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EFFECT OF CARBON ADDITION ON THE DENSIFICATION AND PROPERTIES OF SINTERED CEMENTED CARBIDE (WC-Co)

***RINGKASAN:** Logam keras merupakan bahan yang terkenal dalam bidang pemotongan logam dan aplikasi-aplikasi yang melibatkan hakisan. Semen karbida (WC-Co) digunakan secara meluas dalam aplikasi-aplikasi tersebut. Penambahan karbon ke dalam WC-Co meningkatkan proses densifikasi. Oleh itu, kajian dilakukan untuk mengkaji kesan penambahan karbon ke atas densifikasi dan sifat-sifat WC-Co yang telah disinter. Sampel dihasilkan menggunakan teknik kaji logam (metalurgi) serbuk, di mana serbuk WC-Co dimampat pada tekanan 625 MPa, tekanan isostatik sejuk pada 200 MPa dan disinter pada suhu antara 1350 °C hingga 1450 °C di dalam medium asas berunsurkan nitrogen. Sifat fizikal dan mekanikal sampel dianalisa. Hasil kajian menunjukkan penambahan 0.8 % karbon dan ke atas akan mengurangkan ketumpatan sampel WC-Co yang telah disinter.*

ABSTRACT: Hardmetal is a well known material in metal cutting and wear related applications. Cemented carbide (WC-Co) is the most widely used for this application, in which addition of carbon to the WC-Co improves densification process. This study investigates the effect of carbon addition on the densification and properties of sintered WC-Co. The samples are fabricated using powder metallurgy technique, in which the powders are compacted at 625 MPa, cold-isostatic pressed at 200 MPa and sintered at temperatures between 1350 °C and 1450 °C under nitrogen-based atmosphere. The physical and mechanical properties of the samples were analyzed. The study reveals that addition of 0.8 % of carbon and above will greatly reduce the density of the WC-Co sintered powders.

Keywords: WC-Co, powder metallurgy, carbon addition.

INTRODUCTION

Hardmetal is a well known material in metal cutting and wear related applications due to its superior mechanical properties and has been used extensively in metal cutting technology and wear related applications. Hard metal containing 95 % cemented carbide has been used as cutting tool. Formation of a complex shape from hard metal is difficult through machining process. In addition, the properties of tungsten alloys are sensitive to processing and can be degraded by residual porosity. Hence, powder metallurgy technique is introduced in this work.

WC-Co conventional powder is usually sintered at relatively high temperature where liquid phase formation occurs due to cobalt melting. This is important as to provide extensive wetting during densification process. Cobalt acts as the metal binder because of its capillary action during liquid phase sintering that enhances densification. The wetting ability of cobalt enables the WC-Co composite to achieve high density and form a rigid skeletal structure.

Complete densification plays an important role in determining the mechanical properties of the composite. Even small proportion of porosity could lead to catastrophic failure. Cha *et al.*, (2003) reported that densification can be enhanced by adding free carbon. Addition of small amount of uncombined carbon also could inhibit grain growth during liquid phase sintering (Yao *et al.*, 1998).

Another important aspect of WC-Co fabrication is the grain growth of WC grains. Since submicron or finer particle size was used during the consolidation process, the large specific surface area of the powders increases the possibility of microstructural engrossment due to high reactivity (Gonzalez *et al.*, 2004). It is a current trend for hardmetal industry to control the grain size of WC particles in order to increase hardness while maintaining a reasonable toughness. Although addition of free carbon is reported to inhibit grain growth, high carbon content will result in abnormal grain growth. Therefore, it is critical to study the limitation of the free carbon percentage added to the formulation.

There is a lack of published work and detailed explanation on the effect of carbon percentage on densification and properties of sintered powders. This paper studies on how the carbon percentage affects physical and mechanical properties of WC-Co sintered powders.

MATERIALS AND METHOD

WC-Co powders were mixed in Turbula Mixer for three hours based on the composition in Table 1. The wet mixing process includes tungsten balls with 3:1 ball to powder ratio, paraffin wax and heptanes. Paraffin wax was added for lubrication during compaction process while heptanes were added to convert the powders into suspension as a preparation for wet mixing. The mixed powders were dried and formed granules after wet mixing was completed.

Table 1. Composition for WC-Co consolidation.

Composition	Tungsten carbide, WC (wt%)	Cobalt, Co (wt%)	Carbon, C (wt%)
0.2%C	93.8	6.0	0.2
0.4%C	93.6	6.0	0.4
0.6%C	93.4	6.0	0.6
0.8%C	93.2	6.0	0.8
1.0%C	93.0	6.0	1.0

Then the powders were compacted at 625 MPa using uniaxial pressing. Cold-isostatic pressing (CIP) was introduced to WC-Co green body at 200 MPa to reduce porosity and to obtain a uniform green density distribution. The green samples were sintered for 1 hour at 1350-1450 °C using 450-1450 °C and 450-1320-1450 °C heating schedule (Figure 1 and Figure 2). The sintering process took place in tube furnace under nitrogen-based atmosphere.

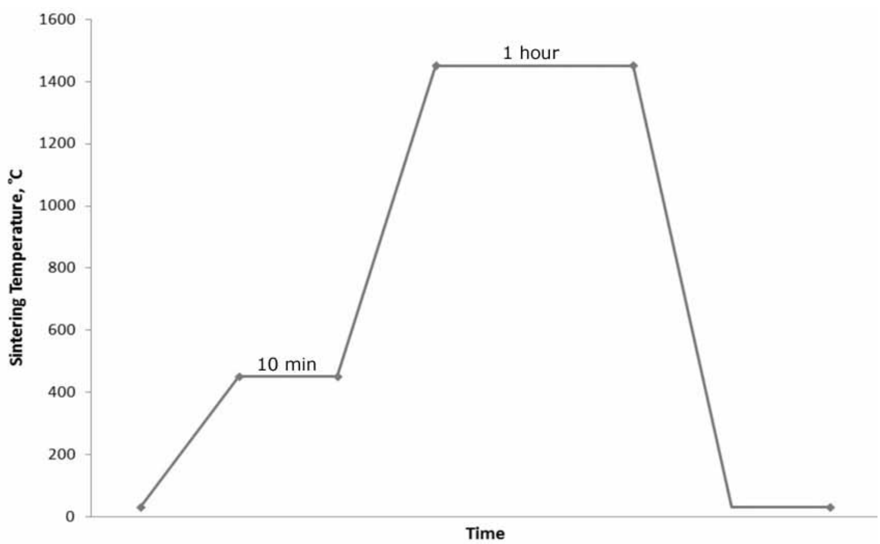

Figure 1. *Direct heating schedule.*

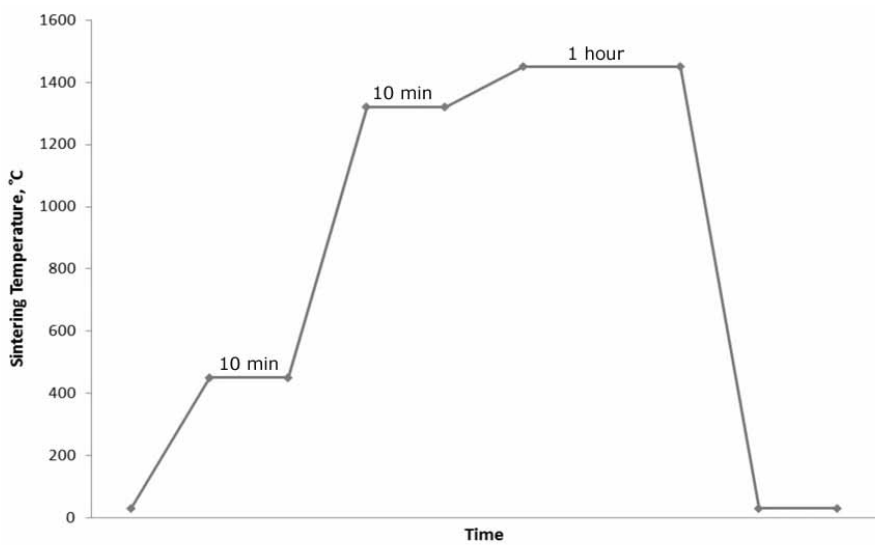

Figure 2. *Heating schedule with holding step at 1320 °C.*

The shrinkage of the sintered WC-Co-C powders was calculated. The density and hardness of the samples were determined using density meter and Vicker's hardness tester, respectively. The strength of the sintered powders was tested using Transverse Rupture Strength (TRS).

RESULTS AND DISCUSSION

The WC-Co-C sintered in liquid phase environment showed the effects of carbon addition in terms of physical and mechanical properties.

Table 2 showed that the percent of shrinkage for WC-Co samples relatively increase with increasing carbon content at fixed sintering temperature. However, the shrinkage drops after more than 0.8 % of carbon was added into the formulation. It is reported that high carbon content leads to high shrinkage rates and resulted in a fully dense materials (Petersson, 2004).

Table 2. Percent of shrinkage of WC-Co sintered powders with different percentage of carbon addition.

Percent of carbon (%)	Shrinkage rate (%)		
	1350°C	1400°C	1450°C
0.2	12.541	17.086	17.409
0.4	17.444	18.189	18.514
0.6	17.452	18.147	18.197
0.8	17.226	17.083	17.545
1	16.851	16.629	17.167

Since submicron WC powders are used, shrinkage may start at a lower temperature (Cha *et al.*, 2003). The finer particle size increase the contact points where the initial bonding takes place, thus enhance the diffusion rate between the particles. This was supported by Silva *et al.*, (2001) whom reported a significant shrinkage takes place during solid state instead of liquid state, in which pores are depleted due to the diffusion between WC and Co particles as well as WC grain growth.

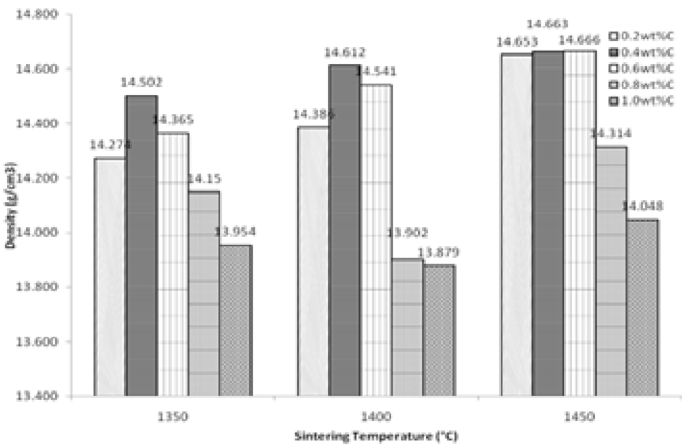

Figure 3. *Relationship between percentage of carbon addition and density of WC-Co at 1350-1450 °C.*

Figure 3 shows that with addition of 0.2 – 0.6 %C, the sintered density increases as sintering temperature increases. Meanwhile the addition of 0.8 %C and 1.0 %C shows fluctuation after the density drops at 1400 °C before increases at 1450 °C. This is probably due to the pores that reemerged during the sintering process at 1400 °C and closed back once again at 1450 °C when the cobalt liquid distribute through out the sample. However, these samples possessed lower density compared to the other three probably because it is over-sintered. At 1350 °C, almost all samples have already achieved 14.00 g/cm^3.

Based on Figure 4, WC-Co with the addition of 0.2 – 0.6 %C has a relatively high hardness at 1350 °C and 1400 °C than 0.8 %C and 1.0 %C. It is due to the fact that 0.2 – 0.6 %C are denser compared to 0.8 %C and 1.0 %C. However, the hardness is almost similar for the sample sintered at 1450 °C when the samples are fully sintered. Among all the sintered powders, WC-Co-0.2 %C sintered at 1400 °C has the highest hardness, which is 1937.0 HV.

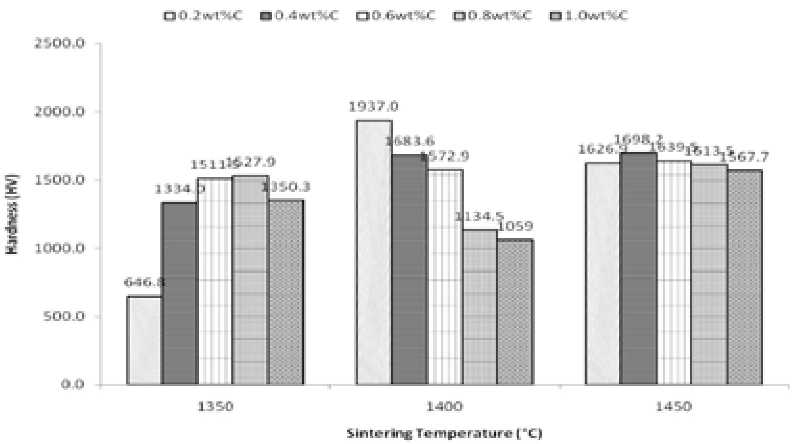

***Figure 4.** Hardness of WC-Co with the addition of 0.2 – 1.0%C at sintering temperature of 1350-1450 °C.*

However, if the direct-heated 0.2 %C is compared with 0.2 %C sintered with holding step, it appeared that direct-heated WC-Co possessed lower strength than the sintered sample using heating schedule with holding step as shown in Table 3. Although the hardness is much higher, its strength may not be sufficient to be used in cutting tool applications.

Table 3. The comparison between WC-Co-0.2%C at 1400°C using direct heating schedule and WC-Co-0.2%C with holding step.

Properties	450-1450°C (direct sinter)	450-1320-1450°C (holding steps)	Commercial Insert
Density (g/cm^3)	14.4	14.5	14.7
Hardness (HV)	1937.0	1793.0	1575.0
Transverse Rupture Strength (MPa)	812.3	1357.5	1700.0

Based on these results, it shows that the holding step at 1320 °C is necessary to improve the properties of the WC-Co-C sintered powders. This is because the holding step promote melting and homogeneous distribution of cobalt (Lee *et al.*, 2006). The melting and distribution of cobalt throughout the sintered powders is very important for densification process that will determine its physical and mechanical properties.

CONCLUSION

The addition of carbon affects the physical and mechanical properties of WC-Co sintered powders. It is clearly shown that by adding 0.8 % of carbon and above, the density of the WC-Co samples is reduced. Small addition of free carbon proved to inhibit grain growth when compared to the conventional WC-Co sintered powders. The study also reveals that introducing holding step at temperature of 1320 °C improved the strength of WC-Co composite.

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