The evolution of interface structure in TLP bonded joints of Al_2O_{3p}/6061Al composites with Cu/Ni/Cu interlayers

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Transient liquid phase (TLP) bonding of aluminum metal matrix composites (Al-MMCs) has been widely investigated using different kinds of interlayers such as Ag [1], Cu [1–4], Ni [5], Ai-Si [6] and Ai-Li [7]. Joints with high mechanical properties were obtained by using the Ni interlayer [5]. However, the bonding temperature used needs to reach 650°C, while excessive deformation occurs during TLP bonding. This letter aims to investigate TLP bonding of Al_2O_{3p}/6061Al composites using Cu/Ni/Cu interlayers at the comparatively low temperature of 580°C.

The materials used in the experiments were cylindrical rods (Φ105 mm) of Al-MMCs (particle diameter 0.4 μm, volume fraction 30%). The thickness of the Cu/Ni/Cu foils was 10/30/10 μm. The Al-MMCs/Cu/Ni/Cu/Al-MMCs couples were TLP bonded at 580°C for 30–90 min in a vacuum furnace (vacuum 8×10^{-3}Pa). The morphologies, chemical composition and structures of the phases formed in TLP bonded joints were investigated by scanning electron microscopy (SEM), electron probe X-ray microanalysis (EPMA) and X-ray diffraction (XRD).

Fig. 1 shows a back-scattered electron image and the elemental distributions of a cross-section of the Al_2O_{3p}/6061Al composites joints bonded at 580°C for 45 min. It can be seen in Fig. 1a that four kinds of reaction zones have formed in the bond region and a diffusion zone has formed in the base metal in the vicinity of the bond region. For the sake of convenience, these zones were named A zone, B zone, C zone, D zone and E zone, respectively, as shown as in Fig. 1a. Fig. 1b shows the concentration profiles of the major elements (Al, Cu and Ni) across the bond region corresponding to the location of the Line MN in Fig. 1a. It can be seen that there is almost no Al in the A zone, and the concentration profile of Al fluctuates in the C, D and E zones and is flat in the B zone. Cu exists in neither A nor B zone, but is present in the C, D and E zones. Ni exists in all zones, and the concentration of Ni reaches a maximum in the A zone and gradually decreases from the A zone to the E zone. It is noted that the concentration profile of Ni is flat in the B and C zones. The results reveal that the A zone is a Ni-rich zone, and the B zone contains an invariant amount of Al and Ni, and the C, D and E zones are mainly composed of Al, Cu and Ni.

TABLE I Chemical compositions of each reaction zone in the bond region (at.%)

Elements	A	B	C_1	C_2	D	E
Al	0.0	45.1	51.6	58.1	46.9	76.1
Cu	0.0	0.0	13.8	7.9	19.9	9.1
Ni	100.0	54.9	34.5	33.8	33.1	12.7

Table I shows the chemical compositions of each reaction zone in the bond region. According to the table and Fig. 1, it can be inferred that the A zone is composed of pure Ni, and the B zone is composed of a constant proportion of nearly 0.9/1.1 of Al and Ni. The phase in the B zone has been identified by area-selected XRD to be $Al_{0.9}Ni_{1.1}$. The C zone is composed of two kinds of Al-Ni-Cu solid solution (i.e. mixture of the C_1 and C_2 zones), while there is more elemental Cu and less elemental Al in the C_1 zone than in the C_2 zone. The D and E zones are also composed of Al-Ni-Cu solid solution. In brief, the microstructures of TLP bonded joints of the Al_2O_{3p}/6061Al composites using Cu/Ni/Cu interlayers are composed of the residual Ni metal, the $Al_{0.9}Ni_{1.1}$ compound and the Al-Ni-Cu solid solution.

Fig. 2 is the interface structure evolution model for TLP bonded joints of the Al_2O_{3p}/6061Al composites with Cu/Ni/Cu interlayers. The evolution process can be divided into five stages. In the first stage, Cu foil reacts with 6061Al matrix to form the Al-Cu eutectic alloy layer at a temperature above 548°C (see Fig. 2a). In the second stage, all of the Cu foil is dissolved into Al-Cu eutectic alloy, and the Al liquid metal in the eutectic alloy is able to react with Ni to form the $Al_{0.9}Ni_{1.1}$ layer (the B zone in Fig. 1a) according to Reaction 1 (see Fig. 2b).

$$Al(L) + Ni(S) \rightarrow Al_{0.9}Ni_{1.1}(S) \quad (1)$$

With the continuance of the diffusion process, the composition of the Al-Cu liquid phase adjacent to Al-MMCs deviates from the eutectic point, and an Al-based solid solution layer (the D zone in Fig. 1a) forms during solidification. While, the eutectic layer (the C zone in Fig. 1a) next to the $Al_{0.9}Ni_{1.1}$ layer is still liquid (see Fig. 2b). In the third stage, the pure Ni layer becomes narrow and ultimately disappears

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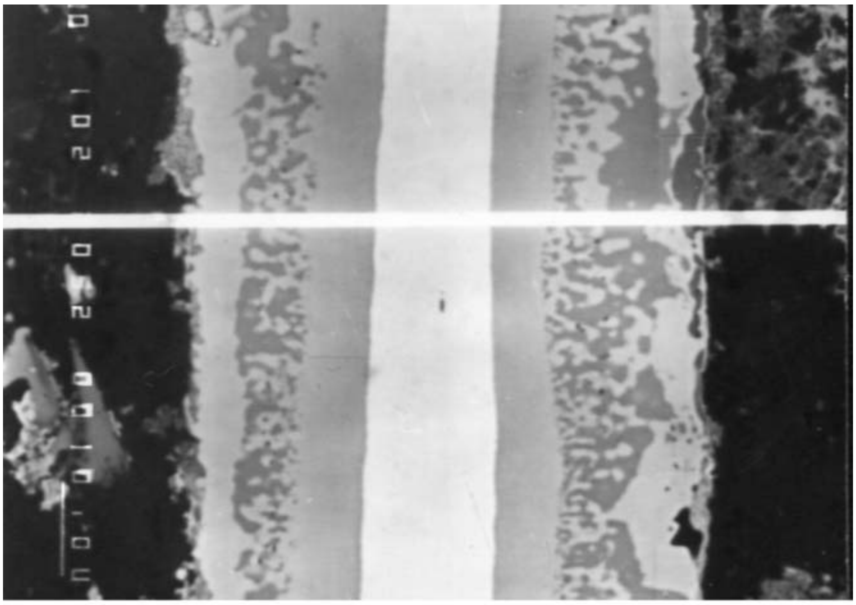
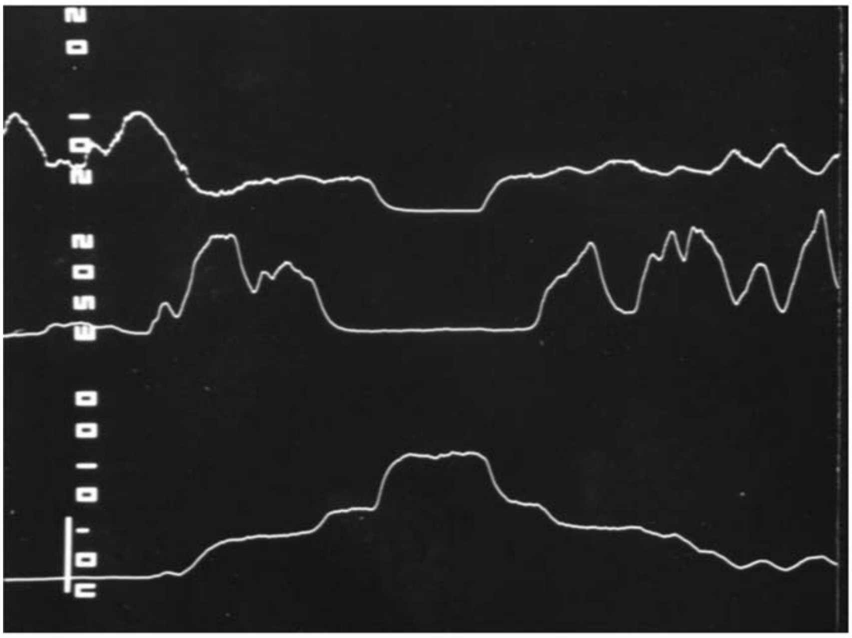


(a)



(b)

Figure 1

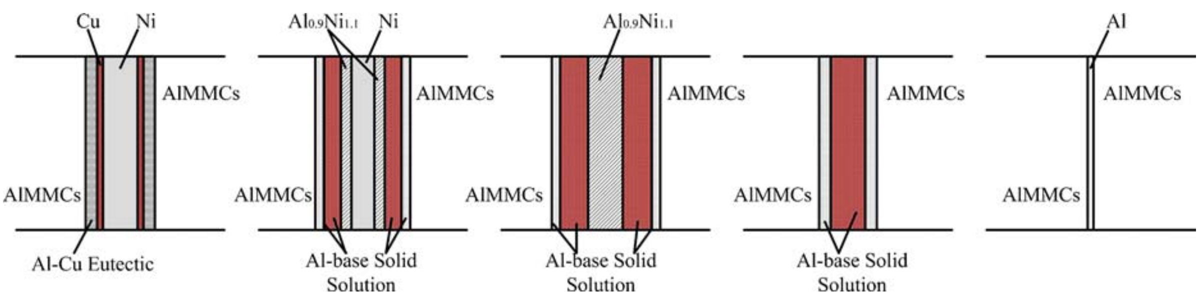


Figure 2

with increasing bonding time, and the thickness of the $Al_{0.9}Ni_{1.1}$ layer increases simultaneously (see Fig. 2c). The layer of Al-Ni-Cu solid solution becomes wider as the $Al_{0.9}Ni_{1.1}$ layer is gradually dissolved. In the fourth stage, the $Al_{0.9}Ni_{1.1}$ layer disappears and two kinds of Al-based solid solution layer remain in the bond region. Meanwhile, the width of the bondline decreases (see Fig. 2d). Finally a thin layer mainly consisting of elemental Al forms in the bond region in the fifth stage (see Fig. 2e).

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References
1. R. KLEHN and T. W EAGAR, *WRC Bulletin*. **385** (1993) 1.
2. Z. LI, W. FEARIS and T. H. NORTH, *Mater. Sci. Technol*. **11** (1995) 363.
3. Z. LI, Y. ZHOU and T. H. NORTH, *J. Mater. Sci*. **30** (1995) 1075.
4. A. A. SHIRZADI and E. R. WALLACH, *Mater. Sci. Technol*. **13** (1997) 135.
5. J. R. ASKEW, J. F. WILDE and T. I. KHAN, *Mater. Sci. Technol*. **14** (1998) 920.
6. X. P. ZHANG, L. YE, Y. W. MAI, G. F. QUAN and W. WEI, *Composites: Part A*. **30** (1999) 1415.
7. P. G. PARTRIDGE and D. V. DUNFORD, *J. Mater. Sci*. **26** (1991) 2255.

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