MICROSTRUCTURE OF AlSi17/Mg JOINTS FABRICATED BY DIFFUSION BONDING AT DIFFERENT TEMPERATURES

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Abstract

The AlSi17/Mg joints under analysis were produced by diffusion bonding. They contained intermetallic phases, which were a result of diffusion occurring at the AlSi17/Mg reactive interface. The microstructure and thickness of the bonding zone were dependent on the heating temperature. Two temperatures were analyzed: 420 °C and 440 °C. The bonding zone produced at the lower temperature was thinner (50 µm). It was composed of an Al_3Mg_2 intermetallic phase (observed on the AlSi17 side), an $Mg_{17}Al_{12}$ intermetallic phase (observed on the Mg side) and an Mg_2Si phase. In this case the Mg_2Si was irregularly distributed over the Al-Mg intermetallic phase matrix. Fine particles of Mg_2Si phase were observed in the region adjacent to the AlSi17 and large areas of this phase were visible locally near large Si particles. When the temperature of the diffusion bonding process was higher, a much thicker bonding zone (about 400 µm) formed. The structural constituents detected there were: Al_3Mg_2 (on the AlSi17 side), $Mg_{17}Al_{12}$ and a solid solution of Al and Si in Mg (on the AZ91 side) and an Mg_2Si phase. The distribution of the Mg_2Si phase in the bonding zone was more regular; fine particles of this phase were visible all over the bonding zone.

Keywords: Magnesium, aluminum alloy, diffusion bonding, intermetallic phases, microstructure

1. INTRODUCTION

Bimetals and composites are materials with unique properties not found in any single material [1]. The increasing demand for lightweight and corrosion-resistant metal structures, particularly in the transport industry, has triggered intensive research to develop effective methods for combining magnesium alloys with aluminum alloys. Various methods can be used to join these light alloys, e.g. MIG and TIG welding [2,3], friction stir welding [4], hot rolling [5], hot extrusion [6], explosive cladding [7], twin-roll casting [8], compound casting [9-14], and diffusion bonding [15-19]. Diffusion bonding is a promising low-temperature technique for joining dissimilar light metals or alloys. The literature data indicate that this method can be applied to join pure Mg with pure Al [15-17], AZ91D magnesium alloy with pure Al [18] or AZ31B magnesium alloy with AA2024 aluminum alloy [19]. The microstructural analysis of Mg/Al joints shows that the $Mg_{17}Al_{12}$ and Al_3Mg_2 intermetallic phases are present in the bonding zone.

This study involved joining an AlSi17 aluminum alloy with pure Mg using the diffusion bonding method. The main aim was to investigate what effect the annealing temperature had on the microstructure and phase constitution of the bonding zone.

2. EXPERIMENTAL PROCEDURE

The materials under study were AlSi17 aluminum alloy and pure Mg. The AlSi17 alloy contained 17.18 wt.% Si, 1.22 wt.% Mg, 0.82 wt.% Ni, 0.72 wt.% Cu, 0.25 wt.% Fe and 0.02 wt.% Zn with a balance of Al. The magnesium specimens sectioned from Mg ingots were thicker (60x20x15 mm) than the AlSi17 specimens (60x20x5 mm). After polishing, the AlSi17 and Mg components were placed in a vacuum furnace, where they were heated from room temperature to a predetermined temperature for 20 min, kept at that temperature for another 20 min, and cooled back to room temperature. The annealing process was performed under a pressure of 5 MPa. Two temperatures were applied to produce the joints: 420 and 440 °C. The AlSi17/Mg bimetallic samples were then cut to reveal their cross-sections. The microstructure of the bonding zone was examined using optical microscopy (Nikon ECLIPSE MA 200) and scanning electron microscopy (JEOL JSM 5400). The scanning electron microscope (SEM) was equipped with an energy dispersive spectrometer (EDS). The chemical composition of the bonding zone was determined through quantitative EDS analysis taking into account the equilibrium phase diagrams for Al-Mg [20] and Al-Mg-Si [21].

3. RESULTS AND DISCUSSION

Figure 1 shows the microstructures of the AlSi17/Mg joints fabricated by diffusion bonding at two annealing temperatures. The bonding zone that formed at 420 °C had a thickness of about 50 μm (**Figure 1(a)**). Applying a higher temperature, i.e. 440 °C led to the formation of a much thicker (about 400 μm) bonding zone (**Figure 1(b)**).

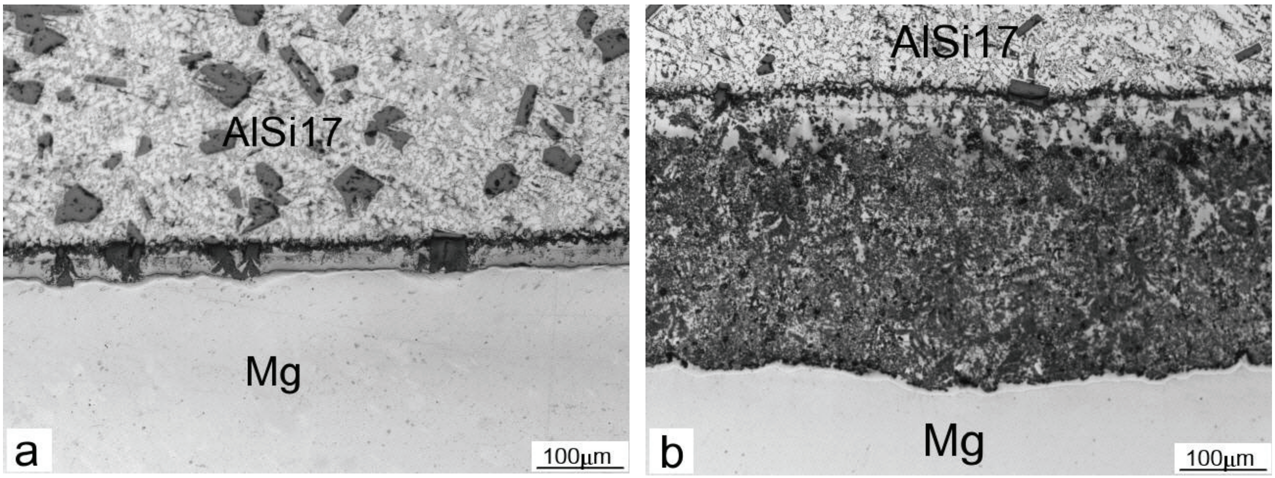

Figure 1 Microstructures of the AlSi17/Mg diffusion joints observed with the optical microscope after annealing at: (a) 420 °C, (b) 440 °C

The microstructure of the bonding zone was analyzed by SEM. **Figure 2(a)** shows an SEM image of the bonding zone formed at the lower temperature (420 °C) and the EDS concentration profiles for the elements found along the scan line. The high concentration of Si in the light area of the AlSi17 alloy adjacent to the bonding zone indicates the presence of a primary Si crystal. The dark area of the bonding zone close to the Si crystal is rich in Mg and Si. The light area of the bonding zone near the Mg is rich in Al. **Figure 2(b)** presents a high magnification SEM image of the bonding zone with points selected for the quantitative EDS analysis. **Table 1** provides EDS results obtained at the points marked in **Figure 2 (b)**. The quantitative analysis of the AlSi17 alloy near the bonding zone in areas 1 and 2 reveals that the primary silicon crystal (marked 1) and the solid solution of Si in Al (marked 2) are the constituents of the AlSi17 silumin. The chemical composition of the dark area of the bonding zone observed below the Si crystal (analysis at point 3) is similar to that of Mg_2Si. The heating process caused a solid-state diffusion reaction between the Mg and Si crystals at the AlSi17/Mg interface, which, in turn, led to the formation of the Mg_2Si phase. The decomposition of the Si grains and the formation of the Mg_2Si phase were due to a high affinity of Si for Mg. A similar observation was made for AlSi20/Mg joints produced by diffusion bonding, as described in [22]. The EDS point analysis conducted in the light area of the bonding zone (analysis at points 4 and 5) showed that the bonding zone was composed of Al-Mg intermetallic phases: Al_3Mg_2 and $Mg_{17}Al_{12}$.The Al_3Mg_2 phase was detected in the area closed to the AlSi17 alloy (analysis at point 4). The chemical composition of the light area adjacent to Mg (analysis at point 5) reveals the occurrence of an $Mg_{17}Al_{12}$ phase. Between the bonding zone and Mg there is a thin zone (about 10 µm) of a solid solution of Al and Si in Mg (analysis at point 6).

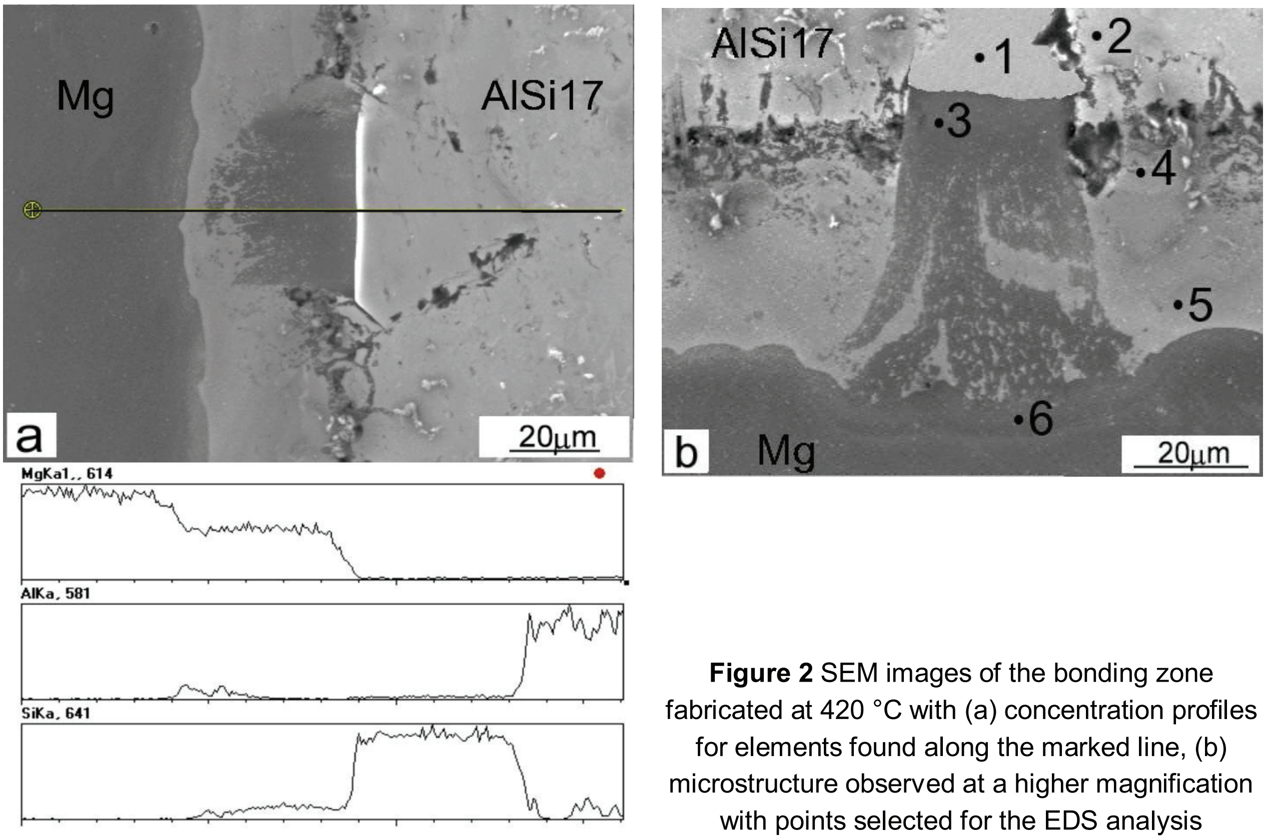

Figure 2 SEM images of the bonding zone fabricated at 420 °C with (a) concentration profiles for elements found along the marked line, (b) microstructure observed at a higher magnification with points selected for the EDS analysis

Table 1 Results of the quantitative EDS analysis corresponding to the points marked in **Figure 2(b)**

Point	Mg (at.%)	Al (at.%)	Si (at.%)
1	-	0.1	99.9
2	-	96.53	3.47
3	65.74	-	34.26
4	41.08	58.92	-
5	64.19	35.30	0.51
6	94.94	4.67	0.38

The SEM micrographs in **Figures 3(a)** and **(b)** show the microstructure of the bonding zone adjacent to AlSi17 and Mg, respectively, for the joints produced at the higher temperature (440 °C). The results of the EDS analysis conducted for the areas marked in **Figures 3(a)** and **(b)** are given in **Tables 2** and **3,** respectively. The quantitative analysis performed in areas 1 and 2 marked in **Figure 3(a)** near the bonding zone also confirmed that the primary silicon crystals (analysis at point 1) and the solid solution of Si in Al (analysis at point 2) were constituents of the AlSi17 alloy. The chemical composition of the dark area of the bonding zone adjacent to the Si crystal (analysis at point 3) indicates an Mg_2Si phase. The composition of the fine dark particles (analysis at point 4) uniformly distributed over the bonding zone was also similar to that of Mg_2Si. The EDS point analysis conducted in the light matrix of the bonding zone (analysis at points 5 and 6) confirmed the presence of Al-Mg intermetallic phases: Al_3Mg_2 in the region close to AlSi17 (analysis at point 5) and $Mg_{17}Al_{12}$ in the region close to Mg (analysis at point 6). **Figure 3(b)** shows the microstructure of the bonding zone observed on the Mg side. The phases detected in this zone were: an $Mg_{17}Al_{12}$ intermetallic phase (light area marked 1), a solid solution of Al and Si in Mg (dark area marked 2) and an Mg_2Si phase (dark particle marked 3). As can be seen, there are small white particles (marked 4) distributed irregularly over the whole bonding zone. The white particles contained 55.15 at.% Al, 24.37 at. % Ni, 17.32 at.% Mg, 2.5 at.% Si and 0.66 at.% Cu, which indicates a multicomponent phase. Ni and Cu are constituents of the AlSi17 alloy; hence the presence of the multicomponent phase was in the diffusion joint. Fine particles of the multicomponent phase were also observed in the joint fabricated at 420 °C (see **Figure 2(b)**). Between the bonding zone and the Mg, there was an area of a solid solution of Al and Si in Mg (analysis at point 5).

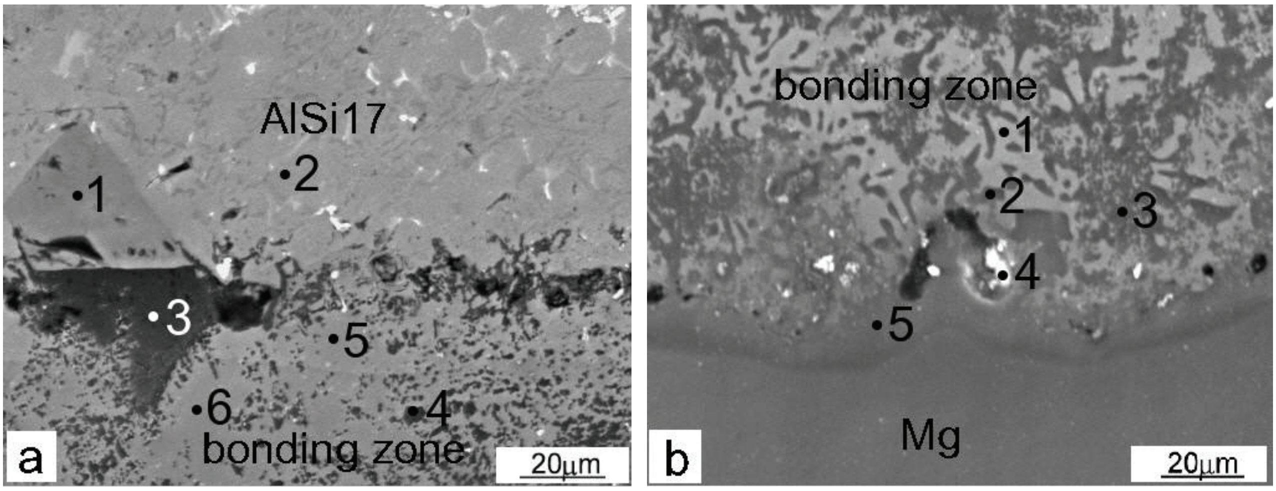

Figure 3 SEM images of the bonding zone fabricated at 440 °C: (a) microstructure on the AlSi17 side with a point selected for the EDS analysis, (b) microstructure on the Mg side with a marked point of the EDS analysis

Table 2 Results of the quantitative EDS analysis for the points marked in **Figure 3(a)**

Point	Mg (at.%)	Al (at.%)	Si (at.%)
1	-	0.23	99.77
2	-	98.58	1.42
3	66.57	-	33.43
4	67.12	0.75	32.13
5	39.50	60.50	-
6	56.21	43.79	-

Table 3 Results of the quantitative EDS analysis for the points marked in **Figure 3(b)**

Point	Mg (at.%)	Al (at.%)	Si (at.%)
1	62.50	37.04	0.46
2	80.62	19.14	0.24
3	66.89	5.38	27.73
5	91.98	7.75	0.27

4. CONCLUSIONS

In this study, AlSi17 alloy and Mg were joined by diffusion bonding. The thickness and microstructure of the bonding zone were dependent on the process temperature. The bonding zone produced at 420 °C had a thickness of about 50 µm. It was composed of an Al_3Mg_2 intermetallic phase (on the AlSi17 side), an $Mg_{17}Al_{12}$ intermetallic phase (on the Mg side) and an irregularly distributed Mg_2Si phase. Applying a higher temperature of the diffusion bonding process (440 °C) led to the formation of a much thicker bonding zone (about 400 µm) containing Al_3Mg_2, $Mg_{17}Al_{12}$, Mg_2Si phases and a solid solution of Al and Si in Mg. In this case, the fine Mg_2Si phase particles were distributed regularly over the whole bonding zone.

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