FF2-3

Proc.of the 7th Int. Sympo., JWS, 2001, Kobe

In-situ Observation of Interlayer Growth during Post-weld Heat Treatment in Friction-welded Joint of Titanium and Aluminum

by Akiyoshi Fuji*, Kenji Ikeuchi**, Masaaki Kimura***,
Yutaka S.Satoh**** and Hiroyuki Kokawa****
* Kitami Institute of Technology, 165 Koen-cho, Kitami, Hokkaido 090-8507, Japan
** Joining and Welding Research Institute, Osaka University,
11-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan
*** Himeji Institute of Technology, 2167 Shosha, Himeji, Hyogo 671-2201, Japan
**** Tohoku University, 02 Aoba-yama, Sendai, Miyagi 980-8579, Japan

Abstract

The growth of intermediate layer (layer) of pure Ti and pure Al friction-welded joint heated at 853K for up to 173ks (580^{o}C-48H) was clarified by in-situ (direct) and continuously observation method with a high temperature optical microscope. The followings are concluded. The layer grew from Al substrate to Ti one, and neither linear nor parabolic time-dependence could be applied to the rate of layer growth. The layer growth stopped for a while (for several hours) after heating of approximately every 36ks (10H). That is, several plateaus appeared during heat treatment. It can be though that nucleation and growth of nuclei of Al-Ti binary intermetallic phase are necessary for layer growth. The rate of layer growth of pure Ti and highly pure Al joint was faster than that of pure Ti and commercially pure Al joint. This is due to silicone content in Al base metal. There was slight difference of the rate of layer growth as for the locations along the radius of the joint and as for friction time.

1. Introduction

Dissimilar welding operations have several severe problems in the industrial usage. One of these occurs when dissimilar welding joints are operated at high temperature environment. That is, an intermediate layer (hereafter called as layer) consisting of brittle intermetallic compound phases grows at the interface of dissimilar joint, and it gives a detrimental damage on the mechanical and metallurgical properties of the joint. There were a lot of and wide range of studies investigated for the diffusion phenomena and the layer growth at the weld interface of dissimilar weld joints or diffusion couples up to date [1-10]. Generally speaking, the relation between the rate of layer growth and heating time is according to parabolic time-dependence, i.e. square root relation when the layer growth occurs due to mutual diffusion of each element in both substrates joined. However the parabolic theory cannot be applied to some combinations of dissimilar joints. For example, it could not be fit to the relation of the layer width versus heating time of a diffusion couple between pure titanium (Ti) and pure aluminum (Al) [1,2,8,9]. This reason is due to the experimental method; most of all researches were carried out to observe the layer growth at room temperature, i.e. specimens were cooled after heat treatment. Therefore, most of the data are intermittent (discontinuous), so that true diffusion phenomena and layer growth by long heating could not be clarified for dissimilar joints because of fracture occurring in layers.

Taking these backgrounds into considerations, the authors have studied for the layer growth of dissimilar friction-welded joints by in-situ (direct) and continuously observation method with a high temperature microscope system that is a more fruitful approach. The present report will describe the phenomena on the layer growth of pure Ti and pure Al friction-welded joint.

2. Experimental Procedures

The material used for the experiment was commercially pure Ti. Commercially pure Al with 0.12%Si and highly pure Al with 0.01%Si were used as foreign metals to examine the effect of silicone (Si) in Al substrates on layer growth. All materials were 30mm in diameter to clarify the effect of the location along joint radius on layer growth. A Brake type friction welding machine was carried out for joining. Polishing with a buff was carried out to finish the faying (contacting) surface of all materials. During friction welding operations, the following conditions were kept constant: rotational speed was 25revolution per second (1500revolution per minute); friction pressure was 50MPa, upsetting pressure was 50MPa; and upsetting time was 6s. To change the width of the layer generating during friction operations, friction time (hereafter called as FT) was varied 2s and 7s.

The specimens with 3mm in diameter and 3mm in thickness for in-situ and continuous observation were extracted perpendicular to as-welded joint interface including an interface by a Wire-Electric Discharge Machining. The locations of the specimens extracted were the centerline of joint axis and 5mm from outer surface of joint (periphery). Each specimen was inserted into the sample holder of a high temperature microscope and heat treated in vacuum environment. Heating temperature was 853K (580^{o}C), and heating time was up to approximately 172.8ks (48H). An optical microscope in the magnification of 400times was used to observe layer width, and the width was recorded with a digital VTR recorder continuously. Figure 1 schematically shows the observation system. The layer width was measured every 3.6ks (1H) by a personnel computer. SEM and TEM analysis were carried out to analyze the chemical composition at interface region. The heat cycles during friction welding were measured.

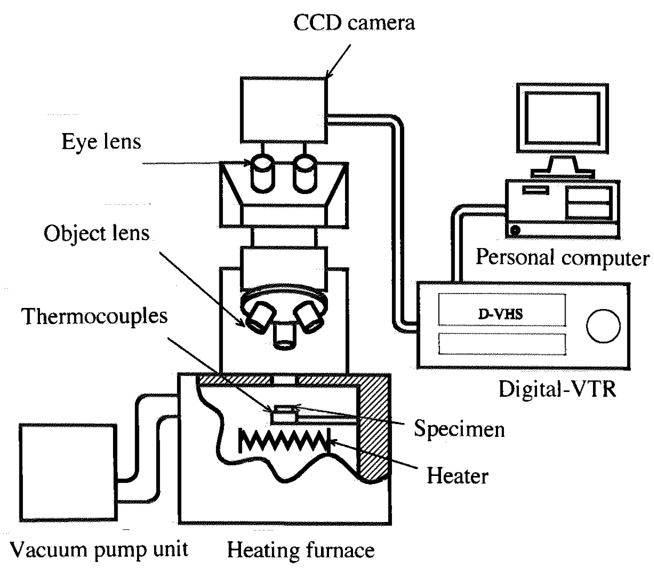


Fig.1 Schematic illustration of in-situ observation system.

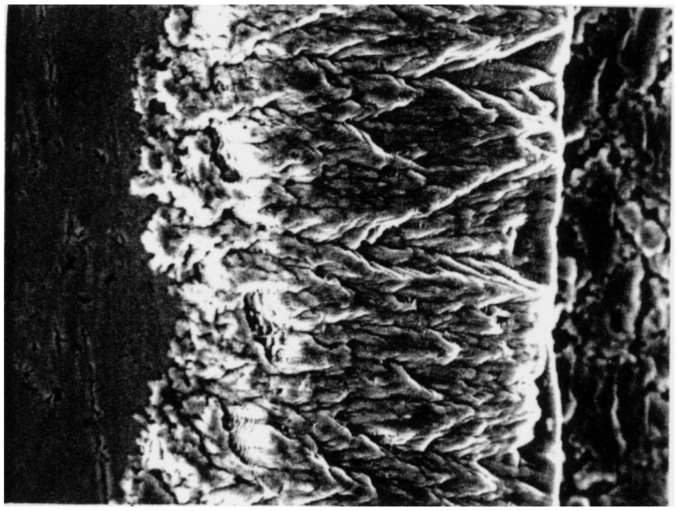
3. Experiment results

Figure 2 shows an example of the optical microstructure at the interface of A-joint heated at 853K(580°C) for 720ks (200H). The joint was welded with FT of 2s. The layer almost grew from Al substrate to Ti one. The interface between the layer and Ti substrate was smooth whilst it was irregular between the layer and Al one. It was assumed that the microstructure of the layer heated after 720ks was composed with Al_3Ti phase by SEM-EDS analysis.

Figure 3 shows the relation between the heating time and the layer width at the interface of centerline portion of A- and B-joints welded with a friction time of 2s. In this case, Fig.3 (a) shows the result by using linear scale for heating time (horizontal axis). On the other hand,

Weld interface

Direction of layer growth ←↓



Ti side →↑←Intermediate→↑←Al side

layer(Al_3Ti)

|---------| 20 μm

Fig.2 Example of optical microstructure at interface of A-joint heated at 853K for 720ks (580°C-200H).

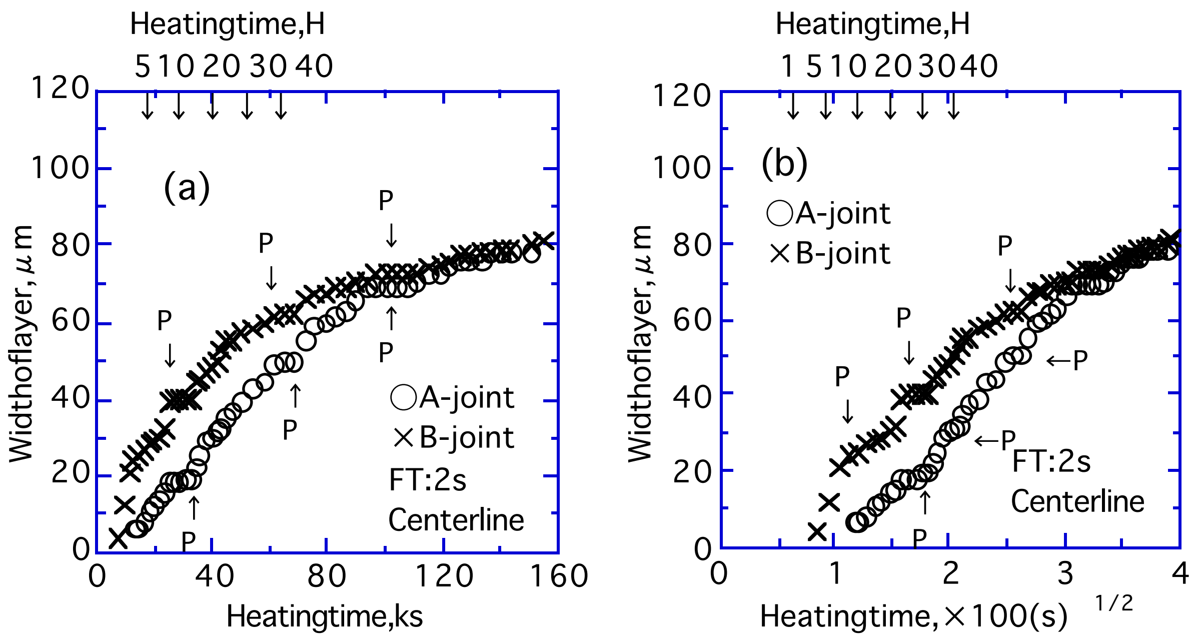


Fig.3 Relations between heating time and layer widths at centerline portion of A- and B-joints with FT of 2s; (a) linear scale for heating time, and (b) square root scale.

Fig.3 (b) shows that by square root scale. The rates of layer growth were depended on neither parabolic nor linear relation for heating time. The layer almost saturated up to approximately 80microns in width for both joints. It is most important to note that the layer growth stopped for a while (several hours) on approximately every 36ks (10H). That is, several plateaus showing as "P" in Figures 3 (a) and (b) appeared. The rate of layer growth of B-joint was faster than that of A-joint.

Figure 4 shows the relation between heating time and layer growth at periphery portion of both joints with FT of 2s by using linear scale for horizontal axis. The layer growth was also depended on neither parabolic nor linear relation for heating time. The layer almost saturated up to approximately 70microns in width for A-joint, and 85microns for B-joint, respectively. The layer growth stopped (plateau region) for several hours on approximately every 36ks (10H). The rate of layer growth of B-joint was also faster than that of A-joint. These results were same as centerline portion (Fig3 (a)). However, there was not so large difference of the rate of layer growth between at centerline (Fig.3 (a)) and at periphery (Fig.4).

Figure 5 shows the relation between the layer width by every 3.6ks (1H) and heating time at centerline of the joint welded with FT of 2s. It can be seen that the rate of layer growth decreased when heating time increased. This result indicates that it takes longer time for element to diffuse through interface as increasing layer width. Furthermore, the rate of layer growth dropped to zero at approximately every 36ks (10H). This is corresponded to the plateau region.

Throughout this experiment, the layer saturated approximately 70-100microns in width, and several plateaus appeared in all joints during heat treatment.

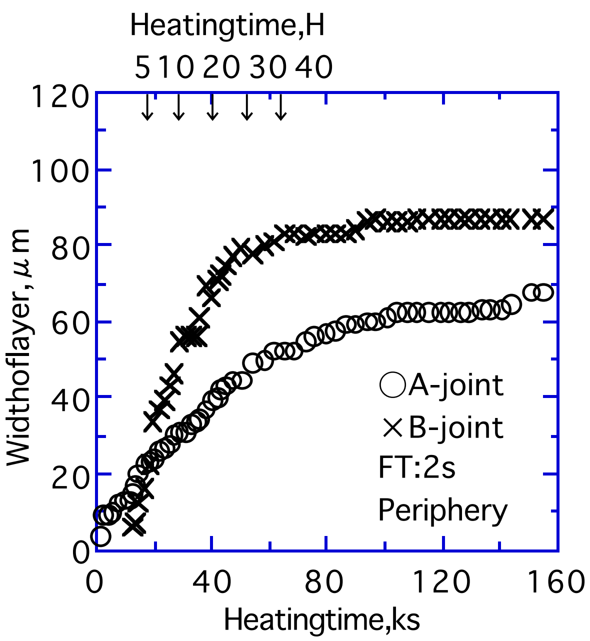


Fig.4 Relations between heating time and layer widths at periphery portion.

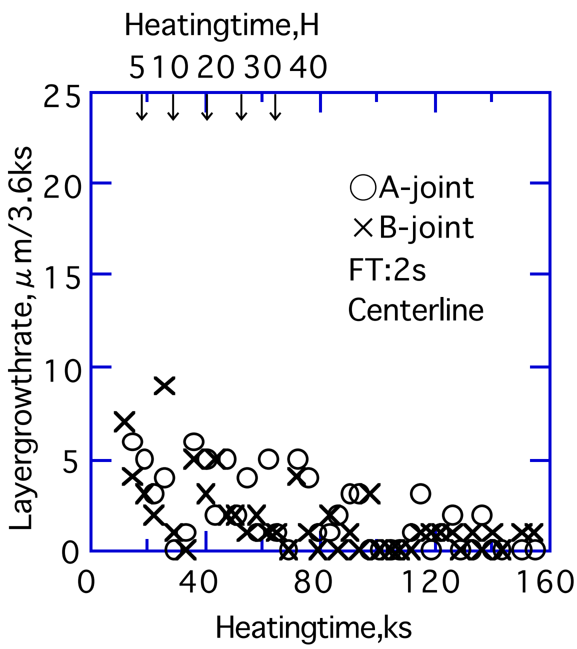


Fig.5 Relations between layer growth rate by every 3.6ks (1H) and heating time.

4. Discussion

It may be seen from the experimental result that the rate of layer growth was depended on neither parabolic nor linear time-dependence relation. This reason might be thought as follows. The growth of intermetallic compound phase (IMC) is not simply depended on the mutual diffusion of both elements through interface or layer. The authors had already reported that, in case of pure Al-pure Ti friction welding joint, the layer of IMC grew according to two steps [10]. That is, nucleation of IMC occurred at the first step, and nuclei of IMC coarsened at the second step. As it can be pointed out in Fig.1, the interface between IMC and Ti substrate was irregular. The crystals are smaller than those between IMC and Al substrate.

By the way, there were several plateaus occurred during heat treating. This reason could not be clarified, however, it might be thought that the microstructure changes when layer growth has stopped. The chemical compositions of the layer of the joint heated for 28.8ks (8H), that is, before the first plateau, was approximately 60mol.%Al-40mol.%Ti by SEM-EDS analysis. On the other hand, that of the joint heated for 45ks (15H), after the first plateau, was about 70mol.%Al-30mol.%Ti. Therefore, the microstructure before the plateau region may be composed with Al_3Ti including a little content of AlTi and Al_2Ti while after the plateau it may be composed with mainly Al_3Ti.

The rate of layer growth of B-joint was faster than that of A-joint. This reason can be thought that Si in commercially pure Al substrate accumulated between the layer and Ti substrate, and Si layer avoided the diffusion of Al element from Al substrate to Ti one as a barrier [10].

It can be estimated that microstructure and strain, generated by the heat cycle during friction welding, affect the layer growth. However, there was slight difference of the rate of layer growth as for locations along radius (e.g., Figs.3 (a) and 4) and as for friction time (not attached here) throughout this experiment. Generally speaking, the highest temperature can be achieved at periphery portion and the lowest one can be at centerline portion during friction welding of similar materials. However, it cannot be applied to the friction welding of dissimilar materials. Figure 6 shows the thermal cycles at centerline, half radius (1/2R) and periphery portions of the joint with friction time of 8s. It is clarified that the peak temperatures were at centerline, 1/2R and periphery portions according to height. This result was reversed. Figure 7 shows the chemical distributions across the interfaces at centerline of A-joint with friction time of 2s by TEM-EDS line analysis. It may be seen that

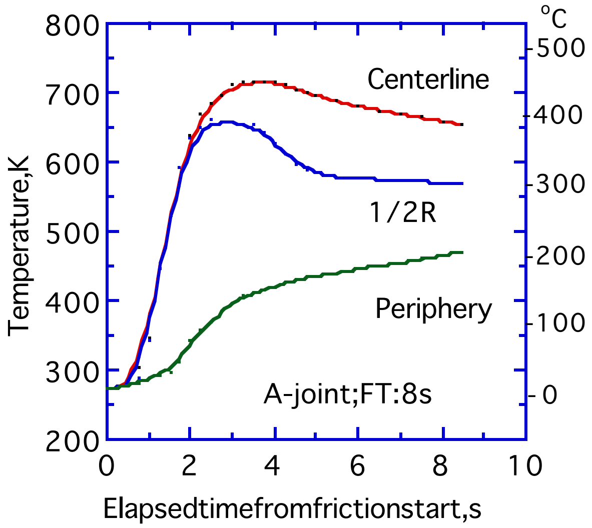


Fig.6 Thermal cycles adjacent to interface of A-joint (FT: 8s).

almost no intermetallic layer was observed at the interface in as-welded condition. This is same result as that of the periphery portion (not attached here). Further investigations have been continued for the effect of the location along radius and friction conditions on the rate of layer growth.

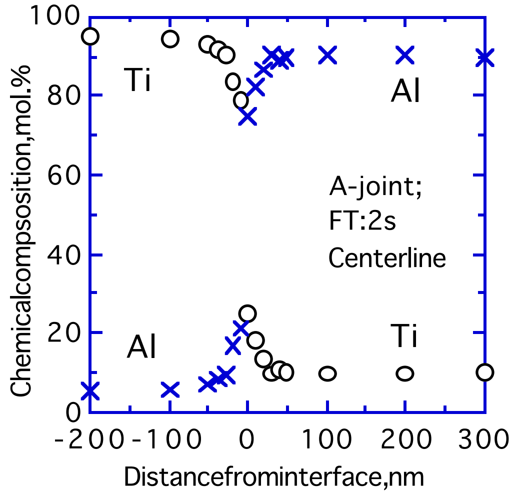


Fig.7 Distributions of Chemical compositions across interface of A-joint by TEM-EDS.

5. Conclusions

The growth of intermediate layer (layer) of pure Ti and pure Al friction-welded joint heated at 853K for up to 173ks (580°C-48H) was clarified by in-situ (direct) and continuously observation method with a high temperature optical microscope. The followings are concluded.

(1) The layer grew from Al substrate to Ti one. Neither linear nor parabolic time-dependence relation could be applied to the rate of layer growth.

(2) The layer growth stopped for several hours on heating of approximately every 36ks (10H). This reason might be thought that nucleation and growth of nuclei of Al-Ti binary intermetallic phases are necessary for layer growth.

(3) The rate of layer growth of pure Ti and highly pure Al joint was faster than that of pure Ti and commercially pure Al joint. This was due to silicone in Al substrate.

(4) There was slight difference of the rate of layer growth between at the centerline and at the periphery portions of the joint.

Acknowledgment

Some parts of this research was carried out by Grant-in-Aid for Scientific Research (C10650700), and cooperated with Japan Welding Research Institute, Osaka University. The authors sincerely thank to Dr.Takenori Hashimoto in Showa Electric Company for his kindly preparing the materials use.

References

1) F.J.J.van Loo and G.D.Rioeck : *ActaMetall.* , **21** (1973), p.61.
2) F.J.J.van Loo and G.D.Rioeck : *ActaMetall.* , **21** (1973), p.73.
3) D.Goold : *J. of Institute of Metals*, **88** (1959-60), p.444.
4) S.Tsuji : *Trans. of Japan Institute of Metals*, **14** (1973), p.377.
5) Y.Wakamatsu, M.Ohnishi and T.Shimozaki : *J. of Japan Institute of Metals*, **53** (1989), 4, p.378.
6) H.Nakajima and M.Koiwa : *Bulletin of Japan Institute of Metals*, **30** (1991), 6, p.526.
7) J.G.Luo and V.L.Acoff : *Welding Journal*, **79** (2000), 9, p.329s.
8) T.Enjo, K.Ikeuchi, M.Kanai and T.Maruyama : *J. of Japan Welding Society*, **46** (1977), 2, p.83.
9) T.Enjo, K.Ikeuchi and T.Akikawa : *J. of Japan Welding Society*, **50** (1981), 10, p.977.
10) T.Hamajima, K.Ameyama and A.FUji : *J. of the Society of Materials Science Japan*, **44** (1995), p.1224.