

X.Y. Gu, Z.Z. Duan, X.P. Gu* and D.Q. Sun

Microstructural Evolution of TLP Bonded Ti_3Al -Nb Alloy Joints

Abstract: In the present study microstructural evolution in transient liquid phase (TLP) bonded Ti_3Al -Nb alloy joints using a pure copper as interlayer was investigated. TLP bonded Ti_3Al -Nb alloy joints composed of intermetallic compound layers were produced. Microstructural evolution of joints depended on both bonding time and bonding temperature. With increasing bonding time and bonding temperature, the joint width increased and amount of compounds in the joint decreased. The joint microstructure at $1173\text{ K} \times 1\text{ min}$ mainly consisted of Ti (solid solution) + Ti_2Cu + $TiCu$ + Ti_3Cu_4 + Ti_2Cu_3 + $TiCu_4$ + Cu (solid solution) phase and it changed to Ti (solid solution) + Ti_2Cu + $TiCu$ at $1223\text{ K} \times 60\text{ min}$. Compounds formed on cooling from the bonding temperature by liquid phase were eliminated from the joint at $1223\text{ K} \times 60\text{ min}$ due to isothermal solidification of liquid phase. The increase of the width of joint is attributed to the composition difference between the isothermal solidification production and its adjacent base material.

Keywords: Ti_3Al -Nb alloy, transient liquid phase bonding, microstructure, copper interlayer

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*Corresponding author: X.P. Gu: Key Laboratory of Automobile Materials, School of Materials Science and Engineering, Jilin University, Changchun 130025, China. E-mail: gxp@163.com

X.Y. Gu, D.Q. Sun: Key Laboratory of Automobile Materials, School of Materials Science and Engineering, Jilin University, Changchun 130025, China

Z.Z. Duan: Changchun Railway Vehicles Co., Ltd., Changchun 130062, China

1 Introduction

Recently, Ti_3Al -based alloys have attracted particular attention as suitable materials for high temperature applications due to their low density, enhanced strength at elevated temperature, good resistance to oxidation and high stiffness [1–7]. However, their low ductility and poor formability at ambient temperature are the major disadvantages for practical applications, which has been solved by

the addition of elements such as Nb, V, and Mo to stabilize the *fcc* Ti_3Al [8–12]. Thus, Ti_3Al -Nb alloys with better comprehensive mechanical properties have been developed in aerospace industry.

The full utilization of any advanced material depends mostly on the development of processing technology. Joining technology is a major factor limiting the application of structural intermetallics. Therefore, welding and joining of Ti_3Al -Nb alloys have been a critical factor that will promote the use of them as components. Transient liquid phase (TLP) bonding takes place as a consequence of element diffusion, during which, isothermal solidification of a liquid phase containing melting point depressant occurs to form high melting point materials [13, 14]. TLP bonding has been successfully applied for joining some metallic and ceramic systems owing to a number of technological and economical advantages.

The present study is to reveal microstructural evolution in transient liquid phase (TLP) bonded Ti_3Al -Nb alloy joints at various bonding temperatures and bonding times. This can give information for understanding the bonding behavior of Ti_3Al -Nb alloy.

2 Experimental

Ti_3Al -Nb alloy with concentration of 72Ti, 10Al and 17Nb in mass% was used as base material and the typical microstructure is shown in Fig. 1. As can be seen, the white

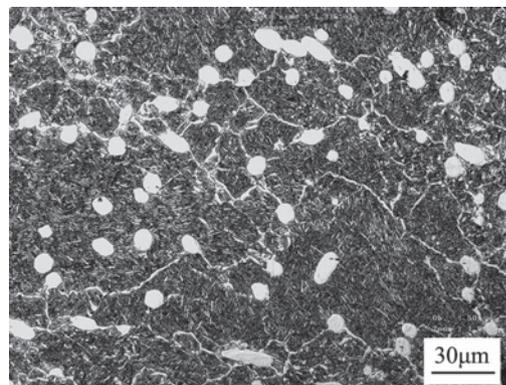


Fig. 1: Microstructure of Ti_3Al -based alloy

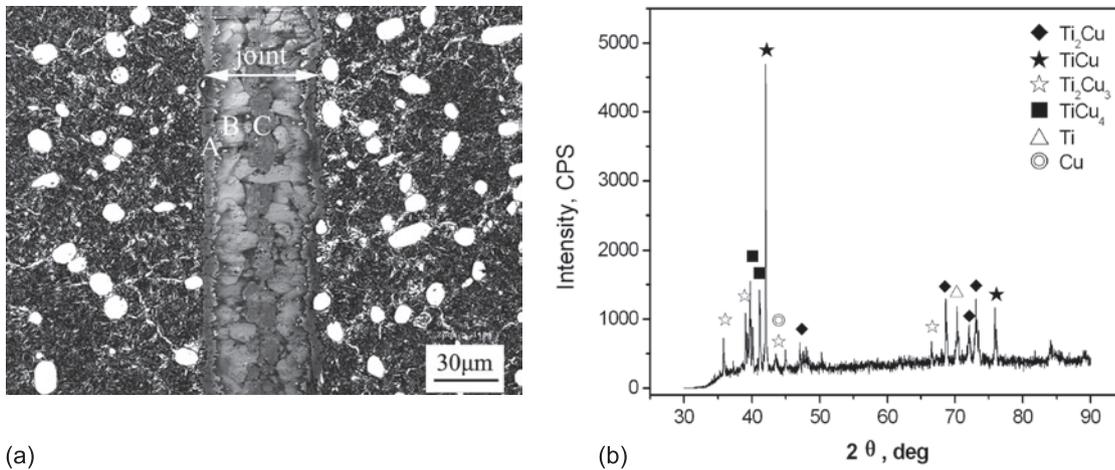


Fig. 2: Joint produced at 900 °C × 1 min. a: joint microstructure, b: XRD pattern taken from the fracture surface of the joint

phase with a spherical shape is α_2 -Ti₃Al and needle-like shape is secondary α_2 -Ti₃Al. In addition, the dark phase is β -Ti. Specimens measuring 8 mm × 5 mm × 3 mm were cut from the base material. Pure copper with a thickness of 20 μ m was chosen as interlayer. Before TLP bonding, the contacting surfaces of base material specimens were polished using 1200 grade emery paper, and ultrasonically cleaned in an acetone bath. The copper interlayer was inserted between two base material surfaces and the test assembly was fixed in place using a specimen jig with a pressure of 1 MPa. TLP bonding was carried out in a vacuum furnace (VQB-10Wd) maintained at 10⁻³ Pa. Bonding temperatures were selected as 1173 K and 1223 K above the Ti-Cu eutectic temperature of 1148 K. When the bonding (holding) stage just finished, specimens were quenched into water for 5 seconds. Bonding times were selected as 1 min, 30 min and 60 min.

TLP bonded Ti₃Al-Nb alloy joints were polished and then etched in a solution of 40 ml H₂O + 5 ml HF + 5 ml HNO₃ for 5 s. The microstructure and composition of joints were examined through laser scanning confocal microscope, energy dispersive X-ray spectroscopy (EDS) and X-ray diffraction (XRD) spectrometer. The XRD analysis was taken from the fracture surface of joints.

3 Results and discussion

TLP bonded Ti₃Al-Nb alloy joint at the bonding temperature of 1173 K for the bonding time of 1 min (1173 K × 1 min) is presented in Fig. 2a. Three distinct compound zones marked by A, B, and C are observed. Table 1 presents the chemical analysis results of these zones by using EDS. XRD pattern taken from the fracture surface of the joint is shown in Fig. 2b. When test assembly was heated to the

Table 1: Chemical analysis results of joints produced at 1173 K × 1 min

mass%	Ti	Cu	Al	Nb	Possible phases
A	49.95	22.69	5.57	21.79	Ti (solid solution) + Ti ₂ Cu
B	21.64	57.38	4.03	16.95	TiCu ₂
C	14.21	81.88	3.97	—	TiCu ₄

bonding temperature, large amount of Ti diffused into the copper interlayer and Cu diffused into Ti₃Al-Nb alloy at the interface due to solid state inter diffusion between surfaces in intimate contact and thus caused melting point decreasing of that portion of the interface region, which led to the appearance of liquid phase. Since diffusion takes place some 100 to 1000 times faster in liquid than in solid, the liquid width broadens rapidly by dissolving more base material until the copper interlayer was completely consumed. Zone B with a wavy boundary is determined as liquid phase. Since bonding time was too short, Ti content that diffused into the centerline of the interlayer (zone C) was relatively low. Thus zone C is in the solid-liquid two phase area based on Ti-Cu binary phase diagram. The joint is composed of solid layer (zone A), solid-liquid layer (zone C) and liquid layer (zone B). When the bonding time finished, the joint went cooling and Cu-solid solution precipitated from the liquid in zone C. Accordingly, the formation of TiCu₄ occurred via a peritectic reaction ((Cu) + L ↔ TiCu₄) at 1158 K. As for zone B, TiCu₄ is the first compound precipitated from the liquid when the temperature decreased to the liquidus of the molten alloy. Finally, the residual liquid is completely solidified into TiCu₄ + TiCu₂ by a eutectic reaction L ↔ TiCu₄ + TiCu₂ at 1148 K. TiCu₂ would transform to Ti₂Cu₃ and TiCu₄ during further cooling. Based on the EDS chem-

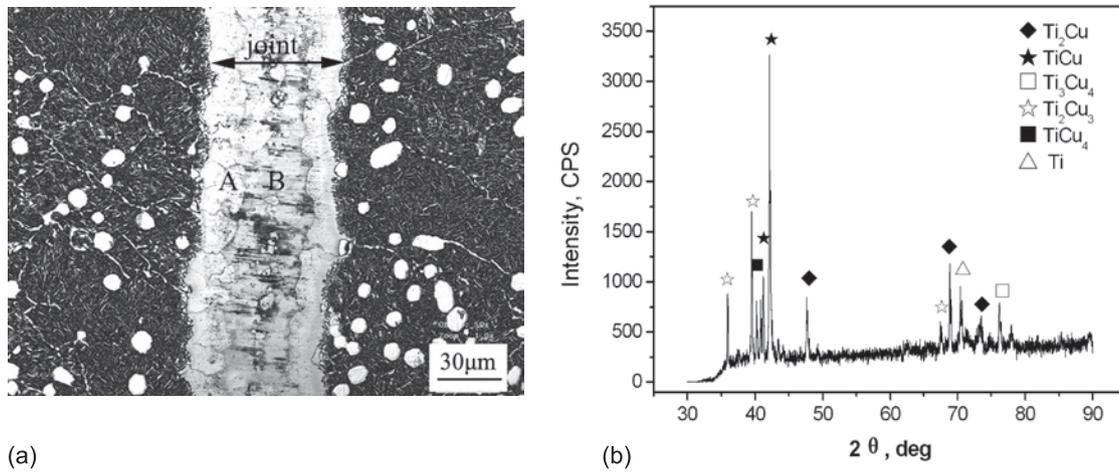


Fig. 3: Joint produced at 950 °C × 1 min. a: joint microstructure, b: XRD pattern taken from the fracture surface of the joint

Table 2: Chemical analysis results of joints produced at 1223 K × 1 min

mass%	Ti	Cu	Al	Nb	Possible phases
A	49.28	19.95	7.49	23.28	Ti (solid solution) + Ti ₂ Cu
B	31.31	45.70	5.77	17.23	TiCu
B	25.24	52.35	6.26	16.14	Ti ₃ Cu ₄

ical analysis results, the stoichiometric ratios between Ti and Cu at the reaction layers are close to TiCu₂ (marked by B) and TiCu₄ (marked by C). So, it could be considered that TiCu₂ and TiCu₄ were formed during the cooling of the joint. Zone A is Ti (solid solution) + Ti₂Cu phase. It is noted that all of these reaction productions were found at the fracture surface of joint according to the XRD result, which indicates that the fracture of joint path was devious and was not along only one compound zone.

When bonding temperature was raised to 1223 K with a constant bonding time of 1 min, the compound zones in the joint decreased as shown in Fig. 3a and Fig. 3b is the XRD pattern taken from fracture surface of the joint. Table 2 presents the chemical analysis results of zones marked by A and B by using EDS. According to Fig. 3a, Cu interlayer completely melted leaving zone B with a wavy boundary indicating the liquid phase. The increasing velocity of the interlayer melting at higher bonding temperature would be owing to the increase of the diffusion coefficient based on the formula $D = D_0 e^{-Q/RT}$ [15], which could subsequently accelerate the diffusion process. Furthermore, it can be seen that the width of solid diffusion layer (zone A) increased with increasing the bonding temperature. When bonding time finished, the liquid phase would experience a serious of reactions at various temperatures during subsequent cooling. TiCu is the first

compound precipitated from the liquid when the temperature decreased to the liquidus of the molten alloy. Since the content of liquid is hypoeutectic, reactions during cooling involve TiCu + L ↔ Ti₃Cu₄ at 1198 K, Ti₃Cu₄ + L ↔ Ti₂Cu at 1163 K and L ↔ TiCu₄ + TiCu₂ at 1148 K. From the EDS analysis, zone B consisted of TiCu and Ti₃Cu₄ phase (EDS analysis was taken from two different areas in zone B). However, these two phases are difficult to distinguish from each other under the present experimental condition. Further work should be carried out to achieve this aim. Zone A was estimated by Ti (solid solution) + Ti₂Cu phase. According to Fig. 3b, all the above reaction productions with Ti solid solution are observed at the fracture surface of joint.

Fig. 4 shows the microstructure of joint at 1223 K × 30 min and XRD pattern taken from the fracture surface. Table 3 is the chemical analysis results of zones marked by A and B by using EDS. It is obvious that the width of joint increased and liquid phase (zone B) decreased. Zone A is solid diffusion layer. When the interlayer completely melted into liquid, its content was unbalanced with the adjacent base metal. Thus inter-diffusion occurred at the liquid/base metal interface during holding stage, which caused the liquid content changing toward increasing Ti content. When the liquid content changed to the liquidus (about 32Ti in mass%), TiCu compound precipitated from it, namely isothermal solidification of TLP bonding. Since isothermal solidification is dominated by solid diffusion with a relative low velocity, it costs a long time for the liquid phase to finish isothermal solidification. The production of isothermal solidification (TiCu) would experience transformations due to element diffusion between itself and its adjacent base metal, which resulted in the increase of joint width. The final transformation results would be owing to the thermodynamics reasons. The

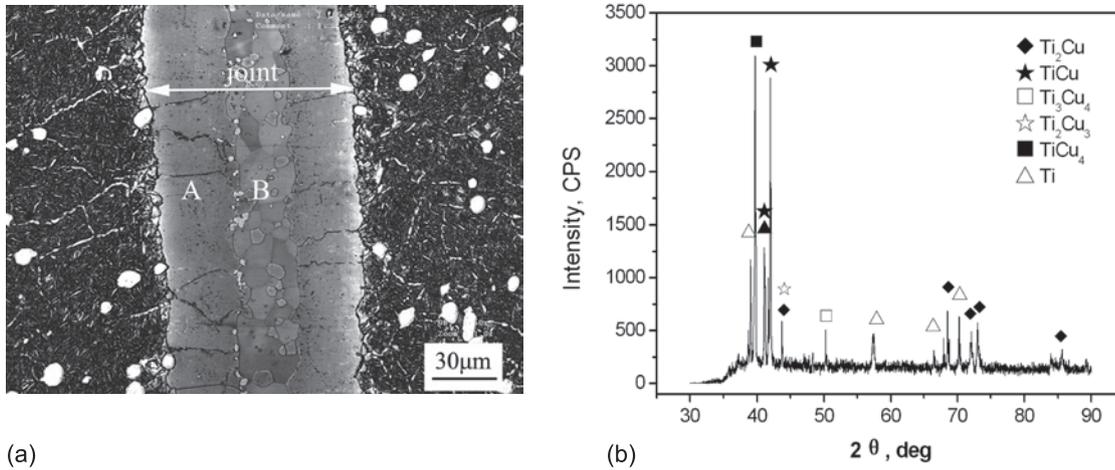


Fig. 4: Joint produced at 950 °C × 30 min. a: joint microstructure, b: XRD pattern taken from the fracture surface of the joint

Table 3: Chemical analysis results of joints produced at 1223 K × 30 min

mass%	Ti	Cu	Al	Nb	Possible phases
A	49.01	22.85	6.90	21.24	Ti (solid solution) + Ti ₂ Cu
B	25.67	52.35	6.72	15.26	Ti ₃ Cu ₄

residual liquid would also experience transformations via reactions involve $\text{TiCu} + \text{L} \leftrightarrow \text{Ti}_3\text{Cu}_4$ at 1198 K, $\text{Ti}_3\text{Cu}_4 + \text{L} \leftrightarrow \text{Ti}_2\text{Cu}$ at 1163 K and $\text{L} \leftrightarrow \text{TiCu}_4 + \text{TiCu}_2$ at 1148 K. In addition, it is also found that the amount of TiCu compound is decreased compared with joint at 1223 K × 1 min. That would be owing to the long bonding time, during which the joint was kept at the bonding temperature, to enable sufficient element diffusion for the transformation of TiCu to Ti₂Cu.

Microstructure of joint at 1223 K × 60 min and XRD pattern taken from the fracture surface is presented in Fig. 5. It is observed that liquid phase was eliminated from the joint, which indicates that isothermal solidification of liquid phase was finished. Based on EDS analysis, the joint comprises The joint width increases and its exhibits a uniform microstructure with Ti (solid solution) + Ti₂Cu phase. Therefore, it is concluded that isothermal solidification rate was slow, such that, more than 60 min bonding at 1223 K was required to fully isothermally solidify the Ti₃Al-Nb alloy joint by TLP bonding. Compounds such as TiCu₄, TiCu₂ and Ti₃Cu₄, produced by liquid phase reaction are absent from the XRD pattern, which further conformed the completion of isothermal solidification of the joint. The increase of the joint width is attributed to the composition difference between the isothermal solidification production and its adjacent base material.

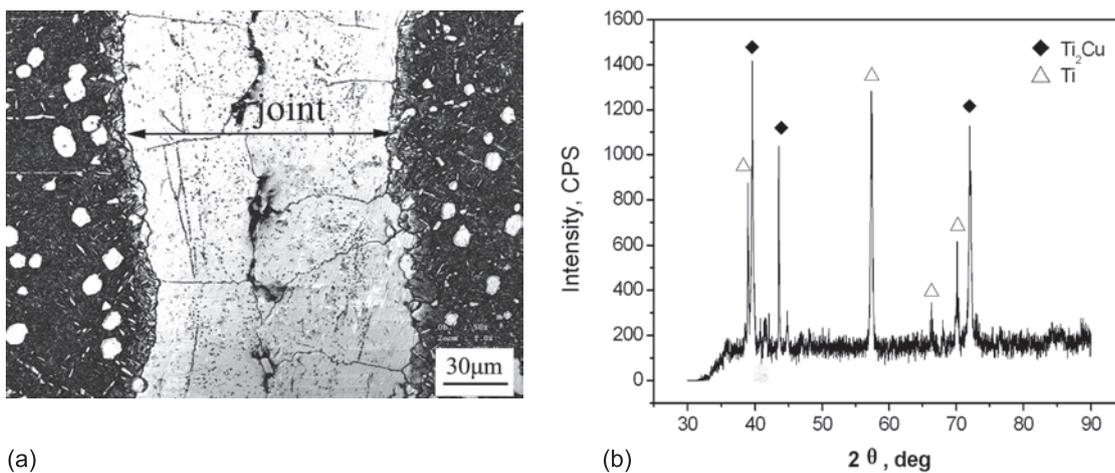


Fig. 5: Joint produced at 950 °C × 60 min. a: joint microstructure, b: XRD pattern taken from the fracture surface of the joint

4 Conclusions

Microstructural evolution of transient liquid phase bonded Ti₃Al-Nb alloy using pure copper as interlayer was investigated in this study. Primary conclusions are summarized as follows:

1. TLP bonded Ti₃Al-Nb alloy joints composed of intermetallic compound layers were produced. Microstructural evolution of joints depended on both bonding time and bonding temperature.
2. With increasing bonding time and bonding temperature, the joint width increased and amount of compounds in the joint decreased. The joint microstructure at 1173 K × 1 min mainly consisted of Ti (solid solution) + Ti₂Cu + TiCu + Ti₃Cu₄ + Ti₂Cu₃ + TiCu₄ + Cu (solid solution) phase and it changed to Ti (solid solution) + Ti₂Cu + TiCu at 1223 K × 60 min.
3. Compounds formed on cooling from the bonding temperature by liquid phase were eliminated from the joint at 1223 K × 60 min due to isothermal solidification of liquid phase. The increase of the width of joint is attributed to the composition difference between the isothermal solidification production and its adjacent base material.

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