*Journal of University of Science and Technology Beijing*
*Volume 11, Number 1, February 2004, Page 85*

**Materials**

# Diffusion welding $SiC_p/ZL101$ with Ni interlayer

*Jitai Niu*[1,2], *Wei Guo*[1], *Qingchang Meng*[1], *and Baoyou Zhang*[1]

1) State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China
2) State Key Laboratory of Metal Matrix Composite, Shanghai Jiaotong University, Shanghai 200030, China
(Received 2003-2-06)

**Abstract:** Through the vacuum diffusion welding $SiC_p/ZL101$ aluminum with Ni interlayer, the effect of welding parameter and the thickness property of Ni on the welded joint was investigated, and the optimal welding parameters were put forward at the same time. The microstructure of joint was analyzed by means of optical-microscope, scanning electron microscope (SEM) in order to study the relationship between the macro-properties of joint and the microstructure. The results show that diffusion welding with Ni interlayer can be used for welding aluminum matrix composites $SiC_p/ZL101$ successfully. Under the welding parameters $T$=560°C, $P$=5 MPa, $t$=60 min, $H$=14 μm, the bonding strength of welded joint can up to 121 MPa. Moreover, the thickness of interlayer should match with the size of reinforced particles. If the thickness of interlayer is too thin, it would have no effect on the welded joint beneficially. If the thickness of interlayer is too thick, it would cause the "no-reinforcement zone" to appear.

**Key words:** aluminum matrix composite; diffusion welding; $SiC_p/ZL101$; Ni interlayer

[*This work was supported by the National Natural Science Foundation of China (No.50171025).*]

## 1 Introduction

Recently the study of composite material has been one of the most important directions in materials research, while aluminum matrix composite has a wide application in the fields of aerospace, automobile and so on, because of their high specific strength, rigidity, wear resistance and good dimensional stability [1,2]. However, its further application and development are faced with the difficulty of bad weldability, caused by great difference between aluminum matrix and particles in physical and chemical properties [1,3-4]. Research on weldability of the aluminum matrix composite is focused on molten welding, diffusion welding, braze welding, friction welding and so on [2-5]. Diffusion bonding is one of the most promising methods for the composites. In this paper, the influence of welding parameters on joint performances was studied by means of diffusion welding for $SiC_p/ZL101$ aluminum matrix composite with Ni interlayer. Meantime the relationship was studied between macro-performances of joint and microstructure with optical microscope and scanning electron microscopy (SEM), *etc.*

## 2 Experimental

### 2.1 Experimental material

The ZL101 aluminum matrix composite reinforced with 20% (volume fraction) SiC particulate with mean size of 12 μm, was made by stirring casting. The microstructure of the composite is shown in **figure 1**, in which some defects such as aggregation of reinforcement can be seen. The chemical composition (mass fraction) of the matrix alloy ZL101 and their mechanical properties are listed in following: $w_{Si}$=6.5%-7.5%, $w_{Mg}$=0.3%-0.5%, $w_{Ti}$=0.08%-0.2%, $w_{Al}$=Bal; $\sigma_b$= 170MPa, $\delta$=2%, HB=50.

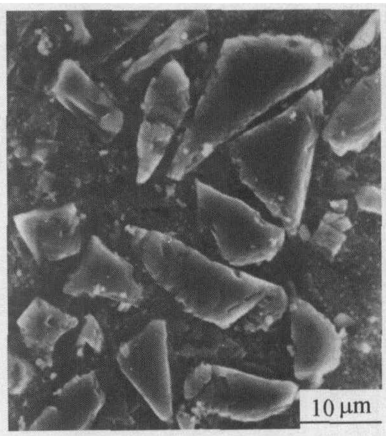


**Figure 1 Microstructure of SiCp/ZL101 aluminum matrix composite.**

### 2.2 Experimental process

Specimen size is 3 mm×10 mm×35 mm, as shown

**Corresponding author:** Jitai Niu, **E-mail:** jtn@hope.hit.edu.cn

in **figure 2**. These specimens were polished by sand paper (400#) to remove the harden quenching layer and oxides away, then cleaned by acetone to get a smooth surface. The vacuum diffusion welding was conducted by Gleeble-1500 thermal/mechanical simulation machine with the 0.4 Pa vacuum chamber.

Tensile strength of the welded joint was measured with the electron-mechanical universal materials testing machine made in Instron Company (USA). The velocity is 0.5 mm/min. The final value of strength is the average of five values. The size of specimen for tensile test was shown in **figure 3**.

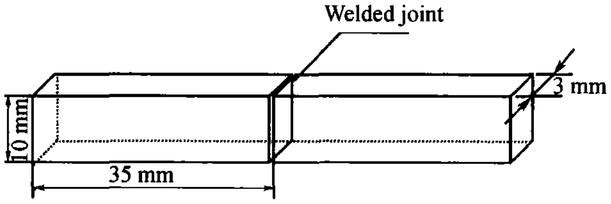


**Figure 2 Shape and dimension of the sample.**

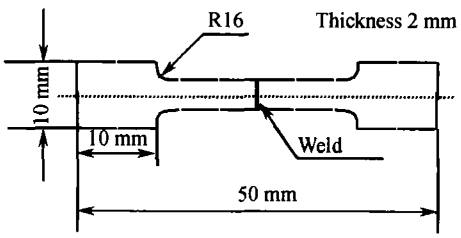


**Figure 3 The size of specimen for tensile test.**

## 3 Results and discussion

### 3.1 The influence of welding temperatures on properties of the welded joint

As for solidus diffusion bonding, the little variation of temperature would make the atom diffusion speed change obviously. To some extent, the strength of bonded joint is increased with the temperature becoming higher. According to phase diagram of Al-Ni binary system (**figure 4**), $SiC_p$/ZL101 aluminum matrix composite was bonded with Ni interlayer by solidus diffusion bonding. The result is shown as **figure 5**, the bonding parameters are bonding pressure $P$=5MPa, bonding time $t$=60 min, the thickness of interlayer $\delta$=14 μm. It can be seen that the strength of bonded joint is up to its maximum value when the temperature varies from 550 to 560°C.

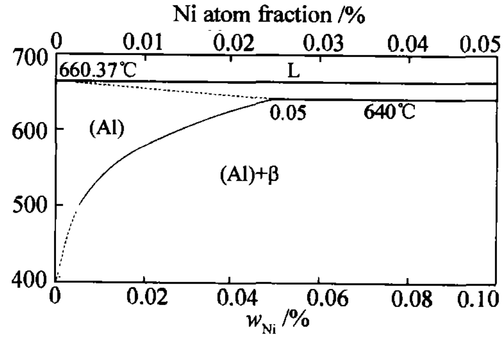


**Figure 4 Phase diagram of Al-Ni binary system.**

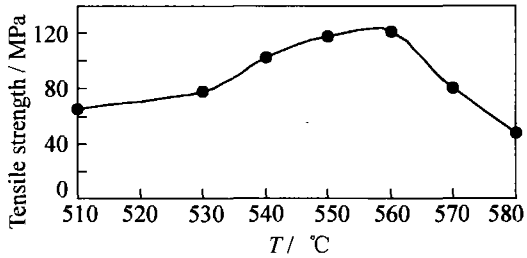


**Figure 5 The relationship between the strength of bonded joint and bonding temperature with Ni interlayer.**

### 3.2 The influence of bonding time on the strength of bonded joint

In course of solidus diffusion bonding, bonding time is another important parameter that affects on the strength of bonded joint. **Figure 6** is the relationship between the strength of bonded joint and bonding time ($T$=560°C, $P$=5 MPa, $\delta$=14 μm). It can be seen that there exists an optimal range in bonding time. If the bonding time is too short, the atom wouldn't diffuse effectively, and its diffusion distance is very short. As a result, the strength of bonded joint is not up to that of parent composite. When the bonding time is 60 min, the atom diffuses adequately. Consequently, the strength of bonded joint will up to its maximum. But, if the bonding time is too long, the strength of bonded joint would descend.

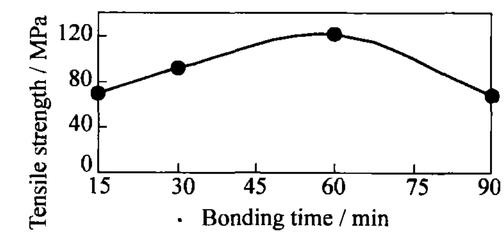


**Figure 6 The relationship between the strength of bonded joint and bonding time.**

It is the SEM micrographs of bonded joint at various bonding times in **figure 7**. When the bonding time is 15 min, the Ni atom doesn't diffuse apparently. When the bonding time is 30 min, the Ni atom diffuses in short distance. There exists lots of micro-hole among the interface between matrix and interlayer, which results in the low strength of bonded joint. When the bonding time is 60 min, the Ni interlayer diffuses obviously, and the diffusion zone forms as shown in figure 7(c). The interlayer and matrix is bonded successfully, the strength of bonded joint is up to 121 MPa. **Figure 8** is the energy spectral analysis of the diffusion zone. It shows that Ni atom diffuses effectively in the diffusion zone. Therefore, the strength of bonded joints is up to its maximum value.

**Figure 9** is the SEM fractographs of bonded joints at various time. When the bonding time is too short, the interface between the reinforced phase/matrix, reinforced phase/reinforcement have not been jointed perfectly due to a large amount of nude SiC particles on the fracture surface as shown in figure 9 (a). With the increasing of bonding time, the nude SiC particles on the fracture surface are decreased gradually as shown in figure 9(b). With the elongation of bonding time, the Ni atom diffuses more and more sufficiently, the contacting area of the reinforcement phase/matrix, reinforced phase/reinforcement is improved prominently, the reinforced/reinforcement contact is changed into reinforced/Ni/reinforcement, and the fracture feature is changed from brittle fracture to plastic fracture with tearing edge, as shown in figure 9(c). However, when the bonding time is too long, because the solidus/liquidus phase temperature is 562.6-578.3°C and the defect of preparation for parent composite, some part of parent composite would be melted, which leads to the reinforcement phase conglomeration, and the property of bonding joint would descend consequently. Therefore, the strength of bonded joints doesn't increase with longer bonding time. For $SiC_p$/ZL101 diffusion welding with Ni interlayer, the optimal bonding time is 60 min.

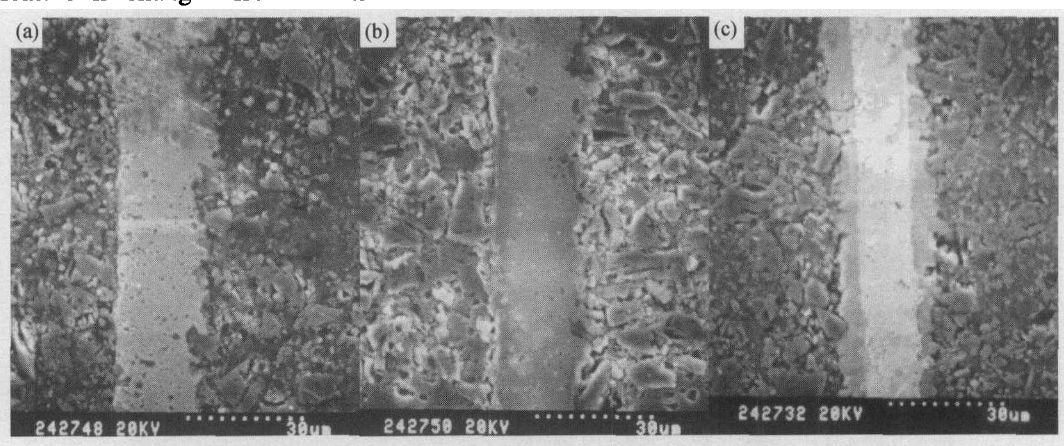


**Figure 7 The influence of bonding time on the bonded joint with Ni interlayer, (a) $t$=15 min; (b) $t$=30 min; (c) $t$=60min.**

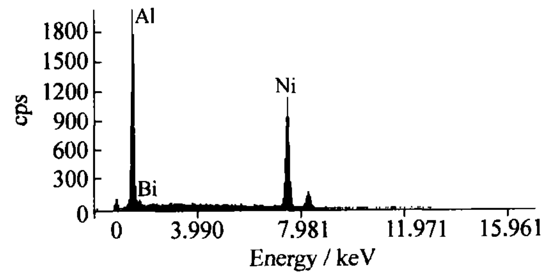


**Figure 8 The energy spectral analysis of the diffusion zone.**

### 3.3 The influence of the thickness of Ni interlayer on the property of bonded joint

It is investigated that the thickness of interlayer should match with the size of reinforcement particles [6,8]. On the grounds of that, $SiC_p$ is bonded with the thickness of Ni interlayer 7, 14, 21, 35 μm respectively. The results are shown in **figure 10.**

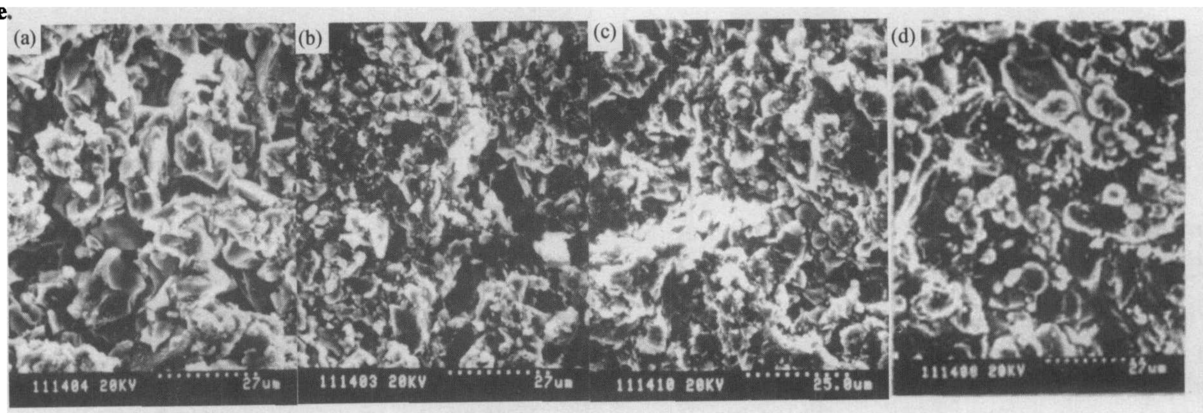


**Figure 9 Fractographs of various times, (a) $t$=15 min; (b) $t$=30 min; (c) $t$=60 min; (d) $t$=90 min.**

It has shown that when the thickness of Ni interlayer is 14 μm, the strength of bonded joint is 121MPa, up to its maximum (about 71.2% of the strength of parent composite). The Ni atom diffuses perfectly in the bonded zone, moreover, no SiC particles conglomeration and the defects of micro-hole are detected, as shown in **figure 11**. Therefore, the joint is bonded preeminently.

With the increasing of the thickness of interlayer, the strength of bonded joint is descended gradually. When the thickness of interlayer is 35 μm, the strength of bonded joint is merely 56 MPa (about

33.1% of the strength of parent composite), as shown in **figure 12**. It will be seen that when the thickness is too thick, the Ni atom doesn't diffuse obviously with the same diffusion parameters of that of 14 μm. Furthermore, there are SiC conglomeration and the defects of micro-hole in the contacting area between the interlayer and parent composite, which make the strength of bonded joint descended. Furthermore, if the thickness of interlayer is too thin, there don't exist enough Ni atoms to change the reinforcement direct contact resulted in the poor properties of bonded joint.

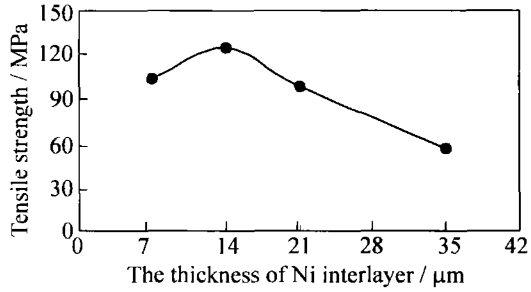


**Figure 10 The relationship between the strength of bonded joint and the thickness of Ni interlayer.**

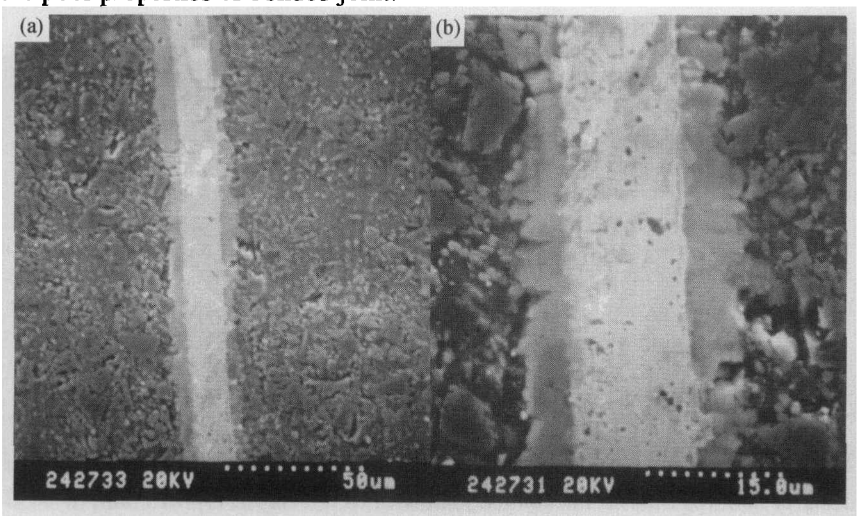


**Figure 11 SEM micrographs of bonded area with Ni interlayer ($\delta$=14 μm), (a) low enlargement; (b) high enlargement.**

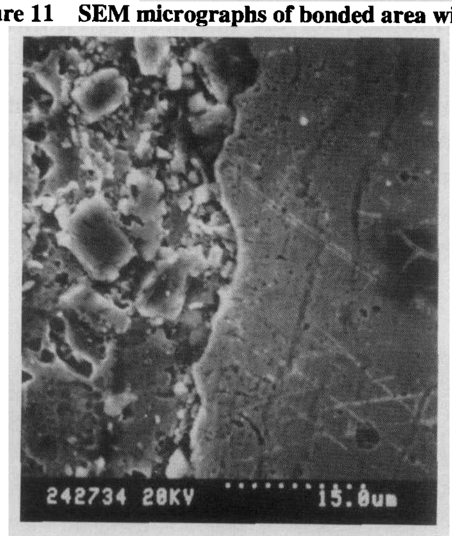


**Figure 12 SEM micrograph of bonded area with the Ni interlayer ($\delta$=35 μm).**

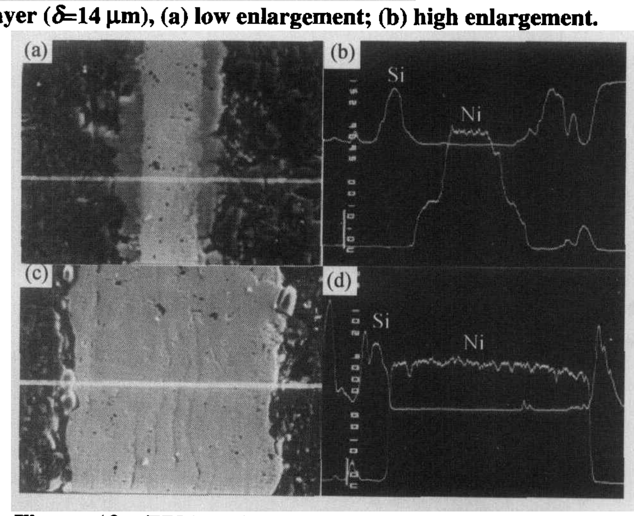


**Figure 13 EPMA photograph of bonded joint with Ni interlayer, (a) back scattering electron image ($\delta$=14 μm); (b) elements dispersion curve of welded joint ($\delta$=14 μm); (c) back scattering electron image ($\delta$=35 μm); (d) elements dispersion curve of welded joint ($\delta$=35 μm).**

**Figure 13** is the Si element and Ni element dispersion in the bonded area with different thickness of Ni interlayer. The results are in accordance with figure 11 and 12 perfectly. It has illuminated that in the course of diffusion welding with interlayer, the thickness of interlayer should match with the size of reinforcement particles. If the thickness of interlayer is too thick, it would cause the "no-reinforcement zone" to appear. If the thickness of interlayer is too thin, it would have no effect on the welded joint beneficially.

## 4 Conclusions

(1) With the Ni interlayer, $SiC_p$/ZL11 aluminum matrix composite can be jointed successfully. Under the welding parameters $T$=560°C, $P$=5 MPa, $t$=60 min, $\delta$=14 μm, the bonding strength of welded joint is 121 MPa (about 71.2% of the strength of parent composite), up to its maximum value.

(2) In the course of diffusion welding with

interlayer, the thickness of interlayer should match with the size of reinforced particles. With the same diffusion welding parameters, if the thickness of interlayer is too thin, it would have no effect on the welded joint beneficially. If the thickness of interlayer is too thick, it would cause the "no-reinforcement zone" to appear. In this experiment, the optimal thickness of Ni interlayer is 14 μm.

## References


[1] J. Eliosson and R. Somclstrom, Applications of aluminum matrix composites [J], *Key Eng. Mater.*, 1995, No.1, p.3.

[2] American Welding Society, *Welding Handbook* [M], Miami, 1996.

[3] B.K. Hun, S.J. Lin, and M.T. Jahn, The interfacial compounds and SEM fractography of squeeeze—cast $SiC_p$/6061Al composites [J], *Mater. Sci. Eng.*, A206(1996), p.11.

[4] A.A. Shirzadi and E.R. Wallach, New approaches for transient liquid phase diffusion bonding of aluminum based metal matrix composites [J], *Mater. Sci. Technol.*, 13(1997), p.135.

[5] M.E. Smagorinski, P.G. Tsantrizos, and S. Grenier, *et al.*, The properties and microstructure of Al-based composites reinforced with ceramic particles [J], *Mater. Sci. Eng.*, A244(1998), p.86.

[6] L.M. Liu, J.T. Niu, and Y.H. Tian, Diffusion bonding mechanism and microstructure of welded joint of aluminum matrix composite $Al_2O_{3p}$/6061Al [J], *Trans. Nonferr. Met. Soc. China*, 9(1999), No.4, p.826.

[7] J.T. Niu and L.M. Liu, Diffusion welding for 6061Al reinforced with $SiC_W$ whisker [J], *J. Wuhan Univ. Technol.* (Mater. Sci. Ed.), 14(1999), No.1, p.1.

[8] J.T. Niu, L.M. Liu, and Zhai J.P., *et al.*, Study on diffusion welding of aluminum matrix composite [J], *Acta Metall. Sin.* (English Letters), 13(2000), No.1, p.12.

[9] J.T. Niu, Y.H. Tian, and B.Y. Li, *et al.*, Age strengthening of diffusion welded joint of $Al_2O_{3p}$/6061Al composite [J], *Acta Metall. Sin.* (English Letters), 13(2000), No.1, p.18.

[10] T.W. Lee and C.H. Lee, Statistical evaluation of strength for die-cast $SiC_p$/Al alloy composites [J], *Mater. Lett.*, 46(2000), p.93.

[11] B.G. Kim, S.L. Dong, and S.D. Park, Effects of thermal processing on thermal expansion coefficient of a 50Vol.% $SiC_p$/Al composite [J], *Mater. Chem. Phys.*, 72(2001), p.42.

[12] J.T. Niu, Z.H. Lai, and M.Z. Wang, *et al.*, Study on laser welding of Al composite [J], *J. Mater. Sci. Technol*, 2001, No.1, p.173.

[13] M. Gupta and T.S. Srivatsan, Interrelationship between matrix microhardness and ultimate tensile strength of discontinuous particulate-reinforced aluminum alloy composites [J], *Mater. Lett.*, 51(2001), p.255.

[14] C.B. Lin, Y.W. Hung, and W.C. Liu, *et al.*, Machining and fluidity of 356Al/$SiC_p$ composites [J], *J. Mater. Process. Technol.*, 110(2001), p.152.

[15] R.R. Castro, R.C. Wetherhold, and M.H. Kelestemur, Microstructure and mechanical behavior of functionally graded Al A359/$SiC_p$ composite [J], *Mater. Sci. Eng.*, A323(2002), p.445.

[16] M. Ksiazek, N. Sobezak, and B. Mikulowski, *et al.*, Wetting and bonding strength in Al/$Al_2O_3$ system [J], *Mater. Sci. Eng.*, A324(2002), p.162.