Algorithm for Determining Optimum Bonding Condition in Solid State Diffusion Bonding by a Numerical Model†

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Abstract

An algorithm to estimate the optimum bonding time is developed by a numerical model, for the purpose of establishing the system of determining the optimum process conditions of the solid state diffusion bonding. The influence of the scattering of surface roughness on the bonding time required to complete the bonding process is mainly examined by the numerical model. The distribution of void spacing in the final stage (bond ratio > 95%) is taken into consideration in order to establish the algorithm. It is shown that the plural trials of measuring surface profiles are beneficial to estimate the complete bonding time.

KEY WORDS: Solid State Bonding, Optimum Bonding Condition, Numerical Model.

1. Introduction

It is very often that residual voids on bonded interface give a bad influence on mechanical properties of the joints by diffusion bonding. We have developed the algorithm to determine the bonding conditions to make them vanish [1,2]. However, we have not established the complete method to estimate the optimum bonding condition for the faying surface which contains the surface roughness with the coarse components. In the present study, we try to develop the algorithm to estimate the optimum bonding time necessary to finish the bonding process by using a numerical model.

2. Surface Profile

The residual voids are mainly caused by the scattering of the surface roughness [2]. The fine surface roughness makes it easy to achieve the full intimate contact of faying surfaces [1]. The fine surface roughness scarcely causes the residual voids. Similarly, the faying surface on which the periodical void-spacing is formed exactly makes it easy to predict the bonding process [1,2]. **Figure 1** shows the surface profile with many uneven pitches and the spectrum of the surface roughness. This is the surface profile for which we failed in the previous paper [2] to predict the complete bonding time t_f required to attain the bonding process. We can list two reasons. Firstly, the faying surface contained too coarse roughnesses to predict t_f. Secondly, the average values of surface roughness included an error. In our previous study [2], the measurement was only once for each faying surface. The plural trials are necessary in measuring surface profiles (the number of trials $N_t > 1$).

In the present study, the plural trials were carried out for every faying surface. The plural trials give a scattering to the average value per one trial. The average said in this paper does not express the whole mean.

3. Void Spacing during Bonding

It is expected that the scattering of the surface roughness changes the void spacing during bonding. The bonding rate largely depends on the void spacing although it is not so influenced by the void height [1]. It is thus necessary to estimate the void spacing before the diffusion bonding, so that we can predict the bonding process. It is possible to estimate it by the overlap process of the faying surfaces [2]. **Figure 2** shows the schematic illustration of the overlap process where a couple of surfaces is overlapped step by step. The overlapped area of the surfaces gives the bond-ratio S and the average of half the void spacing L_m. Also, this method gives the distributions of the void spacing at

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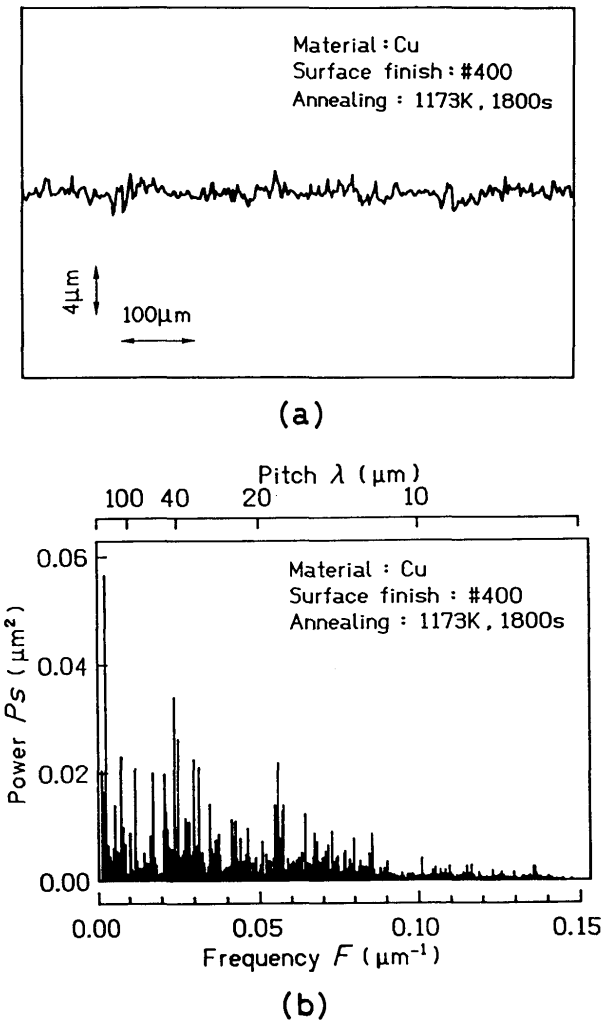

Fig. 1 Surface profile(a) and its spectrum(b).

each S which are shown in **Fig. 3**. The region of S = 20~90% exhibits the tight distribution as shown in (a). But, it becomes broad like (b) around $S \simeq 90\%$, and reaches the distributions like (c) in the final stage of bonding ($S >$ 95%). The distributions could be classified to three types of A, B and C by the mode. For type C, the average seems to make nonsense. The distributions for $S < 20\%$ were pretty broad like (b). But, it had no effect on the complete bonding time, i.e., for $S < 20\%$, the average value was sufficient to predict the time taken to finish the bonding process.

Figure 4 shows the mean half void spacing L_m changing with S. The average per one trial has a scattering expressed by the bar. The scattering in **Fig. 4** comes from ten trials in measuring the surface profiles. The width of scatter is saturated at $n_t \geqq 5$. A diamond pin of the instrument of measuring the surface profile was swept over the faying surface from edge to edge of the specimen (a diameter of 10 or 5mm, material: oxygen free copper). The region swept by the diamond pin was different between all trials with

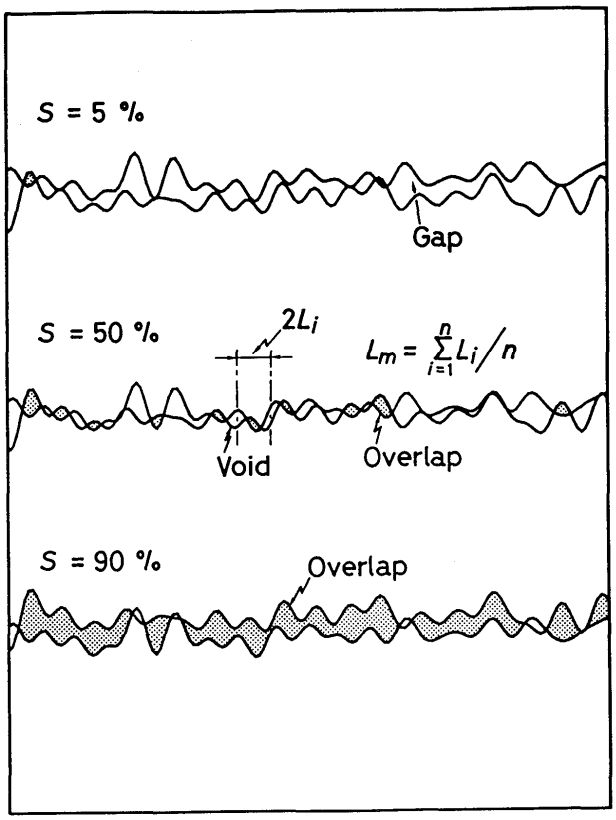

Fig. 2 Schematic illustration of overlap process.

respect to the position. It is found that the scattering of L_m is relatively small in the range of S = 20~80%. L_m calculated by the overlap process is in good agreement with the real void spacing [2]. If the scattering of L_m in $S < 20\%$ is neglected, it appears that L_m of $S < 90\%$ is a good approximation to the real void spacing.

4. Numerical Model

Figure 5 is the schematic drawings about the approximation from the actual voids (left hand side) to the models (right hand side). It is assumed in the numerical model that the voids are arrayed two dimensionally at regular intervals $2L$. The volume of the void per unit length is calculated under the condition of mass conservation as described in our previous report [2]. The sum of the void volume which needs to shrink is determined by the initial local contact of two surfaces of the specimens. The initial void height h_o is solved at the initial contact. In fact, they were estimated by the contact of S = 3% in the overlap process [2]. **Fig. 5** was applied only for estimating L_m.

The bonding process is assumed to be achieved as follows: The initial local contact is attained by plastic flow immediately after the two surfaces are pressed to each other by applying the bonding pressure P. After that, the bonding process is achieved by three independent mechanisms of volume diffusion, interface diffusion and creep deforma-

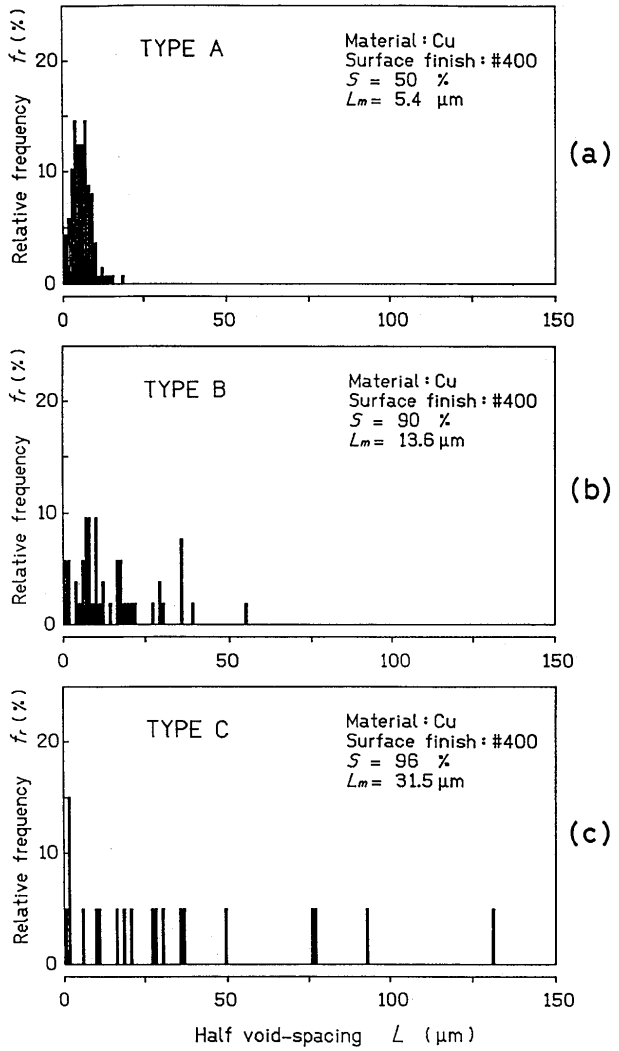

Fig. 3 Distributions of half void spacing L. (a) Type A, (b) Type B, (c) Type C.

tion, resulting in the percent bonded area S reaching 100%. The interface diffusion is the atom transport along the bonded interface and assumed to be independent of the surface diffusion which cannot shrink the void for itself but keeps the void shape lenticular during bonding because of the high diffusion rate [1]. The total bonding rate is solved as the sum of the three contributions. The rate equations have been described in our previous papers[1, 2].

5. Algorithm for assuring the bonding time to finish the bonding process

The scattering of the mean void spacing disperses the

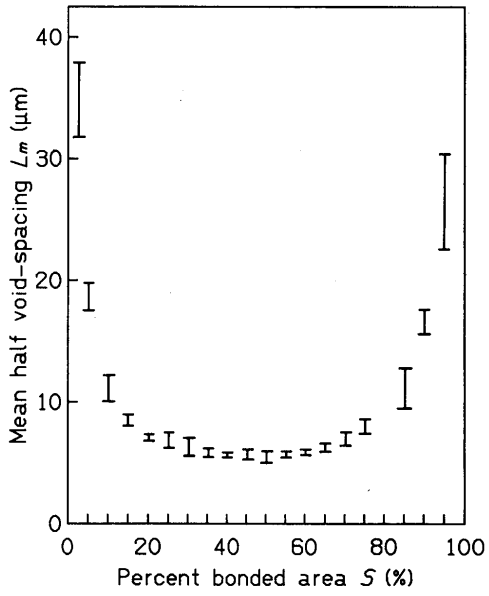

Fig. 4 Change in mean half void spacing with S.

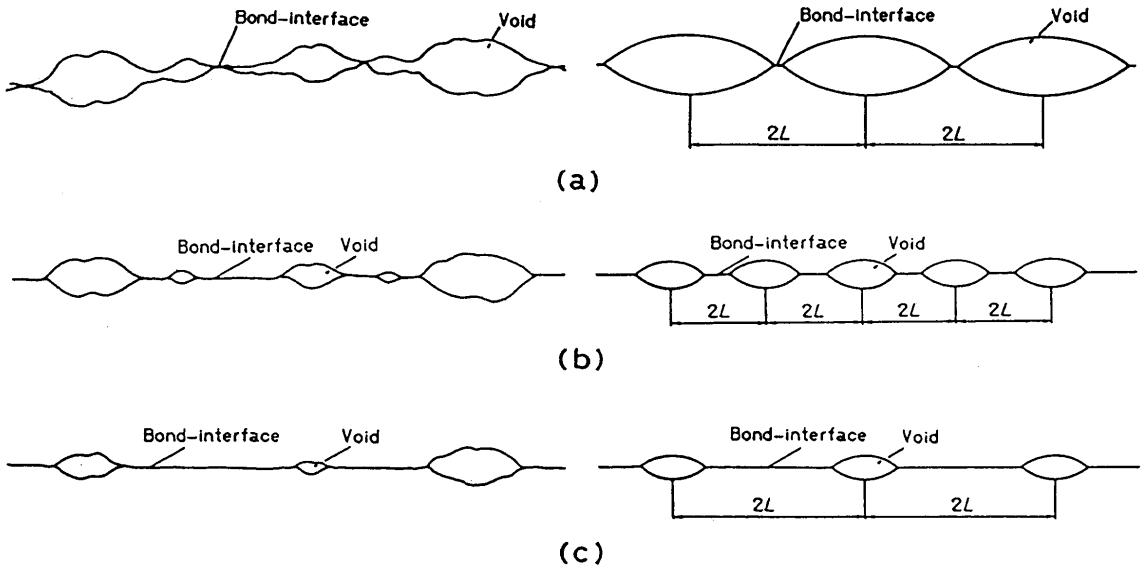

Fig. 5 Converting the real bond zone to the numerical model. (a) Early stage, (b) Middle stage and (c) Latter stage.

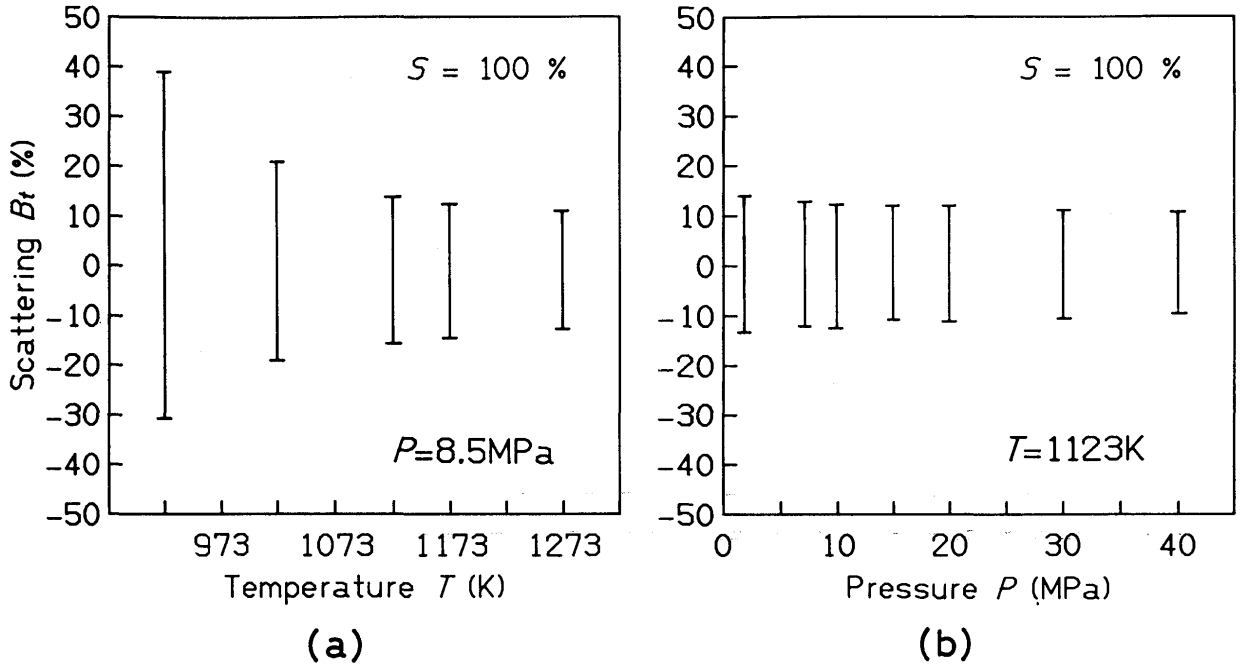

Fig. 6 The scattering of t_f depending on process conditions. (a) Temperature dependence, (b) Pressure dependence.

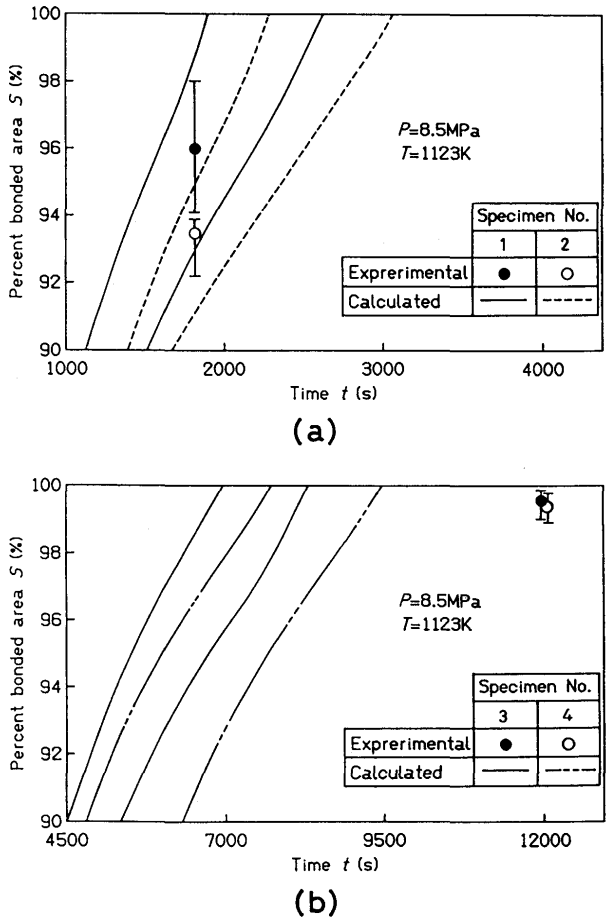

Fig. 7 Comparisons between calculated results and experimental ones. (a) For S = 90~98%, (b) For S > 98%.

magnitude of t_f. **Figure 6** shows the scattering of the bonding time calculated only by the change in L_m with S. The ordinate B_t is defined as the range of [max A_i~min A_i] for i = 1 to 5. Here, A_i is $(t_i-t_m)/t_m$, where t_i is the bonding time estimated from each trial of measuring the surface profile and t_m is the average of t_i. It appears that we cannot make B_t zero, although we can reduce it with increasing temperature and pressure. In particular, temperature has a large effect on B_t. The magnitude of B_t is due to the difference between the contribution of diffusion and creep [1].

Figure 7 shows the comparisons of the experimental results with the calculated ones. This figure takes account of the variation of L_m with S. The calculated results are represented by the zone between two curves. The two curves, respectively, express the maximum and minimum of S calculated by the numerical model and are caused by the scattering of L_m (n_t = 5). The experimental results of S > 98% deviate from the calculated ones (two curves) which can predict the bonding process below S = 98%. This is caused by the distribution of type C (cf. **Fig. 3**). It is, therefore, necessary to take into account the distribution of type C in order to produce the algorithm for assuring the complete bonding time. In this study, we adopt the maximum value of L as a substitute of L_m for type C.

Figure 8 is the algorithm for assuring the bonding time to give S = 100%. The plural trial of measuring the surface profiles and the consideration of the distribution of type C are strong points of this algorithm. **Figure 9** is an application of the algorithm. In this case, we adopted the maxi-

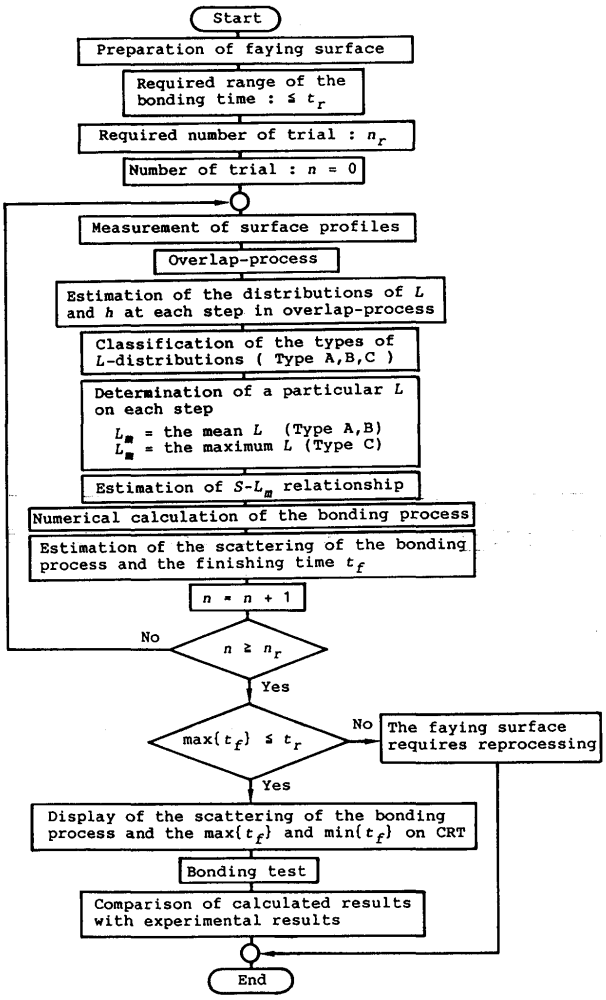

Fig. 8 The algorithm to determine the complete bonding time.

mum value of L at $S > 96\%$, on the basis of the distribution of L. The time t_f calculated was 36681s. The photograph in this figure (SEM) shows the fractured surface of the bond-interface. Overall area is like dimples and no traces of voids are observed at all. The experimental results is in good agreement with the prediction.

6. Conclusion

The algorithm has been developed in order to assure the complete bonding time t_f. It is found that we need take account of the variation of the void spacing with the bonding process and the distribution of the void spacing. The plural trial for measuring the surface profiles is beneficial to produce the algorithm. This algorithm is very useful to form the void free interface by the solid state diffusion bonding. This algorithm will be a powerful tool to determine the optimum bonding conditions (T, P, t_f).

References

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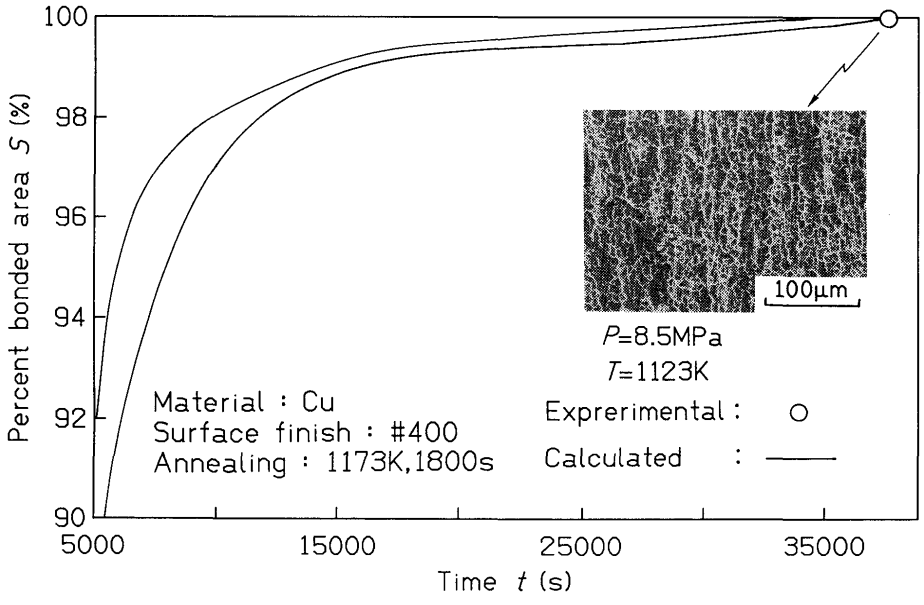

Fig. 9 An example of application of the algorithm to the determination of the complete bonding time.