INFLUENCE OF CARBON FIBRE INTERLAYER ON JOINING ALUMINA-STAINLESS STEEL BY AgCuTi BRAZING ALLOY

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In the paper the influence of short T 300 carbon fibre embedded by two Ag72Cu26.5-Ti1.5 brazing alloy foils as an interlayer is presented when joining alumina and stainless steel. Carbon fibre interlayer lowers the thermal expansion mismatch between both constituents so that cracking of the ceramics does not occur. Shear strength of the joint with the carbon fibre interlayer was 35 MPa in comparison with the one without the carbon fibre interlayer which was 6 MPa. Titanium from the brazing alloy diffuses into both interfaces as well as around each carbon fibre. Similarly, chromium diffuses to the ceramic-brazing alloy interface as well as around each carbon fibre. After brazing neither titanium nor main steel elements (Fe, Ni, Cr) are present in the brazing alloy itself.

VPLYV MEDZIVRSTVY Z UHLÍKOVÝCH VLÁKIEN NA SPÁJANIE OXIDU HLINÍKA A NEHRDZAVEJÚCEJ OCELE SPÁJKOU AgCuTi

V článku sa zaoberáme vplyvom krátkych T 300 uhlíkových vlákien uzavretých v dvoch fóliách spájky Ag72Cu26.5Ti1.5 tvoriacimi medzivrstvu pri spájaní oxidu hliníka s nehrdzavejúcou oceľou. Medzivrstva z uhlíkových vlákien znižuje nesúlad v teplotnej rozťažnosti oboch zložiek tak, že nedochádza k narušovaniu keramiky. Strihová pevnosť spoja s použitím medzivrstvy z uhlíkových vlákien bola 35 MPa v porovnaní so strihovou pevnosťou spoja bez medzivrstvy z uhlíkových vlákien, ktorá bola 6 MPa. Titán nachádzajúci sa v spájke difunduje do oboch rozhraní, ako aj okolo každého uhlíkového vlákna. Podobne chróm difunduje do rozhrania keramika–spájka, ako aj okolo každého vlákna. Po spájaní ani titán, ani iný z hlavných prvkov ocele (Fe, Ni, Cr) sa nenachádza vo vlastnej spájke.

1. Introduction

The application of ceramics in structural components such as turbine engines, combustible engines, etc., has in recent decades received extensive attention due

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to the excellent high temperature strength and resistance to corrosion and wear. However, because of their brittle nature, joining of ceramics to metals is frequently required. As a consequence, the lack of a joining technique has limited their use in many cases.

One of the ways how to obtain good ceramic-metal joint is based on adhesive bonding by active brazing, where the filler alloy contains active element such as titanium [1].

Brazing compared with conventional welding has a great advantage as the base material does not melt or by other words the brazing allows to be applied in the joining of dissimilar materials which cannot be joined by fusion processes due to the metallurgical incompatibility. However, the main problem, which is still present, is the effect of mismatch in thermal expansion between the joined members on the mechanical properties of ceramic-metal directly brazed joints. In most cases, brazing ceramics to metal is performed at elevated temperature. Owing to the large difference in the thermal expansion coefficients of two materials, a significant magnitude of residual stress is produced during the cooling process after joining. Such residual stress created at the bonding zone may cause cracking or reduce the bonding strength. Therefore, it is desirable to minimize the residual stress magnitude. Hao et al. [2] investigated the effects of interlayers of molybdenum and copper on the strength of alumina ceramics and Cr18Ni9Ti stainless steel bonding with Ag57Cu38Ti5 filler metal. When using a molybdenum interlayer, the joint strength could be greatly improved because molybdenum not only reduced the interfacial residual stress, but also did not affect the interfacial reaction between the ceramics and the filler metal. When using copper as an interlayer, the joint strength decreased because copper reduced the activity of titanium in the filler metal, resulting in an insufficient interfacial reaction between the ceramics and the filler metal, and the formation of poor interfacial adhesion. Zhu and Chung [3] tested the effect of addition of 8.4 vol.% short carbon fibres coated by metal to an active brazing alloy on the debonding strength of metal/ceramic joints. This strength increased by 18–28%.

The aim of the paper is to test the influence of carbon fibres in metal filler from the point of view of ceramic cracking in the ceramic-stainless steel joint and of joint strength.

2. Experimental procedure

Alumina ceramics (99.7% purity) in the form of a plate 12 × 12 × 2 mm and two 30 × 10 × 0.5 mm pieces of Cr18Ni10 stainless steel were used as the bonded materials. The filler metal was prepared by a very rapid quenching of a stream of liquid Ag72Cu26.5Ti1.5 alloy to a thickness of 50 μm. The carbon fibre interlayer was prepared by chopping the Torayca T 300 fibres to the length of 2–4 mm, washing them ultrasonically in acetone and drying on filtration paper. Such a "carpet" was embedded by two brazing sheets. Two types of specimens were prepared: joints with brazing metal only and joints with carbon fibre interlayer located between two brazing metal sheets.

Before brazing, the surfaces of all materials to be brazed were carefully ultrasonically cleaned in acetone for 5 minutes. After drying them, all three parts were inserted into a graphite fixture and loaded by 0.4 Pa pressure (Fig. 1).

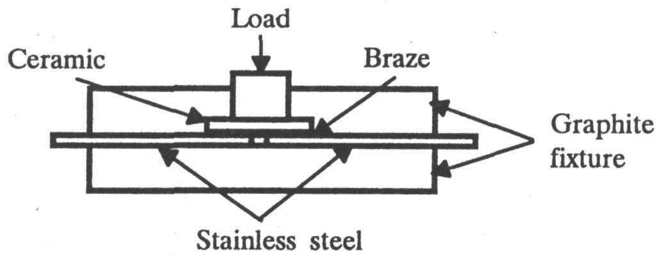

Fig. 1. Schematic arrangement of assembly for specimen preparation.

The assembly of the sandwich joint was placed into a vacuum furnace and heated at 1123–1173 K for 1800 s, then cooled to 873 K at a cooling rate of 3–5°/min, and finally cooled to the room temperature. A vacuum of about 5×10^{-3} Pa was maintained during the brazing.

The joint strength was measured in air at the room temperature by the shear test with the crosshead speed of 0.5 mm/min on the Instron machine. At least three samples of each type were tested. The microstructure and fracture surfaces of the joints were observed and analysed by the scanning electron microscopy (SEM) and the interfacial reaction products were determined by KEVEX Delta IV spectrometer.

3. Results and discussion

For bonds between the dissimilar materials, it is well recognized that a coefficient of thermal expansion mismatch may influence the joint strength considerably through the formation of large stresses and strains at cooling. In all samples joined without an interlayer the cracks were thermally introduced in the ceramics. These were mostly parallel to the interface and only occasionally perpendicular to it. The bond strength of such specimens was about 6 MPa which is lower than the strength of the filler or the ceramics. The fracture path was along the interface between the filler and the ceramics but mostly in the ceramics itself. We assume that the ceramics was cracked due to the internal stress and thermal expansion mismatch before the strength was measured and later the fracture proceeded along this interface already under a low applied load.

The boundary between the ceramics and the filler as well as between the filler and the stainless steel is important for finding out what happened in the bond during the brazing process. The energy-dispersive analysis of X-rays revealed [4] that titanium diffuses into the interface between the ceramics and the brazing alloy (~ 25 w.% Ti after brazing at 1123 K and 0.5 h) as well as to the interface between the brazing alloy and the stainless steel (about the same concentration of titanium at the given brazing condition). Main steel elements (Fe, Ni, Cr) also diffuse to the interface between the ceramics and the brazing alloy forming together with titanium a 7 μm thick zone. No titanium was detected in the brazing alloy itself after brazing.

The thermal expansion mismatch effect is a serious problem because, even if a strong interface could be achieved, joints with large residual stress are easily to be broken. To avoid this thermal expansion mismatch effect, a chopped carbon fibre interlayer was put between the brazing sheets.

Joints of ceramics and stainless steel with the Ag-Cu-Ti brazing alloy containing carbon fibre interlayer were prepared at the same temperature and vacuum condition as those without carbon fibre interlayer. Time of brazing was between 600 to 2400 s. No apparent influence of brazing time on shear strength of the joint was observed. The joining strength, when using carbon fibre interlayer, was 35 MPa. Titanium also in this case diffuses to both boundaries between the braze and the steel as well as between the braze and the ceramics of brazing alloy with much lower concentration (~ 10 w.%) than in the case without carbon fibre in braze (Fig. 2b). Titanium diffuses also to each carbon fibre giving rise to an interaction zone (Fig. 2a,b).

Chromium shows a similar behaviour. Chromium diffuses with high concentration (15%) to the zone around each carbon fibre. Similarly, high concentration of chromium (~ 40%) is in the interface between the ceramics and the brazing alloy (Fig. 2c). It can be supposed that there are reactions of carbon with titanium as well as with chromium which can lead to forming of titanium and/or chromium carbides. A comparison of the diffusion of main steel elements (Fe, Cr, Ni) in the joint with and without carbon fibre interlayer reveals that iron does not diffuse to the ceramic side of brazing alloy with carbon fibre interlayer whereas in the case of joint without the carbon fibre interlayer there is a strong iron component on the ceramic side (~ 55% Fe for joining at 1123 K, 1800 s) [4]. There are neither steel elements (Fe, Cr, Ni) nor titanium in the brazing alloy itself.

Carbon fibre interlayer reconciles the negative influence of thermal expansion mismatch, and the ceramics after joining with the stainless steel is not cracked. After the shear test the fracture starts in the ceramics in a plane parallel to the interface when about 3/4 thickness of the ceramics peeled off followed by a ten-

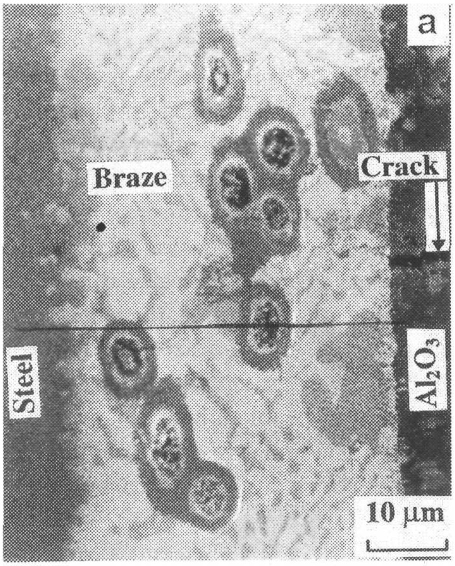

Fig. 2a. Joint of alumina and stainless steel made with AgCuTi brazing alloy and carbon fibre interlayer (1173 K, 1200 s). Trace of profile measurement is shown.

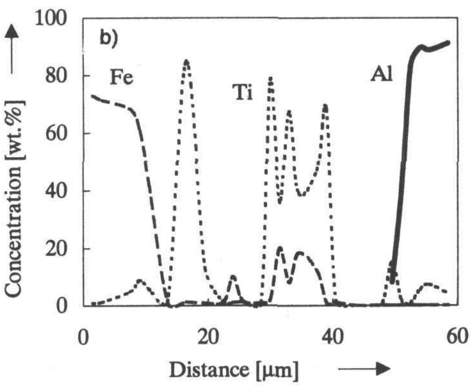

Fig. 2b. Concentration profile recorded by an energy dispersion microprobe for the Al_2O_3/stainless steel assembly (Al, Ti, Fe).

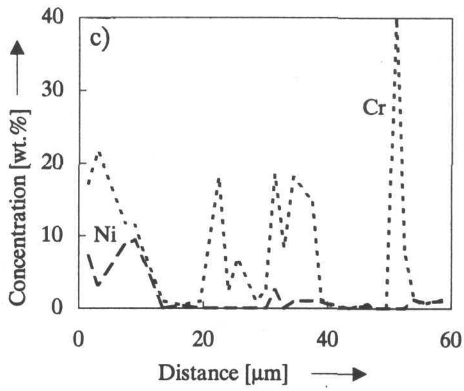

Fig. 2c. Concentration profile recorded by an energy dispersion microprobe for the Al_2O_3/stainless steel assembly (Cr, Ni).

sile rupture of the rest of the ceramics. In this part of the ceramics there exist cracks perpendicular to the interface (Fig. 2a). Adhesion of the brazing alloy to the ceramics is excellent and any fracture occur neither in the brazing alloy nor at any of the two interfaces. Compare with Fig. 3 where longitudinal cracks occurred in the brazing alloy (without a carbon fibre interlayer) near to the ceramics.

In alumina-stainless steel joints the cracks, when using carbon fibre interlayer are perpendicular to the bonding interface (Fig. 4). It is supposed that during the shear test, the applied load results in a tensile stress acting on a plane perpendicular to the interface and is initiated in very brittle titanium and/or chromium carbides.

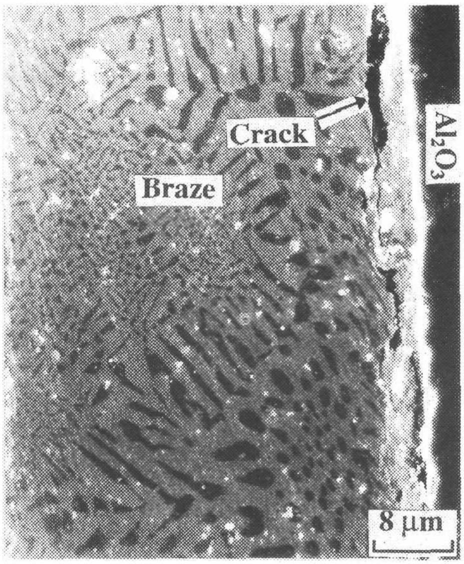

Fig. 3. Joint of alumina and stainless steel made with AgCuTi brazing alloy (1123 K, 1800 s).

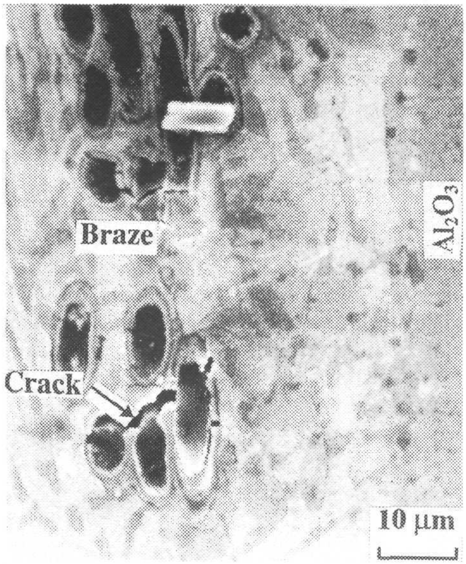

Fig. 4. Cracks close to carbon fibres after shear test of Al_2O_3 – stainless steel joint with AgCuTi filler metal containing carbon fibre interlayer (1173 K, 1200 s).

4. Conclusions

The obtained results can be summarized as follows:

1. An interlayer consisting of short carbon fibre was prepared by sedimentation of short T 300 carbon fibres onto filtration paper and inserted between two foils of AgCuTi brazing alloy.

2. The carbon fibre interlayer lowers the thermal expansion mismatch between ceramics and steel reducing, thus, the interfacial residual stress which imply no cracking of ceramics.

3. The carbon fibre interlayer increases bonding strength. Shear strength of the joint was up to 35 MPa.

4. During the brazing titanium from the brazing alloy diffuses to both interfaces (ceramic-brazing alloy and brazing alloy-steel) and to each carbon fibre forming a zone around each fibre.

5. Chromium, similarly as titanium, diffuses to the interface on the ceramic side as well as around each carbon fibre.

6. After brazing neither titanium nor steel elements (Fe, Ni, Cr) are in the brazing alloy itself.

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