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Statistical Analysis of Alumina/Metal Brazed Joints under Applying of Ultrasonic Waves

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Abstract

Ultrasonic waves were applied during brazing of alumina to different metals using a Zn – 5 mass % Al brazing filler alloy, where the intensity of the ultrasonic wave was 1 kW and 18 kHz.

Ultrasonic waves were also applied during brazing of alumina to copper. First, alumina was metallized by applying ultrasonic waves in a Zn-Al braze bath. Then the metallized alumina was brazed with metal using the same filler alloy.

The tensile strength data obtained were analysed using a statistical Weibull distribution. That distribution was based on weakest-link theory. The application of ultrasonic waves was intended to improve the wetting in the molten Zn-Al bath by accelerating the removing bubbles from the interface between alumina and the filler, and this would help to improve joint strength. The Weibull modulus obtained from this analysis was 5.1.

KEY WORDS: (Ultrasonic) (Brazing) (Alumina ceramic) (Thermal stress) (Fracture stress) (Weibull analysis)

1. Introduction

In recent years an increasing effort has been expended towards the joining of ceramics to metals. Several methods such as solid state bonding and brazing have been reported for joining ceramics to metals. Brazing methods provide an easy process to produce ceramic/metal components with high reliability of the ceramic joint, but several important problems such as the poor wettability, residual stresses due to thermal expansion mismatch between ceramic and the metal still remain unsolved[1,2]. Ultrasonic waves are thought to have an effect in resolving the ceramic stability problem, by creating the necessary driving force for surface wetting [3]. In the present study, the results of brazing of alumina ceramic to a variety of metals were conducted using Zn-Al filler alloy.

Analysis of fracture data in brazed joints can be achieved by applying probabilistic theories. The statistical function most commonly used in analysis of strength data of ceramics is the cumulative distribution function proposed by Weibull[4]. The objective of this work was to improve the brazeability of Zn-Al filler, and analyse the fracture stress values by Weibull analysis to determine the Weibull modulus values (*m*).

2. Experimental

Alumina ceramics of 99.62 mass % Al_2O_3, containing 0.1 mass % SiO_2 were joined to various high purity metals such as Ti, Ni, Nb, Fe, and AISI 304 stainless steel. All materials were used as solid cylinders of 6 mm diameter and 4 mm length. **Fig. 1** shows an illustration of the specimen after joining. Brazing methods were used to join the Alumina with the various metals by using a Zn- 5 mass % Al braze filler.

Prior to joining, the surface of the ceramics was metallized in a Zn-5 wt% Al filler bath at 723 K for 40 seconds under ultrasonic waves (see **Fig.2**).

Ultrasonic intensity and frequency were 1 kW and 18 kHz. The thickness of the metallized layer varied between 0.3 to 0.5 mm. Joining was performed at a temperature of 723 K for a time interval of 15 seconds, and the cooling rate after brazing was 0.6 °C/sec. Bond strength measurements were conducted using a fracture shear test with a 1.67 X10-2 mm/sec cross head speed. **Fig. 3** shows a schematic drawing of the fracture specimen inside the testing fixture.

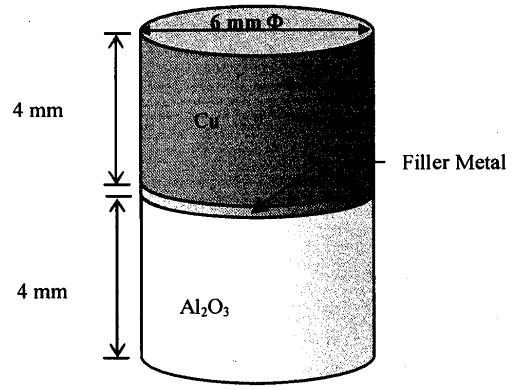

Fig.1 Configuration of the brazed joint.

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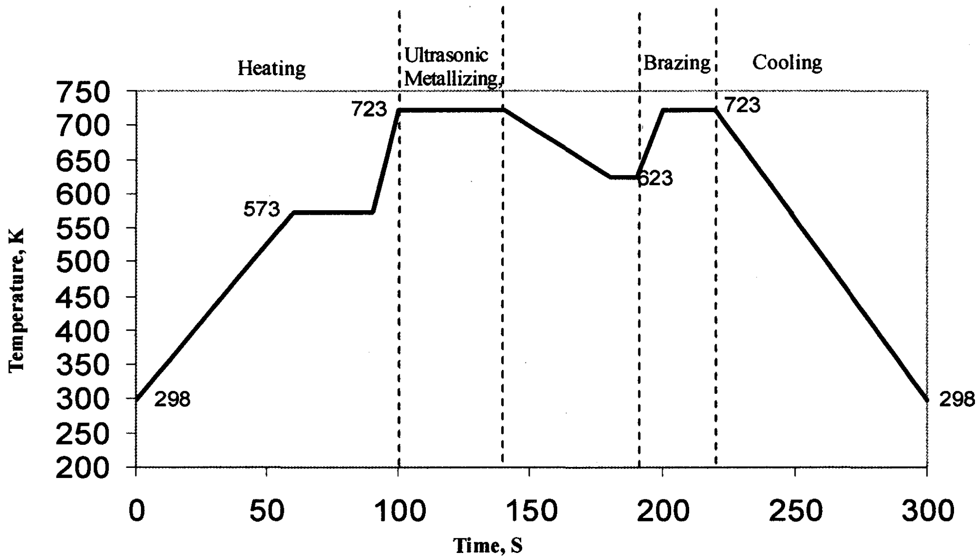

Fig. 2 Schematic illustration of metallizing and brazing procedure.

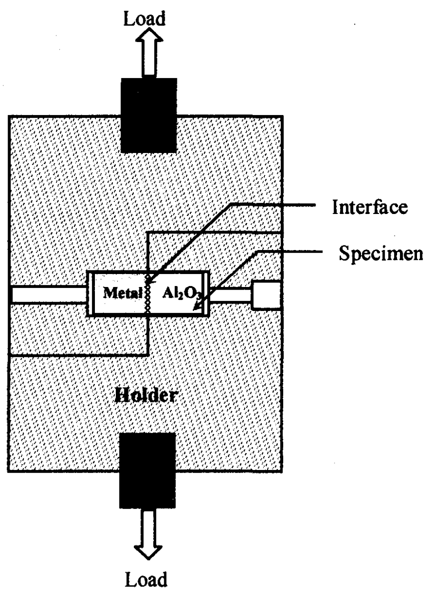

Fig. 3 A schematic of testing jig and specimen fixation for the shear test.

3. Results and Discussions

3.1 Bond strength measurements

A ceramic surface has a low thermodynamic driving force for interface formation (wetting), in contrast to metals which have a higher surface energy surface and hence are wetted [1]. Applying ultrasonic waves removes the macro air bubbles at the interface between filler and alumina thus increased the wetting of the alumina by the filler. The improvement in wetting improves the joint strength [5].

In most metal/ceramic joints the mismatch of the elastic constant and thermal expansion coefficients of the bonded materials will cause a large stress concentration at the edge of the interface when the joint is mechanically and thermally loaded [6].

This can be explained by the influence of residual stress on the joint strength, using a simple analytical formula that assumes elastic behavior. The normal residual stress parallel to the interface can be calculated as follows.

$$\sigma_m = -\sigma_c = \frac{E_m E_c}{E_m + E_c}(\alpha_m - \alpha_c)\Delta T \qquad (1)$$

Where m and c denote metal and ceramic, ΔT is the temperature difference between the solidus temperature of the filler and room temperature, α is the thermal expansion coefficient, and E is the elastic modulus[6]. According to eq.1, the thermal stress for alumina/filler and metal/filler are listed in **Fig. 4**, it can be noticed that the thermal stress at the alumina/filler edge more than thermal stress at the metal/filler edge **(Fig. 5)**.

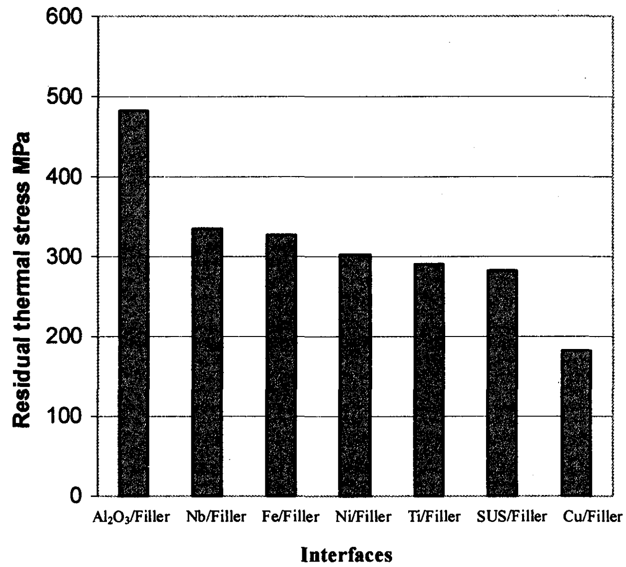

Fig. 4 Normal thermal stress at the interfaces.

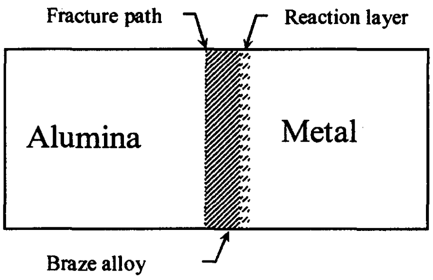

Fig.5 Illustration of brazed joint showing the fracture path.

3.2 Weibull Distribution

The tensile strength data obtained from Al_2O_3/Cu joints are analysed using a statistical distribution. The Weibull distribution is often used for this purpose. The Weibull distribution is based on the weakest-link theory, according to which the flaw in the material with highest stress intensity factor governs the strength of the material [7)].

To describe the strength behavior of ceramics, suppose that under a stress σ there is a probability P_s, that stress varies from point to point in the component;

$$P_s = \exp\left[-\int_v \left(\frac{\sigma-\sigma_u}{\sigma_o}\right)\frac{dV}{V_o}\right] \qquad (2)$$

If the material is under constant stress

$$P_s = \exp\left[-V\left(\frac{\sigma-\sigma_u}{\sigma_o}\right)^m\right] \text{[4,8,9]} \qquad (3)$$

σ_u is a critical stress below which fracture does not occur (called "threshold strength").

σ_o is a normalizing parameter of no physical significance.

m is the Weibull modulus, which reflects the degree of variability in strength, the higher the value of *m* is the less variable is strength.

Fracture probability (P_f)= 1-P_s;

$$P_f = 1-\exp\left[-V\left(\frac{\sigma-\sigma_u}{\sigma_o}\right)^m\right] \qquad (4)$$

For the purpose of plotting data it is convenient to take logarithms twice and rearrange thus,

$$\ln\ln(1-Pf) = -\ln V + m\ln(\sigma-\sigma_u) \qquad (5)$$

$$P_f = i/(N+1) \qquad (6)$$

Where i is the sample rank and N is number of samples. It is recommended to put the threshold strength to zero, for the interest of safety and for consistency in the definition of the Weibull modulus [9)].

$$\ln\ln(1-Pf) = \ln V + m\ln\sigma \qquad (7)$$

The Zn5Al filler alloy has a low working temperature and should promote good wetting with alumina ceramic [5,10]. So using a filler with 5% Al, a brazing temperature 723 K and applying ultrasonic waves for 40 s could be a representative way to calculate the Weibull modulus for Al_2O_3/Cu joint.

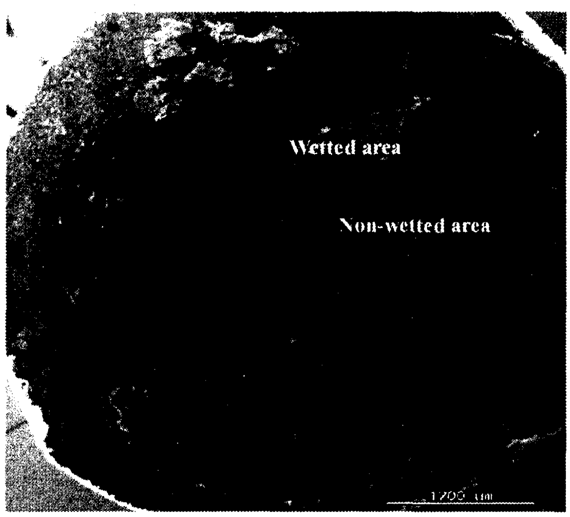

Fig. 6, Fracture surface of Al_2O_3 Joint using Zn-5%Al filler, (Al_2O_3 side).

The room temperature strength results of the brazed Al_2O_3/Cu joints are shown in **Table 1**, the tested samples which broke in the ceramic are excluded from the analysis, while the results obtained only in the case of fractured at the interface. SEM observations of the corresponding fracture surfaces at the ceramic sides of joints broken macroscopically at the interface revealed that the fracture path alternated between the ceramic and the braze filler **(Fig. 6)** and thus reveal wetted and non-wetted areas. **Figure 7** shows a plot of fracture probability (P_f) as ordinate and Fracture stress (σ) as abscissa. The Weibull modulus *m* is given by the value of the slope and is 5.1 for these joints. This value of *m* is common for ceramics. It was noticed that there is spread within the samples of 20% -37% about the mean, the mean strength being 47.54 MPa.

Table 1 Tensile strength dada for Al_2O_3/Cu joint suing Zn-5% Al as filler.

Rank	1	2	3	4	5	6	7	8	9	10
stress	34.70	35.50	38.00	40.30	43.90	45.10	45.60	45.60	46.30	47.20
Pf	0.05	0.10	0.14	0.19	0.24	0.29	0.33	0.38	0.43	0.48
Rank	11	12	13	14	15	16	17	18	19	20
stress	48.00	48.30	49.30	50.00	50.80	52.30	55.00	57.20	58.00	59.70
Pf	0.52	0.57	0.62	0.67	0.71	0.76	0.81	0.86	0.91	0.95

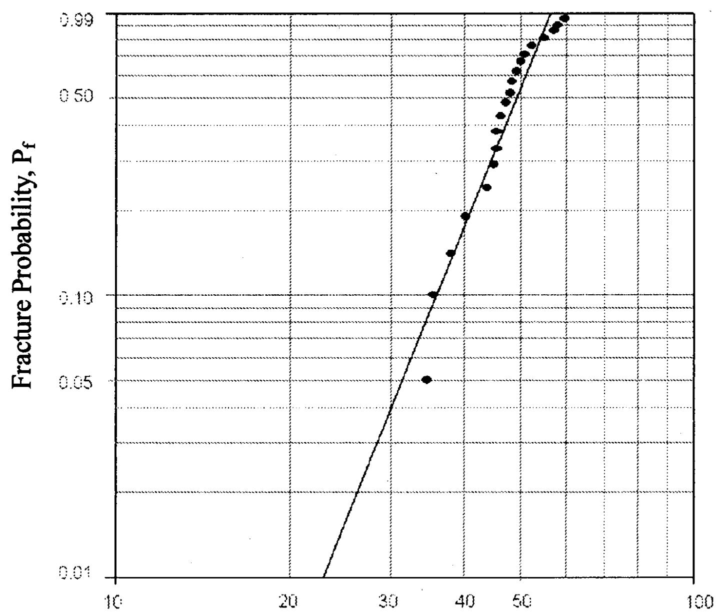

Fig.7 Weibull strength distribution of Al_2O_3 /Cu braze joint using Zn-5%Al as filler metal.

4. Conclusion

A Zn-5 wt% Al brazing filler was used to join alumina ceramics to different metals such as Ti, Ni, Nb, Fe, and AISI 304 stainless steel under the application of ultrasonic wave during brazing:-

Brazed joints of alumina to metal were improved by applying ultrasonic waves. Ultrasonic could promote the wetting of filler alloy against alumina and raise the joining strength.

Since the thermal stress at the alumina/filler interface is higher than metal/filler interface, all alumina/metal joints fractured at the alumina/filler interface.

The tensile strength data obtained using Zn-5% Al filler alloy are analysed using a Weibull statistical distribution. The Weibull modulus *m* obtained from this analysis was 5.1 which is common for ceramics.

References

[1] M.G. Nicholas and D.A.Mortimer Material Science and Technology, pp. 657-665, Sep. (1985).
[2] A.J.Moorhead and W.H. Elliott, ASM Handbook, ASM International, pp.948-958, V6,(1993).
[3] Khalid M.Hafez and M. Naka,, Trans. JWRI, pp. 177-180, V. 31 No. 2, (2002).
[4] A.D.Papargyris, Estimator Type and Population size for Estimating the Weibull Modulus in Ceramics, Journal of the European Ceramic Society, pp.451-455, 18 (1998).
[5] M. Naka and Khalid M. Hafez, Journal of Material Science ,pp. 3491-3494, Vol. 38, No. 16 (2003).
[6] S.D. Peteves, M.G. Nicholas "Journal of American Ceramic Society" pp1553-1562, Vol. 79, 6 (1996)
[7] S.N. Patankar, Journal of Materials since letters, p 1176, V10 (1991)
[8] R.W.Davidge, Mechanical Behaviour of Ceramics, Cambridge University Press, pp. 133-139
[9] Herwig PETERLIK, Relationship of strength and Defects of ceramic Materials and their treatment by Weibull Theory., Journal of the Ceramic Socity of Japan, pp. S121-S126 ,8,(2001).
[10] B. Wielage and F. Trommer "Technical J. for Welding and Allied Processes" pp.185-187, 4 (2003)