Jurnal Teknologi

Full paper

The Influence of Carbon Addition on the Physical and Mechanical Properties of WC-Co Sintered Powders

Ahmad Aswad Mahaidin[a*], Mohd Asri Selamat[a], Samsiah Abdul Manaf[a], Talib Ria Jaafar[a]

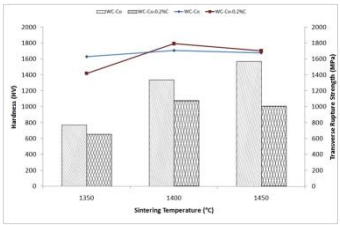
[a]*Structural Material Programme, Advanced Materials Research Centre (AMREC) SIRIM Berhad, Lot 34, Jalan Hi-Tech 2/3, Kulim Hi-Tech Park, 09000, Kulim, Kedah, Malaysia*

*Corresponding author: aswad@sirim.my

Article history

Received : 29 March 2012
Received in revised form : 4 July 2012
Accepted : 30 October 2012

Graphical abstract



Abstract

The mechanical properties of WC-Co are highly dependent on its cobalt content, density and grain size of the WC particles. Addition of free carbon during the consolidation of process is said to improve the densification process and inhibit grain growth. However, there are still plenty of works needs to be done regarding this matter to support the fact. Therefore, this study is to evaluate the effect of carbon addition on the physical and mechanical properties of WC-Co-C sintered powders. The WC-Co-C sample is fabricated using powder metallurgy technique, in which the powders were uniaxially pressed at 625 MPa and cold-isostatic pressed at 200 MPa. Then, the sample is sintered in nitrogen-based atmosphere at temperature range of 1350-1450°C. The physical and mechanical properties of the WC-Co sintered powders were analysed. It is found that WC-Co-C has a relatively higher density and hardness but exhibit lower transverse rupture strength compared to WC-Co.

Keywords: WC-Co; powder metallurgy; carbon addition; nitrogen-based

Abstrak

Sifat mekanikal WC-Co dipengaruhi oleh kandungan kobalt, ketumpatan dan saiz butir partikel WC. Penambahan karbon bebas semasa proses pencampuran dikatakan dapat meningkatkan proses densifikasi di samping dapat menghalang pembesaran butir daripada berlaku. Namun begitu, kajian yang lebih lanjut diperlukan untuk memastikan perkara tersebut. Oleh itu, penyelidikan ini dilaksanakan untuk mengkaji kesan penambahan karbon ke atas sifat-sifat fizikal dan mekanikal WC-Co-C sampel. Sampel WC-Co-C dihasilkan menggunakan teknik metalurgi serbuk di mana serbuk yang telah dicampur akan dimampatkan pada 625 MPa dan tekanan isostatik sejuk dikenakan pada 200 MPa. Kemudian sampel disinter pada suhu antara 1350-1450°C. Sifat fizikal dan mekanikal sampel WC-Co-C dikaji. Berdasarkan penemuan yang diperolehi, WC-Co-C mempunyai ketumpatan relatif dan kekerasan yang tinggi tetapi mempunyai kekuatan retak-lintang yang lebih rendah berbanding WC-Co.

Kata kunci: WC-Co; tekanan serbuk; tambahan karbon; asas nitrogen

1.0 INTRODUCTION

Hardmetal have been extensively used for metal cutting technology due to its superior mechanical properties. Fabrication of hardmetal using powder metallurgy (PM) technique has been well established. WC-Co is one of the hardmetals that is fabricated using PM for mass production. WC-Co is widely used in high speed machining application due to its high mechanical properties. The WC contributes to the hardness of the composite while cobalt provides the toughness.

Densification process plays a major role in determine the mechanical properties of the sintered powders produced using powder metallurgy technique. This is because the density of the sintered powder is related to pores presence which also affects the toughness of the material. Therefore, complete densification process is required. Cobalt is used as bonding matrix and act as metal binder to enhance WC-Co densification by providing extensive wetting to the system via liquid phase sintering. Cobalt has a good wetting behaviour as well as favorable solubility for WC.

Further development and optimization on cutting tools has been made to improve the cutting performance while reducing cost and increase productivity. Thus, the focus has turn to the used of finer WC powders. However, finer WC powders (submicron and ultrafine grades) are extremely reactive and has higher tendency for WC grain growth during consolidation process [1].

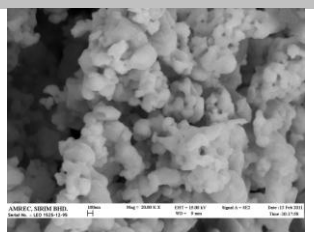
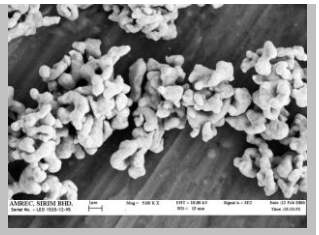
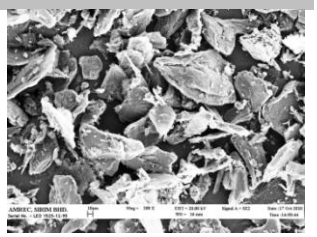
Grain growth inhibitors are used to inhibit grain growth during sintering or post-sintering heat treatments [2-6]. A liquid phase that is saturated with inhibitor carbide reduce the solubility of WC, thus reduce its coarsening rate [7]. Therefore, addition of grain growth inhibitor will improve the hardness and flexural strength of sintered WC-Co powders.

Since most of the grain growth inhibitors are metal carbide, there is possibility that adding free carbon alone would also inhibit grain growth. This theory is supported by the fact limiting step for grain growth depends on carbon content, which affects the driving force and the limiting step of the precipitation process [8]. However, the carbon content should be carefully controlled because high carbon content would leads to abnormal grain growth as reported by some researchers [3]. Addition of free carbon also was reported to assist densification process [9]. However, the extend of its effectiveness yet to study.

2.0 RESEARCH METHODOLOGY

The morphology and particle size of the powders used in this study is shown in Table 1. Finer cobalt powders were used due to its effectiveness to form cobalt pooling and reduce porosity. The percentage of cobalt used for consolidation process is 6% and the rest is WC. As for WC-Co-C, 0.2% of free carbon was added into the formulation. Paraffin wax was added to act as lubricant during compaction.

Table 1 Characteristics and morphology of the raw materials

Powders	Powder Characterization	
	Particle size@D50, µm	Morphology
Tungsten Carbide, WC	0.80	
Cobalt, Co	3.51	
Graphite, C	70.39	

WC-Co powders were mixed in turbula mixer for three hours. Wet mixing is preferable compared to dry mixing since it is more suitable for fine powders, which is below 1 µm. Heptanes were added to form the powders into suspension as sample preparation for wet mixing. Tungsten balls were also added with 1:3 powder to ball ratio to obtain homogeneous mixing. The mixed powders were dried and granule after wet mixing was completed.

The powders were compacted at 625 MPa using uniaxial pressing application to obtain a green body of 16 mm length, 16 mm width and 3-4 mm thickness. The green body was subjected to cold-isostatic pressing to obtain denser sample with uniform density distribution. Cold-isostatic pressing also contributes in minimizing porosity level and improves mechanical properties.

The green body of both WC-Co and WC-Co-C were sintered under three different temperatures which are 1350°C, 1400°C and 1450°C for one hour under nitrogen-based atmosphere ($95\%N_2+5\%H_2$). Figure 1 shows the heating schedule for the sintering process.

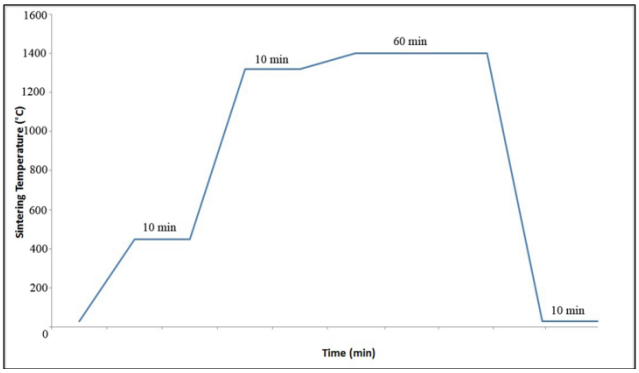


Figure 1 Heating schedule during the sintering process of WC-Co

The density and hardness of the samples were determined using densitymeter and Vicker's hardness tester respectively. The rupture strength of the sintered powders was tested using universal testing machine. Microstructure analysis was made using Field Emission Scanning Electron Microscopy (FESEM). The samples were cut, ground, polished and etched using Murakami solution prior to SEM analysis.

3.0 RESULTS AND DISCUSSION

The sintering process took place through several sintering steps. The first holding step at 450°C is to eliminate residual gases and the second holding step at 1320°C is to promote melting and homogeneously distribution of cobalt [4]. The holding step introduced during the sintering process is crucial to enhance densification and development of rigid skeletal structure.

Table 2 Density of sintered WC-Co powders

Sintering Temperature (°C)	Density (g/cm^3)	
	WC-Co	WC-Co-0.2C
1350	13.79	13.37
1400	14.74	14.45
1450	14.82	14.86

Based on Table 2, addition of 0.2% of free carbon affects the physical properties of the composite in term of density. WC-Co has relatively higher density than WC-Co-0.2C. However, density

of WC-Co-0.2C is slightly higher than WC-Co at 1450°C. It is suggest that addition of free carbon initially delay densification process before eventually leads to a fully dense material [10]. Thus explain the reason behind the slightly higher density achieved by WC-Co-0.2C at 1450°C although WC-Co has higher density at 1350°C and 1400°C. High difference in density between 1350°C and 1400°C is mostly likely due to cobalt pooling actively distributed throughout the sintered WC-Co powders.

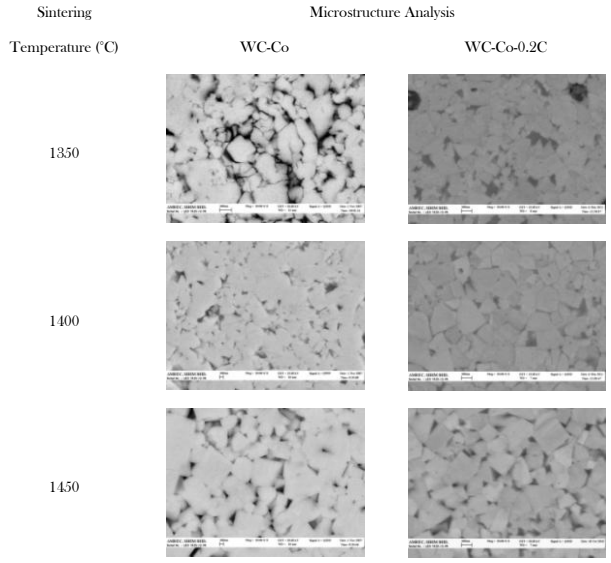


Figure 2 Microstructure of WC-Co and WC-Co-0.2C.

Figure 2 shows the microstructure of both sintered WC-Co powders. Backscattered electron is used to analyse the topography of the WC-Co. At 1350°C, both WC-Co and WC-Co-0.2C still exhibit some pores. WC-Co exhibit irregular grain shape and the size are not uniform. The irregular shape of WC grains shows that the diffusion between the particles is still incomplete. Contact flattening through solution-reprecipitation does not occur entirely throughout the sample at this temperature since some of WC particles are still evident. The WC grains started to become faceted at 1400°C and the microstructure reveals a better distribution of WC particles in Co matrix. These findings confirm the high density achieved at this temperature.

Although WC-Co-0.2C has lower density at 1350°C compared to WC-Co, the microstructure is more homogeneous and well distributed. Unlike WC-Co, WC grains in WC-Co-0.2C have already become faceted at 1350°C. It is likely that addition of free carbon helps to obtain a more homogeneous microstructure and assist in densification process.

At sintering temperature 1450°C, smaller grain size can be observed in WC-Co-0.2C compared to WC-Co. This is most likely cause by the addition of 0.2% free carbon. Z. Yao *et. al.* (1998) reported a similar finding in which addition of uncombined carbon markedly inhibits grain growth during liquid phase sintering [7]. After comparison between the microstructures at 1400°C and 1450°C, significant grain growth can be clearly observed in WC-Co due to microstructural coarsening during solution-reprecipitation process. Meanwhile, there is only slight difference in grain size observed in WC-Co-0.2C.

Based on Figure 3, WC-Co-0.2C has slightly higher hardness than WC-Co. This is due to the smaller grain size observed in WC-Co-0.2C. Smaller grain size provides more resistant to deformation due to existence of high number of grain boundaries which act as barrier to dislocation movement [11]. Both sintered powders achieved highest hardness at 1400°C before it drops at 1450°C.

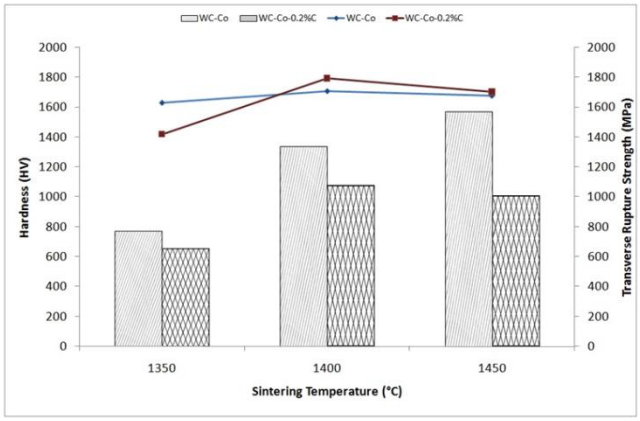


Figure 3 Mechanical properties of sintered WC-Co powders

High improvement of transverse rupture strength at 1400°C implies that cobalt is more actively closing pores during 1350-1400°C interval. The result agrees with the density result obtained earlier. Although hardness of WC-Co-0.2C is relatively higher than WC-Co, it exhibit lower rupture strength. Hardness is inversely proportional to strength and best described the hardness and TRS result obtained. However, there are some possibilities that the addition of free carbon has adverse effect on rupture strength. Addition of 0.2% free carbon increase the carbon content in WC-Co system, which leads to harder but more brittle materials.

4.0 CONCLUSION

Powder metallurgy technique was used to fabricate WC-Co and WC-Co-0.2C and the green bodies were sintered under nitrogen-based atmosphere. WC-Co exhibit higher density compared to WC-Co-0.2C. Although WC-Co-0.2C has relatively higher hardness than WC-Co, it has lower rupture strength. Based on microstructure analysis, addition of free carbon lead to homogeneous microstructure and assist densification at lower temperature than WC-Co. Smaller grain size observed in WC-Co-0.2C also proves that addition of 0.2% of free carbon inhibits grain growth.

Acknowledgement

This work was funded by the government techno-fund project Ministry of Science, Technology and Innovation (MOSTI). The authors would like to express gratitude to AMREC, SIRIM Berhad for providing access to the research facilities

References

[1] R. Gonzalez, A. Ordonez, and J. M. Sanchez. 2004. HIP After Sintering of Ultrafine WC-Co. International Journal of Refractory Metals and Hard Materials. 23: 193–198.

[2] F. A. Costa Oliveira, A. C. Lopes, J. C. Fernandez, J. Sacramento and M. A. Valente. 2008. Fracture Behaviour of a New Submicron Grained Cemented Carbide. *Fracture Behaviour of Hardmetal*. 20: 52–59.

[3] A. Delanoe, and S. Lay.2009. Evolution of the WC Grain Shape in WC-Co Alloys During Sintering–Effect of Carbon Content. *International Journal of Refractory Metals and Hard Materials*. 27: 140–148.

[4] G.-H. Lee, and S. Kang. 2006. Sintering of Nano-sized WC-Co Powders Produced by a Gas Reduction-carburization Process. *Journal of Alloy Compounds.* 419: 281–289.

[5] X. D. Hong, H. Y. Hui, L. W. Hong, and S. Min. 2009. Effect of VC and NbC Additions on Microstructures and Properties of Ultrafine WC-10Co Cemented Carbides. Transactions of Nonferrous Metals Society of China. 19: 1520–1525.

[6] L. Sun, C. Jia, R. Cao, and C. Lin. 2007. Effect of Cr_3C_2Additions on the Densification, Grain Growth and Properties of Ultrafine WC-11Co Composites by Spark Plasma Sintering. International Journal of Refractory Metals and Hard Materials. 26: 357–361.

[7] Z. Yao, J. J. Stiglich, and T. T. Sudarshan. Nanosized WC-Co Holds Promise for the Future. Metal Powder Report. 53: 26–33.

[8] Y. Wang, A. Delanoe, S. Lay, E. Pauty and C. H. Allibert. 2002. *Morphology and Growth of WC Grains in WC-Co Cermets – Effects of C/W Ratio and Cr Addition*. Materiaux

[9] S. I. Cha, and S. H. Hang. 2003. Microstructures of Binderless Tungsten Carbides Sintered by Spark Plasma Sintering Process. *Materials Science and Engineering*. 356: 381–389.

[10] A. Petersson. 2004. Sintering Shrinkage of WC-Co and WC-(Ti,W)C-Co Materials with Different Carbon Contents. *International Journal of Refractory Metals and Hard Materials.* 22: 211–217.

[11] W. F. Smith and J. Hashemi. 2006. *Foundations of Materials Science and Engineering*. New York: McGraw Hill.