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THE INFLUENCE OF WC POWDER PARTICLE ON MICROSTRUCTURE AND PROPERTIES OF CEMENTED CARBIDE

Ahmad Aswad Mahaidin
AMREC, SIRIM Berhad
Lot 34, Jalan Hi-Tech 2/3
Kulim Hi-Tech Park
09000, Kulim, Kedah
Malaysia
aswad@sirim.my

Mohd Asri Selamat
AMREC, SIRIM Berhad
Lot 34, Jalan Hi-Tech 2/3
Kulim Hi-Tech Park
09000, Kulim, Kedah
Malaysia
masri@sirim.my

Zaim Syazwan Sulaiman
AMREC, SIRIM Berhad
Lot 34, Jalan Hi-Tech 2/3
Kulim Hi-Tech Park
09000, Kulim, Kedah
Malaysia
zaim@sirim.my

ABSTRACT

The properties of cemented carbide (WC-Co) composite is enhance by using finer particle size powders. The reduction of the particle size improve hardness and flexural strength as well as fracture toughness and wear resistance of the composite. The effect of two different particle size of WC powders are evaluated in term of the microstructure and mechanical properties of the cemented carbide. WC-Co sintered powders are produced using wet mixing process before undergo sintering process at 1300-1400°C under nitrogen-based atmosphere. The physical and mechanical properties of the sintered powders were analysed and it is found that WC-Co using WC powder with average particle size of 1 µm has better properties compared to powder with average particle size of 0.2 µm. However, processing route as well as particle size of cobalt used also should be considered as one of the factors influence the result obtained.

General Terms

Cemented carbide.

Keywords

WC-Co, cemented carbide, powder metallurgy, fine powder

1. INTRODUCTION

WC hardmetals has been widely used in metal cutting industry and wear related application due to its exceptional hardness and wear resistance resistance. WC exhibit high hardness and strength at wide temperature interval, thus provide thermal stability at elevated temperature. Therefore, it is used in variety of machinng, drilling, cutting and other applications. The properties of the WC-Co composite depends on the hard and brittle WC grains that embedded in softer, ductile binder which consist of cobalt, tungsten and carbon which act as the matrix [1].

Nowadays, productivity plays important part in manufacturing industry. The needs of improvement in term of machining operation is considered as one of the factors to provide greater cost reduction. The machining conditions is more severe than before, leading to an increase in demand for a better cutting tool bit with improved mechanical properties to withstand high temperature operation [2-4]. Thus, hardmetal industry is mainly concern on improving the manufacturing process to produce finer grained WC-Co composite to maximize hardness while maintaining reasonable toughness.

It has been reported that nanocrystalline WC-Co based tool materials exhibit enhanced mechanical properties. The increase in hardness and flexural strength was obtained by reducing WC grain size below 1 µm [5-7]. Besides grain size reduction, smaller particle size also provide such improvement to the hardness, fracture toughness as well as wear resistance [2]. However, finer powders are extremely sensitive to processing conditions and prone to carbide grain growth during consolidation process, which could reduce the properties of the composte [8, 9].

Grain growth is oftenly associated with the reduction of free energy in the grain boundaries of the system. The reduction of free energy is due to the vaporization of cobalt from the surface of WC grains. This leads to increase in mobility of atoms diffusing along the surface compared to atoms within the bulk material [10]. Another concern when using fine powders is the densification of the WC-Co sintered powders. Complete densification is important since there is high relationship between pore presence and material toughness in which only 0.1 vol% of porosity maybe enough to cause catastrophic failure [11]. Therefore, extensive wetting is necessary to aids densification process to develop a rigid skeletal structure.

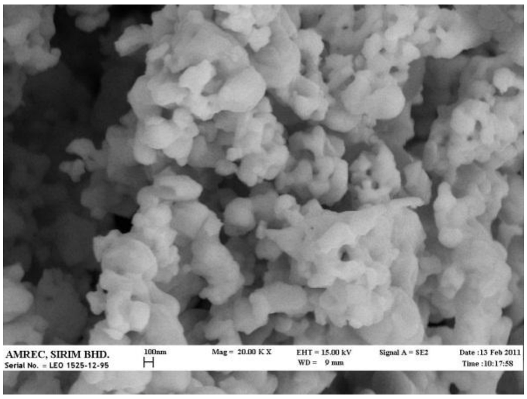
Since there is a huge demand for wear resistant materials to perform under severe condition, preferably without lubrication, continuous study on producing better and improved WC-Co composite has been done by researchers. Although lots of publication on WC grain size reduction and finer WC particle size powders, comparison is difficult due to different precursors and processing route. Thus, this study is done to obtain a comparable result.

2. METHODS AND MATERIALS

Two different particle size of WC powders were used, which are 1 µm and 0.2 µm. 6 vol% of cobalt was added as metal binder. The information of the powders used are as shown in Table 1 while the morphology of the powders are shown in Figure 1. Wet mixing process was used for the consolidation process since it is preferable for processing of finer powders compared to dry mixing and conventional milling.

Table 1. Characteristics of raw materials

Powders	Particle Size	Manufacturer
Tungsten carbide, WC	1.0 µm	Buffalo Tungsten
Tungsten carbide, WC	0.2 µm	Buffalo Tungsten
Cobalt, Co	1.26 µm	Buffalo Tungsten
Graphite	5 µm	Asbury Graphite



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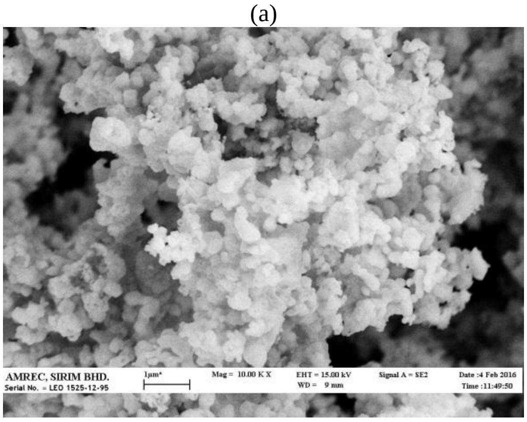

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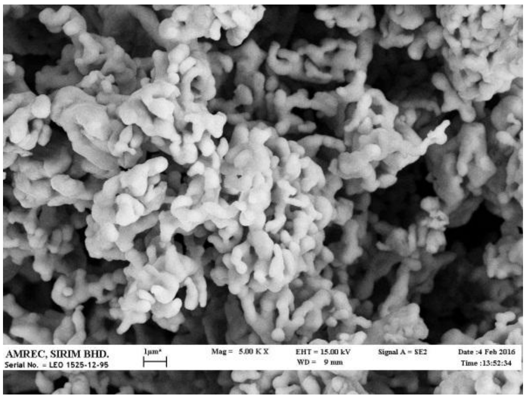


(c)

Fig.1. Powder morphology of (a) WC 1.0 µm, (b) WC 0.2 µm and (c) cobalt respectively.

The well-mixed powders were compacted using uniaxial pressing application at 625 MPa. The green body is subjected to cold-isostatic pressing at 200 MPa to obtain denser green body with uniform density distribution. The compacted powders were sintered at temperature range of 1300-1400°C in tube furnace under nitrogen-based atmosphere (95% N_2 + 5%H_2) for one hour. Figure 2 shows the heating schedule for the sintering process.

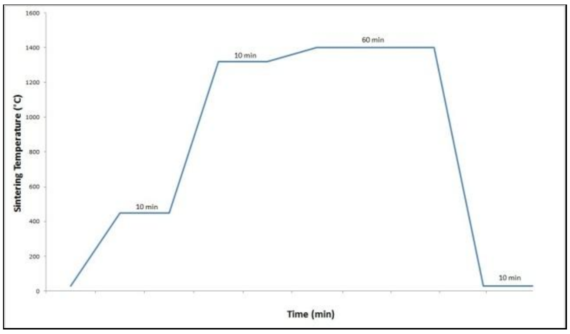


Fig. 2. Heating schedule used for the sintering process

3. RESULTS AND DISCUSSION

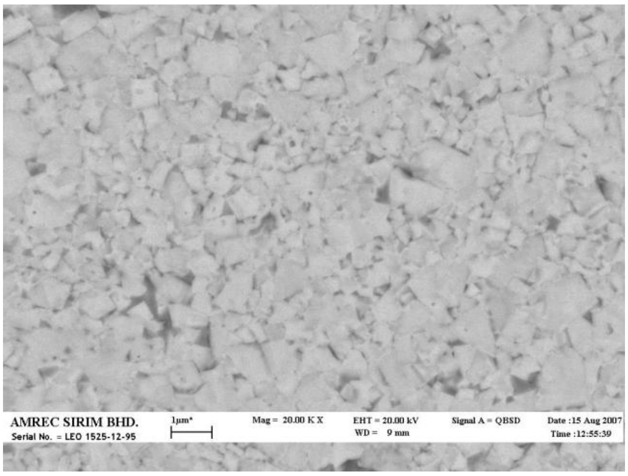
The study on the influence of different WC particle size is done at different sintering temperature, which is between 1300°C to 1400°C. This is to study the optimum sintering temperature to obtain WC-Co with excellent mechanical properties. Based on Table 2, it is found that WC0.2µm-Co has lower density compared WC1µm-Co. Although it is expected to have higher density, the opposite of the theory occurred. However, it is proven that the sintering step introduced at 1320°C help to enhance the distribution of cobalt throughout the sample, explaining the rapid increase in density at 1350°C and 1400°C.

Table 2. Density comparison between WC-Co composite using different size of WC particle size

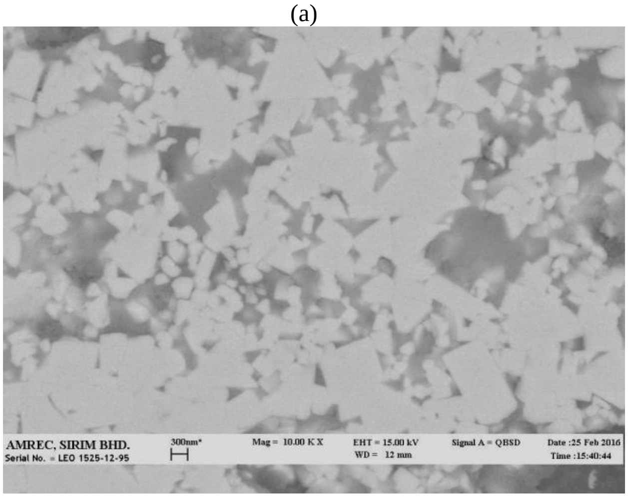
Sintering Temperature, °C	Density, g/cm^3	
	WC1µm-Co	WC0.2µm-Co
1300°C	10.13	8.26
1350°C	13.79	10.90
1400°C	14.74	13.37

The sintering process of WC-Co composite include several sintering steps which has been proven to be more effective than direct heating [12]. This is because the holding steps help to improve densification process which is crucial for the mechanical properties of the composite. The first holding step at 450°C is for residual gases elimination while second holding step at 1320°C is to promote melting and homogeneous distribution of cobalt [13]. The temperature at 1320°C was selected since cobalt starts to melt and wet the WC particles in the range of 1350-1450°C [9, 14].

The sintering of WC-Co involves liquid phase sintering. The sintering mechanisms include particle arrangement, solution reprecipation and solid state sintering [15]. Figure 3 shows the faceted WC grains and distribution of cobalt phase at sintering temperature of 1400°C. Despite the introduction of sintering step to enhance distribution of cobalt during sintering process, it is found that WC0.2μm-Co exhibits higher porosity. This explains its lower density compared toWC1μm-Co. It is believed that the cobalt particle itself contribute to the formation of the pores.



(a)



(b)

Fig. 3. SEM microrgraph of WC1μm-Co (a) and WC0.2μm-Co (b) sintered at 1400°C.

In the case for WC0.2μm-Co, the difference between WC and Co particle size can be considered as quite high, with cobalt powder has higher particle size. Thus, the cobalt is difficult to penetrate the small gap between the WC particles resulting to inhomogeneous distribution of cobalt. Since WC particle size is reduce from 1.0 μm to 0.2μm, the work done shows that it is also necessary to use finer cobalt powder in order to maintain or decrease distance between neighboring particles of major phase, in this case is WC [16]. The decrease in distance will improve cobalt distribution during consolidation, therefore enhance densification process to produce denser WC-Co composite with less porosity.

Besides porosity, comparison is also made based on grain size. The average grain size of WC1μm-Co is around 0.5 – 0.8 μm. Although the grain size is slightly larger, the grain size can be considered as consistence compared to WC0.2μm-Co. Although WC0.2μm-Co exhibited smaller grain size, which is 0.3 μm, larger grain size as large as 1.5 μm is evident. This is probably due to WC grain growth that occurred during the sintering process. It is reported that finer grade WC powders are extremely sensitive to processing conditions and prone to carbide grain growth during consolidation [8-9].

Since submicron and ultrafine powders have higher specific surface area, it is very reactive and leads to significant microstructural coarsening during sintering process. Initial rapid grain growth is partially attributed by coalescence of grain via elamination of common grain boundary before further coarsening took place during solution-reprecipation stage where smaller WC grains with higher solubility dissolve in liquid and reprecipate to form larger WC grains [17-20].

Table 3. Mechanical properties of WC-Co composite.

Sintering Termperature, °C	WC1μm-Co	WC0.2μm-Co
	Hardness, HV	
1300 °C	1052	187
1350 °C	1630	539
1400 °C	1710	1137
	Rupture Strength, MPa	
1300 °C	326	87
1350 °C	772	269
1400 °C	1340	603

The hardness and rupture strength results shown in Table 3 can be correlated with density in which WC1μm-Co with higher density has better mechanical properties than WC0.2μm-Co. WC grain growth and formation of pores in WC0.2μm-Co certainly influence the mechanical properties of the composite, with its hardness and transverse rupture strength inferior to WC1μm-Co. The porous structure obviously effect is on the strength of the composite where the strength of WC1μm-Co is almost double than that of WC0.2μm-

Co. Unlike WC0.2μm-Co, WC1μm-Co has higher density and homogeneous structure which contributed to its mechanical properties.

4. CONCLUSION

The effect of different WC particle sizes on microstructure and mechanical properties of WC-Co composite were studied. Based on the results obtained, it is found that WC1μm-Co exhibit better mechanical properties compared WC0.2μm-Co due to better its homogeneous structure and good distribution of cobalt. The mechanical properties of WC0.2μm-Co is lower than WC1μm-Co due to the WC grain growth and porous structure evident, with the latter highly influenced the rupture strength of the composite. However, it is suggested that further study on this matter should be done, especially on solving of the problem of cobalt distribution during sintering process.

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