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Author(s)	Naka, Masaaki; Noma, Junichi
Citation	Transactions of JWRI. 23(1) P.67-P.70
Issue Date	1994-06
Text Version	publisher
URL	http://hdl.handle.net/11094/4357
DOI	
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Joining Ability of Al-Base Filler Metals against Al_2O_3†

Masaaki NAKA* and Junichi NOMA**

Abstract

The wettability of Al and Al-4mass% Cu alloy against Al_2O_3 was evaluated by measuring contact angles and strengths of Al_2O_3/metal joints. The contact angle of the molten aluminum and alloys definitely decreases with the metallizing time at 1373 K in vacuum. The alloys wet and strongly join to the alumina. The metallized Al_2O_3 is brazed to metals of Nb, Ti, Ni and Fe. Nb and Ti which possess the lower thermal expansion coefifcients represent the higher strength of the Al_2O_3/metal joint.

KEY WORDS: (Brazing) (Ceramics) (Ceramic Metals Joining) (Alumina) (Aluminum) (Filler Metal)

1. Introduction

Wetting is important when a liquid phase is presented at the interface between cermic and metal during brazing. It is reported that molten aluminum shows good wettability against alumina[1-3], silicon nitride[4] and silicon carbide[5]. Aluminum was also reported as inserting materia for bonding alumina to steel[6], because aluminum is a soft metal that relaxes the stress generated from the difference in thermal expansion between ceramics and metal. In this work, the wettability of Al and Al-4mass% Cu alloy was investigated by a sessile drop tequnique, and Al_2O_3 was brazed to metals. The joining mechanism was clarified by measuring the strength of the joints and obsering the microstructure of the interfaces.

2. Experimetal Procedures

The metal used were Al and Al-4Cu (mass%) filler metals. Alumina (Al_2O_3) used in the purity of 99.62 mass% contained 0.1 mass% Mgo, 0.11 mass% CaO, and 0.09 mass% of other impuities. The metals for the Al_2O_3/metal joint were Nb, Ti, Ni and Fe. The wettability of Al and Al-4Cu alloy was evaluated by measuring the contact angle in a vacuum below 1.33 mPa. Al_2O_3 of 15 mm dia. and 3 mm thickness and metals of 6 mm dia. and 3 mm thickness were used for a lap joint, where the metals were Nb, Ti, Ni and Fe. For a lap joint, alumina was first metallized with Al or Al-4Cu alloy at 1373 K for 3.6 ks in vacuum, and the lap joint was made at 973-1123 K for 300 s with the filler thinned to 0.1 mm thickness. The joining mechanism was investigated by observing the microstructure of Al_2O_3/metal joint, and analyzing the element distribution of the interface. The strength of Al2O3/metal joint was determined under fracture shear loading at a cross speed of 1.7×10^{-2} mms^{-1}.

3. Results and Discussion

3.1 Wetting of Al_2O_3 with Al and Al-4Cu alloy

The contact angles of Al and Al-4Cu alloy gradually decrease by increasing the holding time at 1373 K, and

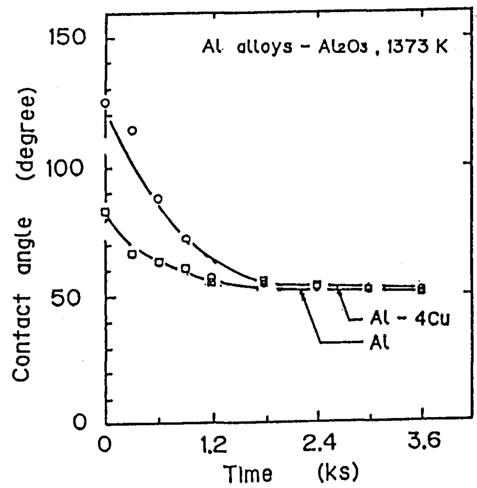

Fig.1 Change in contact angle of Al and Al-4Cu alloy on Al_2O_3 with time at 1373 K.

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Transactions of JWRI is published by Welding Research Institute of Osaka University, Ibaraki, Osaka 567, Japan.

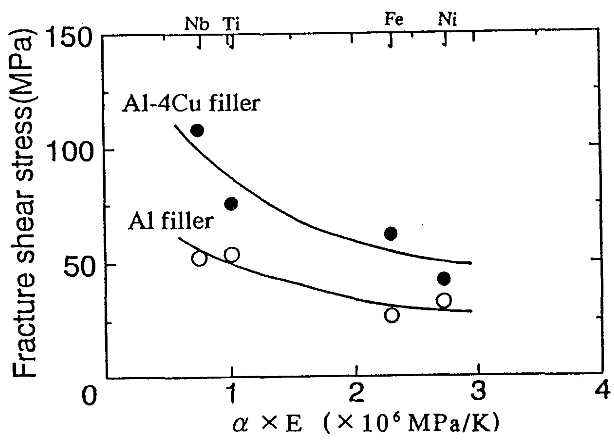

Fig.2 Strength of Al_2O_3/metal joints related to $\alpha \times E$ factor.

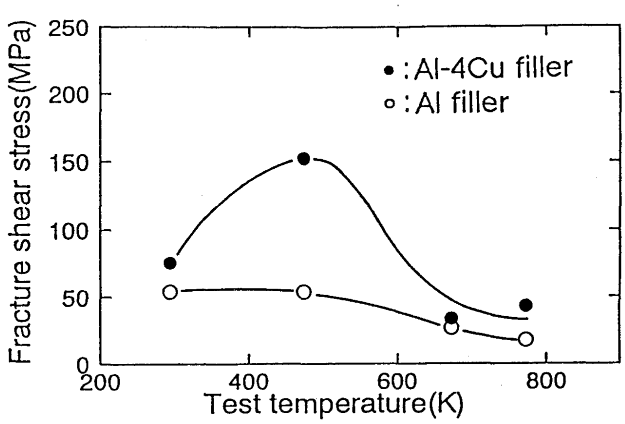

Fig.4 Strength of Al_2O_3-4Cu/Ti joint at eelevated temperatures.

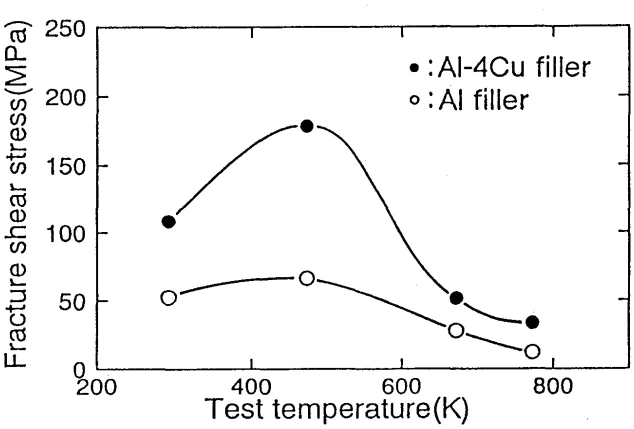

FIg.3 Strength of Al_2O_3/Al-4Cu/Nb joint at elevated temperatures.

reach the equilibrium values for 3.6 ks as shown in Fig. 1. Although the decreasing rates of contact angles with time are differnt, the molten Al and Al-4Cu alloy represent the same equilibrium contact angle of 50 degrees. Since the metals which possess the contact angle below 90 degrees are in a wetting state, the molten Al and Al-4Cu alloy well wet Al_2O_3 at 1373 K in a vacuum. The results of **Fig.1** indicate that Al and Al-4Cu alloy are applicable for brazing for brazing filler metals for alumina.

3.2 Joining of Al_2O_3 to metals

The joining of Al_2O_3 to metal of Nb, Ti, Ni or Fe was conducted using Al or Al-4Cu filler. The metallized alumina was brazed to the metal. The strength of the Al2O3/metal joints is shown in **Fig.2**, where the strength is plotted against $\alpha \cdot E$, where α and E are the thermal expansion coefficient and elastic modulus of metal, respectively. The stress generated from the difference in the thermal expansion between alumina and metal remains in Al_2O_3/metal joint using the soft aluminum base metals. Nb and Ti which possess lower thermal expansion coefficients among metals show the higher strength of Al_2O_3/metal joints. The strength of Al_2O_3/metal joints brazed with Al-4Cu alloy is higher than that of the joints brazed with Al. The strength of

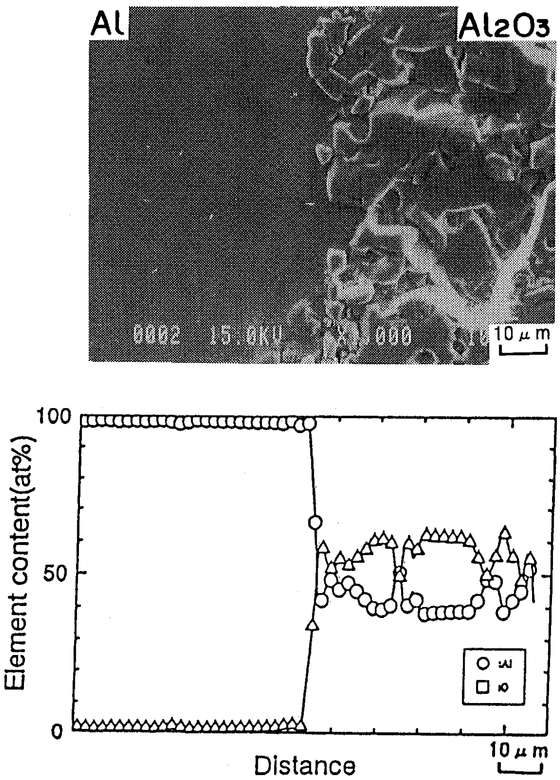

Fig.5 Micostructure of Al_2O_3/Al joint.

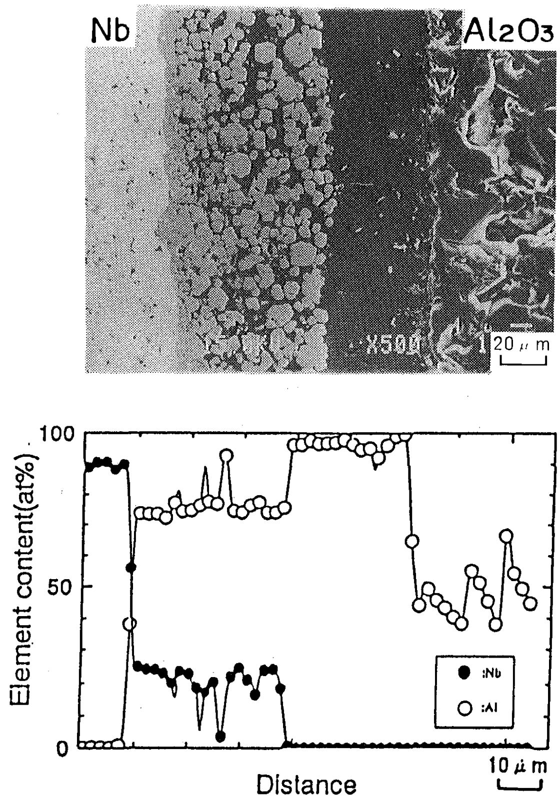

Fig.6 Microstructure of Al_2O_3/Nb joint brazed with Al-4Cu alloy.

the filler metal affects the strength of the Al_2O_3/metal joints. The strength of the joints with Al-4Cu fillers, which possesses the higher mechanical property, is higher than that of the joints with Al filler.

3.3 Strength of Al_2O_3/metal joints at elevated temperatures

Figs.3 and 4 show the strength of Al_2O_3/Nb and Al_2O_3/Ti joints at elevated temperatures up to 800 K. The Al-4Cu alloy that possesses the higher mechanical strength remains at the interface between Al_2O_3 and metal. The superior strength of Al-4Cu alloy is also attributable to the improved strength of the joints at the high testing temperatures. In particular, both joints exhibit the maximum strength at the test temperture of 473 K. The stress relief during heating leads to the rise in strength of Al_2O_3/Nb and Al_2O_3/Ti joints.

3.4 Interface microstructures of Al_2O_3/metal joints.

Fig.5 shows the microstrucute and element analyses of Al/Al_2O_3 after holding at 1373 K for 3.6 ks. No intermediate phase was observed at the interface, and aluminum directly joined with Al_2O_3. The Al-Al_2O_3 diagram[7] also indicates the coexistence of aluminum and alumina at tempertures below the melting point of aluminum. The structure of the Al_2O_3/Nb joint brazed at 1173 K for 300 s using Al-4Cu alloy is shown in **Fig.6**. The structure of the joint wit Al-4Cu alloy is almost the same as that of the joint with Al. The Al-4Cu alloy directly joins to Al_2O_3 without the intermediate phase, and the granular $NbAl_3$ phases are formed at the interface between the Nb and Al-4Cu.

Fig.7 represents the microsturcture of the Al_2O_3/Ti joint brazed at 973 K for 300 s using the Al-4Cu alloy. At the interface between Ti and the Al-4Cu alloy, small amounts of $TiAl_3$ are formed. Comparing Al_2O_3/Ti using Al, the copper in the Al filler promotes the formation of $TiAl_3$ phases at the Ti/Al interface. As shown in **Fig.8**, the two intermediate phases of Ni_2Al_3 and $NiAl_3$ at the interface between Ni and the Al-4Cu alloy are formed in the Al_2O_3/Ni joint brazed at 973 K for 300 s. Compared with the structure of the joint with Al filler, the copper in the Al-4Cu alloy accelerates to form $NiAl_3$ phases at the interface of the alloy side.

Since iron reacts with Al and forms the brittle intermetallics in the Al_2O_3/Fe joint, the iron was platted with Ni of a thickness of 60 μm. At the interface between Ni and the Al-4Cu alloy brazed with 973 K for 300 s, Ni_2Al_3 and $NiAl_3$ are formed, and the Al-4Cu alloy remains at the Al_2O_3 side.

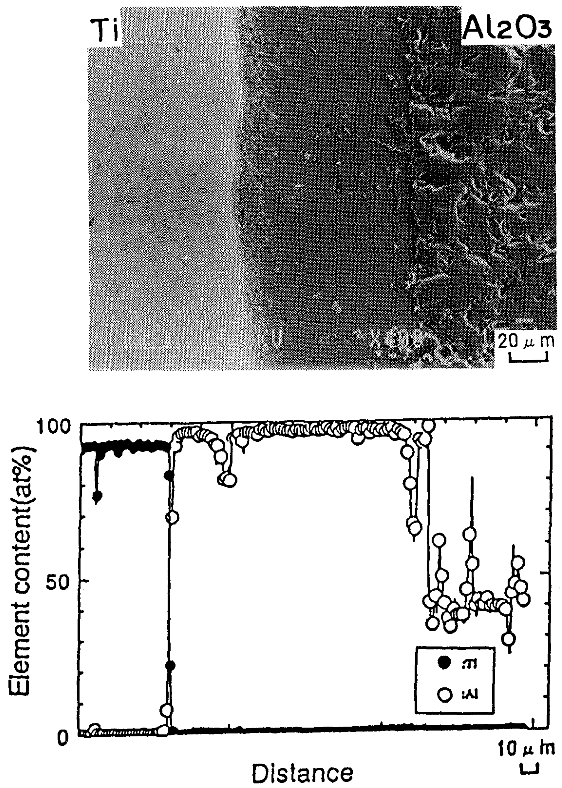

Fig.7 Microstructure of Al_2O_3/Ti joint brazed with Al-4Cu alloy.

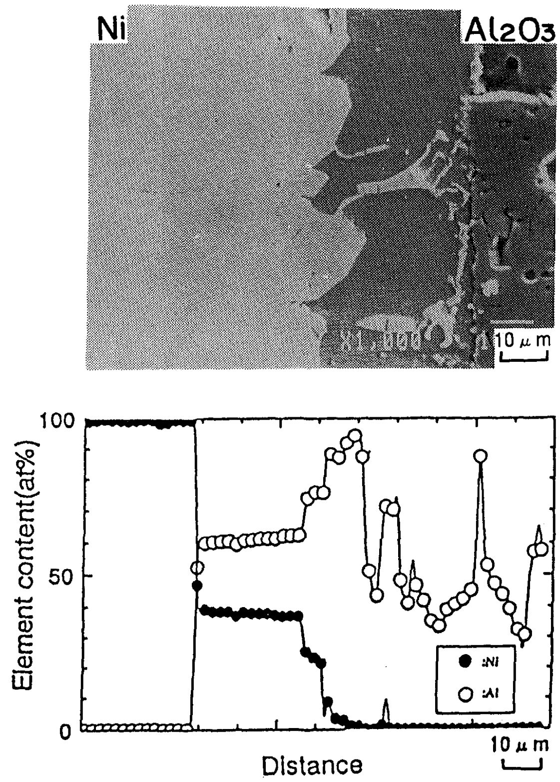

Fig.8 Microstructure of Al_2O_3/Ni joint brazed with Al-4Cu alloy.

4. Conclusions

The joining ability of Al and Al-4Cu alloy against Al_2O_3 was evaluated by measuring the contact angle of the molten metals and the strength of Al_2O_3/metal joints brazed with fillers, where the metals were Nb, Ti, Ni and Fe. The Al and Al-4Cu alloy show a superior wettability against Al_2O_3. Nb and Ti, which possess the lower thermal expansion coefficients among metals, show a higher strength of Al_2O_3/metal joints. The strength of Al_2O_3/metal joints brazed with Al-4Cu alloy is higher than that of the joints brazed with Al.

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