# Optimization of TLP Diffusion Bonding Parameters for Joining AA2219 and Ti-6Al-4V with Copper as Interlayer Using RSM-BBD Method

**Manjunath Vatnalmath[1*], Virupaxi Auradi[2], Bharath V[1] and Madeva Nagaral[3]**

[1] Department of Mechanical Engineering, RNS Institute of Technology, Bengaluru, Karnataka, India-560098
[2] Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumakuru, Karnataka, India-572103
[3] Aircraft Research and Design Centre, Hindustan Aeronautics Limited, Bangalore, Karnataka, 560037, India
* Correspondence: manjunathvatnalmath@rnsit.ac.in

**ABSTRACT**

The transient liquid phase (TLP) diffusion bonding is carried out using the Box Behnken design matrix, and the bonding parameters such as temperature, pressure and holding time have been optimized using the desirability function. The diffusion bonded joints are studied for their microstructure, intermetallic formation, hardness, and joint strength for various bonding parameters. In addition, the effect of bonding parameters on these important properties has been noted. The transient liquid phase (TLP) diffusion bonding of AA2219 and Ti-6Al-4V utilizing a copper interlayer was statistically evaluated and optimized using a Box-Behnken Design coupled with Response Surface Methodology (BBD-RSM).

**KEYWORDS:** TLP; RSM-BBD; Intermetallic

## 1. INTRODUCTION

Transient liquid phase (TLP) diffusion bonding is a futuristic joining method to integrate different metals and alloys [1-2]. This method greatly impacted the microstructure and mechanical properties of the joints by adding a suitable interlayer between the different metals to be joined together, which resulted in avoiding the formation of unsolicited intermetallics [3]. Compared to fusion welding, the TLP process does not impart on melting base metals, eliminating the formation of heat-affected zones, cracks, pores, and inclusions in the joint section [4]. Recently, joining aluminium (Al) and titanium (Ti) alloys has become most vital for aerospace and military applications. In contrast, joining Al and Ti alloys is unambiguously challenging due to differences in their mechanical and thermal properties, which poses difficulties in getting good metallurgical bonds at the interface [5]. Currently, very limited reports on the diffusion bonding of Al and Ti alloys using the TLP method have been reported. In this context, the Cu interlayer fabricates the TLP diffusion bonded joints of AA2219 and Ti- 6Al-4V. The resulting TLP joints are studied for the interface microstructure and intermetallic formed at the Al-Cu and Cu-Ti interface during the diffusion bonding. The diffusion bonding experiments are constructed using a statistical algorithm, such as RSM-BBD (Response surface methodology-Box Behnken Design), to optimize the intermetallic thickness, shear strength, and hardness.

## 2. MATERIALS AND METHODS

AA2219 (Mallinath Metals, Mumbai) and Ti-6Al-4V (Hindco Steels and Alloys, Mumbai) alloys are prepared to the dimension of 50x50x50 mm3 using wire cut EDM (electric discharge machining) and grounded using different SiC grit papers (#220-#1000). The chemical composition of the base metals is shown in Table 1. The roughness of joining surfaces is an essential parameter besides the actual bonding parameters, which also influence the microstructure and mechanical properties of the TLP diffusion bonded joints. The surface roughness of the joining surfaces is measured by Park NX20, and the topography is characterized by AFM (atomic force microscopy). The TLP bonding parameters are varied at three levels: minimum (-1), mean (0), and maximum (+1), as shown in Table 1.

## 3. RESULTS

Fig. 1 shows the BSE micrographs of the joint bonded at 520ºC, 2.5 MPa and for 75 minutes, which is the centre point of the BBD model. The RLT of 44±1.6 µm is observed at the Cu-Al interface. A few scraggly voids are observed at the interface of the Cu interlayer and reaction layer R. However, unbonded regions and delamination are not observed at the interface of the reaction layers. A maximum shear strength of 32.3 is observed for specimen bonded at 520ºC, 2.5 MPa and for 75 minutes

© The Author(s) 2026
D. Nikam et al. (eds.), *Proceedings of the Global Symposium on Adaptive Manufacturing (GSAM 2026)*, Advances in Engineering Research 308,
https://doi.org/10.2991/978-94-6239-813-9_2

**Table 1** Bonding parameters and their levels in BBD

| Bonding Parameters | | Range and Level | | |
|---|---|---|---|---|
| | Coded symbols | -1 | 0 | 1 |
| Temperature (°C) | A | 500 | 520 | 540 |
| Pressure (MPa) | B | 1 | 2.5 | 4 |
| Time (min) | C | 30 | 75 | 120 |

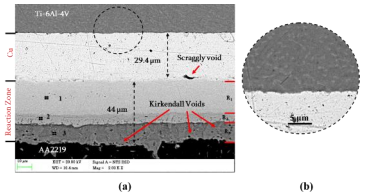



**Figure 1. a**) BSE image of the TLP joint J6; b) magnified view of the Cu-Ti interface

Table 2 shows the ANOVA for RLT and shear strength. The high $R^2$ values (>0.99) obtained for both RLT and shear strength indicate that the second-order polynomial model adequately captures the true, physically governed (diffusion-controlled) relationship between the bonding parameters and the measured responses. This is further supported by the non-significant Lack of Fit test for both models, confirming the absence of any systematic deviation between the predicted and experimental values, and by the low pure error observed at the replicated centre-point runs, reflecting good experimental reproducibility."

**Table 2** ANOVA for RLT and Shear Strength

| Source | F-value | p-value | F-value | p-value | |
|---|---|---|---|---|---|
| | RLT | | Shear Strength | | |
| **Model** | 199.27 | < 0.0001 | 413.30 | < 0.0001 | significant |
| A-Temp | 280.53 | < 0.0001 | 603.97 | < 0.0001 | |
| B-Pressure | 202.29 | < 0.0001 | 451.76 | < 0.0001 | |
| C-Time | 1028.52 | < 0.0001 | 671.03 | < 0.0001 | |
| AB | 6.57 | 0.0505 | 0.8824 | 0.3907 | |
| AC | 51.05 | 0.0008 | 56.47 | 0.0007 | |
| BC | 67.77 | 0.0004 | 0.8824 | 0.3907 | |

## 4. CONCLUSION

The BBD–RSM model successfully optimized the TLP diffusion bonding parameters for AA2219/Ti-6Al-4V joints with a copper interlayer, yielding highly significant models ($p < 0.05$) and excellent predictive accuracy ($R^2 > 0.99$). A maximum shear strength of 32.3 MPa was observed for specimen bonded at 520°C, 2.5 MPa, and 75 minutes. A reaction layer thickness of 44 µm was found to be optimum, yielding the maximum shear strength. Beyond this optimum thickness, the shear strength decreased with increasing reaction layer thickness.

## REFERENCES

[1] Zou T, Lang Z, Chen H, Ye Z, Wu T, Wang W, Yang J, Huang J. Rapidly achieving high-performance joining of single crystal superalloy and powder metallurgy superalloy via partial transient liquid phase diffusion bonding. Journal of Manufacturing Processes. 2024 Jan 17;109:79-88.

[2] Vazirian S, Moshkbar Bakhshayesh M, Farzadi A. Time-dependent effects in transient liquid phase bonding of 304L and Cp-Ti using an Ag-Cu interlayer. Journal of Central South University. 2024 Jul;31(7):2237-55.

[3] Salehi Mobarakeh V, Niroumand B. Effects of Homogenization Heat Treatment on Microstructure, Mechanical and Corrosion Properties of Transient Liquid Phase (TLP)-Bonded Inconel 617/AISI 310 Stainless Steel. Metallography, Microstructure, and Analysis. 2024 Feb;13(1):29-39.

[4] Shirzadi AA, Wallach ER. Analytical modelling of transient liquid phase (TLP) diffusion bonding when a temperature gradient is imposed. Acta materialia. 1999 Oct 8;47(13):3551-60.

[5] Alhazaa AN, Khan TI. Diffusion bonding of Al7075 to Ti–6Al–4V using Cu coatings and Sn–3.6 Ag–1Cu interlayers. Journal of Alloys and Compounds. 2010 Apr 2;494(1-2):351-8.

**Open Access** This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

