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Mechanism of Ultrasonic Irradiation on Joining of Alumina/Copper

Khalid M. HAFEZ* and NAKA Masaaki**

Abstract

Ultrasonic waves were applied during the brazing of alumina to copper using Zn-Al alloys as filler metal. The intensity of the ultrasonic wave was 1 kW and 18 kHz, the aim of this work being to study the mechanism of ultrasonic waves during the brazing of alumina and copper. The joining mechanism was investigated by measuring the joining strength and analyzing the microstructure at the interface of the joint. The effect of ultrasound was derived primarily from acoustic cavitations, impact and friction between filler and alumina ceramic. This was to improve the wetting between alumina and the filler, it meant that the percentage of wetted area on the alumina surface increased by increasing the application time of ultrasonic waves and this was reflected in improved joint strength. Another advantage of the ultrasonic method is that it can reduce the joining temperature and so reduce the thermal stress in the braze joint.

KEYWORDS: Alumina, Copper, (Ultrasonic waves), (Fracture stress), Brazing, Mechanism

1. Introduction

The study of the effects of ultrasound is a rapidly growing research area, and the use of ultrasound to accelerate chemical reactions in liquid-solid heterogeneous systems has become increasingly widespread.[1,2].

In recent years we have attempted applying ultrasound waves during the brazing of ceramic to metal for the purpose of accelerating the wetting of filler metals during brazing.

Brazing is often the preferred method for joining ceramics to metal because it can provide hermetic seals and the plasticity of the braze accommodates the differential expansion between the ceramic and the metal. But several important problems such as poor wettability and residual stresses due to thermal expansion mismatch between ceramics and the metal still remain unsolved.[3] Ultrasound has a role to play in resolving this problem, the use of ultrasonic vibrations during brazing makes it possible to greatly improve the joint quality.

Understanding the mechanism of ultrasonic irradiation during brazing is very important to optimize the brazing process.

2. Experimental procedure

The materials used in the present investigation were alumina (99.62 mass% Al_2O_3 , 0.1 mass% SiO_2 and others) of 6 mm diameter and 4 mm thickness, and copper (0.03 mass %O) of 6 mm diameter and 4 mm thickness. Braze filler was Zn-Al, containing 5 wt% Al

(Fig. 1 shows the phase diagram). Alumina was first metalized by applying ultrasonic waves in a Zn-Al filler bath.

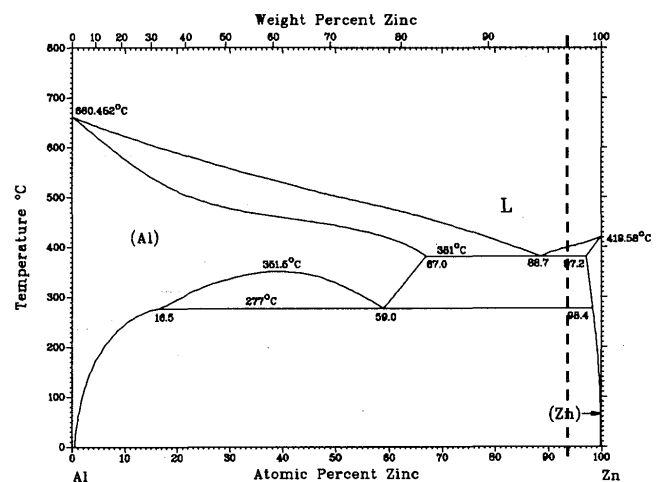


Fig. 1 Phase diagram of Zn-Al binary alloys [6]

The intensity of ultrasonic waves was 1 kW and 18 kHz. The brazing temperature was 723 K. Fig. 2 shows illustration of the brazing equipment. Alumina was lap-joined to copper that was coated with the same filler by applying ultrasonic waves for 10 sec (Fig. 3). The joining strength of the $\text{Al}_2\text{O}_3/\text{Cu}$ joint was evaluated by fracture shear loading using a cross head speed of 1.67×10^{-2} mm/s. The fracture surface and joint cross section was observed and analyzed using SEM, EPMA and EDX.

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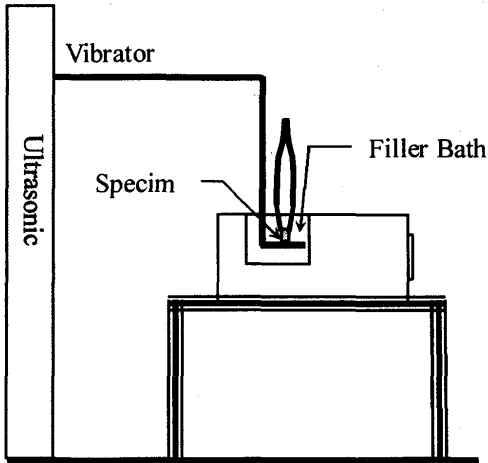


Fig. 2 Metalizing and brazing machine.

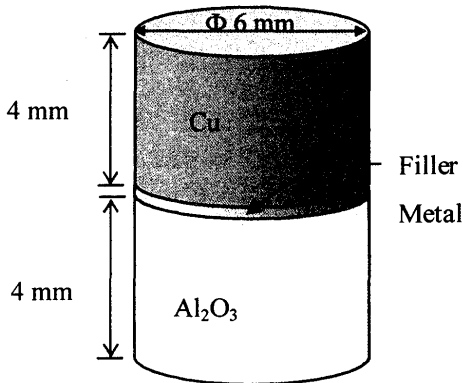


Fig.3 Specimen after joining.

3.Results

3.1 Effect of ultrasonic applying time.

Figure 4 show the change in joining strength of Al₂O₃/Cu joint with application time of ultrasonic wave using Zn-5%Al as filler alloy at a joining temperature of 723 K. Applying ultrasonic waves during brazing improves the strength of the Al₂O₃/Cu joint. For instance, the strength of the joint changes from 18.9 MPa to 65 MPa when the applying time changes from 10s to 90s respectively at a joining temperature of 723 K. Moorhead *et al.* [4] reported that ceramic surface has no thermodynamic driving force for interface formation (wetting), as would be the case of metals in which a higher surface energy surface was being wetted. Applying ultrasonic waves removes the macro air bubbles at the interface between filler and alumina, thus increase the wetting of the filler with alumina. Therefore the improvement in wetting of filler alloys against alumina improves the joint strength.

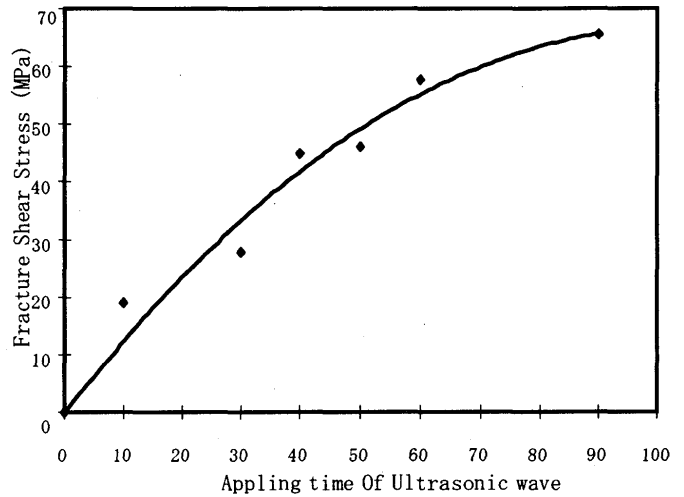
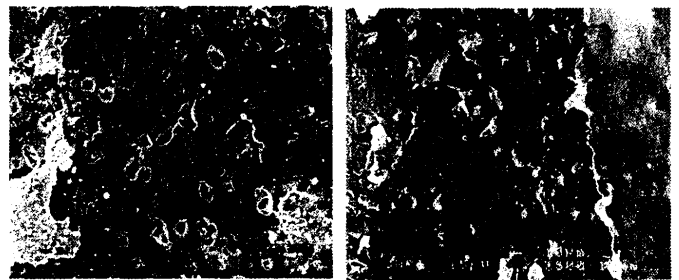


Fig. 4 Change in joining strength of Al₂O₃/Cu joint with application time of ultrasonic waves

3.2 Fracture surface observation

The fracture surface area of braze without and with applying ultrasonic waves was observed. In all brazed joints, the fracture occurs at the filler/alumina interface. This may be due to the metallic bonding between copper and filler being stronger than the bonding between alumina and filler alloy. Observing the fracture surface area of braze without applying ultrasonic (Fig. 5a), shows a smooth surface with many mortises “the surface is almost the same as the alumina surface before brazing”, the filler metal couldn’t wet the alumina surface and it appears as small nuggets at the alumina surface. Observing the fracture surface area of the braze after applying ultrasonic waves (Fig. 5b), shows a rough surface and the mortises filled with filler metal. The filler metal could clearly wet many areas of the alumina surface and it was noticed that by increasing the applying time of ultrasonic waves the strongly wetted area increased (Fig. 6).



(a) without applying of ultrasonic waves (b) with applying of ultrasonic waves for 40s

Fig.5 Fracture surface of Al₂O₃/Cu joint using Zn-5% Al filler, (Al₂O₃ side)

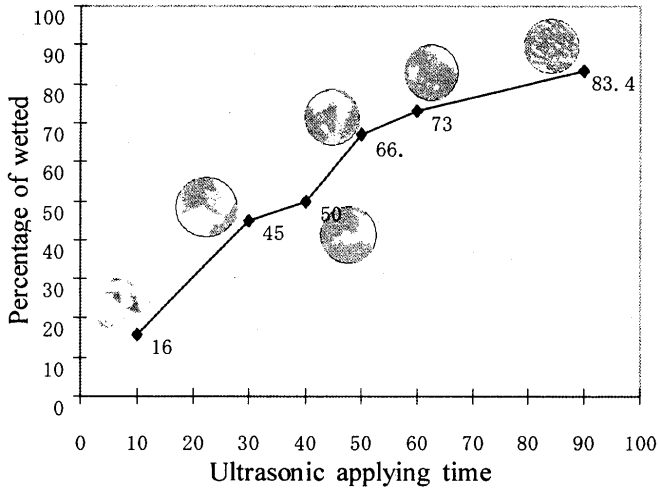
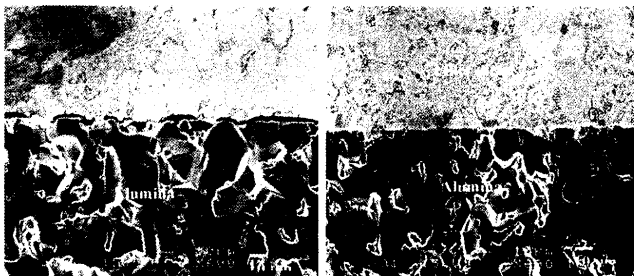


Fig. 6 Effect of ultrasonic applying time on the fracture surface area

3.2 Microstructure of joint interface

The observation of the microstructure of the joint interface without applying ultrasonic (Fig. 7a) shows the incomplete wetting between alumina and filler metal. The filler didn't penetrate the alumina surface, but the microstructure of a joint interface after applying ultrasonic waves (Fig. 7b) shows complete contact between filler metal and alumina free porosity and high wettability. Ultrasound was also found to enhance the penetration of filler metal into the alumina ceramic.



(a) without applying of ultrasonic waves (b) with applying of ultrasonic waves for 40s

Fig. 7 Microstructures of Al₂O₃/Cu joint using Zn-5% Al filler

4. Discussion

Due to the fact that the ceramic surface has very low surface energy, this means that there is no thermodynamic driving force for interface formation (wetting), as would be the case of metals in which higher surface energy surfaces were being wetted. Thus, the creation of a metal/ceramic interface requires more energy than the creation of a metal/metal interface resulting in poor wetting.[3,4] The effect of ultrasonic vibrations on the wetting by the liquid phase of solid substrate is of primary importance. Applying ultrasonic waves during brazing could help to decrease joining temperature which will in turn reduce the thermal stress in ceramic/metal

joints [5,6]. Wetting largely controls the physicochemical process at the liquid-solid interface and eventually the production of high-quality joining.

4.1 Cavitations

Abramov[1] found that the main effect of ultrasonic vibration in liquid metal is cavitations. Cavitations involve the formation, growth, pulsating, and collapsing of tiny discontinuities or bubbles in liquid metal. The presence of various microscopic discontinuities in liquid metal, for example solid, vapor, and gas inclusions will act as "weak" points and provide the nuclei for cavitation bubbles. The bubble will expand and then begin to collapse until a rapid rise in pressure inside the cavity. When the cavitation occurs near a ceramic surface, cavity collapse is non-spherical and drives high-speed jets of liquid into the surface. These jets and associated shock waves can cause substantial surface damage (Fig. 8), and it is clear from figure 5b that the alumina surface will become rougher. It may also be noticed that at an excess of applied ultrasonic time, there is a high probability of cracking occurring inside a ceramic specimen during tensile test of a Al₂O₃/Cu joint.

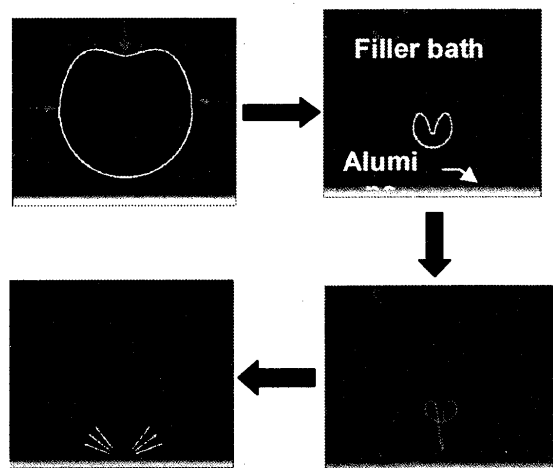


Fig. 8 Formation and collapse of cavities in the filler bath due to ultrasonic waves

4.2 Friction

Ultrasonic irradiation in the filler bath also produces another effect. The breaking up of the ceramic surface can also be produced by viscous friction which arises when the melt moves relative to substrate and by inertial forces due to the added pressure.

4.3 Atoms impact

S.J. Doktycz, K.S. [7] reported that ultrasonic irradiation of liquid-powder suspensions produces another effect, that is high velocity inter-particle collisions into the extended surface. Ultrasonics could have the same effect in liquid metal in that ultrasonic irradiation causes high velocity filler atom collisions with the alumina surface, thus it could improve the wetting between filler and ceramic (Fig. 9).

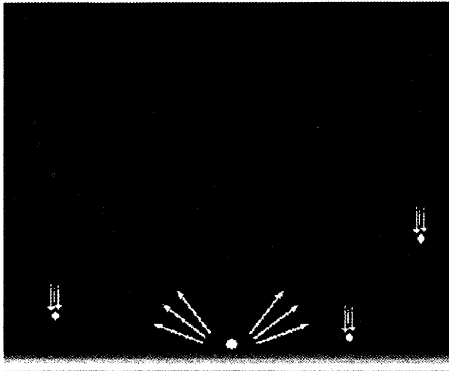


Fig. 9 Shock of filler atoms to ceramic surface

5. Conclusion

The joining of Al_2O_3 to Cu using Zn- 5%Al as filler alloys was conducted by applying ultrasonic waves with the intensity of 1 kW and 18kHz. The joining mechanism was investigated by measuring the joint strength, observing the fracture surface and observing the microstructure of the interface of Al_2O_3 /Cu joint.

Applying ultrasonic during brazing of ceramic to metal could give interface free from defects. The applying of ultrasonic waves could improve the wetting between filler and ceramic, since the percentage of highly wetted area increased from 16% at ultrasonic applying time of 10s to be 83.4% at 90s. The applying time of ultrasonic waves from 10 to 90s also raised the joining

strength from 18.95 MPa to 65.37 MPa respectively. The mechanism of the ultrasonic effect during brazing could be summarised to three points, cavitations and collapse of the bubbles near ceramic surfaces, atoms impacting the ceramic surface with high speed and friction between filler and ceramic. These three factors serve to improve the wetting between ceramic and filler.

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