

Dissimilar Brazed Joints Between Steel and Tungsten Carbide

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Abstract. Brazing is a joining process used to obtain heterogeneous assemblies between different materials, such as steels, irons, non-ferrous metals, ceramics etc. Some application, like asphalt cutters, require quick solutions to obtain dissimilar joints at acceptable costs, given the very short period of operation of these parts. This paper presents some results obtained during the brazing of dissimilar joints between steel and tungsten carbide by using different types of Ag-Cu system filler materials alloyed with P and Sn. The brazing techniques used were oxygen-gas flame and induction joining. The brazing behaviour was analysed in cross sections by optical and electron microscopy. The metallographic analysis enhanced the adhesion features and the length of penetration in the joining gap. The melting range of the filler materials was measured using thermal analysis.

1. Introduction

Joints between different materials, such as steel and tungsten carbide, are often made by brazing. During brazing, filler materials having a liquidus temperature above 450°C and below the solidus temperature of the base metal are melted and then enter the joining gap, by means of the capillarity action [1].

The main problem encountered during the brazing of heterogeneous materials (ceramics and steels) is the fact that most common filler materials cannot cover, at the same time, the entire ceramic surface, due to their strong ionic and covalent bonds [2].

Ceramics are used in a multitude of industrial fields and the possibilities to use of them in combination with other materials (metallic or ceramic) have great economic importance. The evolution and development of more advanced types of ceramics was favoured by the challenge to work in difficult operating conditions, such as abrasive and erosive environments. To be able to work in such severe conditions, substantial high values of mechanical properties (hardness and wear resistance) must be obtained.

One of these applications is the asphalt cutter, which requires an assembly of numerous small cutters made of tungsten carbide placed on the large steel rollers. The main issue in this case is to obtain a good assembly between the ceramic parts and the steel support, which allows long periods of operation until the replacement of the worn parts [3]. The cooling of a dissimilar joint after brazing (i.e. steel brazed with tungsten carbide) is very important due to the high expansion coefficient of the steel, which tends to contract faster than the part of tungsten carbide to which it is brazed.

This mismatch develops shear stresses within the interfaces of the joint. If high strength brazing filler material is used, these stresses will be directly transmitted to the brittle tungsten carbide and



could cause its cracking (figure 1). For this reason, the filler metal must have a low yield point, to be able to deform and to allow the dissipation of the shear stresses [4-9].

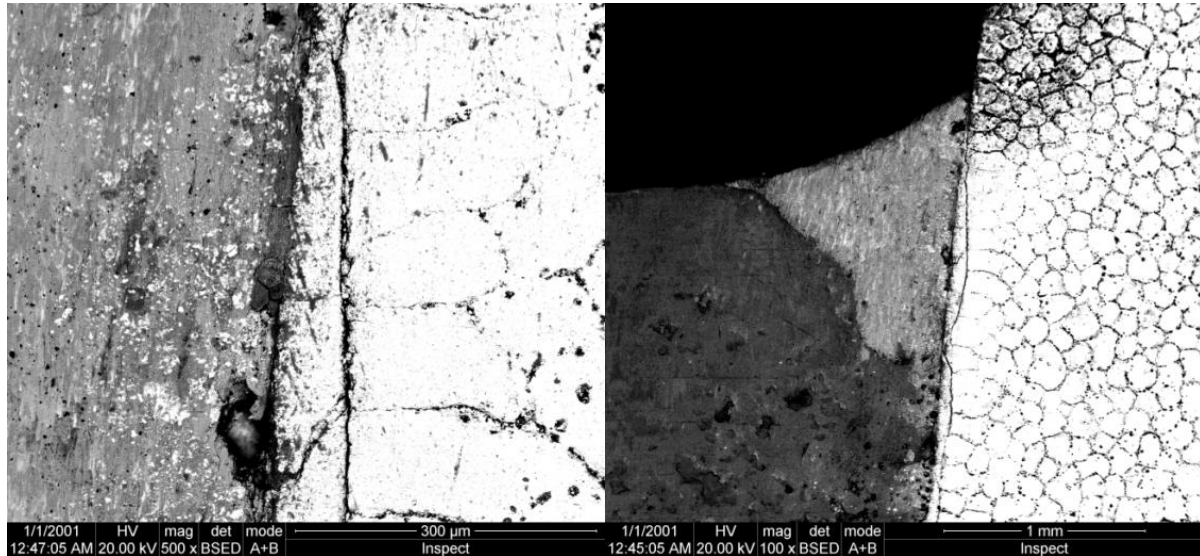


Figure 1. Crack formation in tungsten carbide brazed with steel components (500x, 100x) [3].

To solve this problem, direct brazing of the ceramic cutters on the steel support can be applied by using active filler metals that contain special alloying elements. The addition to regular silver-based brazing alloys of metals having strong affinity for the elements constituting the ceramic can improve wetting and adhesion effects. Thus, metals having strong affinity for oxygen, such as titanium, aluminium, zirconium, hafnium, lithium, silicon or manganese, help the conventional brazing alloys in the wetting of oxide ceramics, without special preparation. Metals that react with silicon, carbon or nitrogen help the wetting of silicon carbide or silicon nitride. The tungsten carbide inserts have high hardness, wear resistance, long life and high cutting performance, but they are prone to breakage during brazing. For this reason, brazing requires a special sandwich filler metal which includes a copper layer to reduce residual stresses.

Another issue that can occur during heating is the oxidation of the tungsten carbide component. The oxidation can occur on both surfaces causing superficial damage and the emergence of micro-cracks. The brazing surface must be completely protected against oxidation by the coating provided by paste or flux. When brazing tungsten carbide with steel components, the heat flow is more effective on the sides and less at the bottom of the joint, as the complete penetration of the brazing alloy in these zones is prevented. Therefore, to balance the heat flow, a few pieces of solder wire can be placed under the tungsten carbide to contribute to the better warming and heat dispersion into the gap, by wetting the entire surface of the parts, from the bottom up [6].

Recent filler materials used for the brazing of tungsten carbide are those alloyed with Ag and Zn (Cd-free), whose drawback is the high potential of evaporation during soldering. For this reason, in the most recent filler materials, Zn is replaced by Sn, Cu, Ni, P and Mn, sometimes accompanied by small amounts of indium or tin, to decrease the melting temperature [10-11].

This paper presents some results obtained during the brazing of dissimilar joints between tungsten carbide and steel, by using different types of Ag-Cu system filler materials alloyed with P and Sn. Phosphorus added to the alloy improves the flowability of the molten alloy, deoxidizing the surfaces (by forming of P_2O_5) and improves mechanical properties by cleaning grain boundaries. Excess phosphorus can decrease the electrical conductivity and it is detrimental for the induction brazing process. Copper combines with tin to form solid solution for concentrations below 15.8% Sn in the temperature range (520-586°C).

For high concentrations of tin (40% Sn), the μ phase occurs together with the α phase. For about 11% Sn, at temperatures in the range of 200 - 350°C, precipitates unstable ε and ε' phases occur, as shown by the Cu-Sn binary diagram [12, 13]. The brazing techniques used were oxygen-gas flame and induction joining. The brazing behavior was analysed in cross sections by optical and electron microscopy. The metallographic analysis enhanced the adhesion features, the length of penetration in the joining gap and the wetting angle. The melting range of the filler materials was measured using thermal analysis.

2. Experimental procedure

In order to establish the optimal regime for the brazing process, two different filler materials and two brazing processes were studied. For each brazing process, 4 tungsten carbide and carbon steel assemblies were prepared for the destructive test (cross sections obtained using the conventional EDM process) in order to study the adherence between the steel parts, tungsten carbide and filler material, the spreading mode into the brazing gap and any possible imperfections.

2.1. Oxy-flame brazing

For the manual oxy-flame brazing process, the experimental filler material used was Ag15CuP6 (cadmium free) (max. 15%wt Ag, max. 82% Cu, max. 3%wt P), 2 mm in diameter and 450 mm long (figure 2). The FH10 flux used in the experimental program is generally used for brazing and soldering, according to EN 1045. The operating temperature range of this flux is 550-80°C, coupled with filler materials that have a melting point below 800°C (typically below 75°C). The condition required is for the selected flux to be active at minimum 50°C, over the liquidus temperature of the brazing alloy. The flux is recommended for homogenous or heterogeneous joints, for components made of carbon or stainless steel, copper, brass, ceramic materials but not aluminium. It is recommended especially for the brazing of aluminium bronzes, steels, tungsten or molybdenum carbide, or whenever protection is needed for components during heating [14-18].



Figure 2. Manual oxy-flame brazing process (a) and filler materials (coated rods) (b).

Before brazing, the wetting test was performed in order to choose the appropriate working regime, the filler material and the cleaning procedure. The water droplet method was applied to test the surface preparation mode. For this purpose, a water droplet is applied on the completely clean surface using a pipette and then it is observed to detect if it has a tendency to agglomerate or to scatter on a larger surface of metal or ceramic. Figure 3 shows clearly that, if a cleaning solution is used, the water droplet spreads on the higher surface both on the surface of the steel part and on the flat surface of the tungsten carbide (figure 3b and 3d).

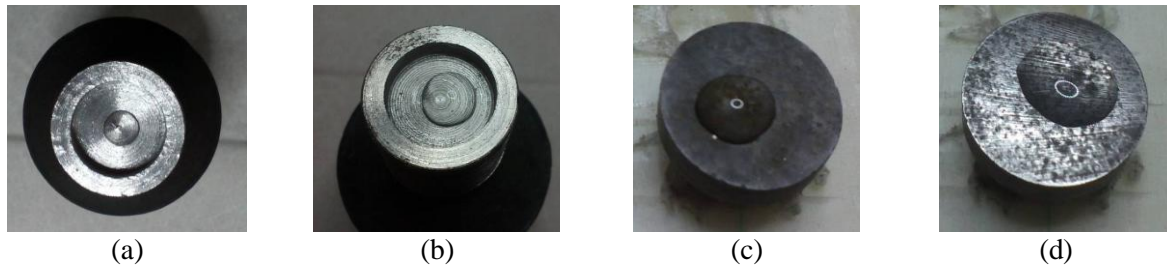


Figure 3. The influence of the cleaning process on the spreading of the water droplet: a) unclean steel surface; b) degreased steel surface; c) tungsten carbide contaminated surface; d) polished and degreased tungsten carbide surface.

The solderability testing of the tungsten carbide is essential before starting the brazing process. During the experimental program, the analysis of the wettability of the filler material was conducted by making small deposits on the surfaces ready to be brazed. It was found that, in the case of tungsten carbide parts, by modifying the conditions of cleaning, the brazed surfaces behave completely different in the case of the 4 analysed samples. In the case of the unclean surface of tungsten carbide, the spreading of the filler material is poor and the droplet of molten metal tends to detach from the surface, the wetting angle being over 90 degrees (figure 4a). The best scattering of the liquid metal is achieved if complete preparation of the ceramic surface was carried out by polishing, scouring and pickling (figure 4d). Based on these assertions, the following succession of phases was introduced into the surface preparation procedure: grinding with 400 grit sandpaper SiC until obtaining a smooth surface, DR-60 solvent degreasing and pickling using brazing flux (FB 10).

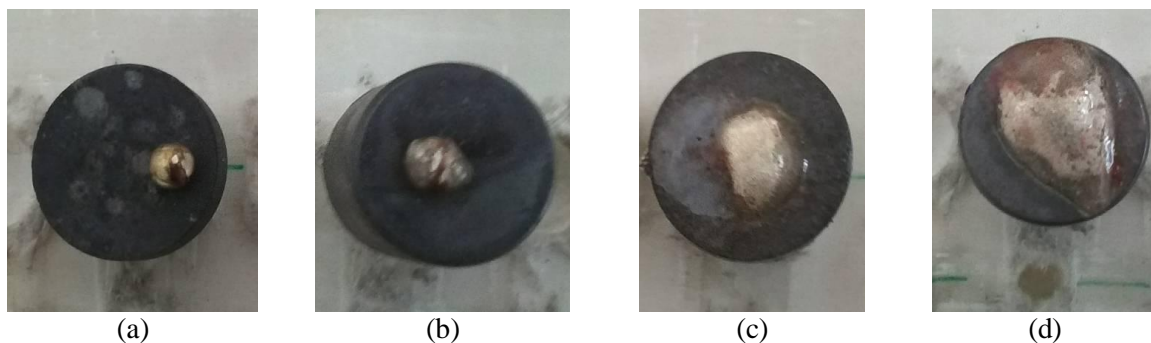


Figure 4. Filler material spreading on the tungsten carbide surface: a) unclean; b) grinded surface; c) degreased surface; d) fully degreased and pickled surface.

The stages of the brazing process were as follows:

- machining the brazing gap (figure 5a);
- application of flux into the brazing gap;
- positioning of the tungsten carbide tip into the brazing gap (figure 5b);
- protecting the free surface of the ceramic body using refractory slurry (dip coating, leak and drying in furnace at 150°C for 1 hour);
- heating the assembly with flame by moving the flame around the steel body until reaching a prescribed preheating temperature, without exceeding the melting temperature of the brazing alloy;
- continuing the heating by positioning the flame on the ceramic tip and adding filler material until a slow refluxing in the brazing gap can be seen;
- slow cooling of the assembly in air;

- removal of the flow excess using hot water (40°C) and alcohol, followed by drying with hot air.

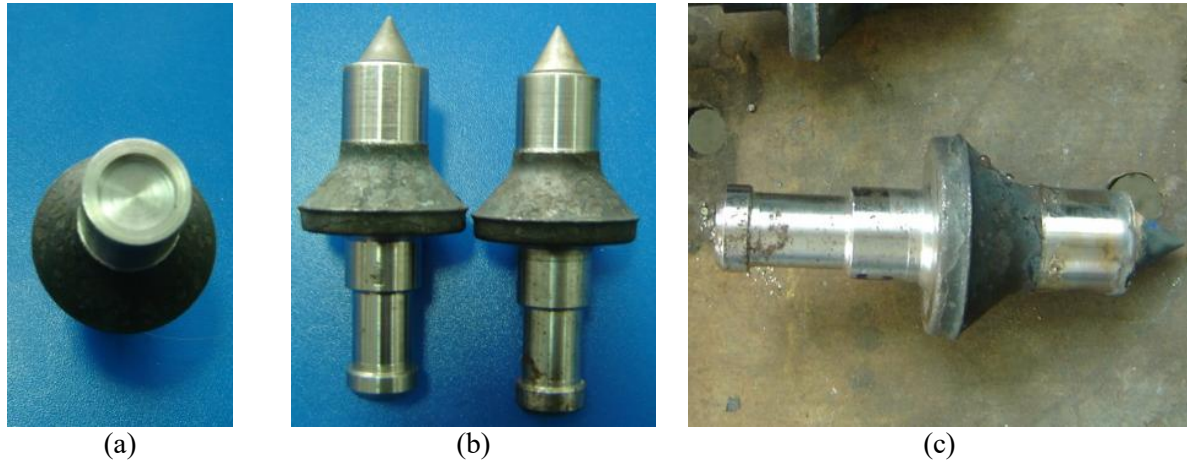


Figure 5. Brazing gap prepared for assembly (a), assembly prepared by oxy-flame brazing (b) and brazed piece (c) [3].

2.2. Induction brazing

A second brazing method used in this study was induction brazing (figure 6), which allows the assembly with the lowest values of actual work time. Brazing is recommended to be performed in protective atmospheres by blowing an inert gas (argon) because tungsten carbide is overheated and exposed to oxidation (figure 6).



Figure 6. Installation for brazing in protective atmosphere and the brazed assembly.

The steps of the induction brazing process are as follows:

- brazing gap processing;
- mechanical and chemical cleansing of assembly surfaces;
- application of flux on the inner surface;
- positioning of filler material at the bottom of the brazing zone;
- positioning of tungsten carbide tip into the brazing gap;
- positioning of the assembly under the inductor coil;
- pre-heating the assembly, without exceeding the melting temperature of the brazing alloy;
- brazing (by increasing progressively the electrical values for the melting of the filler material);
- slow cooling of the assembly in argon atmosphere;

- removing excess flow by polishing with wire brush followed by washing with warm water (40°C) and alcohol, followed by drying in hot air;
- visual inspection of the brazed assembly.

The parameter values for induction brazing are presented in table 1.

Table 1. Brazing parameters.

Sample	Gap dimension, [mm]	Voltage, [V]		Current, [A]		Frequency, [Hz]		Time, [sec]	
		P*	B**	P	B	P	B	P	B
P1	0.1	175	240	7	8	30	30	60	90
P2	0.05	160	240	8	10	30	30	60	120
P3	0.15	160	217	8	8	30	30	60	120

P* - Pre-heating; B** - Brazing

3. Results

After brazing, the assembly was sectioned as well: Cutting transversely to the axis of the assembly, at a distance of 3 mm from the brazing gap, using a cutting precision machine Isomet 4000 and a metallographic disk for hard materials, 0.76 mm thick; Cutting in the cross section of the assembly, through the tungsten carbide, filler material and steel part, using the spark erosion cutting procedure (figure 7).



Figure 7. Spark erosion cutting of the brazed assembly.

The cross sections were then polished using sandpaper SiC, alumina and diamond paste, in order to analyse the joining zone. The analysis of the joining zones was carried out by optical (OM) and scanning electron microscopy (SEM) (figure 8).

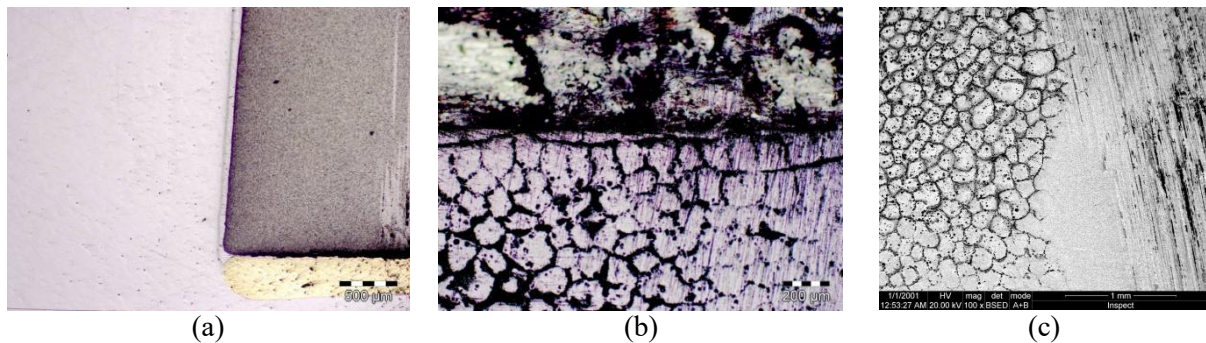


Figure 8. Cross section microstructure of the brazed assembly: a) global picture of the assembly zone, 50x (OM); b) details on transition between the tungsten carbide and steel (200x); c) bonding zone with very good adherence (SEM), 100x.

4. Conclusions

During the brazing of tungsten carbide with steel parts, there must be ensured a good penetration of the molten filler material into the brazing gap, given that the wettability of the two types of material is different and problems related to the bond strength can occur.

Oxy-flame brazing allows getting good quality brazed joints between steel and tungsten carbide, using a Ag-Cu alloy filler material. As silver is in greater proportion (over 30% wt Ag), the brazing behaviour is better and the carbide surface wetting is achieved more easily. The main drawback in this case is the lower productivity.

During induction, brazing requires a protective atmosphere to mitigate the oxidation effects of tungsten carbide. At the same time, excessive heating of tungsten carbide can promote hardness reduction. Recent filler materials used for the brazing of tungsten carbide are those alloyed with Ag and Zn (Cd-free), whose drawback is the high potential of evaporation during soldering. For this reason, in the most recent filler materials, Zn is replaced by Cu, Ni and Mn, sometimes accompanied by small amounts of indium or tin, to decrease the melting temperature.

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