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Effect of Post-Braze Heat Treatment on the Microstructure and Shear Strength of Cemented Carbide and Steel Using Ag-Based Alloy

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Abstract. The aim of the present study was to investigate the effect temperature of heat treatment process on the interfacial microstructure and mechanical properties of cemented carbide/ carbon steel single lap joint brazed using Ag based alloy filler metal. The brazing process was carried out using torch brazing. Heat treatment process was carried out in induction furnace on the temperature of 700, 725, and 750°C, for 30 minutes. Microstructural examinations and phase analysis were performed using scanning electron microscopy (SEM) equipped with energy dispersion spectrometry (EDS). Shear strength of the joints was measured by the universal testing machine. The results of the microstructural analyses of the brazed area indicate that the increase temperature of treatment lead to the increase of solid solution phase of enrichted Cu. Based on EDS test, the carbon elements spread to all brazed area, which is disseminated by base metals. Shear strength joint is increased with temperature treatment. The highest shear strength of the brazed joint was 214,14 MPa when the heated up at 725°C.

1. Introduction

In the manufacturing process, the function of cutting tools is very important. However, it needs high cost to make a high quality-cutting tool. It makes the process focuses on selecting and manufacturing cutting tools, so efficiency process is reduced. WC-Co is one of cemented carbide, which is widely used as a cutting tool. Its main compositions are tungsten and cobalt. Tungsten has good strength and resistance, while cobalt serves as a binder and toughness [1, 2]. In order to manufacture a high quality-cutting tool and low-cost production, WC-Co is generally joined with steel. However, the joining of those two materials is difficult. It is because of the differences in properties of both materials. A study shows that joining by welding will produce residual stress. It is because of high difference in coefficient thermal expansion (CTE) [3,4,5].

The joining cemented carbide and steel requires a particular process, such as mechanical assembly, brazing, and diffusion bonding [6]. Brazing is a very potential process and able to joint dissimilar metal. The brazing process consists of several kinds, including vacuum brazing, induction brazing, furnace brazing, and torch brazing. Despite this, brazing is influenced by several elements, such as filler metal selection, characteristics of base metal, heat input, and post brazed treatment. The selection of filler metal is the first step in the brazing process. The filler metal must be compatible with base metals. The good filler metal has a low melting point, high wetness properties, and is able to form bonds with base metals [7].

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In recent years, the joining cemented carbide has received real attention. Kaiwa et al [8] examined the effect of adding Ni and Co in the filler metal of induction brazing between the cemented carbides and the martensitic stainless steels. During the brazing process, the specimens were heated to 750ºC with a heating rate of 5ºC / s, and held for 30 seconds. The study results showed that the strength of the joint increased by adding 2.0% mass of Ni and 0.5% mass of Co. In brazing microstructure, Co zone decreases due to dissolution of Co in cemented carbide. Chiu et al [9] studied the effect of temperature and holding time of vacuum brazing between SAE1045 carbon steel with hard alloy WC-Co using copper and brass alloys. Based on the results of the study, the rises in temperature and time of brazing influence on microstructure and mechanical strength. The result of microstructure observation, Fe-Co-Cu alloy layer is formed on the surface of base metal. The higher temperature causes the thickness of Fe-Co-Cu layer to increase. The maximum shear strength is 320 ± 10 MPa was brazed at 1140ºC for 15 minutes.

Besides, Temperature also plays an important role because the filler metal melts at a certain temperature. Based on literature review, temperature rise can improve the properties of the joints. Mousavi et al [10] examine the CK35 steel joint brazed with the cemented carbide using copper filler metal at different temperatures. In this study, it is focused on the properties of wetting, metallographic, and mechanical properties. Wet tests show that brazing time increases, the contact angle decreases. The microstructure in the brazing region indicates a copper-enriched primary phase. The eutectic structure of the silver matrix consists of copper-enriched particles. The shear test results show that the maximum shear strength is 108 MPa at 800°C.

Criss and Meyers [11] investigated the joining of cobalt using silver-copper alloy. The observation results indicate that the weld crack can be minimized, while the bending test indicates the delamination of the filler base does not cause a failure. Effect of holding time on the microstructure and mechanical properties of ZrO2 / TiAl joints brazed with Ag-Cu filler metals using vacuum brazing was reported by Sun et al [12]. The investigation results show that the Cu3Ti3O + TiO layer is formed adjacent to the ZrO2 ceramic while the AlCu2Ti layer is formed on the TiAl substrate. The highest shear strength of 48.4 Mpa was achieved at 880 ° C for 10 minutes. In this study, cemented carbides and carbon steel were brazed using silver filler metal. Then post brazed heat treatment is used to improve the joint properties. The effect of treatment temperature is discussed and studied.

2. Experimental

Silver-based metal alloys are used for filler metals. The chemical composition is shown in Table 1. Carbide tips (YG6) from Zigong Carbide Corp. Ltd. China with size 25x15x8.5 mm and low carbon steel (SS400) with size 40x15x10 mm serve as test specimen. The chemical composition of the two base metals is shown in Table 2. SiC abrasive papers are used to rub the surface of test specimens. Dirt or contaminants on both surfaces of test specimens are cleaned using acetone. Before it is joined, the test specimen is assembled as shown in Figure 1. Thickness gauge 0.1 mm is used to control the spacing between specimen surfaces. To facilitate during the joining process, a jig tool is used, as shown in Figure 2(a).

Table 1. Chemical composition of filler metal

Metal	Ag	Cu	Zn	Ti	P	Other
(wt%)	Main	30	30	0.3	-	-

Table 2. The chemical composition of specimen

Metal	C	Si	Mn	P	S	Ni	Cr	Fe	WC	Co
SS400	0.22	0.59	0.59	0.017	0.02	-	-	Main	-	-
YG6	-	-	-	-	-	-	-	-	94	6

The brazing process is carried out using torch brazing. After brazing, all specimens are removed from the remaining flux attached to the specimen's surface. Then the test specimen is prepared for the heat treatment process. The induction furnace is used as a heater. The treatment temperature was set at 700, 725, and 750°C respectively and held for 30 minutes. After that, all specimens were cooled to room temperature. All test specimen surfaces are grinded using diamond grinding and pureed using a SiC abrasive paper (grit 320-5000). Then it is polished using a metal polish paste. Microstructures In brazing regions characterized by an electron-scanning microscope (SEM) equipped with X-ray dispersion energy spectrometer (EDS). The mechanical strength of the joint is tested using a universal test machine (UTM-SANS SHT 4106) with a constant velocity of 0.5 mm/min at room temperature. The shear test scheme is illustrated in Figure 2(b).

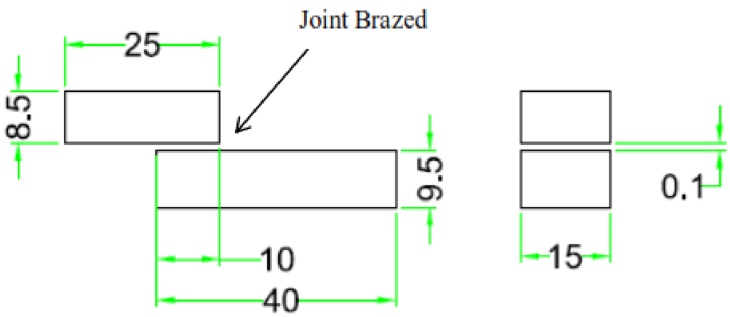
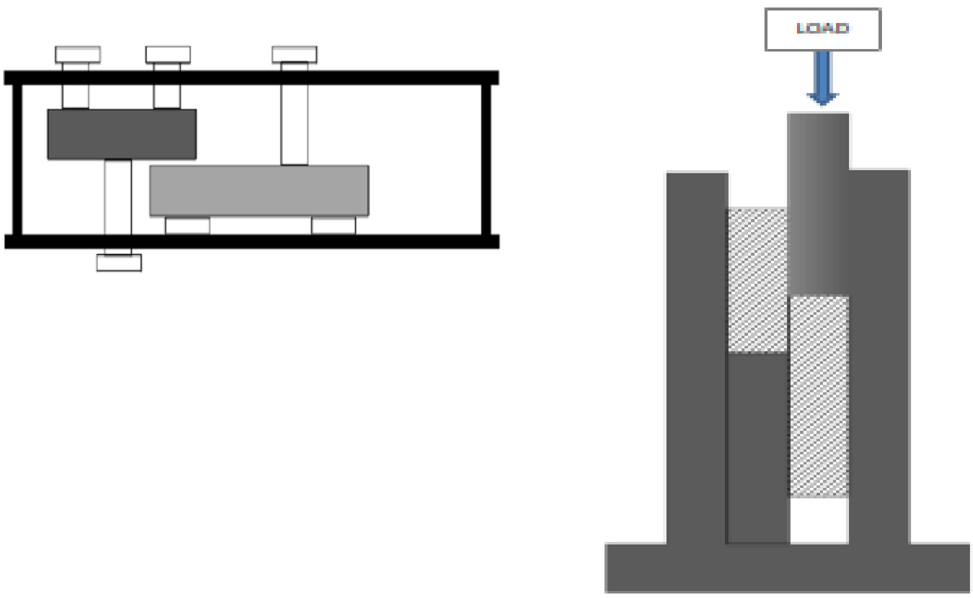


Figure 1. Schematic and types of joints



(a) (b)

Figure 2. (a). Jig, (b). Schematic of shear testing

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3. Results and Discussion

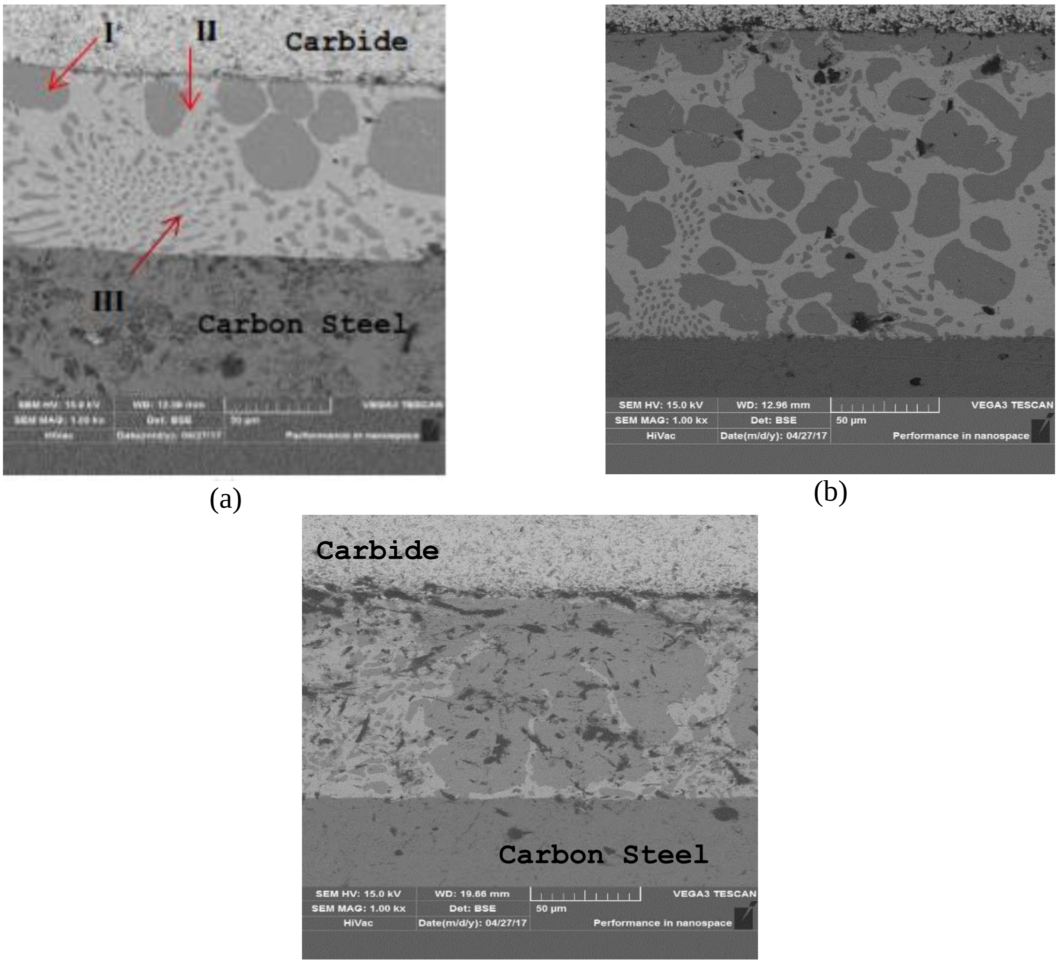
The microstructure of brazed joints between carbide tips and carbon steel was observed with SEM, as shown in Figure 3. The results showed that the brazing area consisted of 3 parts: I) Dark colored area with a large texture, II) Light colored areas, and III) Darker areas with smaller textures. Region I is a solid solution phase of filler metal enriched with Cu, Zn, C and Ag. Region II is an Ag matrix enriched with Zn, C, and Cu. Region III is the eutectic phase of Ag-Cu-Zn and C with lower copper elements. The element is widespread in the brazing area. The results of the EDS test on the different region show that the three regions contain C elements released by the parent metal into the area of brazing. This indicates that the C element is capable of diffusing into the filler metal solid solution. The results of the EDS tes are shown in Table 3. Based on the Ag-Cu-Zn phase diagram [13], the eutectic phase occurs at 780 ° C, but with the addition of Zn 10-30 wt% into the alloy may decrease the fill metal liquids to 500^{o}C [14]. Then this can be found at brazed joints by treatment at 700^{o}C for 30 min, as shown in Figure 3(a) but this number of phases gradually decreases with increasing treatment temperature. Figure 3(b) shows the microstructure of the joint brazed at 725^{o}C.

Table 3. Chemical composition on the different region

Region	Chemical Compositions (wt%)				
	Ag	Cu	Zn	Fe	C
I	5.1	55	34.3	-	5.7
II	86.5	3.4	5.6	-	4.5
III	5.6	48.8	39.6	1.4	1.4

It is seen that the eutectic phase spread is less and vice versa the solid solution phase of Cu is greater. Moreover, the enlarged solid phase of Cu-enriched solution is increasing at 750 ° C as shown in Figure 3(c). A previous study [10] states that the cooling rate during solidification has a very important role in the formation of microstructure. It has a slower cooling rate compared to lower treatment temperatures at higher treatment temperatures. Therefore, Cu grainds have more time to grow. So the homogeneity of microstructure can be achieved.

Figure 4. shows the average shear strength of the joints, which are treated at different temperatures for a constant holding time of 30 minutes. It can be seen that the average shear strength increases up to 725^{o}C, and then decrease when the temperature of treatment increases. The maximum shear strength of the joints was 214,14 MPa at 725^{o}C. Increasing of the treatment temperature can improve the fluidity of filler metals and promote the diffusion of elements to achieve a homogeneous microstructure, as reported by the previous literature [9,15,16,17]. Nevertheless, the increasing temperature of treatment can cause the grain growth, and reduce the shear strength.



(a) (b)

(c)

Figure 3. SEM image of brazed joint using silver filler metal (a). 700ºC, (b). 725ºC, (c). 750ºC

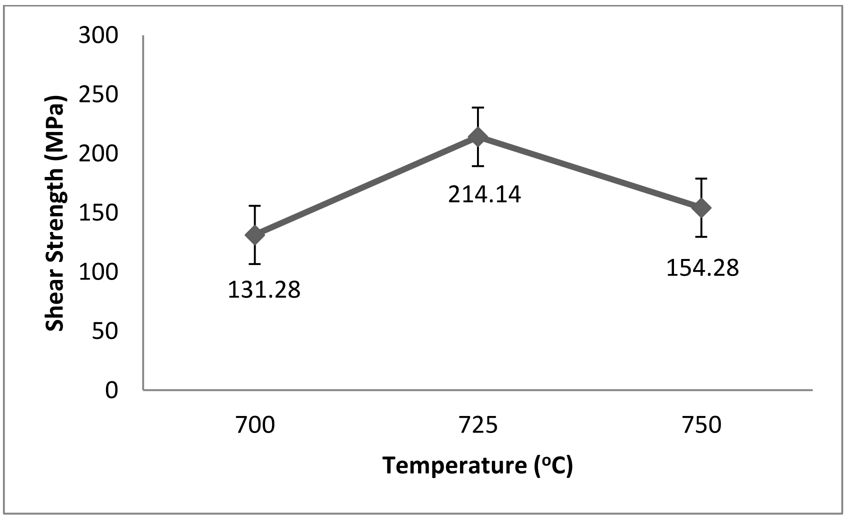


Figure 4. Shear strength of the joints brazed at different temperatures for 30 minute.

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4. Conclusions

This study aims to know the effect of post brazed heat treatment on the microstructure and mechanical properties of cemented carbide and steel using silver filler metal. The results obtained are summarized as follows: Microscopic observation results show that the dark area is the phase of Cu-enriched solid solution. Rising treatment temperatures increase the area of Cu solid phase. This is because, during the solidification process, Cu solid phase has more time to grow and develop. The brightest area of the brazing area is the Zn-enriched Ag matrix. EDS test results show that C element is spread to all brazed area. The shear strength of brazing joints increases with the treatment temperature, and then decrease when the temperature up to 750ºC. The maximum shear strength reaches 214,14 MPa at 725ºC.

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