High frequency induction brazing of TiC cermets to steel with Ag–Cu–Zn foil

L. X. Zhang*, J. C. Feng and H. B. Liu

High frequency induction brazing of TiC cermets to steel using Ag–54Cu–33Zn (wt-%) foil at 1073–1273 K for 30–300 s was investigated in the present paper. Both interfacial microstructure and mechanical properties of the brazed joints were studied. Microstructural analysis results show that the interface can be divided into three reaction layers and the formation products on the joint are Cu (SS) (where SS means solid solution), Ni$_2$ZnC$_{0.7}$ and Ag (SS). With increasing brazing parameters, the thickness of Cu (SS)+Ni$_2$ZnC$_{0.7}$ layers beside base metals increases. The relationship between processing parameters and shear strength of the joints indicates that the highest shear strength value 105 MPa can be achieved when the joint is brazed at 1123 K for 60 s.

**Keywords:** High frequency induction brazing, Microstructure, Mechanical properties, Cermets, Steel

**Introduction**

As a new type of materials, synthesised TiC cermets by *in situ* combustion method has attractive properties and great potential to become an important candidate for advanced application owing to its high hardness, excellent wear resistance and high elevated temperature strength. However in some practical applications, the bonding of cermets to metals is necessary. Although the research on the bonding technologies of ceramics to metals is well documented, such as brazing, diffusion bonding, microwave welding and ultrasonic welding, only few reports discuss the bonding of cermets to metals.

In these reports about the bonding of cermets to metals, vacuum brazing is a main joining method. To increase the bonding efficiency and minimise the adverse effects of extensive reaction during vacuum brazing, high frequency induction brazing method is used to bond TiC cermets and steel. The present paper aims to study the process of high frequency induction brazing of TiC cermets to steel with Ag–Cu–Zn foil, and the focus is on the interface microstructure and mechanical properties of the joint.

**Experiment**

The TiC cermets material used in this experiment was synthesised with 60 wt-%TiC and 40 wt-%Ni, the micro-structure of which is shown in Fig. 1a. Commercially obtained steel and Ag–54Cu–33Zn (wt-%) brazing foil (thickness 100 µm) were used in the experiments. The microstructure of the Ag–54Cu–33Zn brazing foil is shown in Fig. 1b.

According to the requirement of shear strength experiment, the size of steel sample was 30×10×5 mm and that of TiC cermets sample was 10×5×3.5 mm. During the brazing experiments, the stacked TiC cermets/Ag–Cu–Zn/steel assembly was placed in the high frequency induction furnace and brazed under an inert atmosphere.

The joined sample was cut perpendicular to the joint interface after the brazing, and the cross-section of the joint was polished with 0.5 µm diamond paste and cleaned in acetone. The microstructure was observed by means of electron probe X-ray microanalysis. The elemental concentration was examined by energy dispersive X-ray spectroscopy (EDS) and the reaction products were determined by X-ray diffraction (XRD). The room temperature shear strength was evaluated with a mechanical testing machine (Instron 1186).

**Results and analysis**

Figure 2 shows the microstructure of the TiC cermets/steel joint brazed at 1123 K for 60 s. For the sake of convenience, the whole interface shown in Fig. 2a is divided into three reaction layers. The black layers beside TiC cermets and steel are respectively called I (namely A zone) and III layer (namely E zone), and the layer between I and III layer is called II layer.

Obviously, II layer is composed of black blocks (C zone) and eutectic duplex phases which are white matrixes (B zone) and black stripes (D zone). In Fig. 2b, a lot of TiC particles flow from TiC cermets into A zone because of the dissolution of Ni matrix in TiC cermets and the existence of convection at TiC cermets/Ag–54Cu–33Zn interface. It also can be known from Fig. 2c that the joining quality of Ag–54Cu–33Zn with steel is good, because there are no voids and cracks observed at the interface between Ag–54Cu–33Zn and steel.
To analyse the reaction products, the average chemical compositions of each zone on the brazed TiC cermet/steel joint were tested by EDS (see in Table 1). According to the EDS result, there are much Cu and a little Zn in A, C, D and E zones. According to Cu–Zn binary phase diagrams and the composition ratio of Cu and Zn in A, C, D and E zones, there is Cu base solid solution, namely Cu (SS) (where SS means solid solution), formed in these zones. It also can be known that B zone is composed of much Ag and a little Cu and Zn. According to Ag–Cu and Ag–Zn binary phase diagrams, there should be Ag base solid solution, namely Ag (SS), existed in B zone.

To determine and verify reaction phases, it is necessary to carry out XRD pattern from the fracture surface of the joint on both steel and TiC cermets sides, the result of which is given in Fig. 3. It can be seen from Fig. 3 that there are not only Cu (SS) and Ag (SS) but Ni₃ZnC₀₋₀.₇ formed. The existence of Ni₃ZnC₀₋₀.₇ compound in Ni–Zn–C ternary system was also mentioned by Bhan before. Based on EDS result above, Ni₃ZnC₀₋₀.₇ intermetallic compound should be in A, C, D and E zones. Thus, the reaction products in black layers (A and E zones) beside substrates are much Cu

<table>
<thead>
<tr>
<th>Zones</th>
<th>Chemical composition, wt-%</th>
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<tbody>
<tr>
<td></td>
<td>Ag</td>
</tr>
<tr>
<td>I layer A</td>
<td>3.83</td>
</tr>
<tr>
<td>II layer B</td>
<td>72.29</td>
</tr>
<tr>
<td>C</td>
<td>5.20</td>
</tr>
<tr>
<td>D</td>
<td>6.09</td>
</tr>
<tr>
<td>III layer E</td>
<td>4.80</td>
</tr>
</tbody>
</table>

1 Microstructures of a TiC cermet and b Ag–54Cu–33Zn brazing foil (A is Cu based solid solution, B is Ag based solid solution – Ag–Zn compound)

2 Microstructure on interface (1123 K, 60 s)

3 X-ray diffraction patterns from fracture surface of joint brazed at 1123 K for 60 s
Figure 4 gives the shear strength of the joints induction brazed with different parameters. It can be seen from Fig. 4 that the shear strength of the joint is not satisfactory when the brazing temperature is low or time is short. Further increasing the brazing temperature or time will result in the appearance of the maximum shear strength values, which is 105 MPa when the brazing temperature is 1123 K and time is 60 s.

From the microstructural point of view, the change of the shear strength is due to the amount change of Cu (SS) and Ag (SS) phases have different hardness values, the amount changes of which can lead to the appearance of maximum shear strength.

4 Shear strength of joints brazed a at different temperature for 60 s and b at 1123 K for different time periods

5 Effect of brazing parameters on microstructure of TiC cermet/steel interface
value. Figure 6 shows the fracture surface morphology of shear test specimens brazed at different temperature for 60 s. It can be seen from Fig. 6 that the joint brazed at 1123 K fractures on two reaction layers (I layer and II layer) after mechanical tests, while the joint brazed at 1273 K fractures on II layer. Because the hardness of Cu (SS) + Ni₃ZnCo₇ (I layer) is higher than that of Ag (SS) (the major product in II layer when the processing parameters are high), the shear strength of the joint fractured on I layer is higher than that of the joint fractured on II layer. That is why the TiC cermet/Ag–54Cu–33Zn/steel joint induction brazed at 1123 K for 60 s obtains a high shear strength value.

Conclusions

TiC cerments and steel can be successfully induction brazed using Ag–54Cu–33Zn brazing alloy at 1073–1273 K for 30–300 s. The induction brazed TiC cerments/steel interface can be expressed as Cu (SS) + Ni₃ZnCo₇ (black layer, A zone)/Cu (SS) + Ni₃ZnCo₇ (black blocks and stripes, C and D zones) + Ag (SS) (white matrixes, B zone)/Cu (SS) + Ni₃ZnCo₇ (black layer, E zone) from TiC cerment to steel side. The maximum shear strength of the joint is 105 MPa when brazed at 1123 K for 60 s, the fracture site of which is located on Cu (SS) + Ni₃ZnCo₇ layer (I layer) beside TiC cerments and Cu (SS) + Ni₃ZnCo₇ + Ag (SS) layer (II layer) in the middle of the brazing alloy.

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References