Joining aluminum directly to aluminum nitride ceramics by a continuous-casting-bonding method

Xiao-Shan Ning[1]*, Wen Xia Pan[2], Heping Zhou[1], Katsuaki Suganuma[3]

[1] The State Key Laboratory of New Ceramics and Fine Processing, Department of Material Science and Technology, Tsinghua University, Beijing 100084, China

[2] Institute of Mechanics, Chinese Academy of Science, Zhong-guan-cun Road 15, Beijing 100080, China

[3] ISIR, Osaka University, Mihogaoka 8-1, Ibaraki 567, Japan

ABSTRACT A new continuous-casting-bonding method is adopted in the work to join aluminum on to aluminum nitride ceramic plates directly. The bonding strength of the directly bonded aluminum/ceramic plate was measured and the interface of the plate was analyzed by an ultrasonic detector and a transmission electron microscope. The results of the study show that aluminum can be bonded tightly on aluminum nitride by using the continuous casting bonding method; the peeling strength of the directly bonded Al/AlN joint is over 15kg/cm; aluminum crystals epitaxially grow on the lattice of aluminum nitride crystals, there is not any reaction product at the interface of aluminum and aluminum nitride in the case.

KEY WORDS: Continuous casting bonding, Al/AlN composite, Al/AlN interface

1. INTRODUCTION

Aluminum is both an excellent engineering material and a good electric conductor, hence has been widely used in electronics, electricity, vehicles, aviation and aerospace industry. Latent needs exist reasonably for advanced application to join aluminum on to ceramics that has a lot of excellent properties over metal, such as an excellent tolerances to high temperature, high resistances to mechanical abrasion and to chemical corrosion, and also some unique functions that other material does not have.

Aluminum can hardly be bonded to aluminum nitride ceramics by conventional methods. The contact angle of aluminum to aluminum nitride ceramics is about 128° even at the temperature of 1373 K, much higher than the 90° of aluminum to alumina [1]. In order to join aluminum to aluminum nitride ceramics, the ceramics are usually pretreated to form an oxide layer on surface of them[2].

In the present work, a new continuous-casting-bonding (CCB) method is adopted to join aluminum on to aluminum nitride ceramic plates. The bonding strength and the interface of the directly bonded aluminum/aluminum nitride ceramic plates are studied for evaluating the continuous-casting-bonding method and for elucidating the bonding mechanism of aluminum to aluminum nitride ceramics by the method.

2. EXPERIMENTAL TECHNIQUE

* Corresponding author: Xiao-Shan Ning, Department of Material Science and Technology, Tsinghua University, Beijing 100084, China. Tel: +86-10-62772548; Fax: +86-10-62772549. E-mail: caike@tsinghua.edu.cn (X. S. Ning)

Aluminum oxidizes easily. A thin alumina layer usually exists on surface of aluminum. In order to eliminate the influence of the layer and to join aluminum directly on to aluminum nitride ceramics, the CCB invented by some of the present author [3] is adopted.

Figure 1 shows a schematic cross section drawing of a continuous casting bonding equipment used in the present work. A carbon die is crossed with a carbon crucible, with the inner part of the die and the crucible being linked together through a window opened on the die. Aluminum nitride plates listed in table 1, with a dimension of 36mm×112mm×0.635mm were inserted into the die from entrance at left and aluminum shots 99.99wt% in purity was charged into the crucible. The inside of the equipment was purged with nitrogen gas to decrease the amount of oxygen to be lower than 20ppm before heating the crucible by the electrical heating elements setting around them.

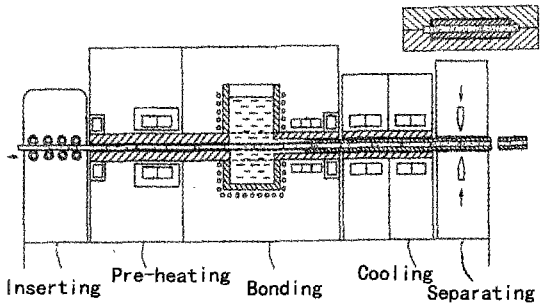

Figure 1. A schematic drawing of a continues casting bonding equipment.

Table1 Supplier and properties of the aluminum nitride plates used in the work

Sample No.	Trade name	Supplier	Sintering additive	Thermal conductivity (W/mK)	Bending strength (MPa)
A	SH-15	Tokuyama Co. Ltd.	Y_2O_3	180	350
B	ATG AlN	ATG Co. Ltd.	Y_2O_3	130	380

After the crucible was heated to over the melting point of aluminum and to a temperature of 1123 K, other aluminum nitride ceramic plates were further inserted into the die from entrance continuously. The ceramic plates were inserted into the crucible, the surface of the plates contacted with the aluminum melt in the crucible and wetted by the melt. Then the ceramic plates were pushed into the right side of the die to solidify aluminum on the plates, to form aluminum layers 28 mm wide and 0.5mm thick on both sides of the ceramic plates. The directly bonded aluminum/ceramic (DBA) plates were separated by cutting aluminum at the gap of two pieces of the ceramic plates.

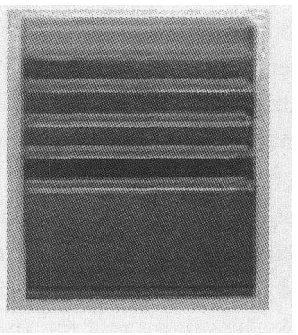

Figure 2. Photograph of some DBA samples.

The interface of the DBA plates was inspected by using an ultrasonic detector made by Hitachi Kenki Co. Ltd. which can indicate the flaw over 0.3mm in diameter in DBA plates. The bonding strength of the interface was measured by a 90° peeling test, performed at a cross-head speed of 830

μm/s. The peeling test samples, 3 mm wide, were cut off from the DBA plates.

The interface was also observed by employing a field emission type analytical transmission electronic microscope (H600FE) made by Hitachi Co. Ltd., with an accelerating voltage being of 100 kV. The specimen was sliced from a DBA plate normal to the interface, grounded to a thickness of about 30 μm thick, and then thinned down by argon ion bombardment.

3. RESULTS AND DISCUSSION

Figure 2 shows a photograph of some DBA samples. Aluminum plates, with a dimension of 28mm×110mm and a thickness of 0.5 mm are bonded on both side of an aluminum nitride ceramic plate. The surface of aluminum plates is smooth and flat, with a metal gloss, the crystal texture with an interlamellar space of about 3 mm formed during the continuous bonding. Figure 3 shows an ultrasonic reflection image of DBA plates. These inspection results listed in table 2 show that there is not any flaw in the DBA plates, dense aluminum plates can be bonded perfectly on to aluminum nitride plates by the CCB method.

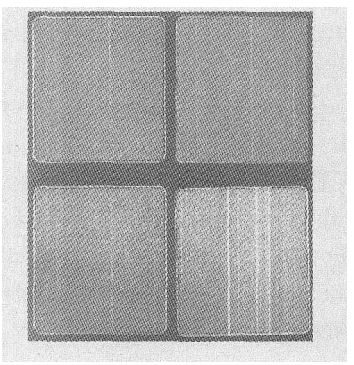

Figure 3. Ultrasonic image of some DBA plates.

Table2 Interfacial properties of AlN DBA plates

Sample No.	AlN plate	Flaw at DBA interface (%)	90° peeling strength (MPa)
A	SH-15	0	17
B	ATG AlN	0	15

The peeling test results listed in table 2 show that all of bonding strength of the joints of aluminum and different kinds of aluminum nitride ceramic plates bonded by the CCB method are over 15 kN/m, being about 5 times as high as that of the joint bonded by the conventional brazing method. During peeling test, the joint bonded by the conventional brazing method broke at interface of aluminum and the ceramic plate, but all of the peeling test samples of the DBA plates broke near the grasp of aluminum but not at interface, that is, the interface strengths of the DBA plates are expected to be higher than those listed in the table. An inherently different bonding mechanism must exists in the two kinds of joints bonded by different methods.

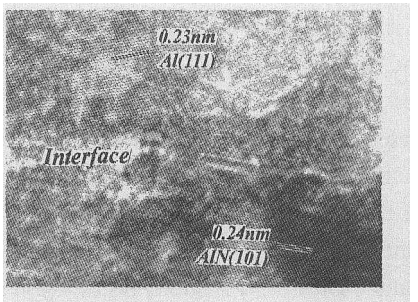

Figure 4. HRTEM image of directly bonded Al/AlN interface.

Figure 4 shows an image of high-resolution transmission electronic microscopy (HRTEM) of a DBA plate. Both the lattice of aluminum and aluminum nitride can be seen clearly. At the interface aluminum crystals grow directly on to the lattice of aluminum nitride crystals, there is not any reaction

product formed at the interface of aluminum and aluminum nitride.

4. CONCLUSIONS

Aluminum can be bonded tightly on to aluminum nitride by using the continuous casting bonding method. The peeling strength of directly bonded Al/AlN joint is over 15kg/cm. In this case the atoms of aluminum crystals epitaxially grow on to the lattice of aluminum nitride crystals, no reaction product forms at the interface of aluminum and aluminum nitride.

REFERENCES:

1. H. Fujii, H. Nakae and K. Okada, Four wetting phases in AlN/Al and AlN composites/Al systems, *Metall. Trans.* 24A, (1993)1391-1397
2. H. Yoshida, Y. Kuromitsu, M. Toriumi and M. Yuzawa, Ceramic substrate used for fabricating electric or electronic circuit, *US Patent* No.5130498(1992).
3. X. S. Ning, C. Nagata, M. Sakuraba, T. Tanaka, K.Suganuma and M. Kimura, Process for preparing a ceramic electronic circuit board and process for preparing aluminum or aluminum alloy bonded ceramic material, *US patent* No. 5965193(1999).

Dr. Xiao-shan Ning earned his B. En and M. En in jiaotong university at Xi'an and Dr. En in Osaka university. He has a 9 years of practical experience in a research laboratory and has a lot of invention. His is now a associate professor at Tsinghua university in China, being conducting the research in ceramics and the bonding of ceramics to metal.