PROCESSIBILITY OF BLACK GARBAGE BAG AS A NOVEL BINDER SYSTEM IN METAL INJECTION MOLDING

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ABSTRACT

The issues to be highlighted here is to fundamentally evaluate the potential of using waste Garbage Bag from High Density Polyethylene (HDPE) as a backbone binder in Metal Injection Molding (MIM.) This is by the fact that the earth has tons of Garbage Bag disposed every day and researcher believes such waste can be converted into more beneficial industrial product. Thus this research investigates the potential uses of garbage bag as a novel binder system in metal injection molding. Stainless steel SS316L was used which is garbage bag (HDPE) and palm kernel acts as binder system. Feedstock with three composition 30%, 40% and 55% powder loading (PL) were injected by injection molding machine with several injection parameter were optimized such as injection temperature (A), barrel temperature (B), injection pressure (C) and Speed (D). The optimum parameter for highest green density, strength were optimized in Taguchi Method orthogonal Array L9 (3^4) and analysed by using Signal to Noise Ratio (S/N ratio).Results shows the optimum variables for 30% PL the highest density is A_0, B_2, C_1 and D_0 while for green strength are combination of A_0, B_0, C_0, D_1. For powder loading 40%, the optimize parameter for highest green part density are A_2, B_2, C_0 and D_2 and A_0, B_0, C_1, and D_0 for green strength. Besides, the highest green density for 0.55 PL by following the optimum variable are A_2 , B_2, C_0 and D_2 while for highest green strength are A_2, B_2, C_2, and D_2. Garbage bag are suitable acted as a binder system in metal injection molding. Furthermore, it could reduce the cost of binder system. The suitable volume ratios in mixing process produce a better feedstock in order to produce the green part by injection molding. Taguchi Method is among the best method in optimizing the injection variables as it can reduce the cost, time, improve accuracy and efficiency

ABSTRAK

Kajian ini menekankan tentang penggunaan sisa beg sampah yang terdiri daripada *High Density Polyethylene (HDPE)* sebagai salah satu bahan pengikat bagi Proses pengacuanan suntikan Logam (*Metal injection molding*) Hal ini berikutan keadaan bumi pada masa kini yang mempunyai petambahan beg sampah yang perlu dilupuskan setiap hari . Oleh itu penyelidik percaya sisa itu boleh ditukar kepada bentuk produk industri yang berfaedah. . kajian ini menekanakan tentang potensi beg sampah bertindak sebagai agen pengikat dalam proses pengacuanan suntikan logam. Dalam kajian ini *Stainless steel* SS316L digunakan sebagai serbuk logam manakala beg sampah dan *palm kernel* sebagai bahan pengikat. Tiga komposisi campuran bahan yang mana terdiri dari pada 30% , 40% dan 50% pembebanan serbuk logam di suntik menggunakan mesin pengacuanan suntikan. Beberapa pemboleh suntikan di optimumkan seperti suhu suntikan (A), suhu *barrel* (B), tekanan suntikan (C) dan kelajuan suntikan (D) dengan menggunakan kaedah Taguchi L9 (3^4) kemudian kekuatan dan ketumpatan sampel dianalasis menggunkan *Signal to Noise Ratio (S/N ratio).* Berdasarkan keputusan yang diperolehi, bagi campuran 30 % pembebanan serbuk logam, parameter bagi menghasilan ketumpatan sampel yang tertinggi adalah A_0, B_0, C_0, D_1 dan A_0, B_0, C_1, and D_0 bagi kekuatan tertinggi. Bagi 40% pembebanan serbuk, parameter yang optimum ketumpatan tertinggi ialah A_2, B_2, C_0 and D_2 manakala untuk kekuatan tertinggi pula ialah A_0, B_0, C_1, and D_0.Seterusnya bagi 55% pembebanan serbuk, parameter suntikan untuk ketumpatan tertinggi ialah A_2 , B_2, C_0 dan D_2 manakala A2, B2, C2, dan D2 untuk kekuatan tertinggi. Plastik sampah sesuai digunakan sebagai bahan pengikat dan dapat mengurangkan kos bahan pengikat. Kaedah Taguchi merupakan antara kaedah yang terbaik dalam mengoptimumkan pemboleh ubah suntikan seterusnya mengurangkan kos, meningkatkan ketepatan dan kecekapan proses.

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LIST OF SYMBOLS

°C	-	Celsius
˚C /min	-	Celcius per minute
mm	-	Milimeter
µm	-	Micrometer
%		Percentages

LIST OF ABBREVIATION

BSE	-	Back Scattered Electron
CCBs -	-	Coal Combustion by-Products
CPCV	-	Critical Powder Volume Concentration
DSC	-	Differential Scanning Calorimetry
EVA	-	Ethylene Vinyl Acetate
HDPE	-	High Density Polyethylene
FTIR	-	Fourier Transform Infrared Spectroscopy
LDPE -	-	Low Density Polyethylene
MIM	-	Material Injection Molding
PP	-	Polypropylene
PW	-	Paraffin Wax
SA	-	Stearic Acid
SEM	-	Scanning Electron Microscope
SS316L	-	Stainless Steel 316 Low Carbon
STS 316	-	Stainless Steel 316
TGA	-	Thermo Gravimetric Analyzer

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent years, metal injection molding (MIM) is being explored due to the mass production of micro part with complex shapes and geometry. The economical factors also lead to this effort in order to develop the cost efficient for manufacturing process. This manufacturing technique is combining with plastic injection molding and powder metallurgy.

The main application of the MIM process is to produce products of intricate shapes that having an excellent mechanical property. Currently the areas of application can be applied in the biochemical, aerospace, computer peripherals and automobile industries. In MIM, binder systems play an important role as it acts as a temporary vehicle as homogeneously factor in order to packing the powder into the desired shape. (Liu *et al* 2005)

Besides that, the binder system is applied to hold the particles in that shape until the beginning of sintering. The binder system has influence on particle packing, mixing, rheology, molding, debinding and dimensional accuracy.

The process begins with mixing process. Hence mixing process is mixed up the SS316L, garbage bag (HDPE) and Palm Kernel into a mixer with a correct volume ratio. Mixing temperature for binder system is higher compare to highest melting point and lowers than the lowest degradation temperature while this process is occurs. Basically mixing process is most of the important process in order to obtain a homogenous binder system. Therefore, both of the waste HDPE and Palm Kernel must be well mixed to each others. The resulting of mixing process is known as a feedstock and used for molding process.

Besides injection molding is also categorized as an importance process in MIM to produce a part. The feedstock will be injected into injection molding machine and then heated at the barrel. Pressure will be supplied to the feedstock and will be force to the mold cavities. The feedstock solidified after the cooling stage and the pressure was released continues with the part.

Next stages are debinding. During debinding process, the binder components will be removed from the part. Basically, the primary and secondary binder which is garbage bag material (HDPE) and Palm Kernel will be removed partially and opens the pores. Here the primary binder system will be removing from the compact, while secondary binder system is in the part for compact retention.

The last stages in this process are call sintering. At this stage, the shapes of the part will homogeneous shrinkage during sintering. Sintering process occur within high temperatures in order to removed the remaining binder system from the part. Therefore, selected suitable binders for metal injection molding categorized as the most important factor that needs to review in order to produce a quality feedstock.

1.2 Background of Research

Previous research that relate to the waste plastic component has been done by Siddique *et al* (2008). Research is being carried out on the utilization of waste products in concrete. Such waste products include discarded tires, plastic, glass, steel, burnt foundry sand, and coal combustion by-products (CCBs). Each of these waste products has provided a specific effect on the properties of fresh and hardened concrete. The use of waste products in concrete not only makes it economical, but also helps in reducing disposal problems. Reuse of bulky wastes is considered the best environmental alternative for solving the problem of disposal. One such waste is plastic, which could be used in various applications.

However, efforts have also been made to explore its use in concrete/asphalt concrete. The development of new construction materials using recycled plastics is important to both the construction and the plastic recycling industries.

Supriadi *et al* (2007) studied the Binder system for STS 316 nanopowder feedstock in micro metal injection molding. The STS 316 (average particle size of 100 nm) acted as metal powders are mixed with thermoplastic binder system in order to produce feedstock for micro metal injection molding by using lost mold method. The chosen binder systems for this research are as listed such as combination of paraffin waxes, bee's waxes, carnauba waxes, ethylene vinyl acetate (EVA), polypropylene (PP) and stearic acid. The results shows that wax based binder system is the most performed for metal powder that applied.

According to Vielma *et al* (2008) the production of alumina parts by powder injection molding with a binder system based on high density polyethylene (HDPE), paraffin wax (PW) and stearic acid were observed in this research. The determinations of optimum binder system were investigated by using torque measurements and rheology. From this research, the best result obtained by using solvent debinding followed by thermal debinding

This research is conducted to determine the potential uses of garbage bag (HDPE) and Palm Kernel as a binder system to debind with selected metal powder which is stainless steel (SS316L). Basically There are four stages that involved which is mixing, molding, debinding and lastly is sintering. Nowadays, due to an exploration of application green technology, this research will be become most of greatest finding for future research.

Overall, previous studies on material injection molding feedstock have various aspects such as types of metal powder, binder system, stages of producing and others. This is depending on their reason significant of the research. This study will focused on processibility of black garbage bag as a novel binder system in metal injection molding

1.3 Problem Statement

This study is carry out to determine the potential uses of garbage bag (HDPE) and Palm Kernel as a binder system to debinding with selected metal powder which is stainless steel (SS316L).

Due to the versatility and enormous potential, it is currently being explored by researchers by some aspects such as mold technology and binder performance. Development of new binders has always been at the most interest of researchers and has led to improvements such as cost reduction and less environmental issues.

To date, extensive research has been done by using natural resources binder but none of them focused in waste material. The issues to be highlighted here is to fundamentally evaluate the potential of using waste Garbage Bag from High Density Polyethylene (HDPE) as a backbone binder in MIM. This is by the fact that the earth has tons of Garbage Bag disposed every day and researcher believes such waste can be converted into more beneficial industrial products.

According to the World watch Institute’s (2004) state of the World report Some 4 to 5 trillion plastic bags including large trash bags, thick shopping bags, and thin grocery bags were produced globally in 2002. Roughly 80 percent of those bags were used in North America and Western Europe. Every year, Americans reportedly throw away 100 billion plastic grocery bags.

In this project, stainless steel SS316L will be mixed with waste HDPE and minimal amount of natural resources binder which is Palm Kernel in order to improve the compact shape retention

1.4 Objective

The objectives of this research consist of as:

i. To determine the potential uses of black garbage bag (HDPE) and Palm Kernel as a binder system in MIM.
ii. To evaluate the better composition ratio between waste garbage bag, Palm Kernel and metal powder.
iii. To investigate and optimize characteristic of green part mechanical properties
iv. To characterize the Palm Kernel diffusion through microscopic behavior during solvent debinding and make recommendation based on the finding for future research to explore the application of “Green MIM”.
v. To optimize the parameter in solvent debinding.

1.5 Scope

The scope of the research as follows:

i. Garbage bag (HDPE) and Palm Kernel are selected as binder system and Stainless Steel (SS316L) act as metal powder.
ii. Investigating the mixing procedure SS 316 L , HDPE and Palm Kernel
iii. Measuring the acceptable volume ratio between binder system and metal powder in order to produce homogeneous feedstock.
iv. Investigating the solvent debinding in order assess the Palm Kernel diffusion through SEM
v. optimization of green and brown part; density, strength, weight loss

1.6 Significant of Study

From the problem statement that discuss earlier there are tons of garbage bag in world that damage to environment because there are there is no disposal method that will really help eliminate the problem. The biggest problem with this issue when the consumer decides to soiled the end up in the trash or ends up in the landfill or burned. Both solutions are very poor for the environment. Burning emits toxic gases that harm the atmosphere while landfills hold them indefinitely as part of the plastic waste problem throughout the globe the effect is consisting either to land or waterways in earth. Significant with this, the potential uses of garbage bag (HDPE) and Palm Kernel as a binder system to produce a better quality feedstock is investigate. Besides, this research will be leading the efforts towards the better finding for future research to explore the application of “Green MIM”

1.7 Expected Result

Resulting from this research will produce a quality feedstock from the combination of garbage bag (HDPE) and Palm Kernel as binder system while stainless steel (SS316L) as metal powder. The findings can indicate the suitable volume ratio for this selected binder system and metal powder. The injection molding process followed by Taguchi method L9 (34) orthogonal array could optimize the injection parameter in this current research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Metal Injection Molding is widely known as a new processing technique which is applied in powder metallurgy industries. The advantages of this process are very cost effective besides beneficial for manufacturing, automotive, medical and others. Moreover this MIM suitable in producing small and complex shapes in large batch. Metal injection molding are includes in four basic steps which is mixing, molding, debinding and sintering. This fact are supported by Jamaludin *et al* (2010).In this chapter, more concern on reading previous studies to obtain related information about this research. From this, it can provide insight in this research. Apart from that, comparison from previous studies made the research more proper. Basically regarding with this reading also, it will ensure that the research was different with others.

Firstly, several journals were reviewed. The journal papers were obtained from Science Direct. The selections of reading materials focus on process of metal injection molding (MIM) but the other relevant information also were reconsidered.

The reading materials related to MIM are review such as by Tam *et al* (1997) study about the effects of the vinyl acetate content and the polymer/wax ratio on the thermal and rheological properties of the binder. Furthermore research by Liu *et al* (2001) is focused on establishing a suitable binder system for MIM technology.

Other than that, research by Agote *et al* (2001) concern on the evaluation of the flow ability of feedstock by using rheological parameters such as critical powder volume concentration (CPVC). However in this research are concentrate on establishing a relation between the powder characteristic and rheological behavior as well as to predict the feedstock behavior. This parameter is useful as gaining information for new researcher.

According to Liu *et al* (2005) were studies about the mixing and characterization of 316L stainless steel feedstock for micro powder injection molding. Basically this study are investigated the effects of powder loading and extrusion on mixing besides the feedstock homogeneity.

Besides that, previous studies by Supriadi *et al* (2007) were focused on binder system for STS 316 nanopowder feedstock in micro metal injection molding. The selections of binder system for STS 316 nonopowder were investigated in this research.

Other than that, according to Vielma *et al* (2008) study a production of alumina parts by powder injection molding with a binder system based on high density polyethylene. The focused on this study are related to the complete process to developed binder system based on High density polyethylene (HDPE), Paraffin wax (PW) and Stearic acid (SA). Besides, the goals of this research are to develop a suitability feedstock for injection molding process.

Samanta *et al* (2011) are study about thermal physical characterization of binder and feedstock for single and multiphase flow of powder injection molding 316L feedstock. Basically this study are focused on thermal characterization and not related with the parameters for processibility of black garbage bag as a novel binder system in metal injection molding. However these reading material were useful because it is involving the methods in order to produce a feedstock.

The Taguchi method also applied in this present research where as to optimize the injection parameter of green part in order to investigate the highest strength. Among researcher that had been used this powerful tool are Ibrahim *et al* and the findings and methods are useful as reference in this present research.

2.2 Stainless Steel 316L Metal Powder

In this present study, the chosen metal powder is stainless steel 316L in range of small particle. Referring to Paul *et al* (2009) the number of 316 refers for the 3% of molybdenum and 16% nickel that added to the alloy iron, chromium and carbon.

The letter L is denotes to low carbon (<0.03%). Hence this metal powder also relatively biocompatible besides strong and cheap. Supported by Liu *et al* (2005), 316L stainless steel powder was used since its good overall mechanical properties and corrosion resistance behavior are suitable for a wide range of applications. Small particle size and a multi-component binder system were used to meet the requirements for metal Injection Molding (MIM). Besides that, SS 316L is an austenitic Chromium-Nickel stainless steel with superior corrosion resistance. Therefore the mean particle size that use in this research is 5.71 µm and the pycnometer density is 8.4071 g/m^3

2.3 Garbage Bag (HDPE)

In this research, waste garbage bag are selected as a primary binder system due to the considerable of environmental pollution. Basically waste plastic are non biodegradable to land and nature. So that recycling of waste plastic bag become an importance issue in a worldwide and supported by Park *et al* (2002). Generally, garbage bag is one of the items that will become as waste garbage bag after used. Technically, garbage bag are produce from High Density Polyethylene (HDPE).

2.4 Palm Kernel

The secondary binder system that will be used in this research is Palm Kernel. According to Chong and Siew (1994) the physical and chemical properties of Palm Kernel had been established. The temperature range is between 35 ˚C to 75˚C. The density in air of Malaysia Palm Kernel relies in range 0.9087 to 0.8809 g/ml. Hence, according to Majestic (2002) specific gravity for Palm Kernel is 0.90 - 0.92. The appearance and odor is likely white to slight yellow color liquid state, opaque solid state, vegetable fat odor and taste. Figure 2.1 shows the portion palm fruit.

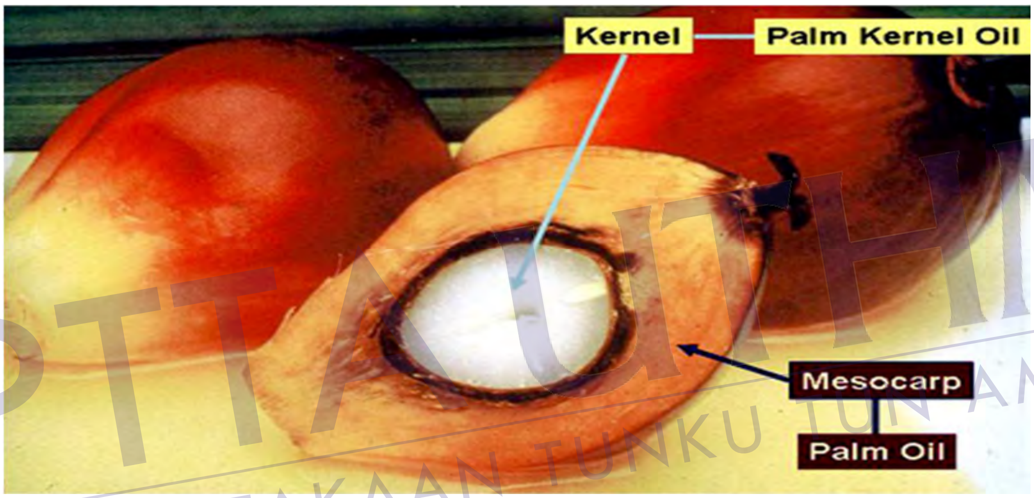

Figure 2.1: The portion palm fruit

2.5 Methods in Metal Injection Molding

Metal injection moldings are process that uses the advantages of injection molding but, this method are also applicable to metals and ceramics. Based on German and Bose, (1997) in this process there are consisting combinations of small quantities of a polymer with an inorganic powder to form a feedstock. Then, after shaping, the binder system is extracted from the shaped part continuous with sintered the metal powder.

Metal injection molding was the important method in this present study. Determination of suitable method depends on conditions of study need to emphasize to get valid results. Due to this, the method from previous study is very useful in new research. The methods that involve in previous study can be used as a guideline in this present research such as mixing, injection, debinding and sintering.

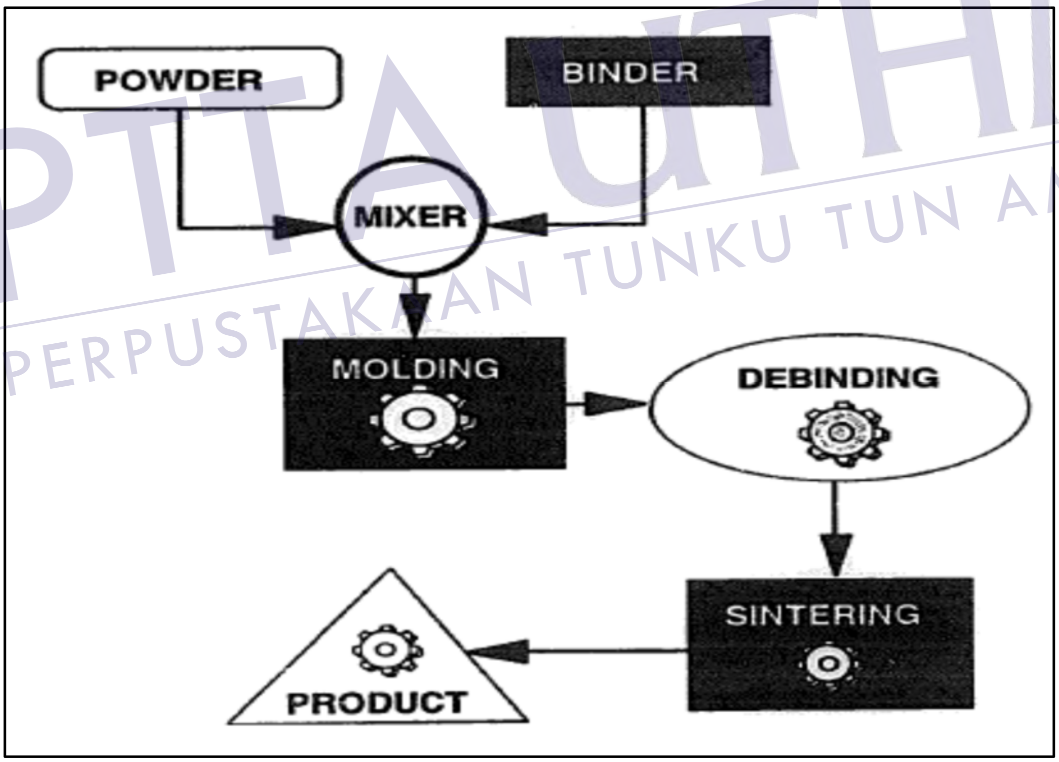

Figure 2.2: Flow chart of Metal Injection Molding Process (Tam et al, 1997)

2.5.1 Mixing

Mixing process is the important method in metal injection molding in order to produce a quality compounding of feedstock. The temperature that was set while mixing process is between the melting point and lowest degradation of binders system. At this temperature, both of compounds between the metal powder and binder system will be mixed homogeneously. The mixing processes from the previous study are useful as a reference in establishing the method in this study. The temperature and rpm that have been used from previous researcher are needed as a relevance reference in this present research. Significant with this, it also functional as guidelines to select a reference parameter for mixing process in this present study and supported by the previous research which is used the difference temperature for difference materials.

Studies of Tam *et al* (1997) were aim to understanding the effect of flow and thermal properties of vinyl acetate in binder system. The experimental work was carried out with six different grades of ethylene-vinyl acetatc (EVA) copolymer. The mixing process using Haake Rheocord mixer with the range temperature around 110 to 120°C and duration about 30 min until a constant torque is obtained. In order to obtain the homogeneity of binder system, the compounds of must be well mixed and it is importance to have a proper understanding regarding the melting temperature behavior of materials.

Liu et al (2001) were investigating on multi component of binder system including of PW, EVA and HDPE. Basically the mixing procedures were using Haake Rheocord mixer with the speed that used is 30 rpm in duration 30 minutes. The mixing temperatures are depends on the material melting behavior. According to thermal properties of binder system, the mixing temperature was set higher than the highest melting point, but lower than the lowest degradation temperatures of the binder system.

Liu *et al* (2005) presented the methodology by mixing process which is using the Haake Rheocord 90 torque rheometer. The researcher set the mixing temperature at 140 ˚C where as between the melting temperature is 127 ˚C and the lowest degradation temperature for binder system equal to 170 ˚C. The outcomes confirmed that the mixing is once of the procedure in order to produce a homogenous feedstock with a suitable rheological behavior.

According to Supriadi *et al* (2007) The STS 316 nonopowder and binder system were mixed in Brabender plastograph mixer in duration 1 hour at 170˚C. While this process is occur, the nanopowder feeding temperature below than 100 ˚C to avoid burning. The mixing speed is constant at 60 rpm. Represent that the homogeneity of the feedstock are corresponding with the mixing torque rates. At the low mixing torque, the feedstock more homogeneity compared to higher mixing torque since the binder material and metal powder are easy to mobilize.

Based on Vielma *et al* (2008) the mixing processes are conducted by using a Haake Rheocord 252p mixer. The compounding is mixed at 140 ˚C and 40 rpm around 10 minutes. The researcher predicted the homogeneity of the mixture is through mixing torque curves, while the uniform mixing is achieved when the torque reaches a steady state value.

Ibrahim *et al* (2008) produced a feedstock according to a mixing sequence by using sigma type blade mixer with 26 rpm. The composition of SS316 L and Stearic acid were mixed first in duration 5 minutes at room temperature. Then the process followed with an addition of PMMA and Acetone 1gm at 4ml in between 15 minutes at room temperature. Mixing process are continues by adding the PEG and then mixed up in 15 minutes more. The mixing ends up after 1 hour at temperatures 70 ˚C. The sequence of mixing process is useful in this present research and the methods are supported by the previous research.

The mixing methods are similar to each other even the composition of material are different. According to Nor *et al* (2010) conducted mixing process by using sigma blade in duration 1hour at 150 ˚C. The composition between of Titanium alloy, Palm stearin and polyethylene are then produced as a feedstock. Besides, Jamaludin *et al* (2010) conducted a mixing process by using Sigma blade Mixer at temperature 70 ˚C.

Studies of Samanta *et al* (2011) setup the experiment with the mixing process of binder system such as PW, LDPE and SA with the preferred composition. The compounding is mixed in sigma blades mixer at 120 ˚C for 120 minutes at 35 rpm. Basically, the binders were take out from the mixer in liquid condition and allowed to become hard at room temperature.

The mixing process is most important process in metal injection molding. So that, in order to produce the quality feedstock, the mixing process between SS316 L, black garbage bag and Palm Kernel need to achieves the homogeneity of mixture. In conclusion the mixing temperatures of the compounds are between the highest melting point and lowest degradation of black garbage bag where as act as a primary binder system. Regarding to this, the method and chosen parameters that had been done by the previous researcher in mixing process are similarly and are useful as a reference in this present research.

2.5.2 Molding

Moldings are known as process where as the feedstock are inject into the mold with the selected injection pressure and temperature respectively. In simplest explanations, molding process are consists of heating the feedstock to a sufficiently high temperature where as it will melts, then forcing it into a mold cavity and followed the shaped of the mold cavity. The objective for molding process is due to attain the desired shape, free of defects with homogenous powder distributions (German and Bose, 1997).

In this present research, injection molding was the one the major steps in metal injection molding. The parameters that have been considered in this process are temperature and d the pressure and it was supported by the previous research.

Most of researchers (Liu *et al.*, 2001; Supriadi *et al.*, 2007; Vielma *et al.*, 2008; Samantha *et al*., 2011) who was involved in MIM area are conducted the experiment by using the injection moldings method. The feedstock that has been cooled at a room temperature was feed in the injection molding machine. The injection molding parameter were optimized which is the temperature and the injection pressure. The barrel of injection molding machine is heated and then the feedstock is melted inside the barrel. Injection is carried out above the upper melting point of the feedstock.

Ibrahim *et al* (2010) conducted an experiment by using an injection molding method. Therefore the injection parameters were optimized by using Taguchi method L27 (3^{13}). Other researcher that used Taguchi Method as a Design of Experiment (DOE) methods are Nor *et al* (2010) and Jamaludin *et al* (2010) in order to optimize the findings of the results such as highest strength. The researcher proved by using Taguchi method in conducted the injection process could reduce the number of trials.

There are varied of temperatures and pressure were obtained in injection molding cycle and depend on the material that used to produce a feedstock. In conclusion, better understanding regarding the thermal properties of the material or feedstock for this present research should be obtain.

2.5.3 Debinding

Debinding are the next steps after the molding process. Recently, there are several debinding techniques which are solvent and thermal process. Solvent extraction involves immersing the compact fluid that dissolves at least one binder phase, leaving an open pore structure for subsequent binder burnout. Another variant of solvent extraction is to heat the compact in the presence of a solvent vapor in a process akin to vapor decreasing. (German and Bose,1997). Debinding is listed as basic steps in this present research. The primary binder system will be removed from the part while the secondary binder system remind in the part to retain the shapes. Most of all researchers are used debinding techniques to remove the binder in their green part, and this section review the published research literature relate to debinding process.

Tam *et al*, (1997) used debinding process due to the multi component binder system in the green parts that have been produced. A single component is not preferred with debinding techniques which is could lead to distortion during debinding. The researcher states that the multi binder system usually made of primary binder or more secondary binder components. Basically the additions of secondary components are used to improve the green strength and debinding behavior of the molded part. Due to this, firstly the removals of primary binder system occur to open the pores. While, the secondary binder system stays in the molded part to retain the shapes.

Liu *et al* (2001), (2001) are conducted debinding process since multi component binder systems were used. The removal process of binder system are occurs at this stages. The remaining binder systems are acts to retain the shape of the part. In order to decompose the binder components, the green micro parts were heated with different heating rates and different holding time. The heating temperatures are near to the highest melting point of the binder. Table 2.1 shows the multi stages of debinding schedule for 316L stainless steel micro parts

Table 2.1: Debinding schedule for 316L stainless steel micro parts (Liu et al (2001))

	Stage 1	Stage 2	Stage 3	Presintering	cooling
Heating rate (˚C/h)	600	50	300	900	900
Temperature (˚C)	150	350	550	950	30
Holding time (min)	10	30	30	15	-

Debinding temperature should be higher than melting point in order to remove the all binder components. (Supriadi *et al*, 2007). Studied of Vielma *et al* (2008) also conducted debinding process to remove the binder system from the part. There instruments used are combination of solvent and thermal debinding. The samples were prepared in n-heptane at different temperature from 25 ˚C to 60 ˚C. For thermal debinding, the samples were conducted in air in a Goceram GC-DC-50 furnace with the basis of thermo gravimetrical analysis. The last stages in this research methods are sintering that were performed in high temperature furnace at 2 hours of duration with difference temperature such as 1500, 1550, 1600 and 1650 ◦C. Outcomes from this research are show an easy thermal degradation lead to debinding process. The best results were found using solvent debinding followed by thermal debinding. Final parts had densities close to 99% after sintering at 1600 ˚C during 2 hours.

According to Samanta *et al* (2011) the removal process for the binder system also occurs in this research. The investigated of this process are done by using thermo-gravimetry analysis (TGA) of feedstock using Pyris Diamond TG/DTA system (Perkin Elmer Instrument, USA). Basically there are two stages debinding process are which is solvent debinding followed by thermal debinding to remove the binder from the green compact. However the binder system are removed by immersing the green compact inside the n-hexane solvent bath and then the remaining binder is removed by thermal debinding by heating the solvent debound compact at 500 ˚C in nitrogen atmosphere.

In conclusion, for this present research the debinding processes are useful to remove the binder all out from the molded part. It is due to the multi component of binder system in the compounds. However at this stage the will reduced the molded part weight. By using solvent debinding process the part will remains in rigid form without chemical reactions and open pore channels for subsequent easy degradation of binder. While by thermal techniques, there are no phase change and minimized defect formation on the parts. Thus, this present research were used the thermal techniques.

2.5.4 Sintering

Sintering is a thermal treatment process for bonding the particles into a coherent and solid mass. This is the necessary step once the binders are extracted from the molded part. Basically pores are eliminated the part of particle bonding during high temperature sintering. The components were shrinks to smaller dimensions after the sintering process. Generally, the sintering densification usually occurs close to the melting temperature for the material.

The atomic motion of the parts is moves faster as the temperature increase. It can predicted that by accompanying particle bonding during sintering is a significantly increase the hardness, strength, ductility, conductivity, wear resistance and corrosion resistance. (German and Bose, 1997) This section reviewed the literature from the published research as a reference to establish the method in the present research.

Most of researchers (Liu *et al.*, 2001; Supriadi et al., 2007; Samantha.S.K *et al.*, 2011) are conducted this steps in their research in order to obtain a better quality molded part whereas good in mechanical properties and surface roughness.

According to Vielma *et al*, (2008) Pieces were sintered during 2 hours at different temperatures (1500, 1550, 1600 and 1650 ˚C) in a high temperature furnace. Microstructure sintered parts were evaluated in a Philips XL 30 Scanning Electron Microscope. Density of sintered samples was determined using a water replacement method (Archimedes method). The outcomes of Vielma *et al*, (2008) shows that the longer sintering times made difficult to control grain growth. The homogeneity from the image confirms that there are not density gradients along the part that could reveal the presence of defects such as holes, internal cracks.

Sintering process is most importance step in metal injection molding. Due to this, this present research were used this method in obtain the high quality of sintered part and supported by the result from the previous research.

2.6 Feedstock Composition

In MIM study, variety type of materials and binder system are used by researcher. Among the chosen material are STS 316 nonopowder, LDPE, Porcelain, and 316L stainless steel. Material selection must be parallel with aim of study. However , in this present research, stainless steel SS316L will be mixed with waste LDPE and minimal amount of natural resources binder which is Palm Kernel in order to improve the compact shape retention. As such, the reading about material and binder system applies in previous studies are used as a reference source.

According to Tam *et al* (1997) the binder chosen for this research is a blend consisting of ethylene vinyl acetate (EVA) co polymer and beeswax. Hence, the (EVA) co polymers are selected in six grades. Since the beeswax also useful in this research, the physical data are summarized in Table 2.2. Moreover, the blends composition between EVA and beeswax are listed as Table 2.3.

Table 2.2: Physical Properties of Beeswax (Tam et al, 2007)

Properties	Description
Color	Deep brown to light taffy, white
Melting point at (˚C)	62-65
Penetration at 25 ˚C	15-20
Flash point	242
Specific gravity at 25 ˚C	0.950- 0.960

Table 2.3: List of names and composition of binder blends (Tam et al, 2007)

Code	Polymer	Polymer weight (%)	Beeswax weight (%)
B26520	EVA Grade 265	20	80
B26540	EVA Grade 265	40	60
B26560	EVA Grade 265	60	40
B26580	EVA Grade 265	80	20
B76020	EVA Grade 270	20	80
B76040	EVA Grade 270	40	60
B76060	EVA Grade 270	60	40
B76080	EVA Grade 270	80	20

Studies of Liu *et al* (2001)used the 316L stainless steel powder acted as the metal powder with the particles size distribution of D_{10} =3.2 µm, D_{50} = 7.3 µm and D_{90} = 10.4 µm. The researcher focus in used the smaller particle size. This researcher quotes that the particle size should be at least about one order of magnitude smaller than the minimum internal dimension of the micro part. The selected binder systems in this research were Paraffin Wax (PW), Ethylene Vinyl Acetate (EVA) and High Density Polyethylene (HDPE). Table 2.4 shows Characteristics of binder components

Table 2.4: Characteristics of binder components (Liu et al (2001))

Characteristic	PW	EVA	HDPE
Melting Point (˚C)	57	85	129
Recrystallization Temperature	52	66	124
degradation (˚C) Temperature	200-300	300-490	300-500

Agote *et al* (2001) used the hard porcelain. The characteristic of this material are composed of kaolin, quartz and feldspar with the firing temperature accurate to 1350 ˚C. Therefore, in this study the researcher are defined to use 2 types of porcelain which is virgin porcelain and wasted porcelain.

Based on Liu *et al* (2005) the selected metal powders in this research are stainless steel 316 L. Since that, the distribution of particle size are determine where as in range of D_{10}=1.21µm, D_{50} =2. 73 µm and D_{90} = 4.03µm.therefore, the researcher used 2 types of binder system compounds of PAN-250S with contains subcomponents such as resin, and wax besides Low Density Polyethylene (LDPE) also acted as a binder system. Since that, the melting temperature and lowest degradation temperature were measured and both parameters are equal to 127 and 170 ˚C.

Studies of Supriadi *et al* (2007) stated that their research used stainless steel 316S nanopowder detailed with particle size within an average of 100 µm. The binder system that listed such as combination of paraffin waxes, bee's waxes, carnauba waxes, ethylene vinyl acetate (EVA), polypropylene (PP) and stearic acid. Table 2.5 shows the detail composition of binder system.

Table 2.5: composition of binder system (Supriadi et al, 2007)

	EVA-based binder system (%)	PP-based binder system (%)	Wax-based binder system (%)
Paraffin wax	30	30	25
Carnauba wax	10	10	20
Bees wax	10	10	20
Ethylene vinyl acetate (EVA)	45	-	25
Polypropylene (PP	-	45	5
Stearic acid 5 5 5	5	5	5
Feedstock identification	FSA	FSB	FSC

Vielma *et al* (2008) presented Alumina Powder commercial purity Alcoa, CT 3000 SG with a particle size/D_{50} Cilas of 0.8µm and D_{90} of 2.5µm by referred the supplier. The binder system chosen in this research are high density polyethylene (HDPE), paraffin wax (PW) and stearic acid (SA). The properties of HDPE are low molecular weight polymer with a melt flow index of 25 are selected in this study.

Ibrahim *et al* (2010) produced a feedstock that mixed from particles powder (SS316L) in range size around 5µm with Polymethyl Methacrilate (PMMA) as primary, polyethelena Glycol (PEG) act as secondary binder composition while steric acid (SA) as the lubricant to the feedstock for wetting stabilize.

According to Samanta *et al* (2011) used the 316L stainless steel as metal powder and binder system consisting of PW, LDPE and SA. The compositions of feedstock in this research are 60-vol. % 316L gas-atomized stainless steel powder having the average particle size of 8 µm and 40-vol. %. The compositions of binder are detail in Table 2.6 while the composition of feedstock as showed in Table 2.7.

Table 2.6: Composition of Binder (Samanta et al, 2011)

Name of ingredients	Morphology	Weight percentage
PW	Flake	65
LDPE	Pallet	32
SA	Flake	3

Table 2.7: Composition of feedstock (Samanta et al, 2011)

Name of ingredients	Weight percentage
316L stainless steel	93
Binder	7

2.7 Metal Powder Characteristics

The powder and the binder characteristics are includes as parameter that need to stress out because it will affect all subsequent processing decision in metal injection molding. Based on the packing behavior, the particle shape affects the MIM process. However, the criteria of metal powder that need to concern are particle size and its distribution, particle shape, surface area and etc. (German and Bose., 1997). The smaller particle are necessary which is could lead to a smaller structural details, higher ratio, and better shape of the parts.

Hence, in this present research the SS316 L were selected as metal powder and supported by Supported by Liu et al (2005), 316L stainless steel powder was used since its good overall mechanical properties and corrosion resistance behavior are suitable for a wide range of applications. Small particle size and a multi-component binder system were used to meet the requirements for metal Injection Molding (MIM).

2.8 Taguchi Method Approach

Taguchi method is one of the techniques that provide a systematic and efficient methodology in optimization process. Besides, this technique is used for product design and process optimization worldwide. Taguchi Method has a several advantages which is includes simplification of experimental plan and feasibility of study of interaction between different parameters. These facts regarding this technique are supported by Kamarudin *et al* (2004).

Furthermore, according to Yang and Tarng (1997) Taguchi parameter design can optimize the performance characteristics of the design parameter. Taguchi Methods also known as the best method in order to optimize the design, performance and costing issue. So that, in this research, Taguchi method is most important technique in order to optimize the strength of the green part in metal injection molding. So far, this technique also implement in previous research and very useful as a guidelines in this present research.

According to Ibrahim *et al* (2010) there are several injection parameters were optimized by screening experiment which is injection pressure (A) , injection parameter (B), mold temperature (C), injection time (D) and holding time (E). The researchers are focused in determination of highest green strength in micro metal injection molding where as by using the Taguchi method. The finding of this research shows Taguchi Method could be the best methods in order to solve the problem with a minimum number of trials.

Studies of Ibrahim *et al* (2010) focused on single performance optimization of micro metal injection molding for the highest green strength by using Taguchi method. This research investigated the optimization of highest green strength which plays an important characteristic in determining the successful of micro MIM. Stainless steel (SS 316L) was used with composite binder, which consists of PEG and PMMA while SA works as a surfactant. The injection parameter that were optimized in this research are injection pressure (A), injection parameter (B), mold temperature (C), injection time (D) and holding time (E).

REFERENCES

German.R and Bose Injection Molding of Metals and Ceramics *Metal. Powder Industries Federation* U.S.A (1997)

G.L Chong, W.L Siew Chemical and physical Properties of Palm Kernel oil (1994) *Proceedings of the World Conference on Lauric Oils: Sources, Processing, and Applications.*

I. Agote a, A. Odriozola, M. Gutierrez, A. Santamarı , J. Quintanilla , P. Coupelle , J. Soares Rheological Study of Waste Porcelain Feedstock for Injection Molding *Journal of the European Ceramic Society* 21 (2001) 2843–2853

Jong Jin Park, Kwinam Park, Jin-Won Park, Dong Chan Kim Characteristics Of LDPE Pyrolysis. *KoreanZ Chem. Eng*., (2002) 19(4), 658-662

K.C. Tam, S.P. Yap, M.L. Foong , N.H. Loh Metal Injection Molding: Effects of the Vinyl Acetate Content on Binder Behavior, *Journal of Materials Processing Technology 67* (1997) 120-125

Majestic Mountain Sage, Inc (2002) Identity: Palm Kernel Oil Partially Hydrogenated Palm Kernel Oil *Material Safety Data Sheet*

M.H.I Ibrahim, N. Muhamad, A.B. Sulong, Murtadhahadi,K.R. Jamaludin, S. Ahmad, N.H.M Nor Rheological Characteristic Of Water Atomised Stainless Steel Powder for Micro Metal InjectionMolding Seminar II - AMReG 08, Bangi, Malaysia (2008)

M.H.I. Ibrahim, N. Muhamad, A.B. Sulong, K.R. Jamaludin, S. Ahmad and N.H.M. Nor Optimization of Micro Metal Injection Molding For Highest Green Strength by Using Taguchi Method *International Journal of Mechanical and Materials Engineering (IJMME), Vol. 5* (2010), No.2, 282-289

M.H.I. Ibrahim, N. Muhamad, A.B. Sulong, K.R. Jamaludin, S. Ahmad and N.H.M. Nor Single Performance Optimization of Micro Metal Injection Molding for the Highest Green Strength by Using Taguchi Method *International Journal of Integrated Engineering (Issue on Mechanical, Materials and Manufacturing Engineering* (2010)

N. H. M. Nora, N. Muhamad, M.H.I. Ibrahim, M. Ruzi and K.R. Jamaludin Optimization of Injection Molding Parameter of Ti-6AL-4V Powder Mix with Palm Stearin and Polyethylene for the Highest Green Strength by Using Taguchi Method *International Journal of Mechanical and Materials Engineering (IJMME), Vol.6* (2011), No.1, 126-132

P. Thomas-Vielma, A. Cervera, B. Levenfeld , A. V arez Production of Alumina Parts by Powder Injection Molding with a Binder system based on High density polyethylene *Journal of the European Ceramic Society 28* (2008) 763–771

Paul A. Webb (2001). Volume and Density Determinations for Particle *Technologists. Micromeritics Instrument Corp. 2/16/01*

Philips (2009) Thermal Analysis. *Technical notes Koninklijke Philips Electronics*

Rafat Siddique , Jamal Khatib , Inderpreet Kaur Use of recycled plastic in concrete: A review. *Waste Management 28* (2008) 1835–1852

S. Kamaruddin, Zahid A. Khan, K. S. Wan The Use Of The Taguchi Method In Determining The Optimum Plastic Injection Molding Parameters For The Production of a Consumer *Jurnal Mekanikal* 2004, Bil.18 98-110

Sirim Berhad (2011) Plastic Technology Group. Retrieved on 15January 2013 From http://www.sirim.my/web/plastics/material-identification-composition-and-contamination-analysis

S. Supriadi, E.R. Baek, C.J. Choi , B.T. Lee Binder system for STS 316 nanopowder feedstocks in micro-metal injection Molding Journal of *Materials Processing Technology 187–188* (2007) 270–273

Sudip K. Samantaa, Himadri Chattopadhyay, Madhab Malhar Godkhindi Thermo-physical characterization of binder and feedstock for single and multiphase flow of PIM 316L feedstock. *Journal of Materials Processing*

Technology 211 (2011) 2114– 2122

W.H.Yang, Y.S Tarng Design Optimization of Cutting parameters for Turning Operations based on Taguchi Methods *Jurnal of Material Processing Technology 84* (1997)P 122-129

Brian Halweil Lisa Mastny World Watch Institute's 2nd Ed. New York :London W W Norton & company (2004)

Z.Y. Liu , N.H. Loh , S.B. Tor , K.A. Khor , Y. Murakoshi , R. Maeda Binder system for micro powder injection molding, *Materials Letters 48* (2001). 31–38

Z.Y. Liu , N.H. Loh , S.B. Tor , K.A. Khor , Y. Murakoshi , R. Maeda Mixing and characterisation of 316L stainless steel feedstock for micro powder injection molding *Materials Characterization 54* (2005) 230– 238