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Studying the Effect of Various Heat Treatment Processes in Hardness of Tungsten Carbide (WC) Alloys

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ABSTRACT:
Heat treatment process is the process of heating the material below its melting point, and then cooling in a control manner to achieve the required certain properties. There are different types of heat treatment, which consists of annealing, normalizing, hardening, and/or tempering. One of the most important material that used in cutting applications and treated by one or more heat treatment methodology is Tungsten carbide (WC). It is equal parts of tungsten and carbon atoms. The heat treatment process have significant effect on the mechanical properties of the tungsten carbide. So, Six samples of coarse grains of WC and WC-Co were prepared by different heat treatment processes; quenching, quenching + annealing in order to select the most proper heat treatment technique to enhance the hardness. All samples specimens were tested; and WC composed with 10%wt of Cobalt; treated by quenching + annealing; was found the most proper material to be used as cutting tools because it has the highest hardness.
Key words: Heat treatment, Hardness, Tungsten carbide, Tungsten carbide – cobalt alloy, cutting tool, mechanical properties enhancement.

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I. Introduction

Heat treatment process is the process of heating the material below its melting point, and then cooling in a control manner to achieve the required certain properties. There are certain heat treatment methodology to make stronger and harder metals or alloys; and other methodology is used to increase the ductility and toughness. Mainly it depends on the residual stresses induced in the treatment process.

Generally, the heat treatment process have three main stages; heat the alloy slowly, wait or hold for a certain time, and then cool the alloy to room temperature rapidly or slowly. There are different types of heat treatment, which consist of annealing, normalizing, hardening, and/or tempering.

Generally, quenching is the process of heating the alloy below the melting temperature, hold for certain period of time, and then perform rapid cooling in order to increase the material hardness and strength but the material become brittle. While, tempering process is considered the final treatment that used to reduce the brittleness of the quenching process to increase the toughness and the ductility. Finally, normalizing process is intermediate process between quenching and annealing, where, its cooling process is faster than annealing and slower than quenching.

One of the most important material that have several application and treated by one or more heat treatment methodology is tungsten carbide (WC). It is an equal parts of tungsten and carbon atoms that existed in fine gray powder form. However, it can be pressed and formed into packed module through sintering heat treatmentproces in order to compact the grains for several industrial applications.

Tungsten Carbide (WC) has high density (15.7 g/cm3) that is often used as cutting tool specially, when it is composed with cobalt (called sintered alloy) to enhance the hardness and toughness properties because of its high melting temperature “1900 ^{o}C”, stiffness, and flexural strength. On the opposite theory, annealing is the process of heating the alloy, hold for certain period of time, and then perform slow cooling inside the furnace. Annealing process remove the microstructure residual stresses and improve the ultimate strength and hardness in some cases.

In this study, six samples of coarse grains of WC and WC-CO were prepared by different heat treatment processes;quenching, normalizing, quenching + annealing. Each was tested to measure the hardness and ultimate strength and the sample that has the higher hardness will be selected to be the suitable one as a cutting tool material.

II. Materials and Methodology

2.1.Research Methodology and Sample Preparation

Three samples were prepared; with size 1cm x 1cm x 1cm;from tungsten carbide with different heat treatment processes illustrated in tale 2.1. Another three samples with the same sizes were prepared from tungsten carbide composed with cobalt (90-10% wt) by the same heat treatment processes. The prepared tungsten carbide has coarse grain size (3 to 5 µm)

The samples that were prepared by quenching; the following processes were performed:

- It was heated inside the furnace up to 1450 °C along five hours.
- Quenching by rapid cooling using oil or water bath (110 – 200 °C per min).

On the other hand, the samples that was prepared by quenching + annealing; the following processes were performed as shown in figure 2.1:

- It was heated to 1450 °C along five hours.
- Quenching by rapid cooling in oil bath.
- Heating to 510 °C and hold for five hours
- Slow cooling with rate (10-15 °C per min.)

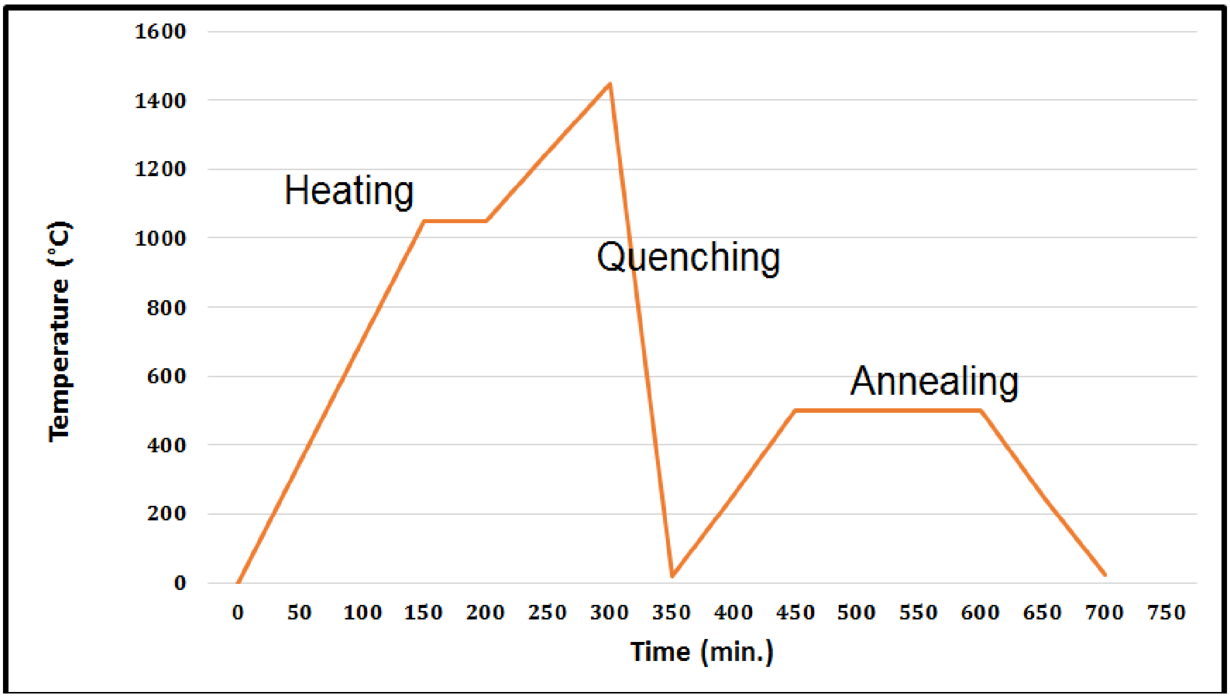

Figure 2.1. Heat treatment process to prepare samples

Table 2.1.Samples symbols and preparation

Symbol	Concentration	Heat treatment process			
		Heating	Holding Time	Cooling	Annealing
WC-1	50%wt Tungsten+ 50%wt Carbon	Heating to 1450° C	Hold For 1 hour	Quenching (Rapid cooling) by oil bath with rate 110° C / min	No
WC-2	50%wt Tungsten+ 50%wt Carbon	Heating to 1450° C	Hold For 1 hour	Quenching (Rapid cooling) by water bath with rate 200° C / min	No
WC-3	50%wt Tungsten+ 50%wt Carbon	Heating to 1450° C	Hold For 1 hour	Quenching (Rapid cooling) by oil bath with rate 200° C / min	Annealed to 500°C for 300 min. and Slow Cooling (10-15 °C per min)
WC-Co-1	45%wt Tungsten+ 45%wt Carbon+	Heating to 1450° C	Hold For 1 hour	Quenching (Rapid cooling) by oil bath	No

	10%wt Co			with rate 110° C / min	
WC-Co-2	45%wt Tungsten+ 45%wt Carbon+ 10%wt Co	Heating to 1450° C	Hold For 1 hour	Quenching (Rapid cooling) by water bath with rate 200° C / min	No
WC-Co-3	45%wt Tungsten+ 45%wt Carbon+ 10%wt Co	Heating to 1450° C	Hold For 1 hour	Quenching (Rapid cooling) by oil bath with rate 200° C / min	Annealed to 500°C for 300min. and Slow Cooling (10-15 °C per min)

Each was tested to measure the hardness and ultimate strength and the sample that has the higher hardness will be selected to be the suitable one as a cutting tool material.

2.2.<u>Instruments Used</u>
There are three testing devices that are used; listed as below:

a.Hardness Tester
Vickers Hardness Tester was used to measure the hardness of each sample specimen. The used hardness tester has measurement monitor; model no. MV-10V.

b.Scanning Electron microscopic
A scanning electron microscope (SEM) is used to provide information on the surface topography and composition of the samples. The used scanning electron microscopic is JSM-IT200.

c.Universal testing machine (UTS)
The universal testing machine is used to test the ultimate tensile strength, toughness and compressive strength of materials. The used universal testing machine has model no. Ute-10.

III. Results and Discussion

From figure 3.1 and 3.3.; it was concluded that the hardness of "WC – Co-3"; composed tungsten carbide with cobalt (90-10 wt%) has the highest hardness compared with other samples.
Generally, figure 3.1 showed that the hardness increases in case of water bath quenching compared with oil bath quenching. Water has higher heat capacity than twice than oil. So, the water cooling process cause more residual stresses and line dislocation inside the crystal structure. This is the primary cause of hardness increasing in water bath compared with oil bath.

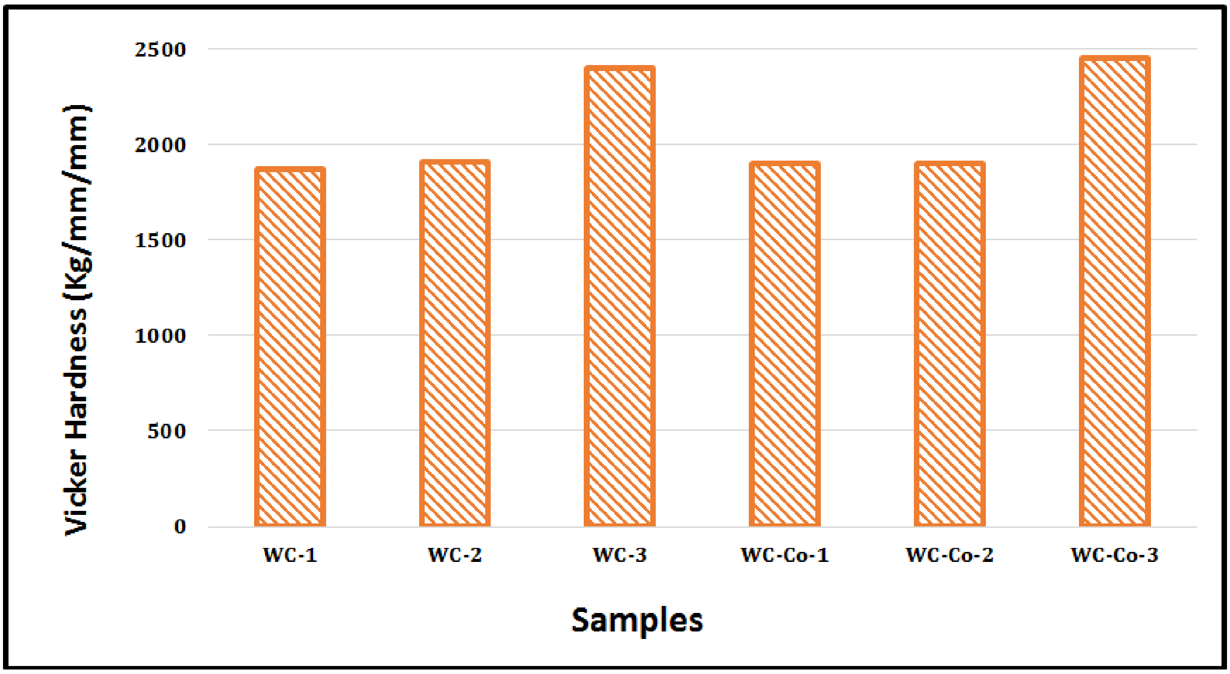

Figure 3.1.Hardness comparison for all samples

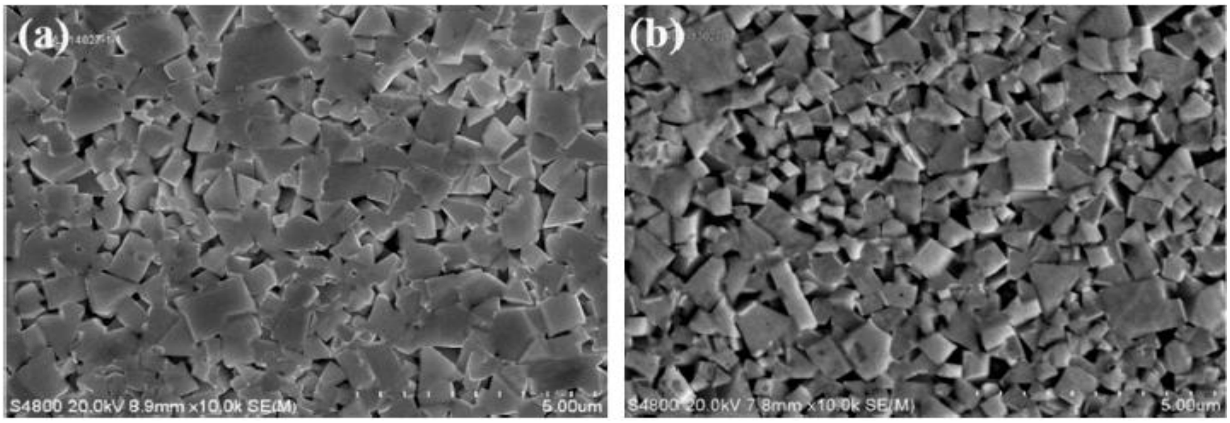

Figure 3.2.SEM for a) Cobalt immersed with WC b) Conventional WC

However, the annealing process reformed the sharp ends of the grains to a rounded shapes. The rounded ends of the grains cause the cobalt immersed and packed inside the FCC (face center cube) crystal structure of WC. This is cause more enhancement in hardness property. Figure 3.2 a showed the rounded ends of WC grains and high packing of cobalt inside WC structure.

Figure 3.3and figure 3.4 showed that the ultimate tensile strength and fracture toughness increase in case of presence of cobalt. This is due to high toughness of cobalt. This enhance the material resistance to fracture and increase its reliability.

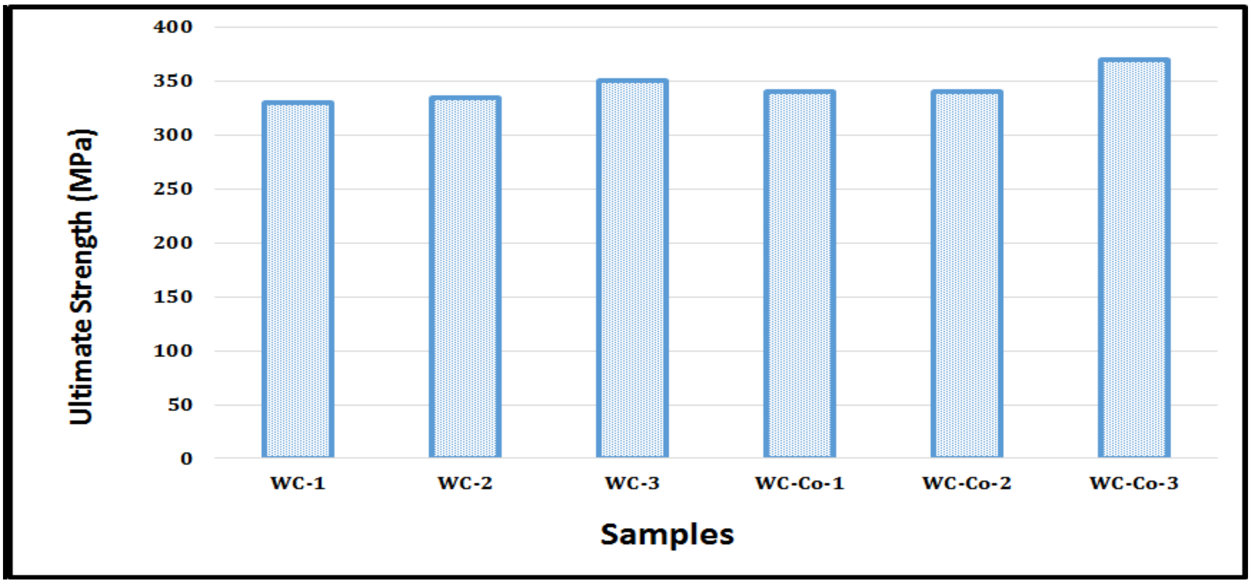

Figure 3.3. Ultimate strength comparison for all samples

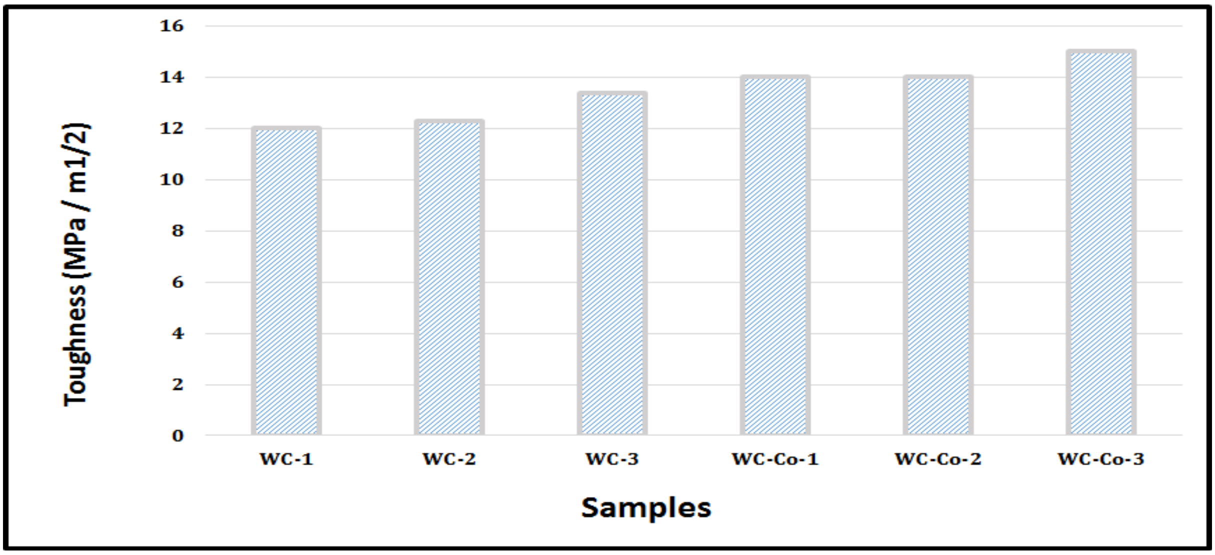

Figure 3.4. Fracturetoughness comparison for all samples

IV. Conclusion

From before, it was concluded that: tungsten carbide composed with cobalt (90-10% wt) that is treated by quenching (in oil bath) with annealing by heating to 500°C for five hour is the most proper material used in cutting tools application due to its high hardness and ultimate strength compared with other samples.

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