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THE EFFECT OF PROCESSING TIME ON THE DIFFUSION BONDING OF A SiC_p REINFORCED ALUMINUM MATRIX COMPOSITE WITH A 380 CASTING ALUMINUM ALLOY

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ABSTRACT

The aluminum matrix composites are becoming more popular due to their superior mechanical properties compared with monolithic aluminum alloys. On the other hand, a main problem in expending the application of aluminum matrix composites (AlMMC) is joining difficulties by conventional welding methods. There is a growing interest in diffusion bonding of Al matrix composites due to the problems occur when conventional welding methods are used. Diffusion bonding is a joining technique in which temperature, time and pressure produce, through diffusion, coalescence of the base metals being bonded.
In the present work, a 17% SiC_p reinforced aluminum matrix composite and a 380 aluminum casting alloy were diffusion bonded at a constant temperature with different processing times. The effect of time on bonding was investigated. Diffusion bonding experiments were carried out at 560ºC under 3 MPa pressure for 30, 60 and 90 minutes holding time in vacuum atmosphere The bonded samples were investigated metallographically by means of light microscopy and scanning electron microscope (SEM). Bonding strengths of the samples were determined with shear tests using a specially designed shear test apparatus. The results showed that the bonding strength increases with increasing bonding time. The highest shear strength was obtained after bonding at 560 ºC under 3 MPa for 90 minutes.
Keywords: Diffusion bonding, SiC, aluminum matrix composite.

BİRLEŞTİRME SÜRESİNİN SiC TAKVİYELİ ALÜMİNYUM MATRİSLİ KOMPOZİTİN 380 ALÜMİNYUM DÖKÜM ALAŞIMI İLE DİFÜZYONLA BİRLEŞTİRİLMESİ ÜZERİNE ETKİSİ

ÖZET

Alüminyum matrisli kompozitlere olan ilgi bu malzemelerin konvansiyonel alüminyum alaşımlarına göre özellikle dayanım ve performans bakımından daha üstün özellikler göstermeleri nedeni ile giderek artmaktadır. Diğer yandan, alüminyum matrisli kompozitlerin (Al MMK) daha geniş bir uygulama alanı bulmasındaki en büyük problemlerden biri, bu malzemelerin konvansiyonel kaynak yöntemleri ile birleştirilmesindeki güçlüklerdir. Alüminyum matrisli kompozitlerin konvansiyonel ergitme kaynağı yöntemleri ile birleştirilmesinde karşılaşılan çeşitli sorunlar nedeni ile difüzyon ile birleştirilmelerine olan ilgi giderek artmaktadır. Difüzyonla birleştirme, sıcaklık ve basıncın etkisi ile birleştirilecek malzemeler arasında difüzyon sonucunda gerçekleşen bir katı hal birleştirme yöntemidir..
Bu çalışmada, %17 SiC takviyeli alüminyum matrisli kompozit malzeme 380 Alüminyum döküm alaşımı malzeme ile sabit sıcaklık ve basınç değerinde farklı sürelerde difüzyonla birleştirilmiştir. Birleştirme süresinin etkisi araştırılmıştır. Difüzyonla birleştirme deneyleri 560 ºC sıcaklık değerinde, 3 MPa basınç altında 30, 60 ve 90 dakika sürede vakum atmosferde gerçekleştirilmiştir. Difüzyonla birleştirilen numunelerin birleşme ara yüzeyleri metalografik olarak incelenmiş, birleşme arayüzeyinde mikrosertlik ölçümleri yapılmıştır. Birleşme dayanımı özel olarak tasarlanan bir kesme testi aparatı kullanılarak belirlenmiştir. Test sonuçları birleşme süresinin artması ile birleşme dayanımının arttığını göstermiştir. 560 ºC sıcaklık değerinde, 3 MPa basınç altında farklı sürelerde vakum atmosferde gerçekleştirilen difüzyonla birleştirme deneylerinde en yüksek dayanım değeri 90 dakika süre sonunda elde edilmiştir.
Anahtar Sözcükler: Difüzyonla birleştirme, SiC, alüminyum matrisli kompozit.

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1. INTRODUCTION

Diffusion bonding is a solid-state process conducted at sufficient temperature for assuring diffusion between the surface layers of the two parts with plastic deformation in order to eliminate the gaps at atomic level [1]. This bonding method can be used mostly for the advanced materials especially in the aerospace field [2]. Diffusion bonding is particularly adaptable to join complex assemblies of various materials to produce an assembly requiring little forming or machining. Diffusion bonding is an alternative joining process which is only considered in very special cases [2, 3].

The aluminum matrix composites (AlMMCs) have become more popular as structural materials especially in aerospace and automotive industries owing to their improved strength, low density and enhanced wear properties [4-9]. On the other hand difficulties in production of complex shapes and joining limit the widespread usage of these advanced materials [4,7]. Recently, the researches related to joining science and technology for the Al-based MMCs have a key-role for their successful engineering applications [5].

The main problems in conventional joining of these advanced materials can be listed as (1) great viscosity and poor flowability of the liquid welding pool, (2) an unusual solidification process due to reinforcement phases (SiC, Al_2O_3 and etc.) and (3) formation of brittle phases (Al_4C_3) when SiC is used as reinforcement. On the other hand, recent researches have shown that it is possible to achieve sound joints of SiC reinforced aluminum metal matrix composites (Al/SiC_p-MMC) by solid state bonding processes such as vacuum brazing, diffusion bonding (including transient liquid phase bonding-TLP) and friction welding [4-10].

In the present work, the effect of processing time on diffusion bonding of an Al/SiC_p-MMC with a 380 aluminum casting alloy has been investigated.

2. EXPERIMENTAL STUDIES

2.1. Material

The materials used in this study were a 17% SiC reinforced aluminum matrix composite and a 380 aluminum alloy. As-received composite material was an extruded rod of Al/SiCp-MMC consisting of Al matrix alloy and 17 wt% silicon carbide particulate reinforcement of very fine grain size. The chemical compositions of aluminum alloy and composite material are given in Table 1 and 2, respectively.

Table 1. Chemical composition of 380 aluminum casting alloy (wt%)

	Si	Cu	Mg	Mn	Fe	Zn	Ni	Sn	Other (total)	Al
380.0	8,65	2,95	0,269	0,336	0,431	1,90	-	-	0,158	balance

Table 2. Chemical composition of Al/SiCp-MMC material (wt%)

Al	SiC	Cu	Mg	Mn
77,3	17,8	3,3	1,2	0,4

Figure 1 shows the microstructures of the 380 aluminum casting alloy and Figure 2 shows the microstrucres of Al/SiCp-MMC.

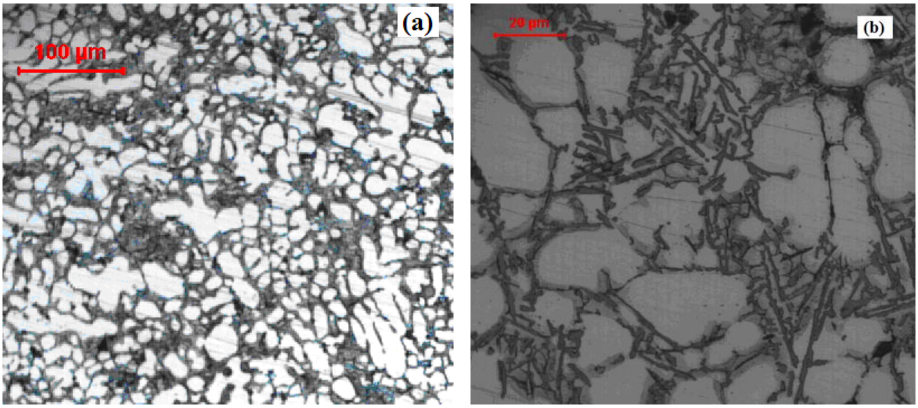

Figure 1. Optical images of the 380 aluminum casting alloy with different magnifications (a)100X (b) 500X

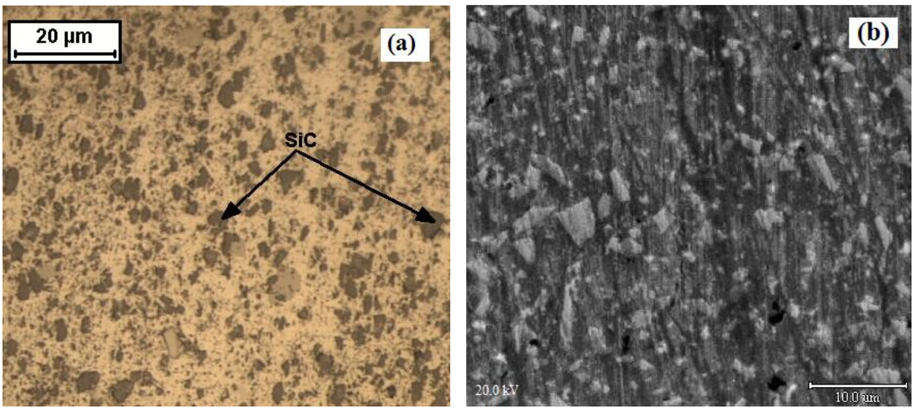

Figure 2. Microstructure of the Al/SiCp-MMC (a) optical micrograph (500X) (b) SEM micrograph (2000X)

2.2. Bonding Process

The extruded rods of Al/SiCp-MMC material and 380 aluminum casting alloy were machined to 8.5 mm diameter and 10 mm height. Bond surfaces were ground to 1200 grit by water cooled silicon carbide papers. Average surface roughness value Ra was found between 0.09-0.11 µm using Mahr PerthometerS2 surface roughness test machine. Bonding surfaces of the samples were cleaned with acid solution containing 15 ml HNO_3-15 ml HCl-15 ml H_2O and 1 ml HF to remove the potential oxide layer. Then, an ultrasonic cleaning in acetone for 30 minutes was performed just before the bonding process.

Specimen couples were placed inside the diffusion bonding chamber. Diffusion bonding of the specimens was carried out at 560ºC under 3 MPa pressure for 30, 60 and 90 minutes holding time in vacuum atmosphere. The bonded specimens were cooled in the furnace to room temperature.

2.3. Characterization of the Bonded Samples

Diffusion bonded specimens were cut perpendicular to bonding interface for metallographic examinations. Specimens were ground 180 to 1200 grit with water cooled silicon carbide papers and polished to 3 μm finish with diamond paste. Metallographic investigations of the bonding interfaces were surveyed using optical microscope and SEM.

Mechanical performance of the bonded specimens was evaluated by shear test. A special shear test apparatus were designed to achieve pure shear stress across the bond interface. The schematic illustration of the shear test apparatus is given in Figure 3. Bonded cylindrical specimens were loaded in the special test apparatus by a 100 kN capacity universal testing machine. The maximum load was divided by the bond area in order to calculate shear strength.

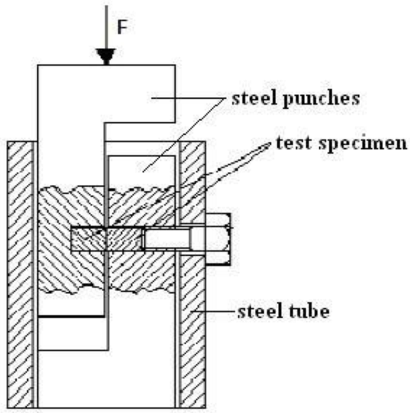

Figure 3. Schematic illustration of the shear test apparatus

3. RESULTS

Al/SiCp-MMC and 380 aluminum alloy material couple were bonded successfully with all bonding times. The macrograph of the samples bonded at 560°C under 3 MPa pressure for 30 minutes can be seen on Figure 4.

Figure 4. The macrograph of the diffusion bonded Al/SiCp-MMC-380 Al alloy couple

Figure 5, 6 and 7 shows the optical and SEM images of the samples were diffusion bonded at 560°C under 3 MPa pressure for 30, 60 and 90 minutes, respectively. The SEM investigations of the bonding interfaces revealed that the bonding line of the joint bonded for 30 minutes is clearly detectable (Fig.5b) and gradually disappearing (Fig.6b and Fig.7b) with increasing holding time. Furthermore, as it can be seen in Figure 5b that there are many gaps at the bonding interface of the samples bonded for 30 minutes that prove the existence of the unbonded areas. On the other hand no gaps were detected at the bonding interface of the samples bonded for 60 and 90 minutes. The samples which were diffusion bonded for 90 minutes have the smoothest bonding interface (Fig. 7b).

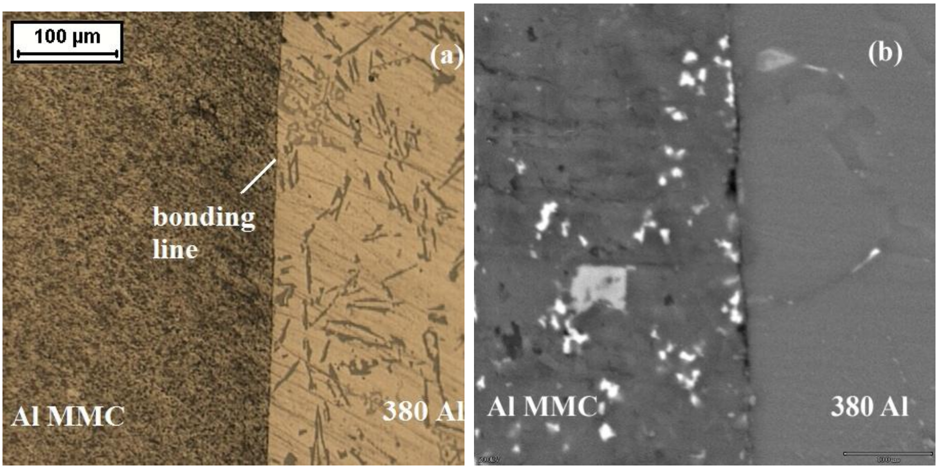

Figure 5. Micrographs of the bonding interface of the samples diffusion bonded at 560°C under 3 MPa pressure for 30 minutes (a) optical micrograph (b) SEM micrograph

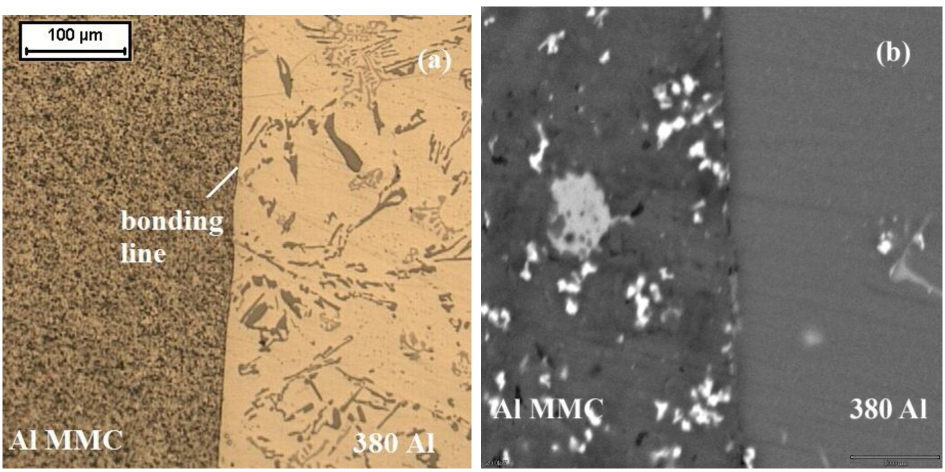

Figure 6. Optical micrographs of the bonding interface of the samples diffusion bonded at 560°C with 3 MPa for 60 minutes (a) optical micrograph (b) SEM micrograph

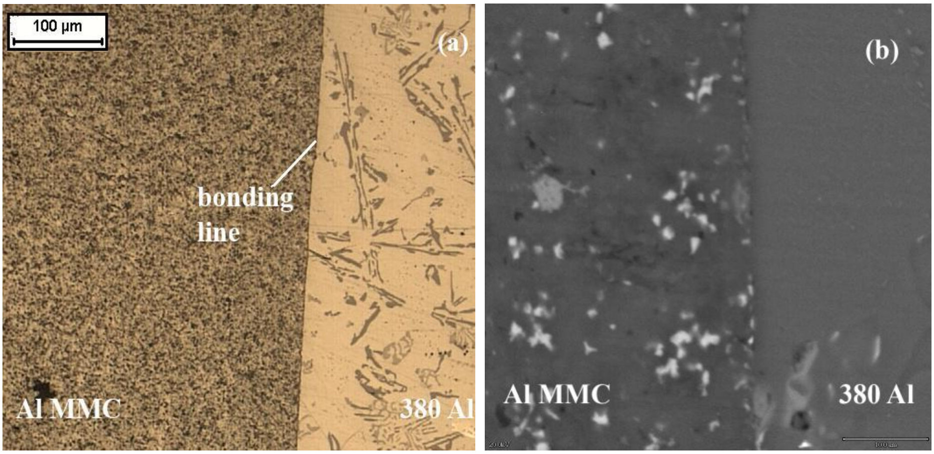

Figure 7. Optical micrographs of the bonding interface of the samples diffusion bonded at 560°C with 3 MPa for 90 minutes (a) optical micrograph (b) SEM micrograph

Figure 8 shows the microhardness profiles of the bonded materials through the bonding interface. Because the diffusion bonding process didn't cause inhomogeneous distribution of the reinforcement particles or segregation, a significant change didn't occur in the microhardness value through the bonding interface to the base materials.

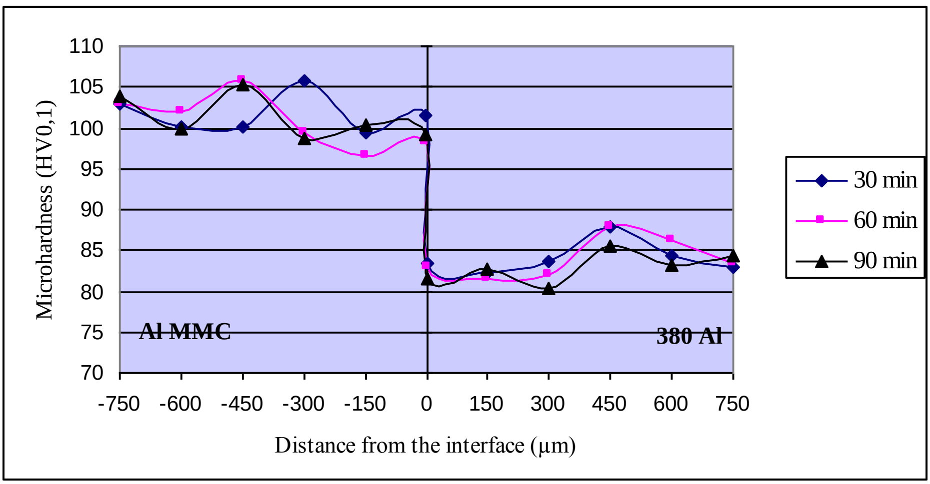

Figure 8. Microhardness values of the bonded specimens through the interface

To calculate the shear strength 3 bonded samples were tested for each bonding condition. The results were given as the average of these 3 test values. The shear strength of the joints bonded at 560°C under 3 MPa pressure for 30-60 and 90 minutes were found 56 MPa, 67 MPa and 93 MPa, respectively. The results can be seen in Figure 9.

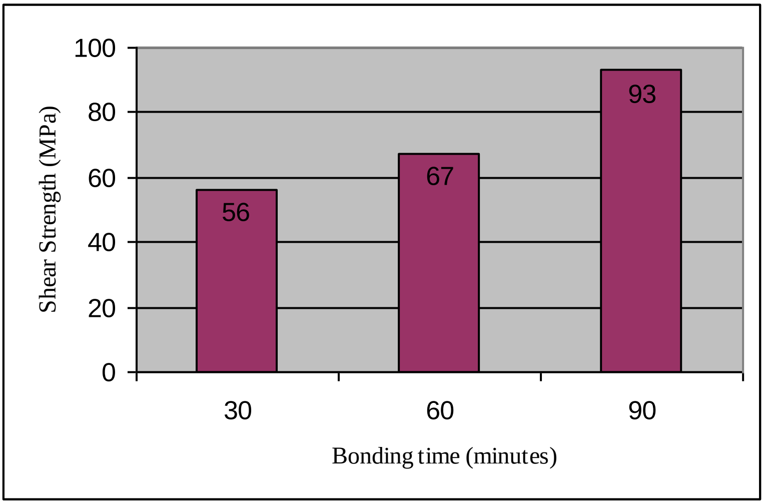

Figure 9. Shear test results of the bonded specimens for different bonding times

It is generally considered that sound bonding is achieved when the bonding line at the interface is undetectable. Eliminations of the bonding line and the gaps at the interface, results higher bonding strengths [11]. As compatible with these phenomena, the mechanical and metallographic investigations showed that the lowest shear strength (56 MPa) value belongs to the joints that have gaps at the bonding interface. These joints were bonded for 30 minutes. Results showed that the mechanical strength increased while the holding time increased. The joint bonded for 90 minutes which has the smoothest bonding interface exhibited the highest shear strength (93 MPa).

As it can be inferred from the results, bonding time has a significant effect on the bonding strength.

4. CONCLUSION

Following conclusions can be drawn from this study is as follow:

- 380 Al alloy-Al/SiCp-MMC material couple were successfully diffusion bonded for all holding times at 560ºC bonding temperature.
- Bonding time affects the microstructure of the joint interface. While the bonding line of the joint bonded for 30 minutes was clearly detectable, it disappeared gradually with increasing holding time. No gaps or unbonded areas were found at the joint interface bonded for 90 minutes.
- Diffusion bonding of the samples at 560ºC for 30-90 minutes didn't cause the inhomogeneous distribution of the SiC particles or segregations at the interface. Consequently, no significant change occurred in the microhardness value of the materials through the bonding interface to the base materials.
- The shear strengths of the specimens which were diffusion bonded at 560ºC with 3 MPa for 30-60 and 90 minutes show that when the bonding time increases the bonding strength increases, too. The bonding time has a significant effect on the diffusion bonding.

REFERENCES / KAYNAKLAR

[1] Hauter G., Mayer H.G., "Diffusion Bonding of Superalloy for Gas Turbines", Proc. Conf. on High Temperature Alloys For Gas Turbines, Belgium, October (1982), Riedel Publishing Co Netherlands.

[2] "Fundamentals of Diffusion Bonding" ASM Handbook Volume 6, Welding and Brazing and Soldering, ASM International, 516-525, 1993.

[3] Daglilar S., Topuz A., " Diffusion Welding of Stainless Steel With an Al-Mg-Si alloy", Practical Metallography, 10, 496-505, 1995.

[4] Ellis MBD. "Joining of Al-based Metal Matrix Composites- A Review", Materials and Manufacturing Processes , 11, 1, 45–66, 1996.

[5] Zhang X.P., Ye l., Mai W.Y., et.al., "Investigation on Diffusion Bonding Characteristics of SiC Particle Reinforced Aluminum Metal Matrix Composites (Al/SiCp MMC)" Composites. Part A: Appl. Sci.Manuf. 30, 12, 1415–1421, 1999.

[6] Urena A., Gomez de Salazar J.M., Escalera M.D., "Diffusion Bonding of Discontinuously Reinforced SiCp/Al Matrix Composites: The Role of Interlayers" Key Eng. Mater., 104–107, 523-540, 1995.

[7] Maity J., Pal T.K., Maiti R., "Transient Liquid Phase Diffusion Bonding of 6061-15wt% SiCp in Argon Environment", Journal of Materials Processing Technology, 209, 3568-3580, 2009.

[8] Shirzadi A.A., Wallach E.R., "New Approaches For Transient Liquid Phase Diffusion Bonding Of Aluminium Based Metal Matrix Composites", Mater. Sci. Technol. 13, 135–142, 1997.

[9] Zhao M.J., Chen L.Q., Bi J., "Effect of Interlayer on Properties of Diffusion Bonded Silicon Carbide Particulate-Reinforced Aluminum Composites", Journal of Materials Science Letters, 18, 205-2006, 1999.

[10] Muratoglu M., Yilmaz O., Aksoy M., "Investigation on Diffusion Bonding Characteristics of Aluminum Metal Matrix Composites (Al/SiCp) with Pure Aluminum for Different Heat Treatments", Journal of Materials Processing Technology 178, 211-217, 2006.

[11] Nami, H., Halvaee, A., Adgi, H., et al., "Investigations on Microstructure and Mechanical Properties of Diffusion Bonded Al/Mg_2Si Metal Matrix Composite Using Copper Interlayer", Journal of Materials Processing Technology, 210, 1282-1289, 2010.