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Processing of M2 High Speed Steel Powder Using Waste Rubber Based BinderBy Metal Injection Moulding Technique

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***Abstract*-This paper presents the compatiblity of waste rubber as one of the binder components in producing powder injection moulding feedstock. M2 High Speed Steel powder with mean diameter particle size 16µm has been used for this study. The metal powder with the powder loading of 65 vol.% were mixed with paraffin wax, polyethylene, waste rubber and stearic acid using z-blade mixer for two hours at 160°C in order to produce the feedstock. The feedstock was injection moulded by using vertical injection moulding machine with a nozzle temperature of 180°C and pressure of 350Bar. The moulded part was immersed into n-heptane at 60°C for five hours in order to remove the paraffin wax and stearic acid. The specimens were then sintered at a temperature range of 1200°C-1260°C in a controlled vacuum atmosphere. The properties of the sintered specimen such as physical, mechanical and microstructure were studied and discussed.**

***Keywords* – metal injection moulding, high speed steel, debinding, sintering**

I. INTRODUCTION

Metal injection moulding (MIM) is an improvement process from the combination of the advantages of polymer metal injection moulding with the flexibility of the conventional powder metallurgy in order to produce a variety of complex and small precision parts with very high volume production [1]. Injection moulding process starts with mixing the metal powder and binder to produce the feedstock, then injection moulding of feedstock into the desired shape, continued with removal of the polymer binder and finally sintering process in order to give high strength to the final product.

Molybdenum high speed steel (M2 HSS) is a steel containing high concentration of molybdenum. The properties of this material are high toughness coupled with good hardness, good wear resistance, red hardness and good cutting power owing to its well-balanced alloy composition, making it suitable for a wide variety of applications. Some research have been conducted in injection moulding M2 HSS using thermosetting binder [2] and other research have developed injection moulding for carbides reinforced M2 [3-8].

This study investigates the compatibility of waste rubber as one of the binder components in injection molding of M2 HSS. The selection of binder is important in MIM process since it promotes the fluidity and rigidity of feedstock during mixing, injection moulding and debinding process. Owing to its highly elastic characteristic, waste rubber has great potential to be utilized as one of the binder components in MIM applications. Hence, there are great opportunities in designing a new formulation of binder system by using waste rubber which are currently underutilized resources and locally available. Establishment of this new binder system may therefore help to reduce the cost of overall injection moulding process.

II. MATERIALS

2.1 Materials

The M2 HSS powder used in the present study was obtained from Sandvik Osprey Powder. The mean particle size distribution was determined by using a Coulter LS 130 Laser Particles Size Analyzer and is summarized in Table 1. It is shown that the powder have a mean particles size of around 16µm. The binders used in this study were consisted of 55wt.% paraffin wax, 21wt.% polyethylene, 14wt.% waste rubber and 10wt.% stearic acid.

Table 1 The Cumulative Particle Size Distribution of M2 HSS Powder.

Fraction (%)	< 10	< 50	< 90
Size (µm)	2.14	6.20	16.55

2.2 Feedstock Preparation and Sintering

The M2 HSS powder was mixed together with the binder components consists of paraffin wax, polyethylene, waste rubber and stearic acid in a designed powder loading using a Z-blade mixer at a temperature of 160°C for aduration of 2 hours at a speed of 50rpm. The feedstock was then granulated into pallet form so that it could be

easily fed into the injection moulding machine. The tensile specimens were fabricated in a vertical injection moulding MCP HEK-GMBH. The injection pressure was 350bar and the mold temperature was 180°C. Solvent debinding process was performed for 300 min at a temperature of 60°C in a bath of heptane in order to remove paraffin wax and stearic acid. Specimens were taken out and dried for 2 hours after bathing. The sintering process was performed in a controlled vacuum atmosphere with heating rate of 5°C/min in a temperature range of 1200°C-1260°C. The specimens were soaked for 2 hours and subsequently furnace cooled.

2.3 Mechanical Properties

The tensile strength of sintered specimen was measured by three point bending test in an Instron universal instrument. Specimens for metallographic examination were prepared using standard techniques and etched in 5% Nital. Microstructural evaluations were performed by both scanning electron microscopy (SEM) and optical microscopy and sintered densities were evaluated by Archimedes' method.

III. RESULTS AND DISCUSSION

Powder Characterization and Moulding Behaviour

Fig. 1 indicates a scanning electron micrograph of the metal powder. Some particles are large and rounded while some are very small.

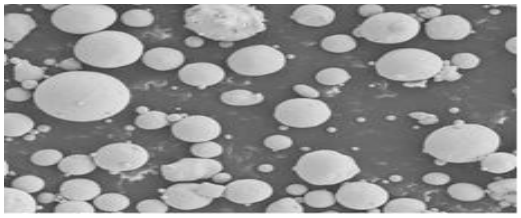


Fig 1: SEM of M2 high speed steel.

These powder characteristics are somewhat well aligned with the desired values for MIM powders. The analysis showed that the powder had a relatively wide particle size distribution which is desirable for efficient particle packing.

Figure 2 shows the tensile shape of the injection moulded specimens (green) with a single gate, located at one end of the specimen. The moulding temperatures (nozzle temperature) used during the study can be considered to be much higher as compared to many works in MIM, which commonly used the temperature range of 100°C to 200°C.

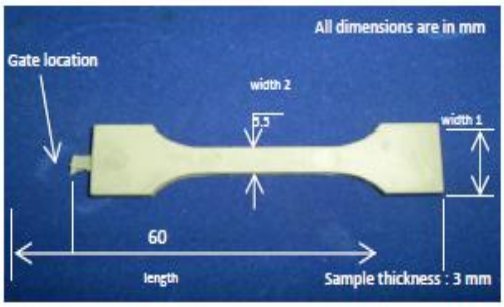


Fig 2: Moulded green specimen

The higher temperature applied was believed due to the use of the high molecular weight of PE in binder system, which led to high viscosity of the feedstock. To ensure that the feedstock can easily flow and be moulded, the applied temperature was set higher to compensate for the high viscosity of the feedstock. At the end of moulding, the binder provides a mechanical interlocking to the particles which gives the compact shape and the necessary handling strength.

Generally, after the mould is filled, heat is extracted from the feedstock through the die. As illustrated in Figure 3, the heat flow is directed towards the wall. Since the wall is the coolest, therefore heat will flow from the hot zone to the cold zone. The combination of high pressure applied, low viscosity and rapid die filling rates lead to trapped air defect of the moulded specimen.

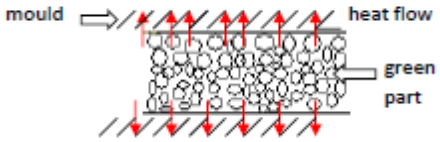
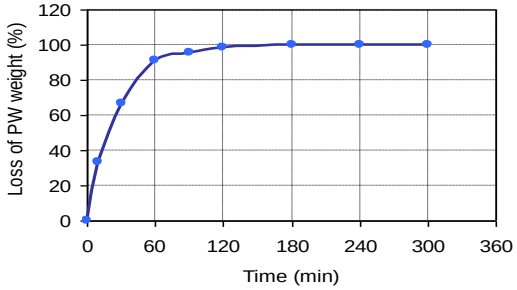


Fig 3: A schematic of the dissipation of heat through the mould.

Solvent Extraction and Sintering Process

Solvent extraction process is a part of debinding process to remove paraffin wax. Observation during debinding revealed that the specimen shape is distortion free and



remained the same after the sintering process.

Fig 4. The percentage of PW removed at different time

The graph in Fig. 4, clearly shows that all the paraffin wax had been effectively removed from the specimen after 180 minutes. During the first 30 minutes, almost 70% of the paraffin wax dissolved and it can be assumed as optimum solvent degradation time.

Evaluation of Physical Properties

Sintering process was performed in a controlled vacuum atmosphere in a temperature range of 1200°C-1260°C with heating rate of 5°C/min in order to avoid cracking and warping of the specimens. The specimens were soaked for 2 hours and subsequently furnace cooled. Density evaluation on the sintered specimens revealed that effective densification took place in the temperature ranging from 1200°C to 1260°C.

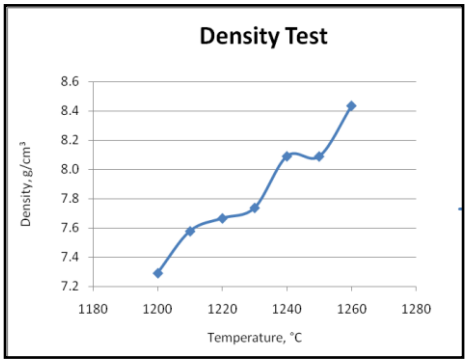


Fig. 5: Sintered density as a function of sintering temperature

Densification rate at temperature range below 1220°C were consistent with solid state diffusion and the sintered density obtained was below the theoretical density, which is 7.97g/cm^3. It is interesting to note that once the liquid phase began to appear, the densification rate became very rapid, resulting in sintered density higher than the theoretical density [4].

Rapid densification that took place in the sintered specimen occurred by super-solidus liquid phase sintering [4,5]. It has been observed that specimen sintered at sintering temperature of 1230°C attained near full density while those sintered at higher sintering temperature possessed sintered density which was greater than the theoretical density. As the metal powder used in this work is coarser, it is expected that the near full density was achieved at higher sintering temperature.

Evaluation of Mechanical Properties

Three point bending test was performed according to MPIF 41 and shows in Fig 6. The results obtained showed that the yield stress of sintered specimen increased with increasing sintering temperature up to 1230°C. The specimen sintered at a temperature of 1230°C had resulted in favorable effect andpossessed maximum yield stress of 2351 MPa, presumably due to enhancement in density and reduction in porosities of the sintered specimen.

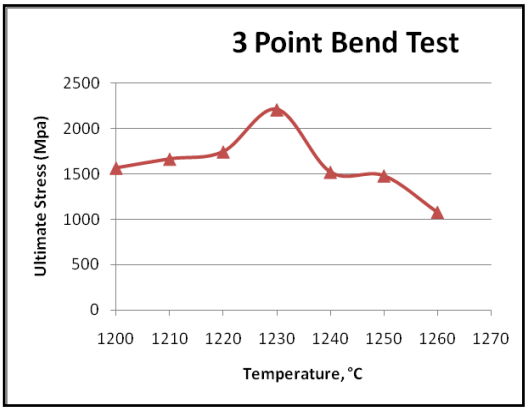


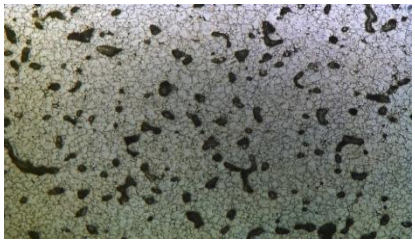
Fig. 6: The bending strength as a function of sintering temperature.

Further increase in the sintering temperature however, had reduced the bending strentgh of the sintered specimens. This could probably be due to grain growth phenomena with the development of discontinuous carbide films and the appearance of brittle eutectic carbide phase at the prior austenite grains. The microstructure changes of the sintered specimens therefore lowered the yield stress and deteriorated the mechanical properties of the sintered specimens [4,5].

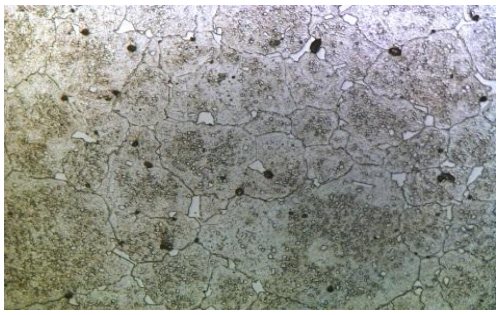
Microstructure Observation

Figure 7 a to c shows the optical micrograph of samples sintered at temperatures from 1200^{o}C, 1230^{o}C and 1260^{o}C after etching. There are much difference in grain size observed as temperature is increased. At that temperature, sintering is likely to slow down, as during this final stage of sintering, spherical pores shrink by a diffusion mechanism. The events lead to the isolation of a pore and spheroidisation due to rapid grain growth (German, 1996). At 1260 ^{o}C, it shows a change in the grain size as well as a decline in the total porosity during sintering as discussed before.

a)1200^{o}C



b)1230^{o}C



c)1260^{o}C

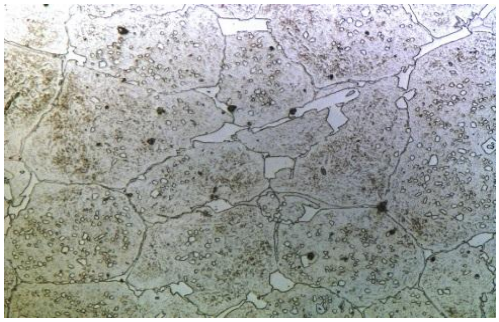


Fig.7 Microstructures of M2 HSS specimens sintered at 1230°C to 1260°C

As depicted in Fig.7, the optical micrograph of specimen sintered at 1230°C had obviously possessed equiaxed grain structure with low fraction of small pores at the grain boundaries. Increasing the sintering temperature beyond 1230°C was found to increase the grain size which was associated with formation of continuous carbide film. It is also interesting to note that the thin carbide film formed had encircled the grain boundaries.

Fig. 8 depicts a scanning electron micrograph of the fracture surface for specimen sintered at a temperature of 1230°C.As the density of the sintered specimen achieved near full density, it can be noted that the metal powder boundaries were replaced by grain boundaries. However, at sintering temperature greater than 1230°C, coarsening of grain structure took place and further deteriorated the yield stress of the sintered specimen.

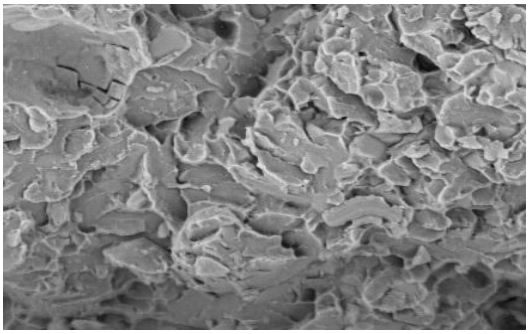


Fig. 8 Fracture microstructure of sintered specimens at 1230°C.

IV CONCLUSIONS

In this work attempts have been made to formulate a new binder system by using waste rubber in MIM of M2 HSS. It is observed that waste rubber has been successfully utilized as one of the binder components in MIM of M2 HSS to produce a homogenous feedstock. The injection molded specimen which was sintered at 1230°C possessed optimum properties with density and yield stress of 7.74 g/cm^{3}and 2351 MPa respectively.

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