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# WC-CO Based Scratch Tools Production and Characterization for Brick Factory

Ayhan EROL[1], Muzaffer ERDOĞAN[1], Ahmet YÖNETKEN[2,♠]

[1]*Afyon Kocatepe University, Faculty of Technology, Afyonkarahisar, TURKEY*
[2]*Afyon Kocatepe University, Faculty of Engineering, Afyonkarahisar, TURKEY*

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**ABSTRACT**

The main objective of this study is to produced WC-Co-Ni ceramic-metal composites Electroless Ni coated WC-Co powders were used in powder metallurgy techniques for making samples. 2 µm - 10µm micron grain size of WC powders and 10µm grain sized Co powders obtained from Sigma Aldrich Company in this work. Co-WC powders were cold pressed under 400bar pressure before sintered 1200oC -1400oC in microwave furnace. 90% N2 + 10% H2 mixed atmosphere were used during sintering. Mechanical tests and metallographic analysis were investigated for characterization of composite materials after sintered.

Experimental results carried out for 1300°C suggest that the best properties as σmax and hardness (HB) were obtained at 1300°C and the microwave furnace sintering WC and Co powders is a promising technique to produce ceramic reinforced Co composites.

**Keywords**: Powder Metallurgy, Ceramic–Metal Composites, Microwave Powder Sintering, Scratch Tools.

## 1. INTRODUCTION

Tungsten carbide has been known for a long time for its extraordinary hardness and wear resistance but poor toughness. Because of poor thoughness ductile metal matrices such as cobalt and nickel generally using with WC for improve the toughness [1]. So far it has been widely used on Tungsten Carbide scribing tools and when abrasion resistance is desired [2].

Due to its superior characteristic properties, cemented tungsten carbide attracts much attention. Conventional cemented tungsten carbide usually contains a 3% - 30% binding phase by weight. Abnormal Grain Growth (AGG) may be observed during sintering of small amount of WC and Co. Abnormal grain growth seems to be affected by the concentration of cobalt and there may be a range of cobalt concentration for high degrees of abnormal grain growth. VC is added to control grain size and this prevents grain growth of WC. Hardness is affected by the addition of VC. To keep the C/W ratio low, in low concentration of cobalt, results in the formation of the W2C phase. Hardness of WC-Co is affected by the amount of W2C phase and during cooling W2C is stable [3].

Tungsten carbide-cobalt (WC-Co) ceramic metals have wide application due to their superior properties of high hardness and wear resistance [1,12,13]. Therefore, they are used in various branches of the manufacturing industry. Due to high hardness, excellent wear and corrosion resistance, WC-Co cermet is used in a wide range of hard metal manufacturing practices (the composition weight of Co: 3% - 30%). Cutting tools, dies and drilling edges can be given as a couple of examples for its application [1,5]. WC-Co composites

♠Corresponding author, e-mail: yonetken@aku.edu.tr

are currently produced by various sintering techniques [2]. Conventional production of powder metallurgy with thermochemical techniques still continues [3].

Thermodynamic reaction properties of WC-Co composites in sintering methods developed original reactions with WO3 Co3O4 and C [4]. When micro-and nano-sized WC grains were produced physical and mechanical properties of cemented carbides improved [6]. Many methods have been developed for the sintering of WC-Co composites. Some examples of this thermomechanical process are spray conversion processes, precipitates and serial chemical reactions [7,8]. Nano-sized WC-Co composite powders can be produced by chemical synthesis processing in a vacuum environment [9].

Hard alloys, refractory carbides and WC cermets are used widely in fields such as metal working and drilling in the mining industry, not only due to high hardness and good wear resistance but also due to corrosion resistance at high pressures and temperatures. However, these alloys have a low toughness strength and brittleness. By adding Co to the alloy, the microstructure, that is, the bonds of WC grains were developed and in this way toughness strength was improved. Microstructure and mechanical properties of composites produced depend on the grain size of WC and Co content [10,11].

Grain size of WC is important for the technical specifications of cemented carbide cutting tools [16]. As a result, it is shown that the coating of nano-structured WC-Co powders and their applicability on massive components are comparable to or better than those of conventional coarse-grained applications [15].

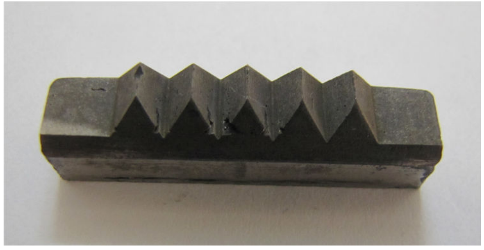
## 2. EXPERIMENTAL METHOD

In this study, tungsten carbide powders and a Co binder were investigated in different mixture ratios. WC-Co ceramic metal composite powders were pressed to the dimensions of a 15 mm in diameter and a 3 mm in thickness under different compositions. The as-received powders were cold compacted using a 300 bar (9000 kg) hydraulic press.

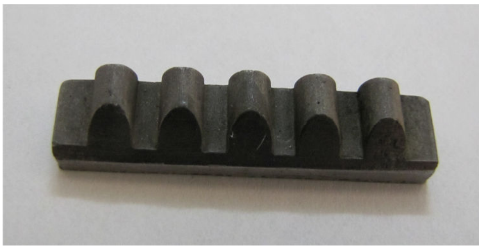
In addition, (2-10) µm microwave sintering was performed on the composition of 90% WC + 10% Co in high temperature regimes of WC powders. Sintering was performed within 1200-1400°C with a 2 h hold time in a microwave oven. The heating rate was 10°C/min. TheSintering type used was solid phase sintering. Conditions in the furnace were preserved by 90N +% 10H2% gas. The use of a microwave oven results in the sintering of the samples along the section volumetrically.

At this stage, in order to produce one specimen from 90% WC + 10% Co compositions with high mechanical properties, and another from the prototypes selected out of the sintering conditions (the production of the triangular and circular toothed scratch tips) a male and a female mold was made from the 8620 cementation steel.

The scratch tools seen in Figure 1 were produced by pressing the raw composites in the molds and sintering them in the selected compositions and sintering conditions.



**a)**



**b)**

Figure 1**.** Scratch Tips Produced

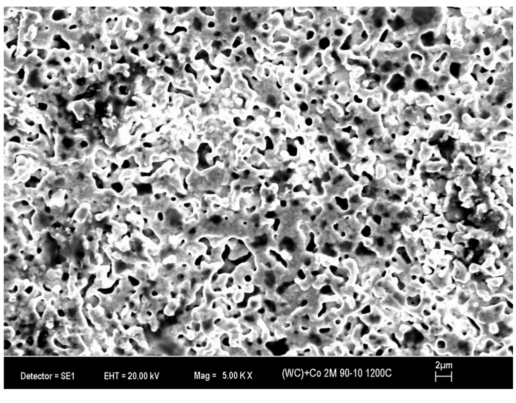
a) Triangular Toothed Specimen

b) Circular toothed Specimen

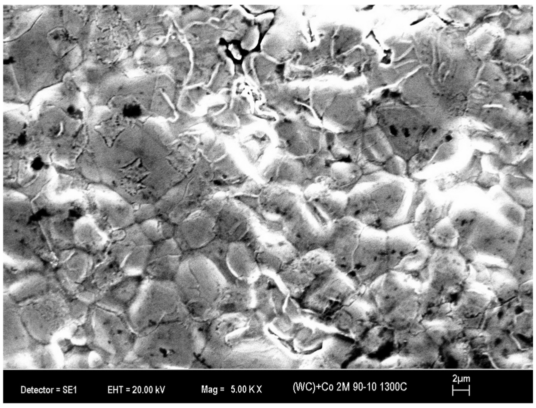
## 3. EXPERIMENTAL RESULTS AND FINDING

### 3.1. Metallographic Analysis

SEM images of 90% WC+10% Co composite materials with various grain sizes are given in Figure 2 and Figure 3. As can be seen in figure 2, when the sintered body has smaller a grain size, the more necks form in (a) leading to a homogeneous pore structure with wetting behavior during sintering. A complete wetting is achieved between powders by sintering composite samples at a high temperature and in this way porosity is eliminated (b). An image of a homogeneous internal structure was obtained in the 90%WC + 10%Co composite material with a 2 µm grain size. Thus, the small grain size enhanced the mechanical properties of the composite material.




a)

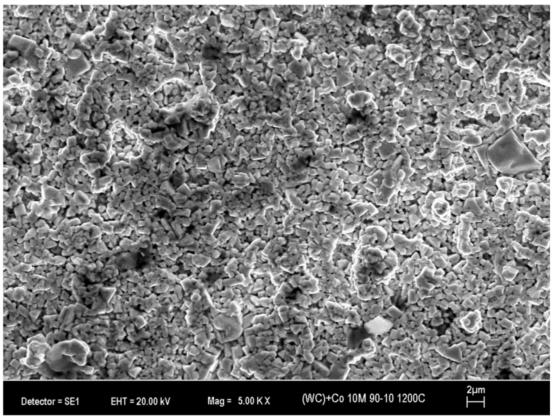



b)

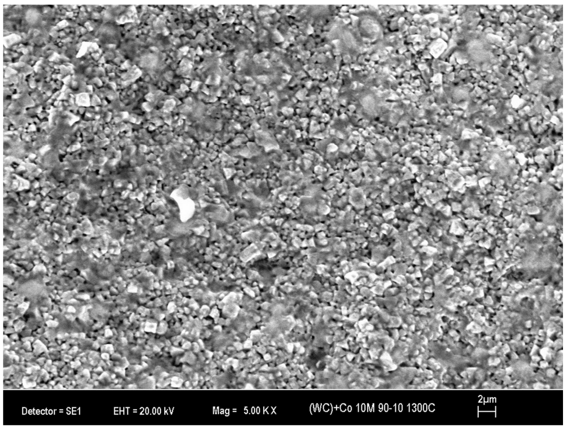
Figure 2. SEM Image of 90% WC+10% Co Composite

a) 1200ºC, 2 µm, 5KX

b) 1300ºC, 2 µm, 5KX




a)




b)

Figure 3. SEM Image of 90% WC + 10% Co Composite

a) 1200ºC, 10 µm, 5KX

b) 1300ºC, 10 µm, 5KX

### 3.2. Density Analysis

**Table 1** Density - Sintering Temperature Values of 90% WC+ 10% Co Composite

| **Temperature (°C)** | **10 µm 90% WC + 10% Co (g/cm$^3$)** | **2 µm 90% WC + 10% Co (g/cm$^3$)** |
|---|---|---|
| 1200 | 13,56 | 13,67 |
| 1300 | 13,71 | 13,82 |
| 1400 | 13,41 | 13,58 |

Table 1 is values of densities of sample at various temperatures. It is observed that after the microwave sintering, there are changes in the intensity depending on the temperature. The highest density value of the composite materials produced was measured to be about 13.90 g/cm$^3$ at 1300ºC in the 90% WC + 10% Co system with a small grain size. The theoretical density of the same composite material was calculated to be 14.84 g/cm$^3$. It was measured to be around 13.70 g/cm$^3$ at 1300$^o$C in the 90% WC+ 10% Co composition with a 10 µm grain size. As the grain size decreased, the density values of the composite samples increased leading to the enhancement of mechanical properties. As the density graph in the table suggests, there is a close relationship between grain size and density.

It can be seen in table 1 that during sintering the highest density values was achieved at 1300ºC. This can be explained by the fact that at this temperature the formation of the liquid phase takes place in the inner-structure, that is, minimum porosity is observed in the inner-structure. The maximum porosity is understood to exist in the composite structure at 1200-1400°C.

### 3.3. Compressive Strength Analysis

**Table 2** Compressive Strength - Sintering Temperature Values of 90% WC+ 10% Co Composites

| **Temperature (°C)** | **10 µm 90% WC + 10% Co (MPa)** | **2 µm 90% WC + 10% Co (MPa)** |
|---|---|---|
| 1200 | 524,91 | 558,34 |
| 1300 | 646,28 | 671,12 |
| 1400 | 482,24 | 496,56 |

The graph of sintering temperature-dependent compressive strength of the 90% WC+ 10% Co composite materials is given in Table 3 Approximately 580 MPa was measured at 1200°C in the 90%WC+ 10% Co composite sample with a grain size of 2 µm produced by microwave sintering, while it was around 690 MPa at 1300°C. WC, $W_2C$ and $Co_3W_3C/Co_6W_6C$, the phases that are detected in the XRD curve (Figure 4), contribute to the compressive strength. The compressive strength of the 90%WC+ 10% Co composite material composed of WC ceramic with the size of 10 µm was measured to be around 680 MPa at 1300°C. As shown in the XRD curve in figure 5, the decrease in the compressive strength is due to the lack of the WC, $W_2C$ ve $Co_3W_3C/Co_6W_6C$ phases.

### 3.4. Hardness Analysis

Table 3. Hardness - Sintering Temperature Values of 90% WC + 10% Co

| **Temperature (°C)** | **10 µm 90% WC + 10% Co (Brinell)** | **2 µm 90% WC + 10% Co (Brinell)** |
|---|---|---|
| 1200 | 439,72 | 448,46 |
| 1300 | 457,78 | 461,92 |
| 1400 | 427,82 | 437,58 |

Brinell hardness numbers of the 90% (WC) + 10% Co ceramic-metal composites sintered at 1200-1400°C were measured (Table 4). The hardness value of the composite sample with a grain size of 2 µm was determined to be about 465 HB at 1300ºC. As seen in Table 3, the decrease in grain size led to a decrease in porosity and an enhancement in mechanical properties. Thus, as can be seen in the density values in table 1, as the grain size increased density decreased. This led to a decrease in the mechanical properties of the composites. Due to the melting and the uniform structure of the samples, hardness values decreased to approximately 440 HB at 1400ºC. The temperature of 1300°C was found to be ideal for the microwave sintering of the 90% (WC) + 10% Co composite samples. The reason for this is that at this temperature the quantity of the WC and $W_2C$ phases, which enhance the mechanical properties, increased. The Brinell hardness number of the 90% (WC) + 10% Co composite material with grain a size of 10 µm was measured to be around 460 HB at 1300°C. The formation peak intensities of the WC and $W_2C$ phases present in the Composite material as a result of sintering was low (figure 5), and therefore, it reduced the compressive strength and the Brinell hardness numbers of the composite.

### 3.5. XRD Analysis

The results of the XRD analysis of the WC ceramic-based 90% (WC+ 10% Co composite materials with various grain sizes are given in figure 4 and figure 5. The WC and $W_2C$ phases are produced by sintering in the internal structure of the composite and have a positive effect on the mechanical properties of the (WC) + Co system. The quantitative abundance of the WC and $W_2C$ phases in the 90% (WC) + 10% Co composite sample with a grain size of 2 µm is evident from figure 5 which shows the intensity of the peaks on the XRD curve. The WC and $W_2C$ phases increased the compressive strength and the Brinell hardness numbers of the ceramic metal composite sample. The intensity of the peak of the WC and $W_2C$ phases formed in the other group (figure 4) was less than that of the 90% (WC) + 10% Co composite material with a grain size of 10 µm in the XRD graph (figure 5). In this case, due to the low amount of intermetallic phases formed in the cermet-based composite sample and due to the low amount of $Co_3W_3C/Co_6W_6C$ ve $Co_3W$ phases, hardness and compressive strength were thought to below.

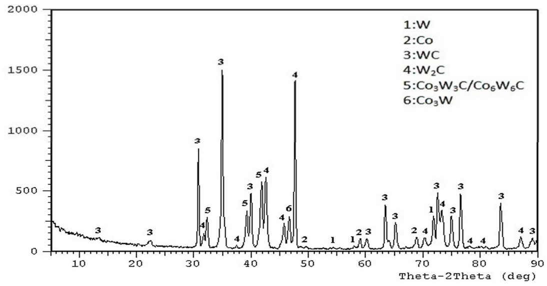



Figure 4. XRD Graph of 90% WC (2 µm) + 10% Co (2 µm) Composite sintered at 1300º in the 90% $N_2$ + 10% $H_2$ Gas Atmosphere

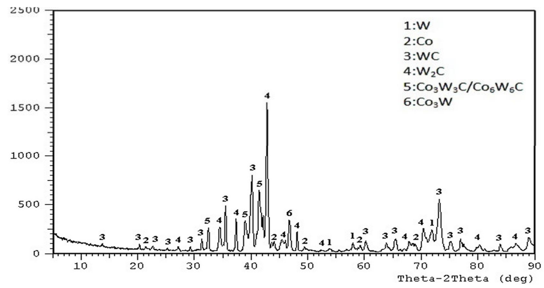



Figure 5. XRD Graph of 90% WC(10 µm) + 10% Co (2 µm) Composite sintered at 1300º in the 90% $N_2$ + 10% $H_2$ Gas Atmosphere

## 4. RESULTS AND DISCUSSION

Taking grain size differences of the powders into account, various compositions have been studied during the manufacture of the WC-Co composite. For this purpose, two different WC and Co powders with grain sizes of 2 µm and 10 µm were used. The effect of the grain size on the composite after sintering and differences in the microstructure were determined.

As can be seen, the ceramic metal composite materials produced in the WC + Co system exhibit good mechanical properties. Comparing the 90% $N_2$ + 10% $H_2$ composite materials sintered in a special mixed gas atmosphere (90% $N_2$ + 10% $H_2$), mechanical property values of the composite samples with a grain size of 2 µm were higher than those of the composite samples with a grain size of 10 µm. The theoretical density of the 90%WC + 10%Co system was determined to be 14.84 $g/cm^3$. The composites were produced after microwave sintering at a density of about 93%. The composites were produced after microwave sintering at a density of about 98%. The density of the 90% WC + 10% Co composite with a grain size of 2 µm was measured to be 13,75 $gr/cm^3$, with the Brinell hardness number being 485 HB and the compressive strength about 688 MPa. The density of the same composite with a grain size of 10 µm was measured to be 13,69 $gr/cm^3$, with the Brinell hardness number being 470 HB and the compressive strength about 675 MPa. The theoretical density of the 90%WC + 10% Co system was determined to be 14.17 g/cm$^3$. The composites in this group were produced after microwave sintering at a density of about 96%.

As a result of experimental study, the density value of the WC + Co composites was measured to be about 13.80 g/cm$^3$. In Akhtar et al.'s (2007) study, the density value of the WC + Co composites was measured to be about 13.70 g/cm$^3$. Wenbin Liu et al (2008) measured the density value of the WC + Co composites to be about 14.81 g/cm$^3$. The hardness value of these composite materials is about 460 HB. These values that affect the mechanical properties of the composite materials seem to be in accordance with the studies conducted by Wenbin Liu et al (2008) and Akhtar et al (2007).

As can be seen in the experimental findings, microwave sintering and the characterization of the internal structure is homogeneous. The XRD graphs of the metallic phases in the samples are in accordance with the studies conducted by Wenbin Liu et al (2008). As the grain size decreased, density increased and led to an increase in the value of the mechanical properties of the composite materials.

The microstructure of the alloy, that is, the bonds of WC grains, were developed by adding Co in the studies conducted by Upadhaya et al (1998) and Zhu and Manthiram (1996). They maintained that the microstructure and mechanical properties of composites produced depend largely on the grain size and Co content of WC. Abnormal Grain Growth (AGG) may occur in the sintering of WC with small amounts of Co. keeping the C/W ratio low in low concentrations of cobalt results in the formation of the $W_2C$ phase. The WC-Co hardness is affected by the amount of $W_2C$ and during cooling the $W_2C$ phase is stable. This leads to an increase in the mechanical properties of the composites and the fact that their sizes and densities are low at low temperatures seem to be in accordance with the study conducted by Tao Li et al (2006).

Microwave sintering of Co metallic powders with WC ceramic particles in the 90% WC + 10% Co composite samples with various grain sizes seems to be successful. Looking at the mechanical tests it is clear that the WC ceramic powders formed a strong bond after sintering, and that this increased the hardness, compressive strength and wear resistance of the composite materials produced. WC particles in the structure did not create pores, therefore, the mechanical properties increased (Krishna et al, 2002). Therefore, wear resistance values of the 90% WC+ 10% Co composite material are similar to the data collected by Krishna et al (2002).

## 5. ACKNOWLEDGEMENT

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