

Fabrication of AZ91/SiC Composites by Accumulated Diffusion Bonding Process

V. Sivaramakrishnan¹
Department of Mechanical
Engineering
E.G.S.Pillay Engineering College,
Nagapattinam, Tamil Nadu,
India

M. Rajamuthamilselvan²
Department of Manufacturing
Engineering,
Annamalai University,
Chidambaram, Tamil Nadu,
India

S. Ramanathan³
Department of Manufacturing
Engineering,
Annamalai University,
Chidambaram, Tamil Nadu,
India

Abstract— Magnesium alloy (AZ91) matrix composites (MMCs) with addition of SiC reinforcement was fabricated by using Accumulated Diffusion Bonding Process. SiC(5 μ m) particles dispersed in magnesium matrix composite are produced through accumulative diffusion bonding (ADB) process under vacuum atmosphere. The mechanical properties of AZ91 and AZ91-SiC composites have been evaluated and the results are compared with the unreinforced AZ91 alloy. Results of the mechanical properties revealed an increase in hardness value, maximum tensile strength. It was proposed that the strength increase due to SiC addition to AZ91 alloy was a result of a change in the matrix strength, i.e. an increase in dislocation density and a reduction of matrix grain size. However, it is also evident that the strain to failure significantly decreased as the volume fraction of the particulate increased.

Keywords— Accumulative Diffusion Bonding, Composites, Tensile strength and Hardness.

1. INTRODUCTION

With the advantages of low density, superior damping capacity, good electromagnetic shielding characteristics and high specific strength, magnesium alloys are broadly used for structural applications as well as automotive, industrial, materials-handling, commercial, and aerospace equipment [1,2]. The disadvantages of these materials are the poor workability, limited ductility and low stiffness because of their hexagonal structure and the degradation of mechanical properties at elevated temperatures [3–5]. Nowadays, the applications of magnesium alloy are still limited because it is inferior in mechanical properties compared to other light weight material, such as aluminum, zinc and titanium alloys. In order to improve the mechanical properties of magnesium alloys, addition of non continuous reinforcements such as Al₂O₃ short fiber, SiC or TiC particulate have been studied by researchers. Among them, SiC particles, in particular, has been extensively chosen as the reinforcement material due to its stronger and stiffer compared to the matrix and also its high wet ability to magnesium on getting a good interface bond. As a general means of materials manufacturing, welding can be used to optimize product design and minimize the cost production. Information published on welding of magnesium alloys were still limited. Welding methods such as TIG, LBW, electron beam welding, friction welding and diffusion welding have already been applied to bond magnesium alloys [6,7].

Many studies on AZ91 magnesium alloys had been focused on the strengthening method such as hard ceramics particles dispersion [8,9]. Hence, diffusion bonding introduces convenience to the bonding of similar or dissimilar materials

which are not possible to bond by conventional welding methods and it is preferred by the materials in which the formation of brittle phase is unavoidable. The quality of a joint is based on its strength. To achieve the maximum strength, it is essential to control the appropriate process parameters completely. Therefore, it is very important to select and control the welding process parameters [10].

The objectives of this study are to characterize the behavior of metal matrix composite during accumulated diffusion bonding process. Accordingly, the present work was undertaken to synthesize magnesium based metal matrix composite, AZ91 reinforced with various volume fractions of SiC particulates using accumulated diffusion bonding process.

In addition, taking the advantage of low melting temperature of magnesium, the ADB was done at high pressure and high temperature to break the oxide layer and initiate the diffusion bonding. The mechanical properties for the produced composites are also evaluated and the results obtained are compared with the unreinforced alloy. In the present study, we propose an accumulative diffusion bonding process for production of SiC particle dispersed magnesium alloy composite using neither magnesium melt nor powder.

Table 1. Chemical Composition (AZ91)

Al	Zn	Mn	Cu	Si	Fe	Ni	Mg
9.08	0.72	0.26	0.07	0.15	0.02	0.001	Bal.

Table 2. Chemical compositions of SiC particles

SiC	C	Si	SiO ₂	Fe	Al ₂ O ₃	Cao	Mgo
99.3	0.2	0.05	0.1	0.005	<0.01	<0.01	0.01

2. EXPERIMENTAL PROCEDURE

2. 1. Diffusion bonding

Commercial cast AZ91 magnesium alloy ingot and pure SiC (5 μ m) particles were used as starting materials. Chemical compositions of these materials are shown in Table 1 & 2. Square shaped specimens (50 mm X 50 mm) were machined from magnesium alloys which were rolled to plates of 4 mm thick (fig.1). Three plates were surface treated by a stainless steel wire brush and stacked with SiC particles. The fig(2) shows accumulated arrangement of AZ91 magnesium plates for diffusion bonding. The polished and chemically treated specimens were stacked in a die made of 316L stainless steel, and the entire diffusion bonding setup was inserted into a vacuum chamber. The furnace temperature was fixed at 723K

and the temperature of AZ91 alloy plates was maintained at about 673K [11, 12]. From Ref.[13] and the previous work done in our laboratory[14], the independently controllable primary process parameters which affect the quality of diffusion bonded joint were identified. They are bonding temperature, bonding pressure and holding time. The plates were ground polished with diamond paste and then cleaned in acetone. The SiC was preheated (300°C) to remove the moister content in the particles and was dispersed over the AZ91 plate. The amount of SiC corresponding to 5, 10, and 15% by weight of the matrix in the composite before inserted in to the vacuum chamber in diffusion bonding machine. The optimum pressure, temperature and holding time for this diffusion bonding is 10MPa, 400°C and 60 minutes respectively. After the diffusion bonding, the samples cooled to room temperature in air and no heat treatment was applied.



Fig. 1 AZ91Magnesium plates before diffusion bonding

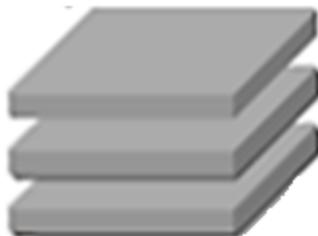


Fig. 2 Accumulated type arrangement of AZ91 plates

2.2.Mechanical properties

Tensile tests of unreinforced alloy and composites were performed on specimens 25 mm gauge length in accordance with the ASTM B557M-2014 as shown in fig.3 Schematic drawing of the tensile test specimen. The tensile test specimen is fixed in jaw of MTS electro mechanical testing machine (Fig.4). This specimen is cut from ADB plate by an electric discharge machine (Fig.5). The test was carried out at an applied strain rate of 0.5 mm/min. The reported results of the tensile tests are the average of three individual tests on three different specimens.

The micro hardness was established by means of Vickers hardness testing using 500 gram load. Hardness test was conducted by using digital micro-hardness tester (Falcon 500), the micro hardness of A91 alloy and composites samples were determined in the as polished condition.

At least 10 micro hardness measurements were made for each specimen to ensure accurate results. The micro hardness values have also been checked for reproducibility with 3 specimens. The results cited are the average values from such multiple tests.

Fracture surface was studied using scanning electron microscope.

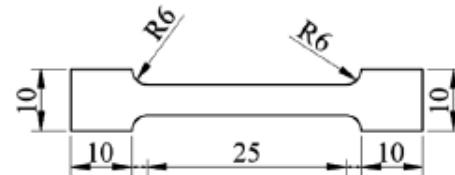


Fig.3. Schematic drawing of tensile test specimen



Fig.4 During tensile testing of composite material



Fig.5. Tensile specimen of composite material

3..RESULTS AND DISCUSSION

3.1.Diffusion bonding result

Accumulated diffusion bonding composite fabricated by varying pressure, temperature and holding time. The optimized parameters used to get the quality of diffusion bonded specimen (Fig.6). At the time of fabrication below the optimum condition, plates were debonded (Fig.7) and above optimum condition, plates were melted (Fig.8).



Fig. 6 Different view of Diffusion bonding of AZ91 with SiC reinforced composite plates (Front & 3D Views)



Fig. 7 Debonding of AZ91 with SiC reinforced plates



Fig.8 Melting the diffusion bonding plates

3.2. Mechanical behaviour

3.2.1 Tensile and Elongation Result

Tensile properties of AZ91 SiC-particulate composite are given in Table 3. The results reveal that the addition of SiC-particulates to the base alloy increases the ultimate tensile strength, but considerably reduces the strain to failure. Tensile properties of AZ91 composite after accumulative diffusion bonding process provides 158MPa ultimate tensile strength (UTS) while after AZ91/SiC 5% Volume fraction of composite using ADB process the ultimate strength tensile increases up to 180MPa. The addition of 10% SiC results in a increase of 67MPa compared with AZ91alloy. The Tensile strength increased significantly to 225MPa when the SiC particles reached 10% of the composite. The fig.9 shows the tensile strength of AZ91 with different Volume fraction of SiC reinforced composites. The curve for the as-cast samples shows that the tensile strength is increasing with the addition of up to 10 % Volume fraction of SiC, but it is reduced with SiC particles additions more than 10%. However, it is also evident that the strain to failure significantly decreases as the volume fraction of the particulate increases. The increase is due to grain refinement and the improved particulate distribution. uniform distribution of the reinforcement particle bearing the stress distribution homogeneously. After the diffusion bonding process the mechanical properties are improved significantly.

Table 3. Mechanical properties

Alloy/Composite	Hardness (HV)	Tensile Strength (MPa)	Elongation (%)
AZ91 Alloy	62	158	2
AZ91/5%SiC	66	180	1.5
AZ91/10%SiC	75	225	1.3
AZ91/15%SiC	77	198	0.8

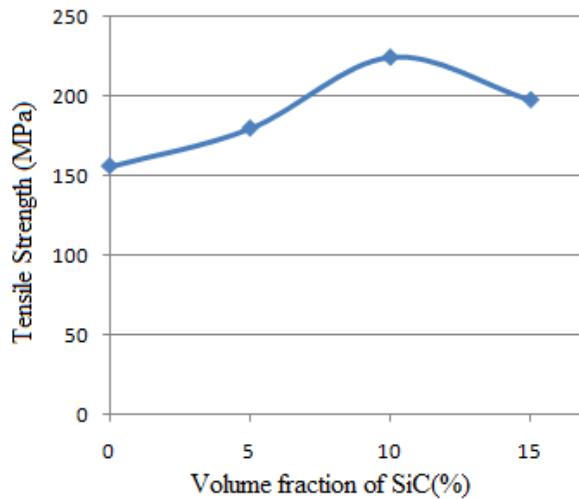


Fig.9 Effect of SiC Content with Tensile strength

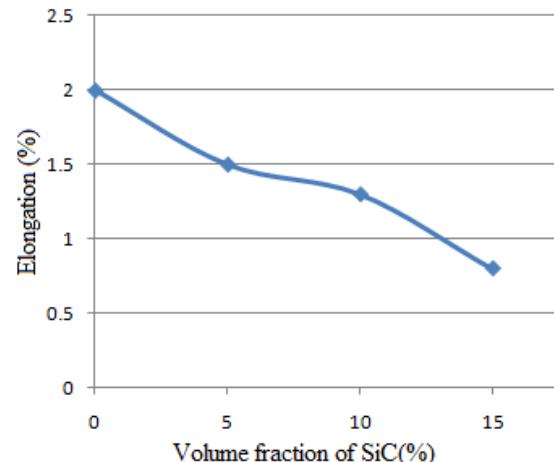


Fig.10 Effect of SiC Content with Elongation

Fig.10 Shows the variation of a elongation with different volume fraction of (AZ91/SiC) composite. The ductility of the AZ91 alloy composite can be affected by reinforcement particle content and matrix alloy. The addition of SiC particle probably overstrained the lattice, and thus the alloys have no longer sufficient strain energy remaining to gain its ductility. The decrease in ductility can be attributed to the void nucleation in advance with increased amount of SiC. The grain refinement and reduction of ductile matrix content when the Volume fraction percentages of SiC particles are increased reduces the ductility of the Composite.

This means that the matrix probably does not have sufficient internal ductility to redistribute the very high localized internal stresses. It is also obvious that the resistance to the dislocation motion of the hard particles reduces the

ductility of the composite materials. Moreover, the presence of the SiC-particulates impedes the plastic flow of the matrix, initiating failure at low strains by the formation of cavities in the vicinity of the particulate. Recent work has demonstrated that composite failures associated with particle cracking and void formation in the matrix within clusters of particles [15].

The volume percentage of the SiC increases the stress distribution to rigid phase, which in turn increases the tensile strength. If the volume percentage of reinforcement reaches certain level the reaction in magnesium alloy with SiC particle cause the formation of transition layers at the constituent interfaces. These layers, although enabling a bond to be obtained the SiC and magnesium alloy, they are not tough enough to carry loads and thus they often contribute to lowering the tensile properties of composites. Work hardening takes place when the composite is strained. The strain mismatch between the matrix and the reinforcement usually generated a higher density of dislocations in the matrix around the reinforcement. Work hardening takes place when the composite is strained. Work hardening rate decreases with increasing particle size (16).

3.2.2. Hardness Result

This was due to the SiC particle on the sample was effectively act as reinforcement for AZ91 matrix. The results of hardness measurements (Table-3) revealed that an increase in the volume fraction percentage of SiC particulates produced an increase in the hardness value of the metallic matrix. The hardness of composites increases from HV = 62 to 77 with increasing the volume fraction of SiC - particles from 0 % to 15 %. The figure 11 shows the Hardness of AZ91 with different Volume fraction of SiC reinforced composites. This can be attributed to increasing the presence of a harder SiC particulate in the matrix, which surrounded by a softer and relatively tough matrix and can contribute to wear resistance by favoring more plastic behavior.

Often the ductility must be considered in the design, especially when it is low as the material becomes less forgiving and already at small deformation, cracks can appear. Generally, the strengthening effects, which can occur in the composite material, can be divided into direct and indirect strengthening.

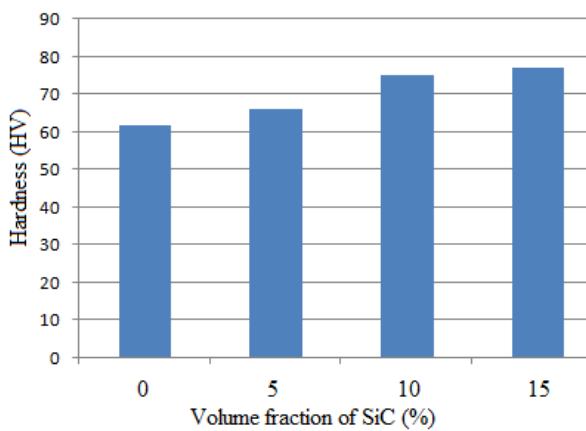


Fig.11 Comparison the hardness with different (%) Volume of SiC

Direct strengthening mechanism includes the ability to transfer stress from the matrix to the stronger reinforcing particles [17]. This, in turn, depends on achieving a strong interfacial bond between the matrix and the reinforcement.

Therefore, If the bonding between the matrix and the reinforcement is strong enough, the applied stress can be transferred from the soft matrix to the hard particle phases. If the interfacial bond is weak, the interface will fail before any effective stress transfer to the particle can occur, and no strengthening is achieved [18]. MMC developed exhibit uniform distribution of the particle in the matrix and good interface bonding between the ceramic phase and the metallic matrix [19].

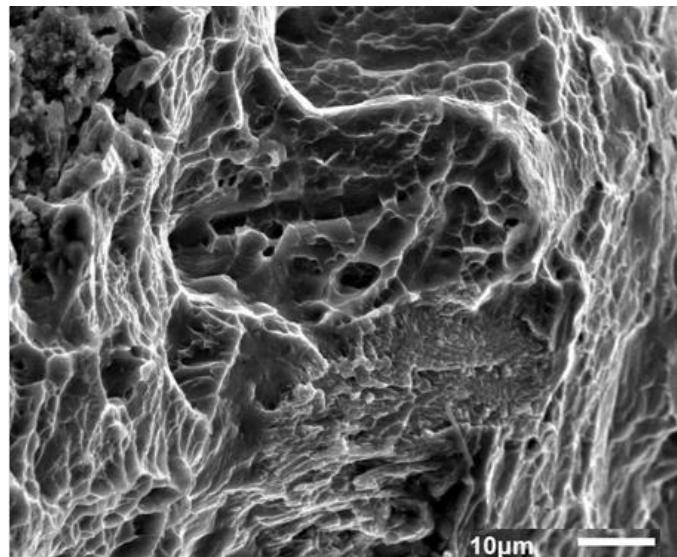


Fig.12 SEM micrograph of tensile specimen fracture surface of AZ91 alloy reinforced with SiC particles

3.3. Fractography

The fracture surface of AZ91/SiC composite in the as cast alloy fracture mode is a ductile condition is shown in Fig. 12. The general form of the fracture surface was found to be the same for all volume fractions. The pits existing in the matrix are caused by the pulling-out of the reinforcing particles from the matrix. Moreover, the pits are featured mainly by the size and distribution of the reinforcing particles, which indicates that the rupture of AZ91/SiC composites is mainly caused by the pulling-out of SiC particles. In addition, there is only a small fraction of fracture surface that is dominated by small dimples. These small dimples are generally distributed at the boundaries between the pits, probably due to the ductile rupture of the magnesium matrix. This has large number of dimple shaped structures no crack found (20). The presence of dimples displays the typical ductile fracture of the matrix alloy. Examine the fracture surface in the SEM shows that the SiC/matrix interface is made up of network of very fine dimples. The extent of SiC particles cracking shows the strong bonding between the SiC and AZ91. However, regions rich in reinforcing SiCp revealed to features of locally brittle failure. The results suggested that the SiC/AZ91 interfacial bonding is reasonably good.

4. CONCLUSION

- Uniform distribution of the reinforced particles reveals that the AZ91/SiC composites were successfully fabricated by accumulative diffusion bonding.

- Mechanical properties of AZ91 magnesium alloy were improved by the ADB processing and dispersion of SiC particles.
- The addition of SiC particles to the AZ91 matrix increases the maximum tensile strength and hardness value compared with the unreinforced alloy.
- However the elongation is lower in the composites, decreasing with increasing the volume fraction of SiC particles.

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