

Diffusion Bonding/Superplastic Forming of Ti-6Al-6V-2Sn/SUS 304 Stainless Steel/Ti-6Al-6V-2Sn

J.S. Shyu and T.H. Chuang

The superplasticity of the Ti-6Al-6V-2Sn alloy for different temperatures was evaluated by single-sheet free blowing. The optimal superplastic temperature for the Ti-6Al-6V-2Sn alloy was found to be 850 °C. Diffusion bonding of Ti-6Al-6V-2Sn and 304 stainless steel was carried out in a vacuum. The interface of both bonded alloys was examined by EPMA. The concentration profile of Ni exhibited a peak at the interlayer and a valley adjacent it, whereas that of Cr exhibited a peak where Ni showed the valley. X-ray diffraction (XRD) analyses showed that the Fe_2Ti, NiTi, and CrMn intermetallic compounds and the Cr element formed at the interface. The thickness profiles of the blown specimens were measured and compared with theoretical calculations.

Keywords
diffusion bonding, dome height, free blowing, interface, line scan, superplastic forming, thickness profile, Ti-6Al-6V-2Sn

1. Introduction

A DUPLEX phase titanium alloy, Ti-6Al-6V-2Sn was developed to improve the strength of the Ti-6Al-4V alloy. With more β phase stabilizer elements of V, the β phase transformation temperature of Ti-6Al-6V-2Sn (948 °C) is lower than that of Ti-6Al-4V (1000 °C). The suitable superplastic forming temperature of Ti-6Al-4V is from about 900 to 950 °C (Ref 1). The application of superplastic forming/diffusion bonding for Ti-6Al-4V has been widely used (Ref 2, 3), but there have been few reports on superplasticity in Ti-6Al-6V-2Sn. This study evaluates the superplasticity of this titanium alloy.

For the superplastic forming of a thin circular diaphragm clamped at the periphery and subjected to one-sided hydrostatic pressure, Ragab (Ref 4) showed that the thickness distribution of the material is:

$$S/S_0 = 1/(1 + \sigma Y_p/a^2)^2$$

where S is instantaneous thickness of sheet, S_0 is initial thickness of sheet, σ is height of bulge annulus or section during free bulging, Y_p is height of bulge during free bulging, and a is die aperture radius or half-width. See Fig. 1.

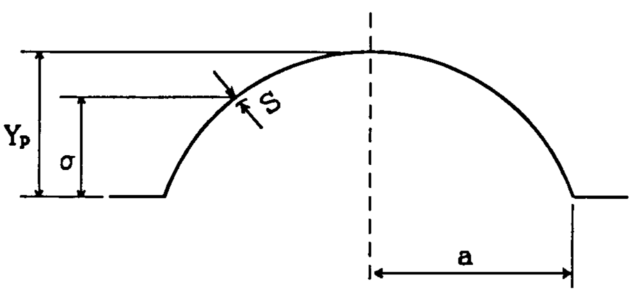

Fig. 1 Geometry of deformation during free bulging of circular sheet

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The theoretical models of Ragab are compared with experimental results.

For practical use in industry, it is difficult to achieve the required combination of properties in a single material, for example, strength and corrosion resistance. One way to solve this problem is to use bimetallic materials; i.e., steel of high strength metallurgically bonded to a thin corrosion-resistant clad alloy (Ref 5). When the bonding was finished, Hinotani showed that $TiNi_3$, TiNi, and Ti_2Ni were formed across the Ti/Ni interface (Ref 6) and that in Ti/Fe couples, intermetallic compound layers of $TiFe_2$ and TiFe were formed. B. Aleman et al. (Ref 7) carried out a detailed examination of the bonding interface of AISI 316L stainless steel and Ti-6Al-2Mo-4Zr-2Sn alloy. They found that several interphases, including Fe_2Ti, FeTi, and others, formed at the interface. In the present study, diffusion bonding of Ti-6Al-6V-2Sn and 304 stainless steel was carried in vacuum by hot press. The interface after bonding was examined by electron probe microanalysis (EPMA). Furthermore, the applicability of the diffusion bonding/superplastic forming technique for manufacturing of Ti-6Al-6V-2Sn hollow spheres was evaluated.

2. Experimental Procedures

Ti-6Al-6V-2Sn plates, 1 mm thick, were cut by a laser beam into two diameters: 28 and 38 mm. (The actual forming diameters are 20 and 30 mm.)

First, the optimal superplastic temperature of Ti-6Al-6V-2Sn was tested by single-sheet free blowing for the plate with a diameter of 38 mm (Fig. 2). Second, the peripheries of two Ti-6Al-6V-2Sn sheets were diffusion bonded by inserting a 304 stainless steel ring between them (Fig. 3a). The height of the 304 stainless steel ring was 6 mm. Further, for the plates of two diameters, the outer diameters of the rings were 38 and 30 mm,

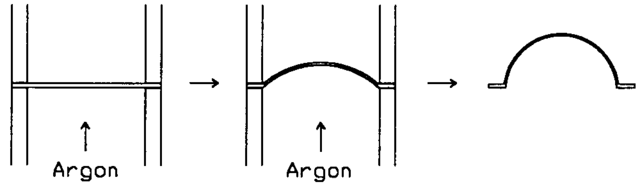


Fig. 2 Free blowing of Ti-6Al-6V-2Sn sheet

and the inner diameters were 28 and 20 mm. Diffusion bonding was conducted in a 25 kW, 20 kHz induction vacuum furnace under the conditions of 890 °C for 1 h under 2000 psi in 10^{-5} torr vacuum and furnace cooling (Fig. 3b). The bonding interface between Ti-6Al-6V-2Sn and 304 stainless steel was then analyzed by EPMA. After bonding, a hole was drilled in the 304 stainless steel ring, and a stainless steel tube was then welded to it (Fig. 3c). The bonded components were then superplastically formed by free blowing with argon pressure in a vacuum furnace (Fig. 3d). Under various blowing conditions, the deformation heights and thickness distributions of the Ti-6Al-6V-2Sn sheets following the diffusion bonding/superplastic forming process were measured.

3. Results and Discussion

For the single-sheet free blowing of 38-mm-diam Ti-6Al-6V-2Sn (the actual forming diameter was 30 mm), Fig. 4 shows the forming dome heights for various forming temperatures and forming times under the blowing condition of 120 psi argon pressure (1 MPa = 145 psi). For 15 min, the dome height increased with the temperature. The surfaces of the specimens were rough after blowing above 950 °C. This phenomena was attributed to the extensive grain growth that occurred during superplastic forming above the β transformation temperature of Ti-6Al-6V-2Sn (948 °C). Thus, temperatures above 948 °C are unsuitable for superplastic forming of Ti-6Al-6V-2Sn. As the forming time increased, the difference in the dome heights for various forming temperatures became more obvious. The two curves representing the data of 30 and 60 min show that 850 °C was the optimal superplastic forming temperature for Ti-6Al-6V-2Sn.

The diffusion-bonded Ti-6Al-6V-2Sn/304 stainless steel interfaces were analyzed by EPMA. Figure 5 shows the line scan profiles of the major elements of both alloys. A comparison of the profiles of Ni and Cr in Fig. 5(d) shows that there was a peak in the profile of Ni on the interlayer formed at the interface and that, beside the peak, there was a valley in the profile near the 304 stainless steel side. The Cr profile, however, exhibited a peak at the same position where Ni formed a valley. Some bonded specimens fractured at the bonding interface. These fractures were presumably due to the thermal stress, which resulted from the difference of the thermal expansion coefficients of the bonding components. The newly formed, two fractured surfaces were flat enough for the XRD analysis. Figure 6(a) shows the x-ray spectrum for the fractured surface on Ti-6Al-6V-2Sn. Fe_2Ti and NiTi formed. Figure 6(b) shows the spectrum for the fractured surface on 304 stainless steel. Cr and CrMn formed. (The Mn content of 304 stainless steel is 0.98 wt%.)

The diffusion-bonded Ti-6Al-6V-2Sn/304 stainless steel/Ti-6Al-6V-2Sn components were then free blown at 850 °C with various pressures and for various time periods. Figure 7(a) and (b) show the average forming dome heights of the spherelike component, 30 and 20 mm diam, blown under different conditions. Two typical spherical products with different diameters are shown in Fig. 8.

For the thickness measurement, the specimens were cut symmetrically across the center, and the thicknesses of the Ti-6Al-6V-2Sn plates were measured and plotted along the diameter. Figure 9(a) and (b) show the thickness distributions of the superplastically blown Ti-6Al-6V-2Sn hemispheres for the 30 mm and 20 mm diam spherelike components. The thickness profiles calculated from the Ragab equation are also presented. For all the specimens, the measured values were higher than the calculated ones, except those near the ends of the diameter. The deviation of the experimental results from the theoretical calculations arises from the assumption that the material of the plate clamped at the periphery is fixed. That is, the volume of the plate that underwent superplastic deformation remained constant. However, in a real situation, due to the compression of

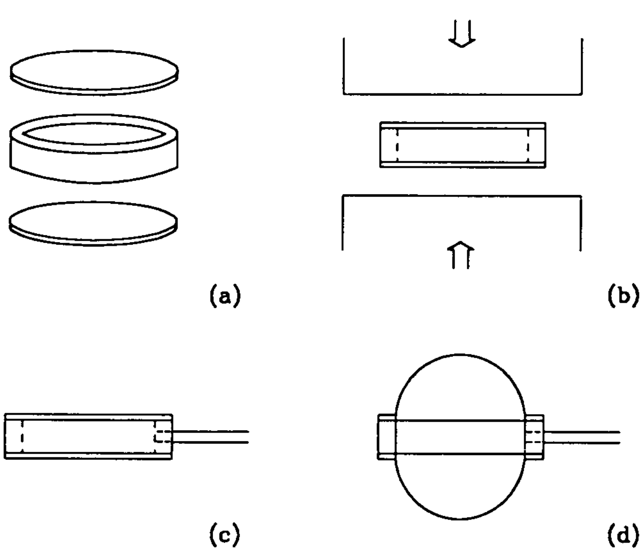


Fig. 3 Manufacturing processes of the Ti-6Al-6V-2Sn hollow sphere

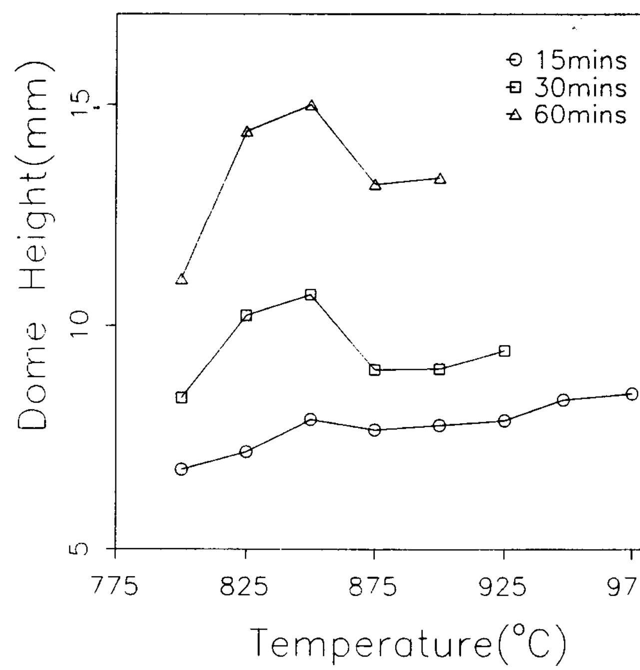
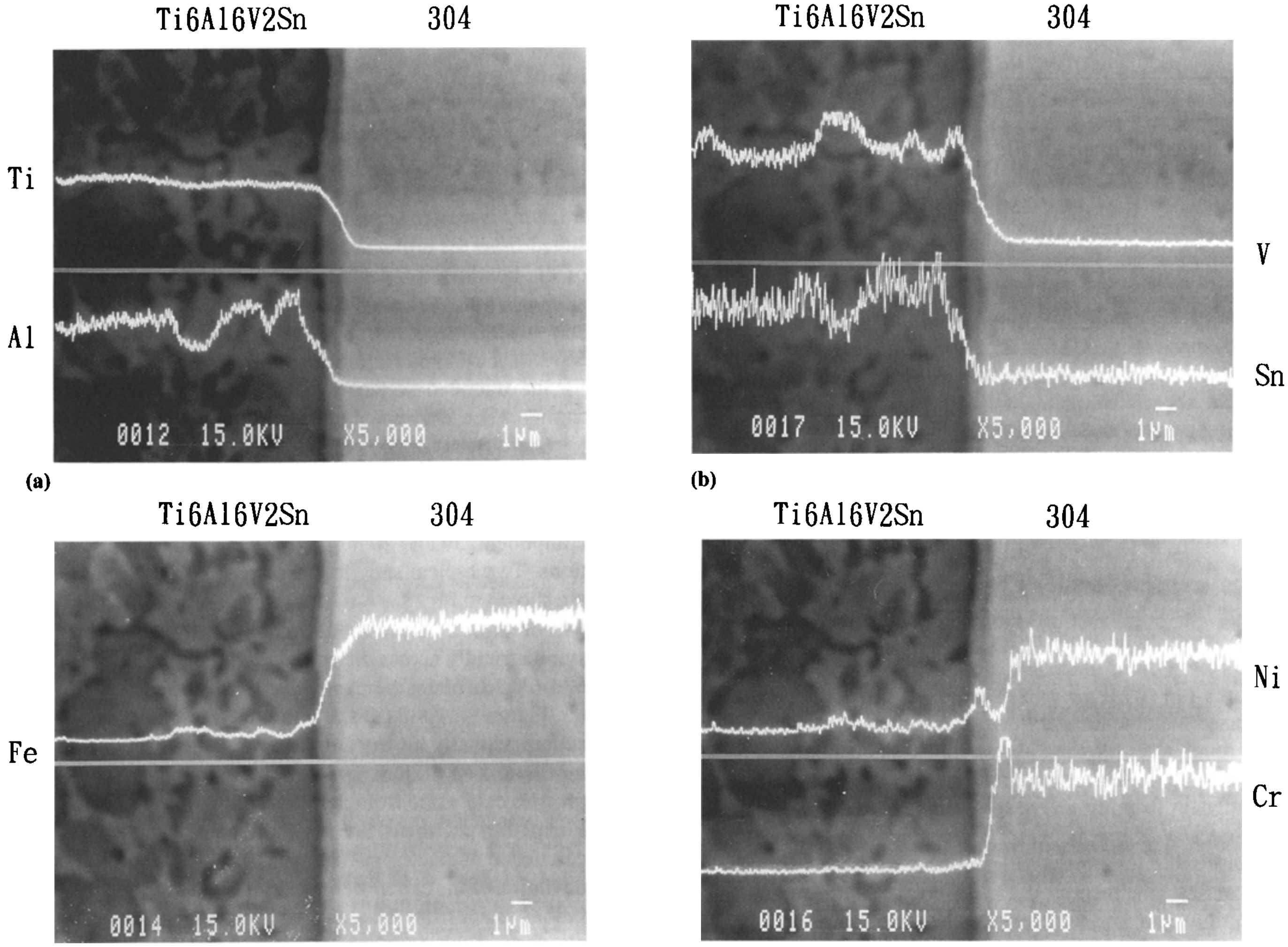
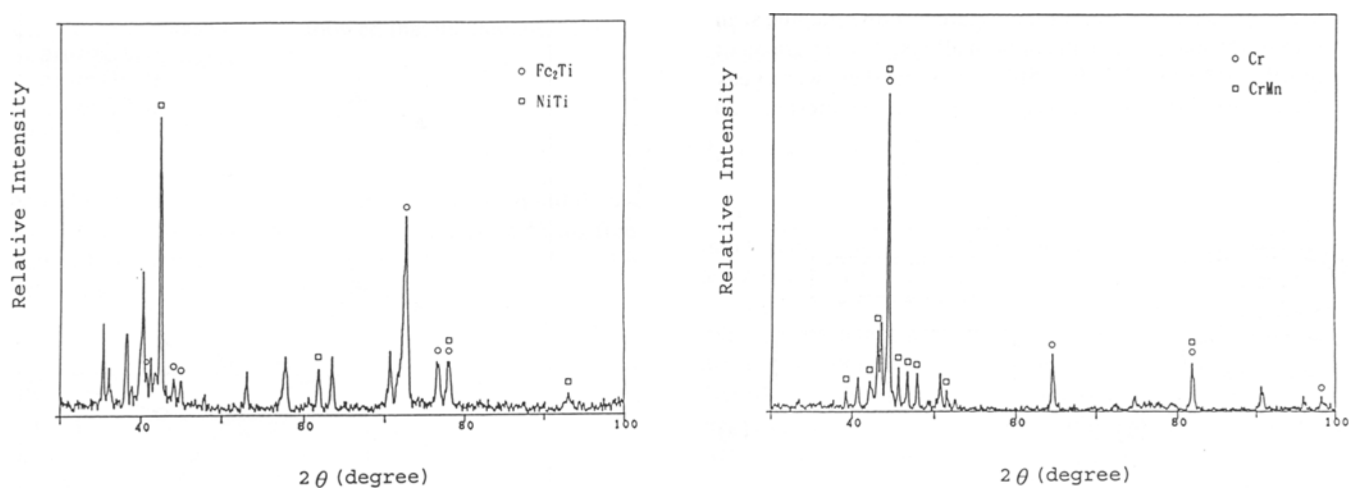


Fig. 4 The single-sheet forming dome heights of Ti-6Al-6V-2Sn blown at various temperatures with 120 psi for 15, 30, and 60 min



(a) (b) (c) (d)

Fig. 5 EPMA line scannings for (a) Ti and Al, (b) V and Sn, (c) Fe, and (d) Ni and Cr across the Ti-6Al-6V-2Sn/304 stainless steel interface



(a) (b)

Fig. 6 XRD patterns from fractured surfaces of Ti-6Al-6V-2Sn / 304 stainless steel couple. (a) Ti-6Al-6V-2Sn side. (b) 304 stainless steel side

the molds and the drag of the part that is superplastically deforming, the material of the plate clamped at the periphery cannot avoid flowing gradually toward the center. Thus the volume is increased. This makes the thickness profile smoother.

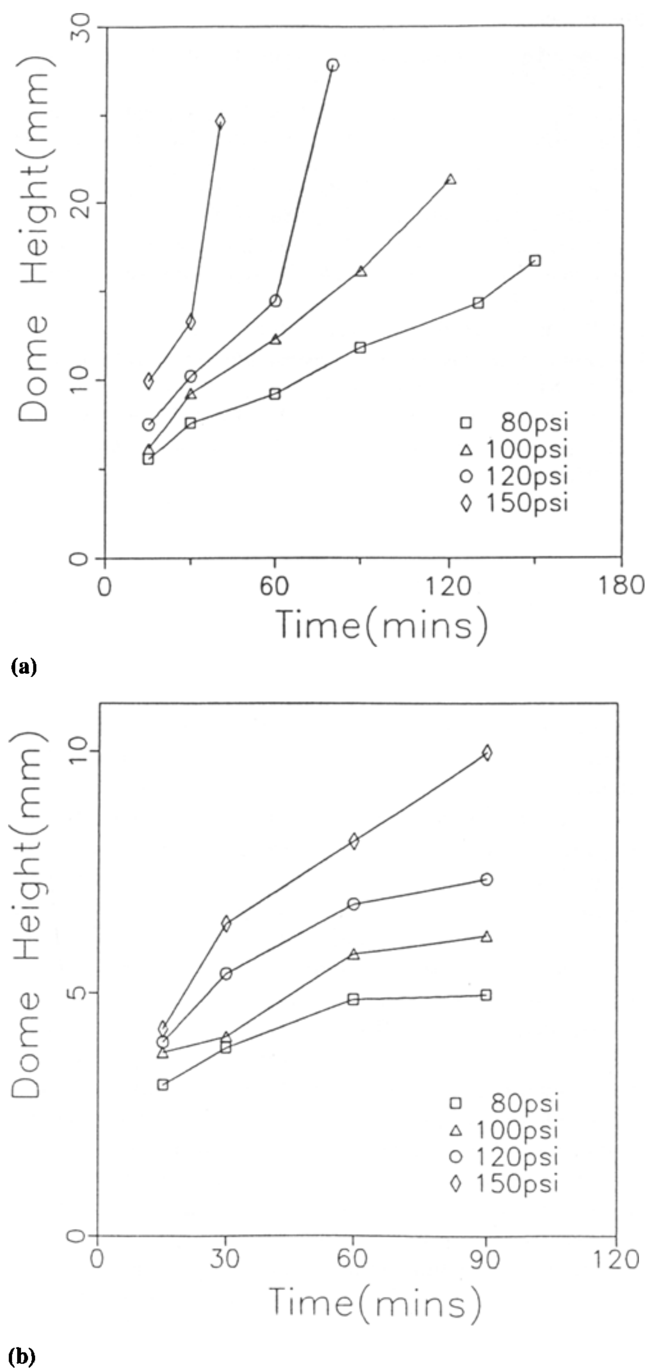


Fig. 7 The forming dome heights of Ti-6Al-6V-2Sn hemispheres with diameters of (a) 30 mm and (b) 20 mm

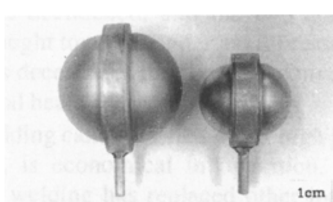


Fig. 8 Ti-6Al-6V-2Sn/304 stainless steel/Ti-6Al-6V-2Sn hollow sphere with diameters of 30 and 20 mm after diffusion bonding and superplastic forming

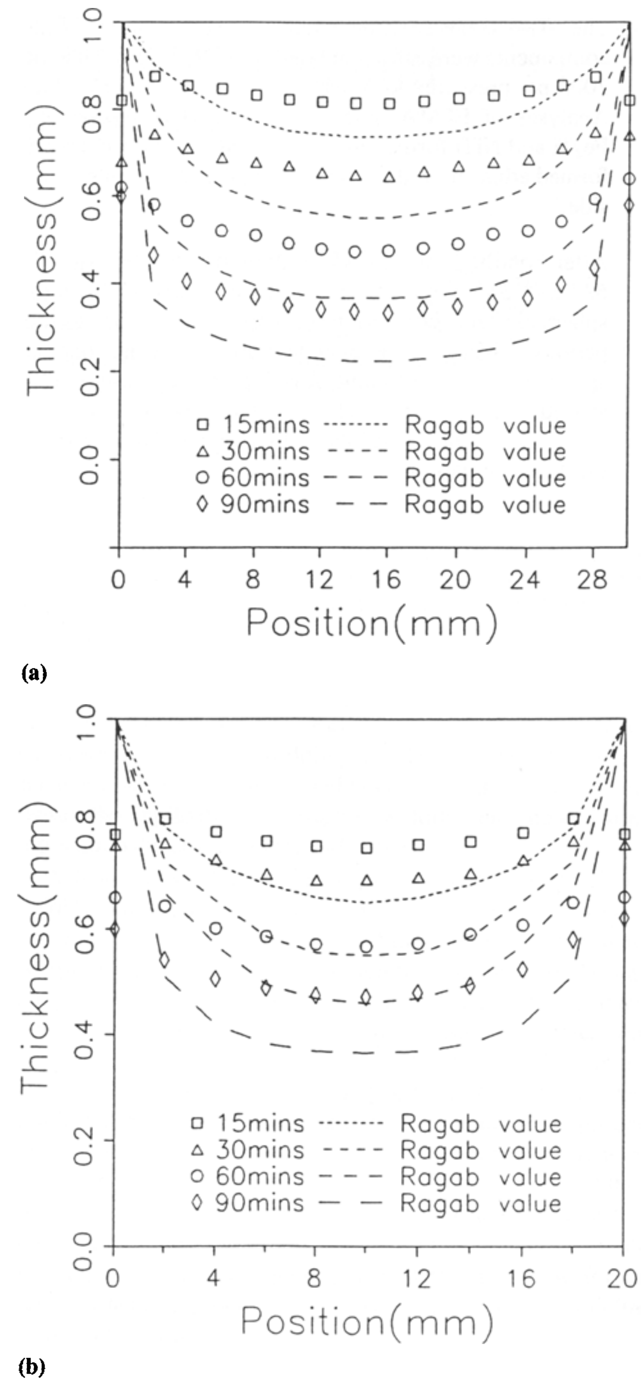


Fig. 9 The thickness distributions of the Ti-6Al-6V-2Sn hemispheres free blown at 850 °C for various periods of time and the results calculated by using Ragab's equation. (a) 30 mm diam hemispheres blown with 100 psi. (b) 20 mm diam hemispheres blown with 120 psi

4. Conclusions

- 850 °C was evaluated and found to be the optimal superplastic forming temperature for Ti-6Al-6V-2Sn by free blowing of single sheet.

- The Ti-6Al-6V-2Sn/304 stainless steel/Ti-6Al-6V-2Sn components were diffusion bonded at 890 °C for 1 h under 2000 psi pressure. An interlayer formed at the interface. Analyses of EPMA, line scans, and XRD showed that Fe_2Ti and NiTi formed in the interlayer, and Cr and CrMn formed adjacent to the interlayer on the 304 stainless steel side.
- After bonding, the Ti-6Al-6V-2Sn/304 stainless steel/Ti-6Al-6V-2Sn components were superplastically blown to a spherical shape with various pressures and for various time periods at 850 °C. The thickness profiles of the spherical specimens with different forming dome heights were smoother than those calculated by the equation deduced by Ragab due to the central flow of the material during superplastic deformation.

References

1. A. Arieli and A. Rosen, *Metall. Trans. A*, Vol 8 (No. 10), 1977, p 1591
2. H.E. Friedrich, R. Furlan, and M. Kullick, Superplastic Forming/Diffusion Bonding on the Way to the Production Stage for Ti and Al, *Proc. Conf. on Superplasticity and Superplastic Forming*, C.H. Hamilton and N.E. Paton, Ed., Blaine, Aug 1988, The Metallurgical Society of AIME, 1988, p 649
3. R.C. Davis, D.M. Royster, and T.T. Bales, Superplastically Formed Titanium Hat-Stiffened Panels, *NASA Tech. Briefs*, Vol 14 (No. 1), 1990, p 63-64
4. A.R. Ragab, *Met. Technol.*, Vol 10, 1983, p 340
5. H. Kato, M. Shibata, and K. Yoshikawa, *Mater. Sci. Technol.*, Vol 2, 1986, p 405
6. S. Hinotani, *The Sumitomo Search*, No. 44, Dec 1990, p 346
7. B. Aleman, I. Gutierrez, and J.J. Urcola, *Mater. Sci. Technol.*, Vol 9, 1993, p 633