Effect of heat treatment on property of brazed joint

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Abstract

Two different filler metal is used to join polycrystalline diamond (PCD) compact into a cemented carbide substrate. The effect of brazing holding technology on shearing strength and microstructure of brazing seam in hi-frequency induction brazing is investigated. Based on analyses of the microstructure of brazing joints by means of scanning electron microscope (SEM) and electron probe microanalyzer (EPMA), it is indicated that the shearing strength of brazing joints increased with the increase of heat preservation temperature; however, the shearing strength increased first and decreased afterward with the prolonging of heat preservation time. And the shearing strength of PCD cutting tools using the way of post-weld heat preservation is higher than that of those using plaster power cooling or air cooling. Thermal damage happened on the PCD cutting tools, and the damage became serious gradually with the increase of post-weld heat preservation time.

Keywords: Polycrystalline Diamond Compact, Cemented Carbide, Brazing Joint, Heat Treatment, Shearing Strength

1 Introduction

Polycrystalline diamond (PCD) compact is composed of PCD layer and carbide substrate[1]. PCD compact is applied in metal cutting processing and oil drilling industries because of the high hardness of PCD layer and good toughness of cemented carbide substrate[2-6]. PCD compact cutting tool is made of a PCD compact cutter head and a metal substrate. Brazing is a key procedure in the manufacturing of cutting tools. The reliability and integrity of PCD compact tools depend on the properties of PCD compact-metal joints during the brazing process.

The brazing of PCD compact and cemented carbide is essentially a brazing process of cemented carbides. The brazing of cemented carbide is generally at about 1000 °C [7, 8]. However, the heat resistance of PCD layer is lower than 700 °C, and thermal damage of PCD will happen when the temperature is too high[9]. Thus the brazing of PCD compact usually use Ag based brazing filler metal that has a relatively low melting point[10].Hi-frequency induction brazing has been widely applied because of the properties such as easy operation, fast heating, high efficiency, less investment and lower operating cost. Studying the brazing parameters of PCD compact and making reasonable welding technology are significantly important for an increased edge quality.

According to the situation that few study on the brazing holding technology of brazing joint of PCD compact and cemented carbide, this paper studied the effects of heat preservation temperature and time, in order to improve the shearing strength of PCD cutting tools.

2 Experimental procedure

PCD compact Syndite CTB010 (Element Six, British) and cemented carbide YG8 (Zhuzhou, China) were selected as welding materials for the brazing process. The properties of substrate material YG8 was shown in Table1. QJ102 with activation temperature of 650–850 °C, was chosen as brazing flux, and the QJ102 flux chemical compositions (wt%) is 42% KF, 23% KBF, 35% BO. The chemical compositions of the two kinds of silver-based solder were shown in Table 2.

TABLE 1 Chemical composition and properties of YG8 cemented carbide

Chemical compositions (wt%)		Bending strength (MPa)	Elastic modulus (Kg·mm-2)	Liner expansion coefficient (10-6/° C)	Hardness (HRA)
WC	Co				
92	8	1500	6.0	4.5	>89

TABLE 2 Chemical composition and melting temperatures of filler alloys

Filler alloy	Chemical composition (wt%)						Melting temperature (° C)
	Ag	Cu	Zn	Ni	Cd	Mn	
1#	54	14	22	3.5	—	6.5	630 ~690
2#	54	13	15.5	1.7	15.8	—	620 ~690

Prior to brazing, both substrates and brazing filler metal were polished with SiC papers, and subsequently cleaned using an ultrasonic bath with acetone as the fluid. The brazing experiments occurred in high frequency induction heating equipment SP-15A (Shuangping, China). The brazing temperature was measured using an infrared radiation thermometer HSM-672 (Wahl, America). According to the thermal stability of CTB010 in air atmosphere, brazing temperature was set at 670 °C. The joint microstructural investigation was carried out using a scanning electron microscopy JSM-6360LV, and the shear strength was determined using a self-made high-precision piezoelectric shear testing device.

In the experiment, the heat preservation temperature was set at 500 °C, 400 °C, 300 °C, and 200 °C respectively, and the heat preservation time was set at 1h, 3h, 5h, 7h, and 9h respectively. Both the effect of heat preservation temperature and heat preservation time on shearing strength of brazing joints was investigated. The influence of different

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cooling way was also investigated, including post-weld heat preservation, plaster power cooling, and air cooling.

3 Results and discussion

3.1 THE EFFECT OF HEAT PRESERVATION TEMPERATURE

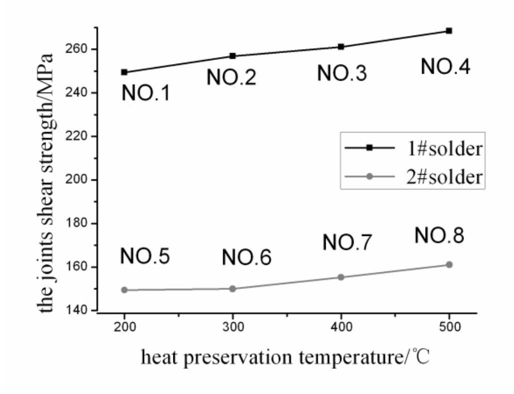


FIGURE 1 Shearing strength of the joints brazed at different heat preservation temperature.

Figure1 shows the results of the shearing strength at different heat preservation temperature, when heat preservation time is 1h, solder is 1# and 2# respectively. The shearing strength reaches a maximum when heat preservation temperature is 500 ° C. Based on the experimental data, the difference of the highest and the lowest shearing strength is 19.02MPa when solder is 1#, and the difference if 11.57MPa when solder is 2#. That shows the shearing strength varied with the changing of temperature. Based on Figure1, The shearing strength increases with the increment of heat preservation temperature in the range of 200~500° C, whether the solder is 1# or 2#. Because the two kinds of solders have some different elements, as shown in Table 2, the shearing strength of cutting tool with 1# solder is generally higher than that with 2# solder. So this paper mainly analysis the former about the effect of brazing holding technology on shearing strength.

The different temperature of parts of the solid material in the brazing process will enable the material to produce thermal stress, which is related to the elastic modulus, thermal expansion coefficient, material temperature of the material. Thermal stress increased with the increase of temperature difference, and increased the tool cracking possibility. While higher heat preservation temperature can reduce the deviation of temperature, and thereby reduce or eliminate the thermal stress that caused by uneven temperature, and increase the shearing strength of the PCD tool.

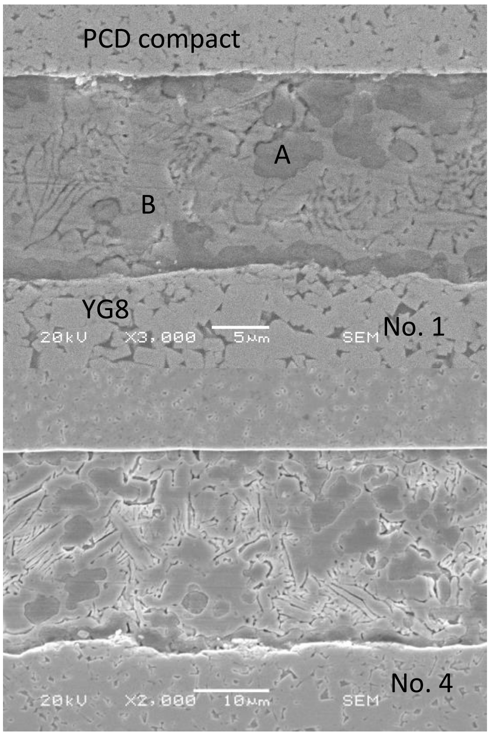


FIGURE 2 Microstructure of the brazing joint of No.1 and No.4 cutting tool in FIGURE 1.

Figure 2 shows the SEM microstructure of brazing joints with 1# solder, when heat preservation temperature was 200°C and 500°C respectively. The upside is PCD compact, the downside is YG8 cemented carbide substrate, and the middle is the filler alloy layer. It can be seen that uneven distribution of gray-black organization and a small amount of white organization existing in the No. 1 joint, and the gray-black organization mainly distribute in the place near both sides of the base metal. On the other hand, both the gray-black organization and white organization distribute evenly over the whole No. 4 joint.

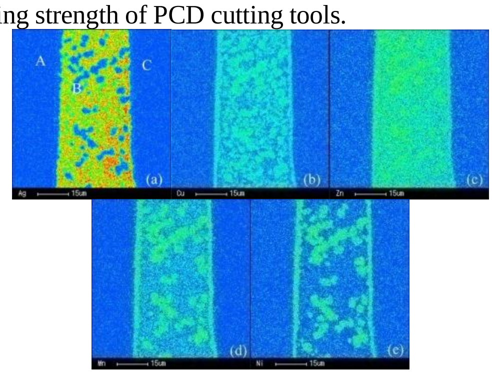
Table 3 is the EDX analysis results of the micro-area of the point A and point B in the No. 1 cutting tool. According to the results, the gray-black organization (point A) is Ag-based solid solution with a small amount of Cu, Zn, and Mn; and the white organization (point B) is Ag-lack phase that mainly contains Cu, Zn, Mn, and Ni. The homogenization of these two organizations is helpful to improve the shearing strength of the PCD cutting tool joints, and that's why the shearing strength of brazing joint of No. 4 is higher than that of No. 1.

TABLE 3 EDX results of brazing joint organizations of No.1 cutting tool in Figure 2

Position	Chemical composition (wt%)				
	Ag	Cu	Zn	Ni	Mn
A	79.96	5.22	10.49	—	4.33
B	5.78	19.75	26.6	24.42	23.45

In order to determine the heat preservation temperature influence on the distribution of elements, Figure 3 and Figure 4 give the results of element distribution in the brazing joints of No. 1 and No. 4 that were analyzed by EPMA. According to the Figure 3, the distribution of Ag and Zn is relatively uniform in No.1 joint, while Cu concentrates near the middle and on both sides of the interface. Diffusion transition band generated along both sides of the interface, and the transition band near the YG8 side is thicker. The distribution of Mn and Ni is similar to Cu, whereas the segregation is more obvious.

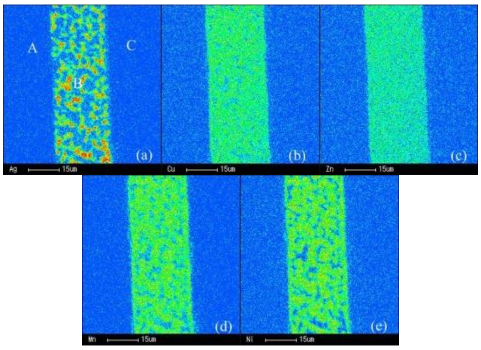
Compared with No. 1 joint, the distribution of Ag and Zn in No. 4 has no difference; while the distribution of Cu, Mn and Ni is relatively even and the segregation is not obvious. So it can be concluded that higher heat preservation temperature can reduce the segregation of some elements in 1# solder, and improve the bonding strength, toughness and ductility of joint. It has been known that the shearing strength of No. 4 is higher than that of No. 1, and therefore a higher heat preservation temperature is benefit to the shearing strength of PCD cutting tools.



A—YG8 Cemented Carbide, B—Joint, C—PCD Compact

(a)~(e)—The Distribution of Ag, Cu, Zn, Mn, Ni

FIGURE 3 Element distribution in No.1 brazing joint



A—YG8 Cemented Carbide, B—Joint, C—PCD Compact

(a)~(e)—The Distribution of Ag, Cu, Zn, Mn, Ni

FIGURE 4. Element distribution in No.4 brazing joint

3.2 THE EFFECT OF HEAT PRESERVATION TIME

Figure 5 gives the results of the shearing strength at different heat preservation time, when heat preservation temperature is 500 °C. It is known from Figure 5 that with the increase of heat preservation time, the shearing strength of 1# solder brazing tool increased first and decreased afterward, and reached a maximum value at 3h. The shearing strength of 2# solder brazing tool also increased at first, but reached a maximum value at 5h , and then decreased.

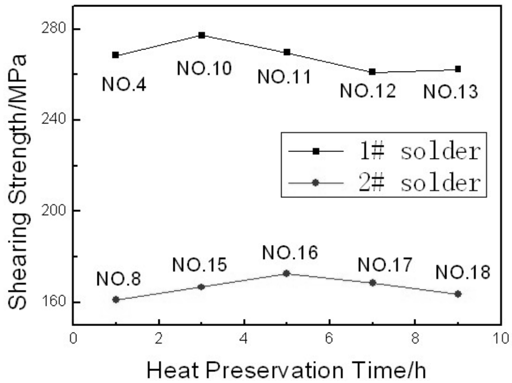


FIGURE 5 Shearing strength of the joints brazed at different heat preservation time

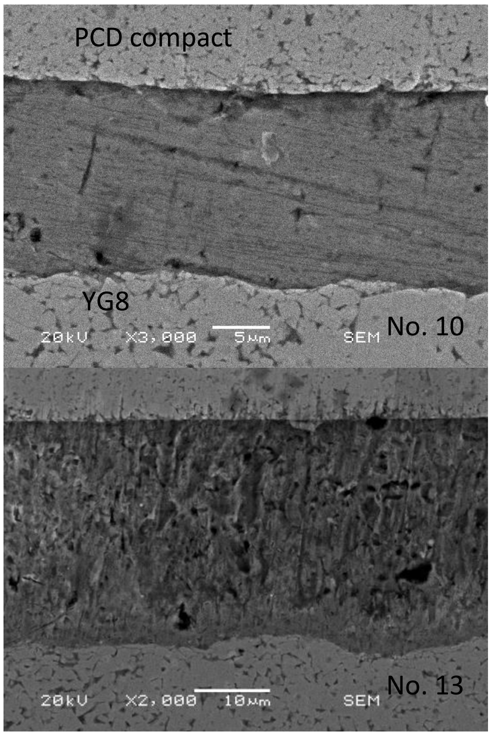
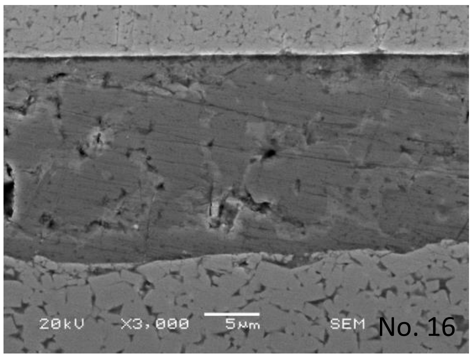


FIGURE 6 Microstructure of the brazing joint of No. 10 and No. 13 cutting tool in FIGURE 5.



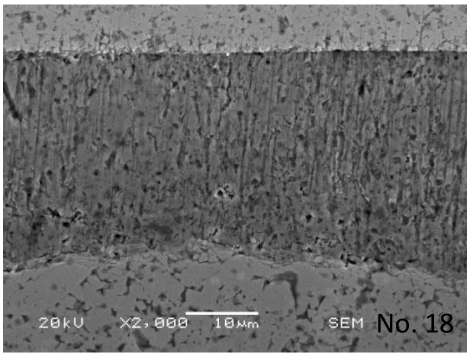


FIGURE 7 Microstructure of the brazing joint of No. 16 and No. 18 cutting tool in FIGURE 5.

Figure 6 presents an overview of the SEM morphology of brazed joints with 1# solder, when the heat preservation time is 3h and 9h, respectively. The upside is PCD compact, the downside is YG8 cemented carbide substrate, and the middle is the filler alloy layer. It can be seen that the organization of No. 10 joint is more compact, and have no obvious defects except for a small amount of microporous. The organization of No. 13 joint is looser with a lot of porosities and slag inclusions, and some of brazing alloy turned into white grey. That's caused by the evaporation of Zn and oxydation under long heat preservation time without protective gas.

Figure 7 shows the microstructure of brazed joints with 2# solder, when the heat preservation time is 5h and 9h. The organization of No. 16 joint is compact and refined, when the No. 18 joint includes a lot of porosities. The reason is also due to the heavy evaporation and oxydation of Zn. Because Zn quantity in the 1# solder is nearly twice as much as in 2# solder, as shown in table 2, the influence of heat preservation time on the property of brazed joint of 1# solder is greater than that of 2# solder. It is consistent with the appearance of shearing strength in Figure 5, and that's why the shearing strength of 1# solder reached a maximum value at 3h earlier than that 2# solder at 5h. After the heavy evaporation and oxydation of Zn, the remaining has little impact on the property and shearing strength of cutting tool joint. Meanwhile, the thermal stress is fully relaxed over the long time, and the shearing strength will be stable. So it can be predicted that the shearing strength of 2# solder brazing tool will be stabile after heat preservation time for 9h.

3.3 THE EFFECT OF DIFFERENT COOLING METHODS

The effect of different cooling methods on the shearing strength of brazed joints is investigated, as the results shown in Figure 8. The cooling methods include air cooling, plaster power cooling, and heat treatment cooling. The heat preservation time is 3h and heat preservation temperature is 500 °C in the way of heat treatment cooling.

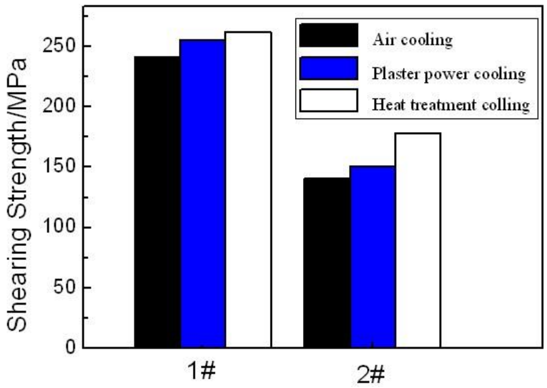


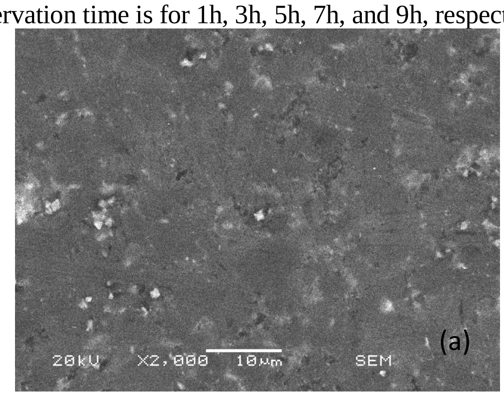
FIGURE 8 Contrast experiment result of shearing strength with different cooling way.

It can be seen that the best cooling way is heat treatment cooling, whether the solder is 1# or 2#. In order to obtain a higher shearing strength, post-weld heat preservation should be applied in hi-frequency induction brazing of PCD compact and cemented carbide.

3.4 THE THERMAL DAMAGE OF PCD COMPACT

Thermal damage of PCD compact refers to the damage caused by hearting during the brazing process[11]. The longer the heating time, the lower the temperature resistance of the compact, as it referred to the effect of heating temperature and time on the thermal properties of CTB010, at the air atmosphere[9].

During the proceed of welding, temperature is very high, but the heating time is very short, normally less than 20s, so thermal damage doesn't obviously happen on the PCD cutting tools. However, post-weld heat preservation time is usually in several hours, though the temperature is low, thermal damage maybe happen. To study the thermal damage, Figure 10 gives the SEM micrograph of the rake face of brazed PCD tools with 1# solder. The post-weld heat preservation temperature is at 500 °C, and the heat preservation time is for 1h, 3h, 5h, 7h, and 9h, respectively.



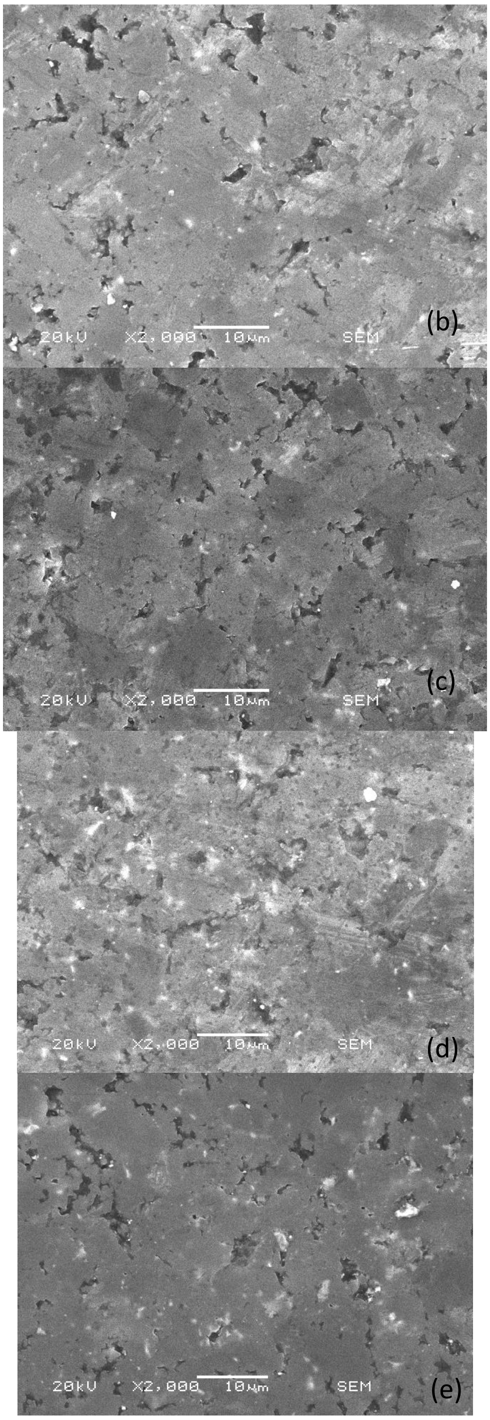


FIGURE 9 SEM micrograph of rake face with different heat preservation time

(a)~(e)—Heat Preservation Time 1h, 3h, 5h, 7h, 9h

When post-weld heat preservation time is 1h, as shown in Figure 9(a), the tool rake face have a small amount of white matter, which is a mixture of Co_3O_4 and CoO caused by oxidation between Co in PCD and O_2 in air. When the preservation time is 3h, the tool rake face exists microviods and pits besides a small amount of white matter, which because Co-oxides fall off. When the preservation time is 5h, the tool rake face generated a lot of microviods. When the preservation time is 7h, there are a lot of porosities and Co-oxides. When the preservation time reaches 9h, there are small amount of Co-oxides, but lots of porosities and large pits.

The SEM micrograph indicated that slight thermal damage happened on PCD cutting tools when post-weld heat preservation time is 1h, and severe thermal damage happened at 5h, 7h, and 9h. The microviods, which caused by bulging and falling of Co-oxides, will damage the smoothness of the surface of PCD, and reduce the wear resistance of rake face. Thermal damage will also affect the smoothness of PCD layer and increase the friction coefficient of tool front face [12]. Therefore, it's better to avoid heavy oxidation of PCD when select post-weld heat preservation parameters.

4 Conclusions

Post-weld heat preservation is better than plaster power cooling and air cooling. The shearing strength of brazed joints increases with the uprising of heat preservation temperature, when heat preservation time is 1h. When heat preservation temperature is 500 °C, the shearing strength of brazed joints increases first and decreases afterward.

The thermal stress caused by uneven temperature can be reduced, even eliminated at high heat preservation temperature and long heat preservation time. But porosities and slag inclusions will be generated in the joint because of heavy evaporation and oxydation of Zn in filler metal.

Thermal damage of PCD compact happened during heat preservation because of Co oxidation, and thermal damage will become worse with the prolonging of preservation time. Heavy oxidation of PCD should be avoid in selecting post-weld heat treatment parameters, if shearing strength of tools is acceptable.

References

[1] Qian J, McMurray CE, Mukhopadhyay DK, Wiggins JK, Vail MA, Bertagnolli KE. (2012) Polycrystalline diamond cutters sintered with magnesium carbonate in cubic anvil press. International Journal of Refractory Metals and Hard Materials, 31, 71-75.

[2] Gittel HJ. (2001) Cutting tool materials for high performance machining. Industrial Diamond Review. 61(588), 17-21.

[3] Nabhani F. (2001) Wear mechanisms of ultra-hard cutting tools materials. Journal of Materials Processing Technology 115(3) 402-412

[4] Clark IE, Bex PA. (1999) The use of PCD for petroleum and mining drilling. Industrial Diamond Review. 59(1), 43-49.

[5] Cook MW, Bossom PK. (2000) Trends and recent developments in the material manufacture and cutting tool application of polycrystalline diamond and polycrystalline cubic boron nitride. International Journal of Refractory Metals and Hard Materials. 18(2-3), 147-152.

[6] Shalaby MA, El Hakim MA, Abdelhameed MM, Krzanowski JE, Veldhuis SC, Dosbaeva GK. (2014) Wear mechanisms of several cutting tool materials in hard turning of high carbon–chromium tool steel. Tribology International. 70(0), 148-154.

[7] Uzkut M, Koksal NS, Unlu BS. (2005) The determination of element diffusion in connecting SAE 1040/WC material by brazing. Journal of Materials Processing Technology. 169(3), 409-413.

[8] Zhang J, Jin LY, Xu JC, Liu XQ. (2007) Microstructure and properties

of brazing joint between YG8 cemented carbide and A3 steel. Proc. Conf. on Designing of Interfacial Structures in Advanced Materials and their Joints, Osaka, Japan, 265-270.
[9] Bex PA, Shafto GR. (1984) The Influence of Temperature and Heating Time on Pcd Performance. Industrial Diamond Review. 44(3) 128-132
[10] Zhang Qi-yun, Zhuang Hong-shou. (2008) Manual of Brazing and Soldering. Mechanical Industry Press: Beijing.
[11] Shi W, Zhang H, Hai D. (2006) Grey relationship analysis and grey forecasting modeling on thermal stability of synthetic single diamond. Journal of Harbin Institute of Technology.13(1), 73-78.
[12] Slutz DE, Gigl PD, Flood GM, Smith GW. (1993) Brazed thermally-stable polycrystalline diamond compact workpieces and their fabrication. EP Patent 0, 329, 954.

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