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STUDY ON THE PROPERTIES OF SINTERED BODY OF WC-10%Co PRODUCED BY METAL INJECTION MOLDING (MIM)

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ABSTRACT

Cemented carbide (WC-Co) is a composite material consisting of a tungsten carbide (WC) embedded in a cobalt (Co) binder. The hardmetal is known for its high hardness, superior toughness and high wear resistance in various applications. This study focused on the effects of sintering parameters of cemented carbide on its properties such as hardness, wear resistance, density, porosity and microstructure. The samples were fabricated through metal injection molding process with palm stearin and polyethylene binder system. The powder loading used was 63% volume and the binders had been removed under 2 stage debinding process without causing any defects onto the samples. The samples were sintered in different sintering temperatures and holding time which are 1400 °C with 30 minutes, 1400 °C with 60 minutes, 1400 °C with 90 minutes, 1450 °C with 30 minutes, 1500 °C with 30 minutes and 1550 °C with 30 minutes respectively. The results show that there are changes in microstructure on the surface of the material and found that abrasive wear resistance is proportional to the hardness of the material. The changes in the density, porosity and the grains growth size also show significant changes and are further discussed.

Keywords: cemented carbide, sintering parameter, microstructure.

INTRODUCTION

WC-10%Co is one of the hard metals which are made up from ceramic, which is tungsten carbide (WC), binded with cobalt (Co) phase (Upadhyaya 2001). One of the applications of WC-Co is used to make cutting tools, and this hard metal possess massive mechanical and physical properties.

Over the past 20 years, powder injection molding (PIM) has been introduced to fabricate WC-Co. Apart of maintain its hard metal metallurgy properties, Powder Injection Molding manage to form precise and complex shape components (German 1999, Prakash 2007). In this process, powders were mixed together with to form feedstock. The feedstock will injected inside a mold cavity with desired shape. The desired products form is called as-green part. Binder then removed from the green part using proper solvent and thermal debinding process. Last step, the debinded part was sintered to get its desired physical and mechanical properties.

The mechanical properties of materials are reaction to anything that involves loads and are important to determine the range of uses and create service life can be expected. Normally, the material characteristics are the strength, ductility, hardness, wear resistance, fracture toughness, and surface roughness. Most of the material is anisotropic structure, which means that their material properties vary with orientation. Recently published work on the properties of WC-Co manufactured by µPIM reported that good surface quality and hardness of microcomponents of WC-Co compared to conventional powder metallurgy (Heng *et al.* 2013, Fayyaz *et al.* 2014). This showed the technologies capability to produce good quality product with standard properties.

This paper attempts to study on the properties of sintered part of WC-Co and analysis were made by microstructural part. To the end, mechanical properties such as hardness, wear resistance, density and microstructure are described.

EXPERIMENTAL

As ready samples were fabricated through PIM of WC-Co powder with palm stearin and polyethylene feedstock at 63% volume powder loading. The binders have been removed via 2 stages debinding process, solvent followed by thermal debinding upon sintering. Sintering process is carried out in a high vacuum furnace of Korea VAC-TEC-500HTSF VTC model. Sintering parameters are varied is the sintering temperature of between 1380 to 1450 ºC and holding time at 30, 60 and 90 minutes, while the heating rate was maintained at 10 ºC / min. Table-1 shows the formation of samples according to different sintering parameters.

Table 1 Number of samples according to sintering parameters.

SAMPLE	TEMPERATURE (°C)	HOLDING TIME (minute)
1	1400	30
2	1400	60
3	1400	90
4	1450	30
5	1500	30
6	1550	30

30N and 45N load were used in the experiment hardness (Rockwell) is following a certain standard WC-Co (certain standard permissible WC-Co). Wear test for 6 samples cemented carbide (WC-Co) is tested at ambient temperature or room temperature. Samples were placed on the Procimet machine. Rotation speed is adjusted to 500

rpm, the load applied is 20N and placed on a stainless steel sample. Time for a sample on the machine is 2 minutes 30 seconds for each sample. The Archimedes principle has been applied to measure the density of each sample. 3 steps involved; to measure the weight of the sample itself (m_1), followed by the weight when it is hanging in the air (m_2) and the last step is the sample weighted when it is fully emerged in water while in hanging condition. The density for each samples are as follow:

$$\rho = \frac{m1}{m2 - m3} \quad (1)$$

The formula in Equation 1 was used to calculate the density where:
m_1 = mass of free body in air
m_2 = mass while hanging in air
m_3 = mass while hanging and fully emerged in water

Sample preparation for microstructural examination performed based on the following sequence; grinding (grinding), followed by polishing (polishing) and finally etching (etching). Diamond grinding disc of 30µm was used to remove the black surface of the sintered samples. For the purpose of examining the microstructure, back scatter images (backscattered image) of a sample is taken using a scanning light microscopy, SEM, Hitachi model S3400N on x2.5k enlargement. The proportion of elements in the sample element is determined by energy dispersive X-ray (EDX) of Horiba EMAX, while the phase change is detected by X-ray diffraction (XRD).

RESULTS AND DISCUSSION

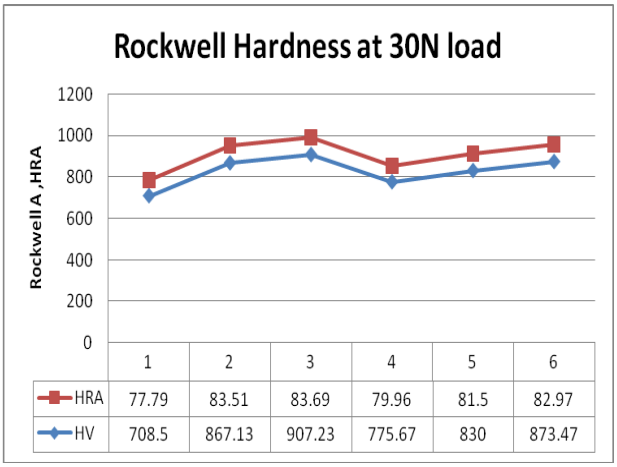
Six samples were subjected to a load of 30N in experimental hardness (Rockwell). Readings taken three times for each sample to obtain an average for each sample. The table embedded in Figure-1 shows the values of HV and HRA. For samples 1,2 and 3 show an average increase upwards of sample 1 (708.50HV, 77.79HRA), sample 2 (867.13HV, 83.51HRA), and sample 3 is (907.23HV, 83.69HRA). The increase shown is due to hold time sintering parameters which vary according to the sample. For samples 4, 5 and 6 were sampled 4 (775.67HV, 79.96HRA), sample 5 (830HV, 81.5HRA) and sample 6 (873.47HV, 82.87HRA). All three samples also showed an increase in the upward because different temperature sintering parameters for each sample 4,5 and 6. Figure-3 shows the 6 samples subjected to a load of 30N.

Samples 1, 2 and 3 showed an increase in the average value of HRA and HV consistently, hold it for a different time on each sample. Hold time influence the hardness of a material. When the holding time increased, the level of violence has also increased since the microstructure of the material to be close to each other.

For samples 4, 5 and 6 also show consistent improvement. High temperature sintering parameters and different materials affect the level of violence. As expected, the increasing of sintering temperature increased the hardness of the materials. It leads to the sizes of the small details of joining materials.

For Figure-1 below shows the average reading and hardness to load 45N. For 45N load samples 1,2 and 3 also showed increased hardness value higher than 30N load. Sample 1 shows the mean (726.30HV, 67.50HRA), sample 2 is (761.55HV, 73.57HRA) and (835.40HV, 73.84HRA) for sample 3. The average value of hardness for sample 1, 2 and 3 increases as time hold influence hardness of a material. For samples 4, 5 and 6 shows the average value increased consistently. Sample 4 shows the mean (784.57HV, 69.96HRA), sample 5 is (827.97HV, 71.32HRA) and (900.50HV, 74.22HRA) for sample 6.

Samples 1,2 and 3 showed an increase in the average value of HRA and HV consistently, hold it for a period influence the hardness of a material. When the holding time increased, the level of hardness has also increased since the microstructure of the material to be close to each other. For samples 4, 5 and 6 also show consistent improvement. High temperature sintering parameters and different materials affect the level of hardness. The higher the sintering temperature, the higher the level hardness of a material. It leads to the sizes of the small details and the materials to be joined to each other.



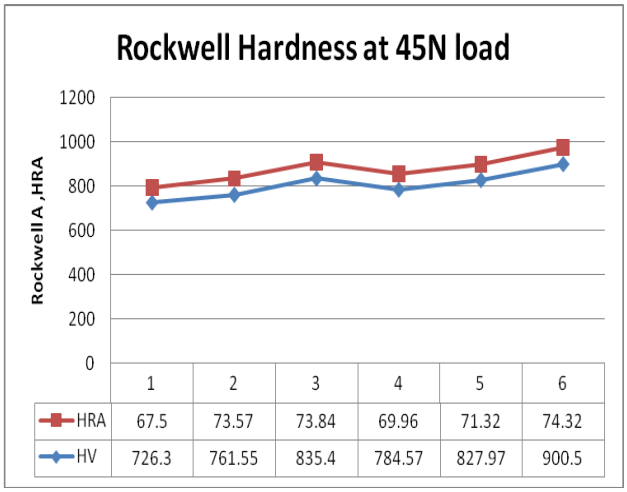


Figure-1. Hardness of samples subjected to load a) 30N and b) 45N.

Sample 3 and 6 perform the highest weight loss, which are 0.135g and 6. Weight loss in the sample is at least one sample of 0.099g and 0.085g of 4 samples. From the analysis, it was found to influence the sintering process for abrasion resistance (A) and the number of thirst (W). For samples through abrasion resistance sintering process will directly proportional to time hold (holding time) and temperature sintering process.

High abrasion resistance occurs at 0.9733 cm^3 of sample 3 and 6 samples of 1.1042 cm^3. Samples 3 through the sintering process with heating rate of 10 ^{0}C, 1400 ^{0}C heating temperature and holding time for 90 minutes while the sample 6 through the sintering process with heating rate of 10 ^{0}C, 1550 ^{0}C heating temperature and holding time for 30 minutes. Sintering process can improve the mechanical properties of materials where it will also increase the abrasion resistance of the material. During the sintering process, the hardness of the material is increased, when a material is improved while the toughness of a material can also be improved.

From the graph in Figure-2 found the weight loss of the sample is proportional to the abrasion resistance of each sample. The more lose weight the higher the abrasion resistance of the material.

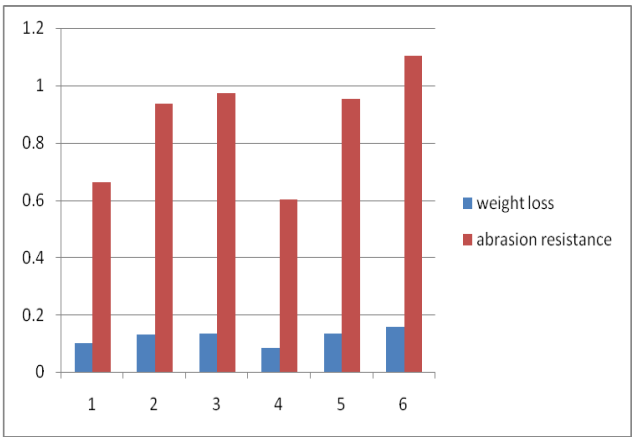


Figure-2. Weight loss and abrasion resistance of each sample.

Table-2 shows the sintered density of each sample. The increasing in the density for each sample is due to the sintering temperatures which keep increasing from sample 1 to sample 6. Large amount of Co melted as the temperature go high and this caused the melted Co flow and fill the pores (Mahmoodan *et al.* 2011). This explained why the density increasing as the temperature increase.

Figure-3 shows the XRD analysis of each sample. The first analysis that can be made from the XRD graph is regarding the carbon content. There are small peak appear in the first line of graph of samples 1, 4, 5 and 6.The small peak in the first line indicated the present of carbon content in the sample. The 2 Theta graph shows us that the holding time for each sample affect the carbon content in each samples. It is known that the width of WC + Co + η zone reduce as the sintering time increase. The width of WC + Co + η zone is approximately 0.8mm when sintered for 15 min at 1400 ℃. However, the width of the zone was reduced to 0.4mm as the sintering time increase to 60 min. The increasing in sintering time also caused the movement of reaction interface and the cobalt distribution peak toward the edge. This shows us that the diffusion of carbon will go further into the layer of carbon deficient and react with eta phase to produce WC-Co as the sintering time increase. This explained why carbon exists in samples which sintered for short time.

Table-2. Sintered density of each sample.

Sample	m_1 (g)	m_2(g)	m_3 (g)	ρ (g/m^3)
1	7.7820	7.7996	6.8454	8.1555
2	14.9663	14.9789	13.9217	14.1566
3	15.1683	15.1851	14.1207	14.2506
4	11.2327	11.2469	10.4625	14.3201
5	14.8792	14.8993	13.820	14.3442
6	7.7649	7.7830	7.2488	14.5356

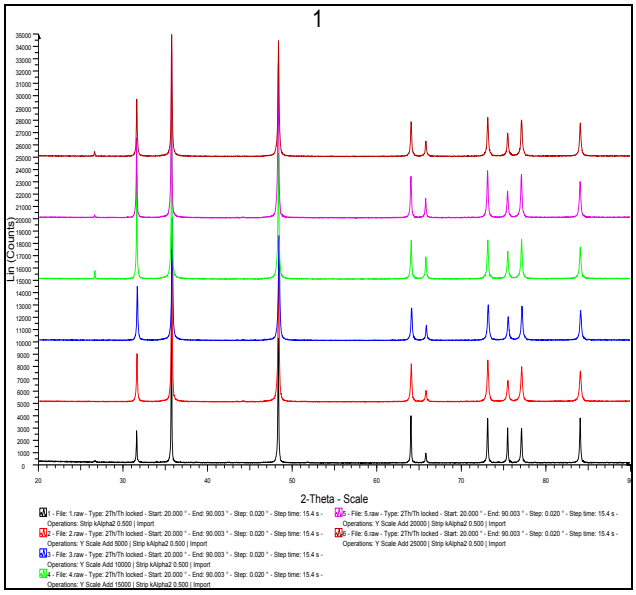


Figure-3. XRD graph of sintered samples.

From Table-3, it is shown the formation of grain growth at sintering temperatures of 1400 ℃ (sample 1, sample 2 and sample 3), 1450 °C (sample 4), 1500 °C (sample 5) and 1550 °C (sample 6). For a sintered part, a certain location inside the microstructure which expected to generate grain growth was observed. At solid-liquid interface, interfacial energy (area) will being reduced by agglomerated powder, which is the grain growth driving force (Bollina & German 2004). The formation of grain growth in a microstructure is due to the enhancement of coalescence among particles by the clustering of the grain (Johnson *et al.* 2009, Wang *et al.* 2008). The higher the

temperature, the faster the growth process will occur and this is explained why high temperatures lead to the formation of grain growth.

Table-3. Grain growth size for each sample.

Sample	Grain growth size (µm)
1	2.45
2	3.96
3	3.70
4	4.60
5	4.95
6	5.06

Lastly, Figure-4 shows the microstructure of the sintered sample. Being porous, the prismatic shape of WC grain shows homogeneus distribution with average grain size of 5 µm. Neither graphite nor phase was found in the microstructure, proving that metal injection molding process is suitable in producing WC-Co part at high quality.

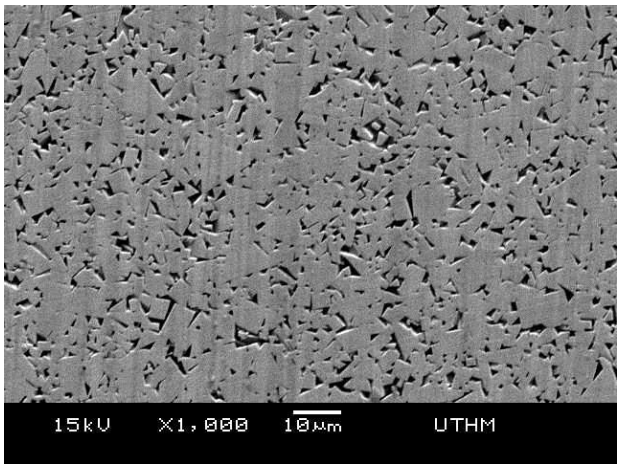


Figure-4. Microstructure of sintered sample.

CONCLUSIONS

In this study, the effect of different sintering parameters to the properties of WC-Co part is studied. The following results can be drawn:

1) The higher the sintering temperature, the higher the level hardness of a material
2) The abrasion resistance of the material increased with higher sintering temperature
3) The density of WC-10%Co increased as the sintering temperatures and times increased
4) As sintering temperature increase, the grain growth increased as well.
5) XRD analysis performed, the peak indicates that density of WC-10%Co increased as the sintering temperature increased.

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