Transactions of the Materials Research Society of Japan 27 [4] 739-742 (2002)

Effect of Surface Profile on Diffusion Bonding of Copper

Airu Wang[1*], Osamu Ohashi[1], Norio Yamaguchi [1], Yasuo Higashi[2], Nobuteru Hitomi[2] and Kunio Takahashi[3]

[1] Graduate School of Science and Technology, Niigata University, Niigata 950-2181, Japan

* Fax: 81-25-262-7373, e-mail: wangairu@gs.niigata-u.ac.jp

[2] High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba 305-0801, Japan

[3] Graduate School of Science and Engineering, Tokyo Institute of Technology, Tokyo 152-8552, Japan

Oxygen-free high conductivity copper rods with three kinds of surface profiles were selected. Diffusion bonding of the selected specimens were carried out in a high vacuum from room temperature to 700℃. The results showed that the joint strength depended on bonding temperature and surface conditions (such as roughness and waviness). The large strength of joints was obtained for the bonding specimens with small roughness and waviness because such specimens could provide the larger bonded area. Furthermore, bonded area at bonded interface was calculated by the two-dimensional model. The calculated values are consistent with the results obtained by the experimental measurement at a wide range of surface roughness.

Key words: diffusion bonding, roughness, waviness, tensile strength, bonded area

1. INTRODUCTION

Diffusion bonding is a solid state joining process in which two metallic surfaces are brought into contact each other, and permits the production of high quality joints with little or no need for post-bonded machining [1]. It is a useful technique, and has been extensively investigated in the past few decades [1-6].

It is important to consider the optimal conditions for diffusion bonding in order to obtain high quality bonded joints, such as bonding temperature, pressure, time, surface profile, and so on. Nishiguchi et al. suggested the modeling analysis of solid-state diffusion bonding process to predict the optimal bonding temperature, pressure, and time [7-10]. On the other hand, several experimental studies had also been carried out to obtain the optimal conditions of diffusion bonding [11-14]. In view of the integrity of the final bonded joints, the roughness and waviness of the surface which is to be joined by solid-state diffusion bonding will play a vital role. However, little work has been carried out on the effect of surface roughness and waviness on the joints properties by diffusion bonding.

In the present study, oxygen-free high conductivity copper rods with three kinds of surface profiles were bonded in a high vacuum from room temperature to 700℃. Effect of surface roughness and waviness on tensile properties of the joints was investigated. The bonded area was estimated by experiment measurement and using the two-dimensional model calculation.

2. EXPERIMENTAL PROCEDURE

Oxygen-free high conductivity copper was used and bonded in the form of cylindrical specimens with a diameter of 12 mm and length of 30 mm. The surface to be used for bonding was prepared by three kinds of methods, i.e. lathe machining, buffing and high precision machining. Surface characterization to obtain the roughness of the surfaces by three kinds of processing methods was carried out using a Taylor Hobson Form Talysurf Series 2. The assessment length used was 1 mm at a traverse speed of 0.5 mm/s with a diamond stylus. Figure 1 shows the typical surface-asperities results of three kinds of processing methods, and Table 1 gives the corresponding values of surface roughness.

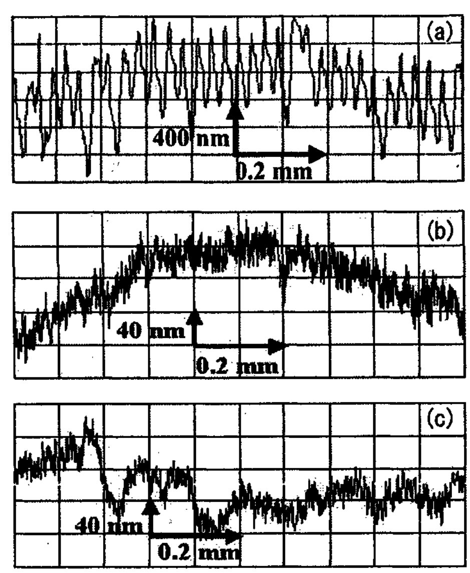


Fig.1 The typical surface-asperities results. (a) by lathe machining; (b) by buffing; (c) by high precision machining.

Table I Roughness values of surface by three kinds of processing methods.

Parameter	Lathe	Buffing	High precision machining
Ra (nm)	256	24	19
Ry (nm)	1235	130	89

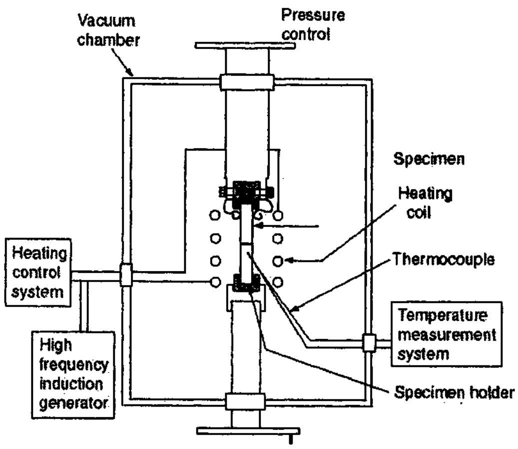


Fig.2 Schematic diagram of the bonding apparatus.

Diffusion bonding was carried out in vacuum chamber at a pressure of 10^{-5} Pa. Bonding pressure applied to the specimens was 600 N. Bonding temperature range was from room temperature to 700℃. Holding time was 20 min. Figure 2 shows the schematic diagram of the bonding apparatus.

Tensile tests of the bonded joints were carried out using AG-250KNG autograph tester. The tensile velocity of 1 mm/min was used. After the tensile test, the fractured surfaces were observed using JSM-6400 scanning microscope.

3. RESULTS AND DISCUSSION

In order to evaluate the deformation, specimen diameter variation before and after bonding was measured. Bonding deformation was calculated from the increase in cross-sectional area at the joint interface. Figure 3 shows the effect of bonding temperature on bonding deformation. The deformation has not been observed at bonding temperature up to 500℃. Therefore, to obtain non-deformable diffusion bonding of copper for load of 600 N, it is expected that the diffusion bonding was carried out below 500℃.

Figure 4 shows the variations of tensile strength with bonding temperature for the three different surfaces. It can be seen that the specimen prepared by lathe machining method (R_y: 1235 nm) can not be bonded at the temperature of 450℃. But the specimens prepared by high precision machining method (R_y: 89 nm) and by

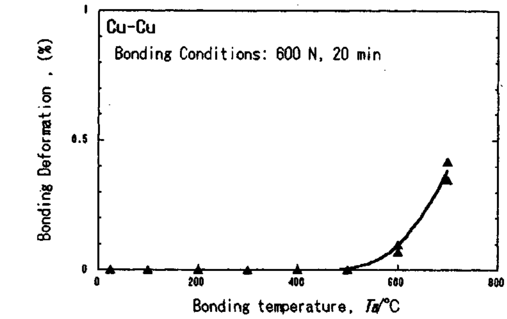


Fig.3 Effect of bonding temperature on deformation ratio.

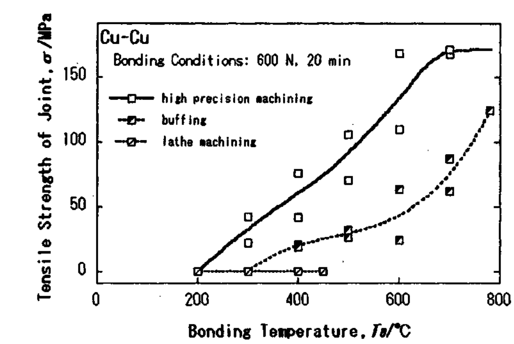


Fig.4 Effect of bonding temperature on the tensile strength of joints for surfaces by three processing conditions.

buffing method (R_y: 130 nm) can be bonded at the temperature of 300 ℃. Increasing in bonding temperature, the tensile strength of two kinds of joints increases. Furthermore, specimens by high precision machining method exhibit larger strength values than that by buffing method. At bonding temperature 500℃, tensile strength of specimen by high precision machining method is three times to that by buffing method. For the specimens prepared by high precision machining and buffing method, their surfaces roughness has not very large difference, but the difference of tensile strength is very large. In order to understand the cause of the difference of tensile strength, the bonding areas for each condition are measured.

After the tensile test, the fracture surfaces of specimens prepared by high precision machining method and by buffing method were observed by means of optical microscopy and SEM. The first, we can determined the bonded zone in the specimen from the optical micrographs using Area Meas program. Second, using SEM micrographs (more than 8 different regions) taken from the bonded zone, fine non-bonded sections can be taken off. Then, the actual bonded area can be obtained by calculating with the results from optical and SEM micrographs. Figure 5 shows the relationship between bonding temperature and bonded area, and the results with the roughness of 1.0~1.5 μm from Nishiguchi [8] is also shown. Increasing in bonding temperature, the bonding area increases. It can be seen that there is more bonded area for specimens prepared by high-precision machining method than those by buffing method at bonding temperature below 600℃. At 500℃, bonded area ratio of specimens prepared by high-precision machining method and buffing method is 67% and 40%, respectively. From these results, it can be seen that the difference of bonded area is an important cause of the different tensile strength at two processing conditions. But, it can also be seen that tensile strength of joints is not in proportion to the bonded area (refer to Fig.4 and Fig.5). It is because of the effect of the diffusion condition of surface oxide film to matrix materials and the bonding temperature. We will report in the other paper about this effect. For the difference of bonded area, it is subject to the surface waviness of specimen to be bonded. For the specimen prepared by high precision machining method, it has smaller surface waviness (as shown in Fig.1(c)), so it can obtain large bonded area. On the other hand, the specimen by buffing method has a spherical surface (as shown in Fig.1 (b)), and it is only bonded at the middle part. However, when bonding temperature is up to 700℃, the bonded area of two kinds specimens is similar. We think because there are large plastic deformation at 700℃, and it can obtain an complete contact throughout the bonding interface.

Nishiguchi et al. developed a two-dimensional model (as shown in Fig.6) for solid state bonding process. The bonding process is assumed to be achieved by four

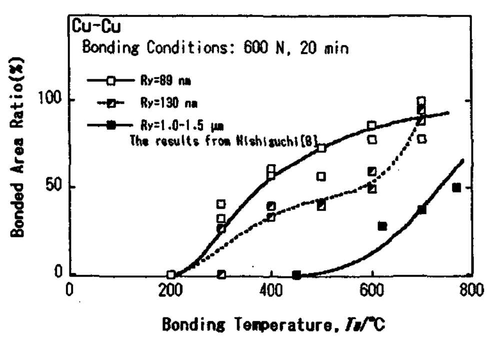


Fig.5 Relationship between bonding area ratio and bonding temperature for surfaces by two processing conditions.

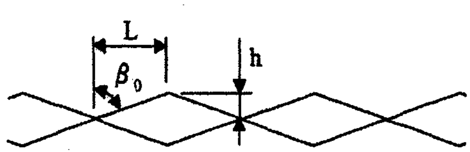
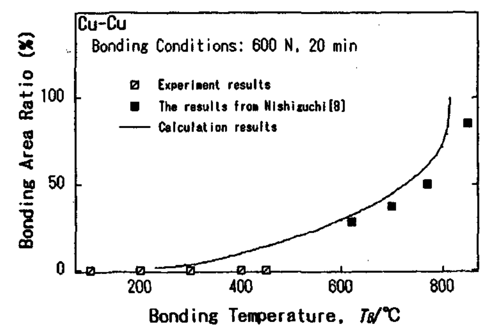
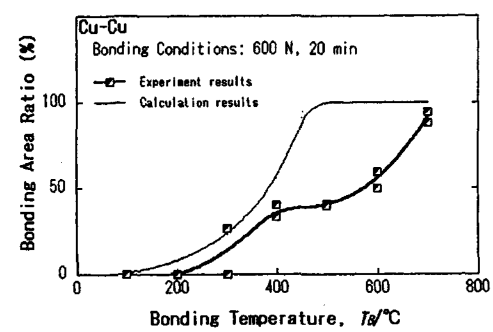


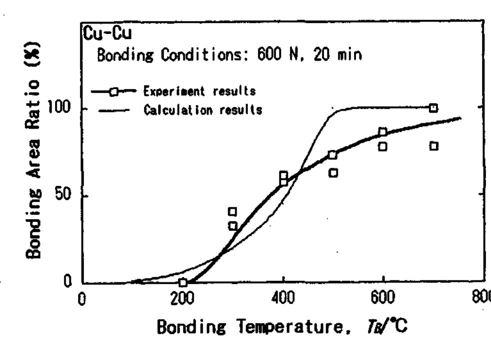
Fig.6 Illustration of a two-dimensional model for bonding process (cross section)[5].



(a)



(b)



(c)

Fig.7 Comparison between experimental and calculated bonding area ratio for specimen by three kinds of processing conditions. (a) lathe machining, (b) buffing, (c) high precision machining method.

fundamental mechanisms: plastic deformation, creep deformation, interface diffusion and volume diffusion. The numerical analysis based on this model makes it possible to estimate the relative contributions of the four bonding mechanisms to the bonded area [7-9].

From actual surface-asperities (as shown in Fig.1), parameters L, h values of specimens were determined. The results are L_a= 14.9 μ m, h_a= 516.8 nm for the specimen by lathe machining method; L_b= 1.26 μ m, h_b= 21.9 nm for that by buffing method; and L_c= 2.25 μ m, h_c= 16.6 nm for that by high precision machining method, respectively. Using the obtained parameters and two-dimensional model program, the bonded area of specimens was calculated. The calculated results along with the results obtained by experimental measurement at various bonding conditions are shown in Fig.7. Figure 7(a), (b) and (c) give the comparison between the actual bonded area and the calculated one, using specimens by lathe machining, buffing and high precision machining method, respectively. In attention, it is only considered an idealize surface for the two-dimensional model calculation, but has not considered the effect of waviness. For the specimens prepared by buffing method and by high precision machining method, there was the similar surface roughness, so that the similar calculated results were obtained. In fact, the specimen by buffing method had a spherical surface. Even if for the specimen by high precision machining method, there was also the waviness. Therefore, there were the differences between the calculated results and the results obtained experimental measurement. Increasing in the bonding temperature, increase of the bonded area was difficult due to the effect of waviness. For the only low bonding temperature, the experimental results of the bonded area were consistent with the calculated ones for the specimens with the three different surfaces. Furthermore, for the specimen by high precision machining method, the temperature range with the consistent results was wider than that by buffing method, because it had a small waviness. From these results, we think that bonded area can be estimated using the two-dimensional model calculation for the copper specimens at a wide range of surface roughness.

4. CONCLUSIONS

Diffusion bonding of oxygen-free high conductivity copper rods with three kinds of surface profiles was carried out from room temperature to 700℃. Effect of surface roughness and waviness on the properties of the joints was investigated. The bonded area was estimated by experiment and calculation. The results obtained were summarized as follows.

(1) The bonded area can be estimated at wide range of surface roughness of copper specimens using the two-dimensional model calculation.

(2) The large strength is obtained for the specimen with small roughness and waviness.

ACKNOWLEDGMENTS

Authors are grateful to the partially financial support from "Sasaki Environment Technology Promotion Foundation".

REFERENCES

[1] O. Ohashi, *J. Jpn. Weld. Soc.*, **69**, 465-474 (2000).
[2] T. Enjo, *J. Jpn. Weld. Soc.*, **50**, 335 (1981).
[3] Z. X. Guo and N. Ridley, *Mater. Sci. Technol.*, **3**, 945-953 (1987).
[4] Y. Kashiba and K. Machida, *J. Jpn. Weld. Soc.*, **59**, 100-104 (1990).
[5] O. Ohashi, *J. Jpn. Weld. Soc.*, **62(7)**, 10 (1993).
[6] O. Ohashi, *JHPI*, **33**, 197-203 (1995).
[7] K. Nishiguchi and Y. Takahashi, *Quarterly J. Jpn. Weld. Soc.*, **3**, 303-309 (1985).
[8] K. Nishiguchi and Y. Takahashi, *Quarterly J. Jpn. Weld. Soc.*, **3**, 309-315 (1985).
[9] K. Nishiguchi, Y. Takahashi and K.Takahashi, *Quarterly J. Jpn. Weld. Soc.*, **4**, 586-592 (1986).
[10] Y. Takahashi, N. Minemoto, K. Inoue and K. Nishiguchi, *Quarterly J. Jpn. Weld. Soc.*, **14**, 674-681 (1996).
[11] Y. Huang, F. J. Humphreys, N. Ridley and Z. C. Wang, *Mater. Sci. Technol.*, **14**, 405-410 (1998).
[12] A. S. Zuruzi, H. Li and G. Dong, *Mater. Sci. Eng.* **A 270**, 244-248 (1999).
[13] H. Sueyoshi and T. Nishida, *Mater. Trans.*, **42**, 1945-1951 (2001).
[14] H. Somekawa, H. Hosokawa, H. Watanabe and K. Higashi, *Mater. Trans.*, **42**, 2075-2079 (2001).

(Received December 20, 2001; Accepted January 31, 2002)