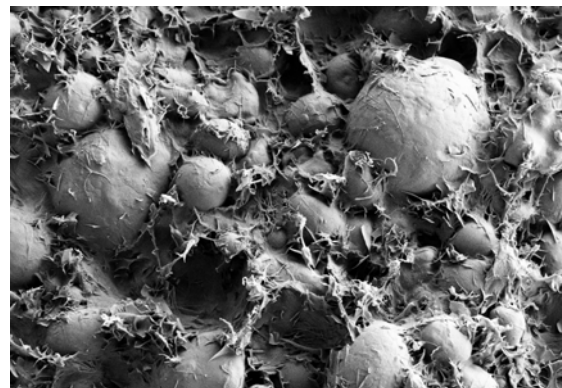


Figure 5: Stainless steel feedstock with binder system palm stearin and polyethylene, most of particle was coated by binder [24].

#### 4.0 RHEOLOGICAL PROPERTIES

Viscosity is important issue in assess quality of feedstock, mold filling of feedstock depend on viscosity value [27]. Pseudoplastic is suitable properties of feedstock for MIM application [28, 29]. Pseudoplastic is which viscosity decreases with increase of shear rate as be defined as:

$$\eta = K\dot{\gamma}^{n-1} \quad (1)$$

Where  $\eta$  is viscosity, K is a constant,  $\dot{\gamma}$ ,  $n$  are defined as shear rate and index of flow behavior, respectively. Flow behavior index ( $n$ ) of pseudoplastic feedstock should be less than 1, since more than 1 powder and binder tend to separate when under high pressure [26, 28].

Liu *et al.* 2003 reported that ideal value of shear rate in range 100 to 10000  $s^{-1}$  with viscosity value under 1000 Pa s [30]. Rheological properties of Palm Stearin have been performed which showed satisfactory result [16,20-23,31]. A result of rheological test is used as indicators for the success of the injection process. Rheology result is showed on Fig. 6.

## 5.0 DEBINDING

Debinding stage is process to remove binder from injected specimen. Rapid debinding without occur defects on part is classic issues that faced by researches [32-34]. A failure to remove binder before sintering stage tend to give effect on the final result, such as, cracking, distortion and contamination [5]. Debinding for removing Palm Stearin consist of solvent and thermal processes.

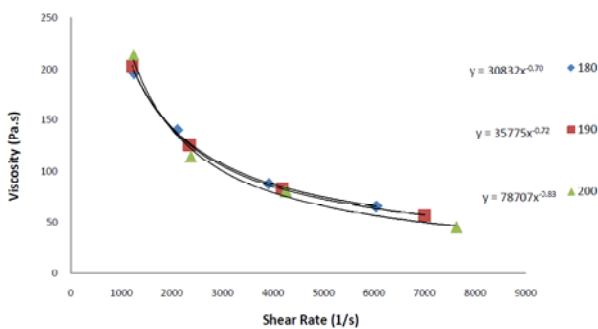


Figure 6: Viscosity vs Shear rate of feedstock using palm stearin and polyethylene as binder system at temperature 180°C, 190°C and 200°C [20].

### 5.1 Solvent debinding

At solvent process, injected part immersed in fluid to dissolve the Palm Stearin for subsequent binder burnout. Moreover, residual stress on specimen tend to decrease when lower molecular binder are removed [35]. Capillary path and hole are provided by palm stearin after solvent process is used to facilitate higher molecular binder out[16] as shown on Fig 7. Fick's second law generally is used to describe about mass transfer process in solvent debinding.

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \quad (2)$$

where C describes as concentration of diffusing substance and x is a distance of normal direction on the section.

Several researchers have been performed using heptanes to dissolves Palm Stearin from injected part [16, 23]. Ibrahim, R *et al.* 2007, has successfully to remove Palm Stearin binder system using heptane for 4 hour at 60°C and followed thermal debinding at temperature 440°C for 2 hour. Cross section thickness is playing important role to increase debinding rate [36]. Moreover, higher temperature on solvent debinding tends to increase the rate of solubility of Palm Stearin [16]. However, pore size tends not to give significant effect on debinding rate [36]. Li. Y et al 2003 has proposed about critical thickness, it have strong correlation on debinding parameters such as, particle size, holding time and powder loading, moreover critical thickness can be used as reference to design optimal debinding time without defect on the part [33].

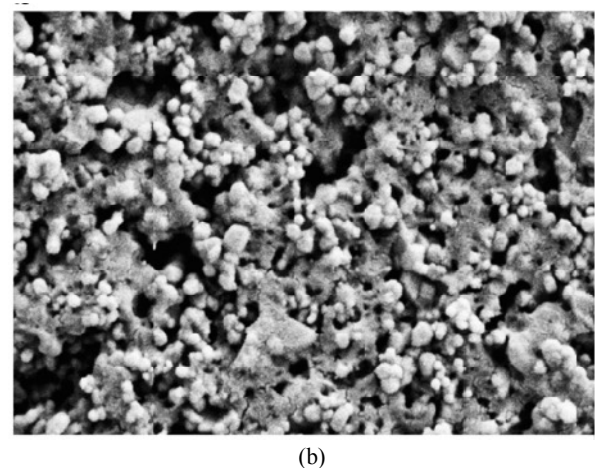
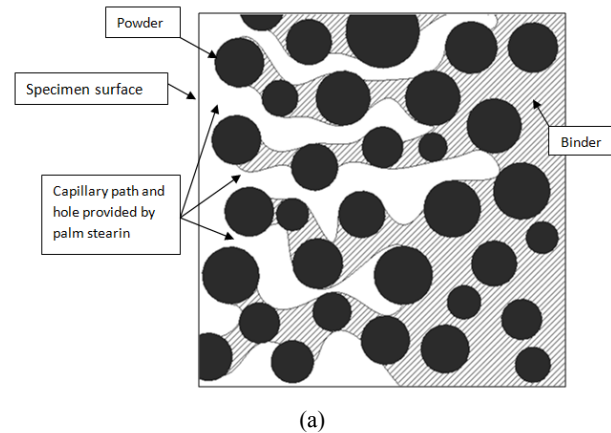


Figure 7: (a) Model of capillary path is provided after removing of palm stearin by solvent debinding, (b) Solvent debound specimen [16]

### 5.2 Thermal Rebinding

Thermal debinding or thermolysis has used widely in powder metallurgy industry, simplicity and ease process as consideration [33, 37]. Normally, thermal debinding is used to remove high molecular weight polymer. In thermal debinding, some events happened such as evaporation, thermal degradation, and oxidative degradation. Usually process is started on degradation of binder component into several molecular structures with various states such as gaseous, liquefied and other component evaporated directly without through degradation process [35, 38]. Degradation of binder component can be expressed as [39-41]:

$$-\frac{dh}{dt} = Kh \quad (3)$$

whereh is weight fraction of binder component/polymer, K is thermal degradation constant, which can be expressed by Arrhenius equation.



## 6.0 CONCLUSION

The use of palm stearin as alternative binder in Metal Injection Molding has positively impact for industry because of the availability is abundant and cheap. Moreover, as organic material Palm stearin tend to environmentally friendly which is an important added value for palm stearin. Based on several experiments, Palm stearin is candidate potentially to be alternative binder in metal injection molding industry. Several experiments have showed palm stearin has fulfilled any standard requirement that is necessary in a metal injection molding process.

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