

# Influence of Waste Plastic Binder on Sintered Properties of Injection Moulded M2 HSS

*Rosniza Rabilah\*, Salina Budin, Talib Ria Jaafar, Siti Mardini Hashim*

*Faculty of Mechanical Engineering,  
Universiti Teknologi MARA (UiTM),  
13500 Permatang Pauh, Pulau Pinang, MALAYSIA  
\*rosniza.rabilah@ppinang.uitm.edu.my*

*Nor 'Aini Wahab*

*Faculty of Mechanical Engineering,  
Universiti Teknologi MARA (UiTM),  
0450 Shah Alam, Selangor, MALAYSIA*

*Mohd Afian Omar, Rosliza Sauti  
Structural Material Program,*

*Advanced Materials Research Centre (AMREC), SIRIM Berhad,  
Lot 34, Jalan Hi-Tech 2/3, Kulim Hi-Tech Park,  
09000 Kulim, Kedah, MALAYSIA*

## ABSTRACT

*Metal injection molding (MIM) is an effective way for producing small and complex-shape components in high production rates. Selection of binder and its removal in debinding process is a crucial stage in MIM process. In this study, the debinding and sintering characteristics of injection molded M2 HSS using waste plastic binder system has been investigated. The feedstock was formulated with 0.65 volume fraction of molybdenum high speed steel (M2 HSS) with the binders system containing 55wt.% paraffin wax, 35wt.% thermoplastic waste plastic and 10wt.% stearic acid. The moulded parts were immersed in n-heptane at 60°C for 5 hours in order to remove the paraffin wax and stearic acid. The parts were rested in standard low temperature furnace for 2 hours at 52°C to ensure the remaining n-heptane was completely removed and dried. The sintering in vacuum condition occurred at temperature ranges of 1200°C to 1260°C with soaking times of 10 minutes, 30 minutes and 60 minutes. The results showed that the maximum shrinkage of sintered samples was 15% which occurred at sintering*

*temperature of 1260°C. However, the maximum transverse rupture strength (TRS) of 3500 MPa was obtained at temperature of 1240°C and the highest hardness was achieved at sintering temperature of 1220°C with the value of 60.7 HRC. The effects of sintering temperature and soaking time on the physical and mechanical properties are discussed.*

**Keywords:** *Metal Injection Moulding, Waste Plastic, Molybdenum High Speed Steel, Physical and Mechanical Properties*

## Introduction

Metal Injection Moulding (MIM) is an advanced technique for producing high complex-shape metal parts. This technology exhibits good properties of parts such as having low porosity, smooth textures and close tolerances with low cost in high production rates [1].

MIM process consists of four different steps. The first step begins with mixing fine metal powder with binder system which consists of polymer and wax binders. This process is called feedstock preparation and it is the most important process because the next step depends on the feedstock characterization. Then, the mixture is injected into the mould with the desired shape, and the green part is produced. After injection moulding, the next process is the debinding process. There are two stages of debinding, which are solvent extraction and thermal debinding. The last step is the sintering process [2]. The brown body undergoes sintering process to impart strength and integrity.

M2 HSS is widely used particularly as a drill bit in cutting tools application. M2 HSS is molybdenum based high-speed steel in tungsten–molybdenum series with the well-balanced toughness, wear resistance and red hardness properties. This grade is generally used in cold work punches and dies and cutting applications comprising high speed and light cuts such as drill bits, taps and reamers. The current binder system used in MIM of M2 HSS is traditional binder system, namely wax and polyether based materials. Unfortunately, these traditional binders are expensive to prepare and unsafe for environment and human.

To overcome the above mentioned situation, a new cost-effective and eco-friendly binder from waste material was developed. This study investigates the influence of waste plastic as a binder system for MIM. The waste plastic was from the plastic bottles that contained polyethylene (PE). The new binder system, utilizing waste plastic is expected to exhibit good physical and mechanical properties of M2 HSS.

## **Experimental**

The 16 $\mu$ m mean diameter particle size of molybdenum high speed steel powder used in this study was obtained from Sandvik Osprey Powder. The microstructures of the raw powders were in rounded and spherical shape as illustrated in Figure 1. The development of new feedstock of M2 HSS metal powder of 65% volume fraction was formulated from previous work. The M2 HSS powder was mixed with binder containing 35 vol. %, of which comprised 55 wt.% paraffin wax (PW), 35 wt.% thermoplastic waste plastic (TPWP) and 10 wt.% stearic acid (SA) at a temperature of 160<sup>0</sup>C in Z-blade mixer for 60 minutes at 60 rpm. Then, the feedstock was removed, dried and granulated into pellet form by using granulator. Tensile samples were prepared using vertical injection moulding machine under injection pressure and injection temperature of 300 bars and 160<sup>0</sup>C respectively. After injection moulding, visual observation on green parts was carried out to ensure all samples were free from any injection molded defect such as cracking, distortion, and so on.

The green parts underwent debinding process which involved solvent extraction, and thermal debinding. Solvent extraction was carried out by immersing the samples in n-heptane solution for 5 hours at temperature of 60<sup>0</sup>C at static condition. In this stage, the paraffin wax and stearic acid were completely removed from the samples. Then, the samples were heated in the low temperature furnace at temperature of 52<sup>0</sup>C for 2 hours to remove the remaining n-heptane and to ensure that the samples were completely dried.

The dried samples were then sintered under vacuum condition at temperature range of 1200<sup>0</sup>C to 1260<sup>0</sup>C using heating rate of 5<sup>0</sup>C/min. The waste plastic binder was removed at this stage. Three sintering soaking time of 10 min, 30 min and 60 min were used to investigate the effect of soaking time on the physical and mechanical properties of the sintered samples.

The physical and mechanical properties were performed by evaluating the shrinkage, density, microstructure, fracture morphology, hardness and transverse rupture strength (TRS) of the sintered samples. The shrinkage of the sintered part was measured from the dimensions of the green parts and sintered samples. The dimensions of each part measured for sintered shrinkage were length, width and thickness. The density of the sintered samples was measured using electronic densimeter by applying the Archimedes method. The sintered samples were then prepared for metallographic observation using an optical microscope. The tensile samples were also analyzed using Scanning Electron Microscopy (SEM) to examine the structure and porosity. The hardness was measured using Rockwell's Hardness Machine according to the standard of ASTM E18, while the three points bending test was carried out using Instron Universal Instrument followed the MPIF 41 procedure in order to evaluate the TRS.

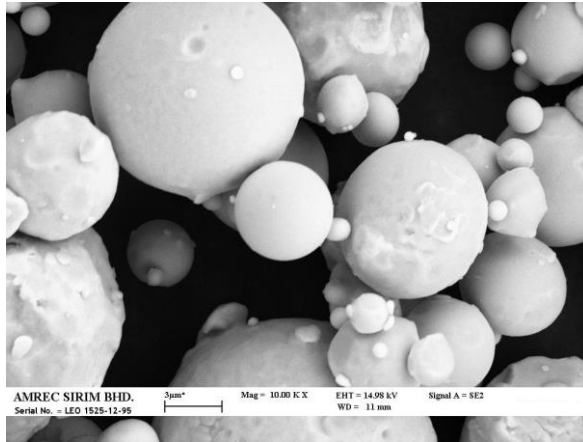


Figure 1: SEM analysis of M2 HSS powder

## Results and Discussion

### Physical Properties

#### Shrinkage

The results showed that the lowest shrinkage was about 10% which was observed at the sintering temperature of 1200°C. The maximum shrinkage of the sintered samples was 15% which was obtained at the sintering temperature of 1260°C. Therefore, it can be concluded that as the sintering temperature increased, the shrinkage also increased. Increasing the sintering temperature will cause high thermal expansion which finally causes high shrinkage upon cooling. Similarly, as the soaking time increased, the shrinkage also increased. Longer sintering soaking time will allow atomic diffusion to diffuse efficiently and consequently, the porosity will be eliminated effectively. Thus, this will increase the shrinkage [3]–[4].

#### Sintered Density

Figure 2 illustrates the density evaluation of the sintered samples exposed at various sintering temperature and sintering soaking times. The density was noticeable increased as the sintering temperature increased. However, the increment reduced at sintering temperature of 1240°C. The maximum density of the sintered samples was 8.11 g/cm<sup>3</sup> attained at the sintering temperature of 1240°C and soaking time of 60 minutes. The value of density attained was approximately 99.3% of theoretical maximum value which was 8.16 g/cm<sup>3</sup>.

The finding is similar to a study reported by Wahab et al. who found that the maximum density of the sintered sample was  $8.1 \text{ g/cm}^3$  obtained using palm stearin/waste rubber binder [4]. Liu et al. reported that the sample parts achieved almost full density when sintered at temperature above of  $1230^\circ\text{C}$  [5]–[6]. It is also supported by another study performed by Sauti et al. who explained the near full density was achieved at higher sintering temperature as the metal powder used was coarser [7]. Thus, rapid densification appeared due to super-solidus liquid phase sintering and resulted in higher sintered density [7].

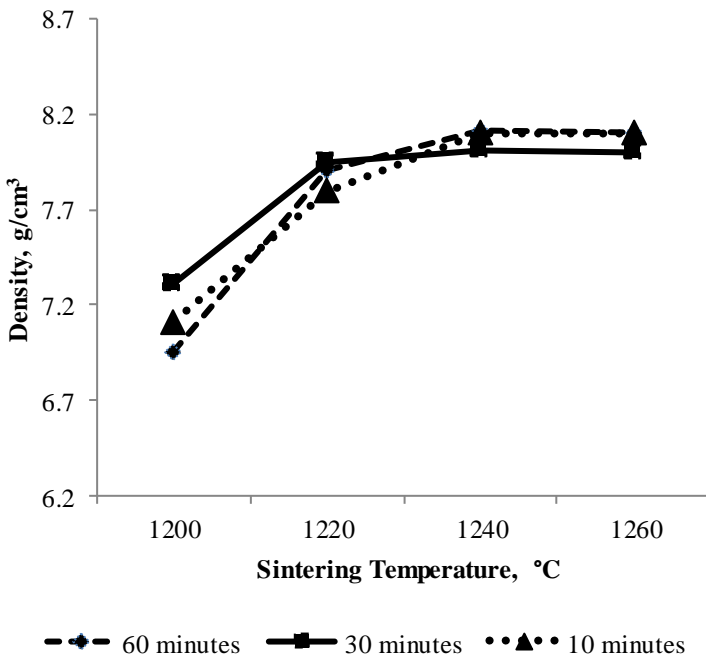


Figure 2: Density against sintering temperature for different soaking time

### Microstructure Analysis

Figure 3 (a) to (c) show the microstructures of etched sintered samples at different temperature of  $1200^\circ\text{C}$  to  $1240^\circ\text{C}$ . Figure 3 (a) illustrates small grain size and large pores. At temperature of  $1200^\circ\text{C}$ , the grain growth began to occur until it reached  $1240^\circ\text{C}$  as shown in Figure 3 (c). At temperature of  $1220^\circ\text{C}$ , the particles of powder began to connect and the shape of pores appeared to be smooth as shown in Figure 3 (b). It is shown that the sintered samples have achieved near full density at this point. It has been reported that small grain size and unequal shape of large pores blowout

inside the grain boundary due to the sintered specimen was not fully densified yet at temperature below 1230<sup>0</sup>C [7]. As sintering temperature increased to 1230<sup>0</sup>C, the grain size of the particles slightly increased and the volume of the pores started to shrink. The finding is similar as reported by Todd et al. [3].

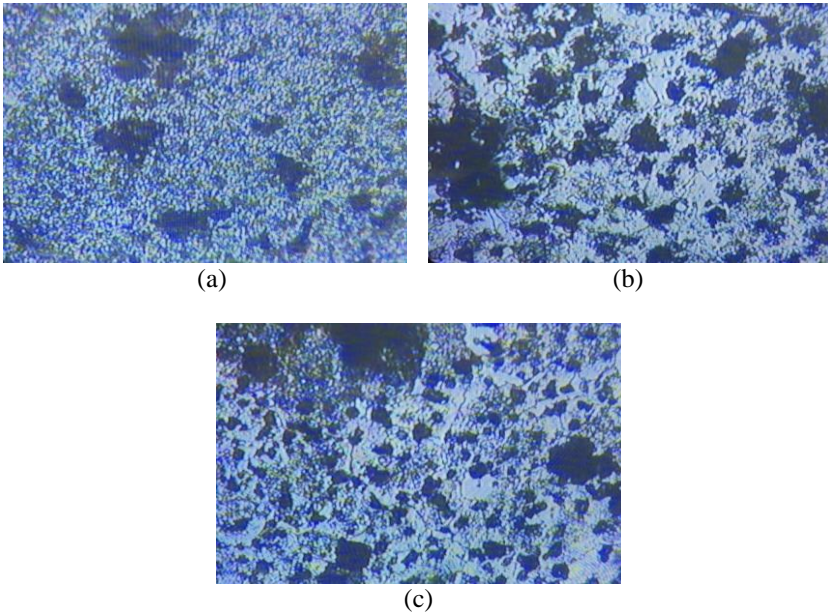


Figure 3: Microstructures of sintered samples at different temperatures (a) 1200<sup>0</sup>C (b) 1220<sup>0</sup>C and (c) 1240<sup>0</sup>C

### Fracture Morphology

Figure 4 illustrates the tensile fracture surface of the sintered samples observed using SEM at temperature ranges of 1200<sup>0</sup>C to 1260<sup>0</sup>C. Figure 4 (a) shows the appearance of large pores between the particles. As the sintering temperature increased, the powder boundary decreased and the grain started to grow. Thus, eliminating the pores. It is clearly shown in Figure 4 (b) that almost fully density was achieved and the grain boundaries appeared. Low porosity of the sintered samples can be seen at the highest temperature as shown in Figure 4 (d). It can be concluded that increasing the sintering temperature has decreased the porosity. No inter-grain-boundary crack was observed, although it has been reported that the inter-grain-boundary crack could be found at the sintering temperature of 1250<sup>0</sup>C to 1260<sup>0</sup>C [5]–[6].

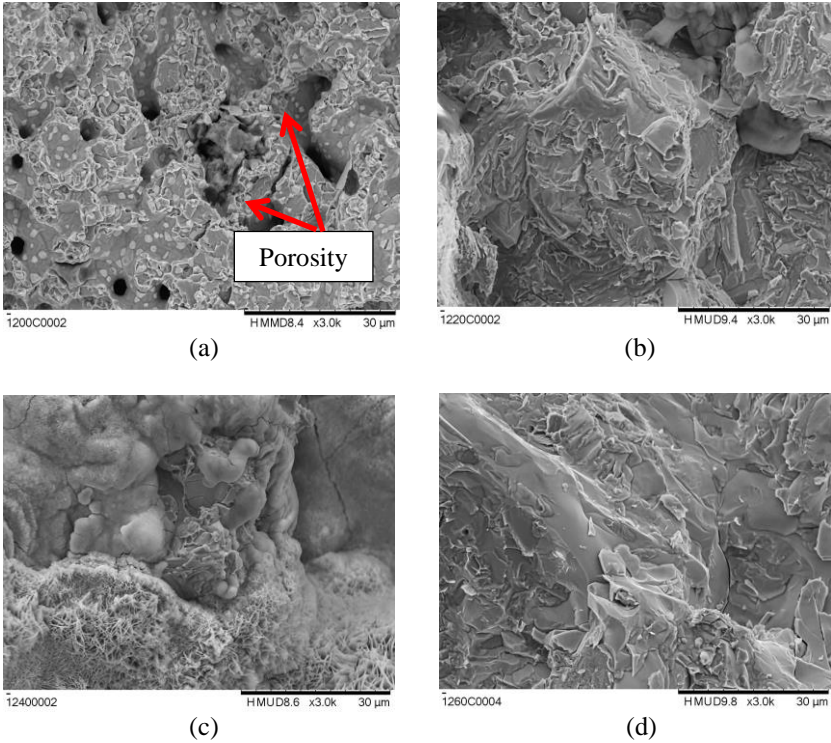


Figure 4: Fracture morphologies of sintered samples at different temperatures (a) 1200°C (b) 1220°C (c) 1240°C and (d) 1260°C

## **Mechanical Properties**

### Hardness

Figure 5 shows the hardness at temperature range of 1200°C to 1260°C and soaking time of 10 minutes to 60 minutes. It is illustrated that the maximum hardness of the sintered samples was 60.67 HRC obtained at sintering temperature of 1220°C and soaking time of 60 minutes. The hardness attained was 98% of theoretical maximum value which was 62 HRC. As the sintering temperature increased, the necking activities became more significant which contributed to high dense and hardness.

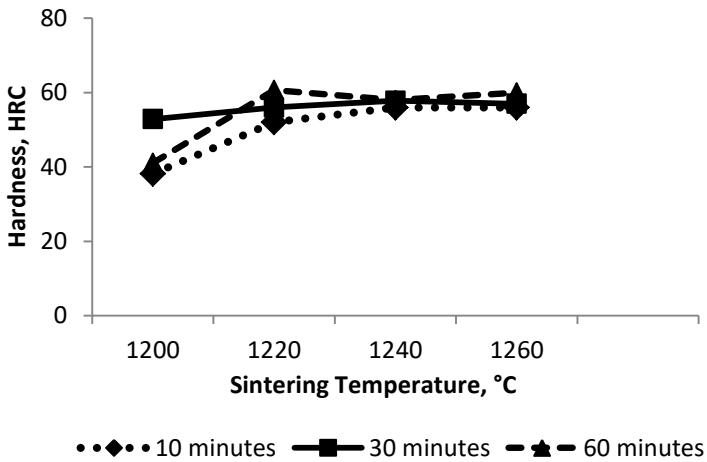


Figure 5: Hardness against sintering temperature for different soaking times

#### Transverse Rupture Strength (TRS)

Figure 6 indicates the ultimate stress of the sintered samples at temperature of 1200°C to 1260°C for different soaking time. The TRS results showed that the maximum ultimate stress was 3500 MPa achieved at temperature of 1240°C for 60 minutes soaking time. The optimum value of ultimate stress was greater than the theoretical maximum value of 3250 MPa. At temperature of 1260°C, the ultimate stress of the sintered samples was 3200 MPa. It is clearly shown that the ultimate stress increased rapidly as the temperature increased to 1240°C. After sintering temperature increased up to 1260°C, the ultimate stress was gradually decreased due to changes in grain growth which improved density and reduced porosities. It has been reported that after temperature of 1230°C, the microstructure changed and the ultimate tensile stress dropped due to grain growth. Therefore, it has affected the development of discontinuous carbide film and a brittle eutectic carbide phase appeared at the former austenite grains [8]. It has been also reported that low yield stress could debilitate the mechanical properties of the sintered samples [5]–[7].



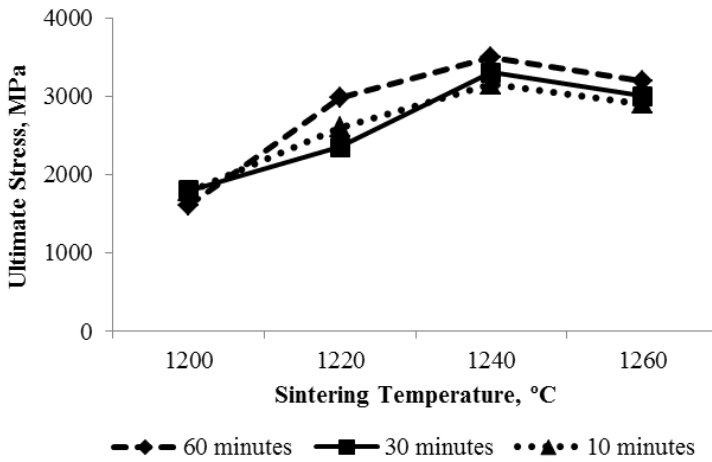


Figure 6: Transverse rupture strength against sintering temperature for different soaking times

## Conclusion

From the results of the study, it can be concluded that the use of waste plastic as a binder in MIM process is compatible with palm stearin and waste rubber binder. The physical and mechanical properties of the sintered part were similar to that of theoretical properties with the replacement of current binder to waste plastic. Waste plastic has demonstrated to be a suitable binder system in injection moulding of M2 HSS. The parts after debinding and sintering were successfully produced with defect-free disorder such as cracks and distortion. The highest sintered density was  $8.11 \text{ g/cm}^3$ , and achieved 99.3% of the theoretical maximum value of  $8.16 \text{ g/cm}^3$  at temperature of  $1240^\circ\text{C}$ . The maximum transverse rupture strength (TRS) obtained was 3500 MPa at sintering temperature of  $1240^\circ\text{C}$ , while the highest hardness was about 60.7 HRC at sintering temperature of  $1220^\circ\text{C}$  for soaking time of 60 minutes. By using waste plastic as a binder, not only reduces material cost but supported world sustainability development program.

## Acknowledgements

This research was supported by iRAGS grant 600-RMI/DANA 5/3/IRAGS (42/2015) from Research Management Centre (RMC) of Universiti Teknologi MARA (UiTM). The authors gratefully appreciate the Advanced

Materials Research Centre (AMREC) SIRIM, Kulim for providing the facilities.

## References

- [1] R. M. German and A. Bose, *Injection Molding of Metals and Ceramics*, Metal Powder Industries Federation, New Jersey, (1997).
- [2] M. A. Omar, I. Subuki and N. Abdullah, "Development of metal injection moulding process for medical applications", *Advanced Materials Research*, 428, 38-42 (2014).
- [3] I. Todd and A. T. Sidambe, "Development in metal injection moulding (MIM)", *Advances in Powder Metallurgy* (Woodhead Publishing Limited, 2013), pp. 109-146.
- [4] N. A. Wahab, M. A. Omar, R. Sauti, N. A. Nordin and I. N. Ahmad, "Rapid debinding of injection moulded M2 high speed steel using palm sterain/waste rubber binder", *Advanced Materials Research*, 879, 112-118 (2014).
- [5] Z. Y. Liu, N. H. Loh, K. A. Khor and S. B. Tor, "Microstructure evolution during sintering of injection molded M2 high speed steel", *Journal of Materials Science and Engineering A*, 293, 46-55 (2000).
- [6] Z. Y. Liu, N. H. Loh, K. A. Khor and S. B. Tor, "Sintering of injection molded M2 high speed steel", *Journal of Materials Letters*, 45, 32-38 (2000).
- [7] R. Sauti, N. A. Wahab, M. A. Omar and I. N. Ahmad, "Effects of binders system on sintered properties of metal injection molding parts of M2 high speed steel", *Advanced Materials Research*, 1024, 201-204 (2014).
- [8] H. Asgharzadeh and A. Simchi, "Effect of sintering atmosphere and carbon content on the densification and microstructure of laser sintered M2 HSS powder", *Material Science and Engineering A*, 403, 290-298 (2005).