The International Journal of Materials and Engineering Technology (TIJMET) (2022) 5(2)
http://dergipark.gov.tr/tijmet
ISSN: 2667-4033

RESEARCH ARTICLE

Fabrication and welding of aluminum composite

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Article Info

Article history:
Received 15.02.2022
Revised: 06.08.2022
Accepted: 05.10.2022
Published Online: 07.11.2022

Keywords:
Al matrix composite (AMCs)
Silicon carbide SiC
Powder metallurgy
Bonding diffusion
Welded joint.

Abstract

In recent years, aluminum alloy-based metal matrix composites (MMC) are gaining importance in several aerospace and automobile applications. Aluminum 6061 has been used as matrix material owing to its excellent mechanical properties coupled with good formability. In the present investigation Al6061–SiCp composites was fabricated by powder metallurgy route with 7.5 and 13 wt. % of SiCp and sintered at 600°C during 2 h. The synthesis samples were welded in solid state by bonding diffusion at 520 °C during 3 h. The effect of SiCp amount on structural and mechanical properties of welded joint of Al matrix was investigated. The main techniques of characterization were optical and scanning electronic microscopy, X ray diffraction, and hardness measurements. We have investigated the effect of silicon carbide quantity on the hardness of the synthesized composite. The microstructure observations showed a homogeneous distribution of SiCp on the welded joint.

1. Introduction

Aluminum-based metal matrix composites (AMCs) are the most appropriate for automotive, thermal management applications and aerospace industry, it isa new generation of engineering materials in which a strong ceramic reinforcement such as Al2O3 and SiC are incorporated into a metal matrix to improve its properties including specific modulus, superior strength, excellent wear resistance, corrosion resistance, and high thermal conductivity, due to their better bonding between the matrix and reinforcement which forms uniform and compact grain boundaries[1−4]. Moreover, the use of nano-reinforcements allows a better bond between the matrix and the reinforcement, which results in better mechanical properties on the MMNC base [2]. Generally, powder metallurgy (PM) process is well known to be one of excellent metal fabrication techniques for producing near net shape products. One of the advantages of PM compared to casting is having better control on the microstructure, where better distribution of the reinforcement is possible in PM compacts and unique qualities which is the reason for its superior properties compared to other processes [5, 6].

AMCs have become a major focus in industry for their excellent properties, Joining of AMCs is machining and welding process replacing conventional aluminum alloys in many applications [7]. Welding processes are vital for the manufacture of a wide variety of products [8]. It able to produce high quality joints of Al-based MMCs of particular interest. Rotundo et al. [9] mentioned that the problem of the application of Al-based MMCs are the low mechanical properties of the joint obtained with the traditional fusion welding techniques. These problems can be significantly reduced by the use of solid-state joining techniques, such as diffusion welding.

The main objective of this study is to explore the effect of SiCp percentage on the mechanical properties of welded joints by bonding diffusion of AA6061-SiCp composite

2. Materials and methods

2.1 Materials and specimen preparation

The raw materials used in the present work to synthesize SiCp reinforced aluminum alloy metallic matrix composites were AA6061 (63 µm) and SiC (50 nm) powders, the powders were supplied by Good Fellow Cambridge Limited Huntington, PE29 WR, England. The composite was manufactured by means of powder metallurgical route with the following parameters: Silicon carbide (SiC) percentage was 7.5 and 13 wt. %, compacted under 10 tons and sintered at 600°C during 2 h. The choice of these proportions was based on bibliographic research. The chemical composition and optical photomicrograph of aluminum alloy AA6061 are respectively presented in Table 1 and Figure 1.

We noticed that just before diffusion bonding test, the cylindrical specimens (14 mm of diameter and 5 mm of high) fabricated by powder metallurgy were carried out carefully by grinding and cleaning by ultrasonic-cleaning in acetone for 10 min. When the both cleaned sides of the base metal are placed inside the metallic support, sufficient pressure is applied to fix the samples and encourage the diffusion mechanism. The bonding diffusion performed at 520°C for 3 h in argon and hydrogen atmosphere.

Table 1. The chemical composition of AA6061alloy powder.

Elements	Si	Fe	Cu	Mg	Aluminum
Wt.%	0.6	0.5	0.4	1	Balance

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How to cite this article:
Melik, W., Boumerzoug, Z., Delaunois, F., Fabrication and welding of aluminum composite, The International Journal of Materials and Engineering Technology (TIJMET), **2022,** 5(2): 71-74

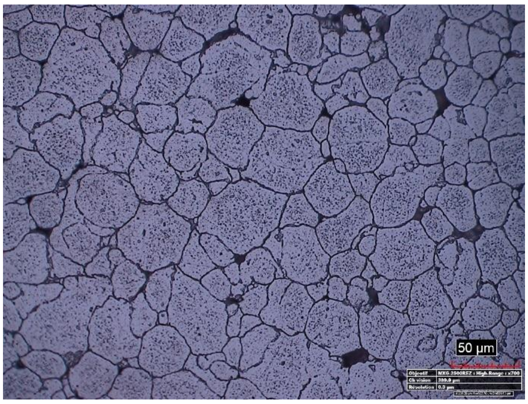

Figure 1. Optical photomicrograph of fabricated AA6061

To reveal microstructure and mechanical properties of the welded samples by bonding diffusion (BD), standard metallographic sample preparation procedure is achieved through mechanical grinding and polishing followed by chemical etching. The microstructure and the distribution of SiC in the profiles and welds were observed using an optical microscope (HIROX Kh-8700) and a scanning electron microscope (HITACHI SU8020) integrated with energy dispersive spectroscopy (EDS) detector, the acceleration voltage was set to 20.0 kV. X-ray diffraction patterns (XRD) were recorded using Panalytical X-ray diffractometer (BRUKER D-5000). The microhardness was measured using a microhardness tester (HM-200) at 0.05 HV.

3. Results and discussion

3.1 X-ray diffraction and microstructure

The XRD patterns of the welded Al6061-SiCp composites reinforced with 7.5 and 13 wt.% of SiCp are shown in Figure 2 indicate that the peaks of Al and SiC particles are obviously visible in both samples. No other phases are formed in the welded joint. This reveals that SiC particles did not react with the aluminum matrix to produce any other compounds during diffusion welding in both cases.

SEM micrographs of the welded samples of AA6061/SiC composite reinforced with different amount of 7.5 and 13 wt.% SiCp, fabricated by PM, are shown in Figure 3, SEM microstructures are followed by the EDS analysis in different areas of welded sample reinforced with 13wt.% SiC presented in Figure 4. SEM images reveal the distribution of SiC particles over the matrix alloy. The distribution of SiC particles is observed fairly homogeneously in the welded joint. There are no clusters or agglomeration of nanoparticles. The magnification of Figure 3(a) is presented in Figure 3(b-c) is and of Figure 3(d) is presented in Figure 3(e-c), the particle distribution can be seen more clearly in Figure 3(c) and Figure 3(f) with the higher magnification.

From the microstructures, it is clear that the diffusion process has been achieved in both cases of welding process, it can be clearly seen the formation of new grains on the bonding line, the migration of particles into the diffusion joint was fast when compared with the samples contained less amount of the reinforcement, So the addition of SiCp improve and encourage the movement of particles in welding process, this is an advantage for mechanical properties.

Figure 3(f) shows micro-cracks at the end of the joint, holes at the interface, it was found to exhibit partially ductile and brittle mode of fracture. The diffusion welded joints shows grains and finer dimples which is due to the uniform deformation of the metal during joining. The same results were reported by Vigneshwara et al. [2], Hascalik et al. [10] and Rotundo et al. [11]. In addition, Feng et al. [12] stated that the SiC particles provided more nucleation sites for the new recrystallized grains by increasing local strain in the matrix and causing lattice misorientation. The particle plays an important role in controlling the recrystallized grain size by particle stimulated nucleation. The resultant grain size will be directly related to the volume fraction and the diameter of particles.

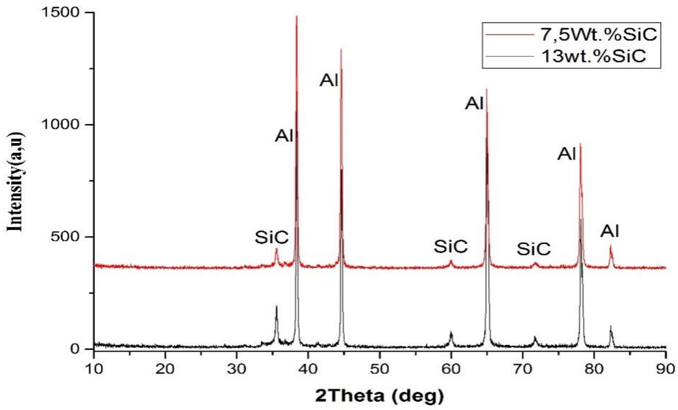

Figure 2. The XRD of the welded samples of AA6061-SiCp reinforced with 7.5 and 13 wt.% of SiCp

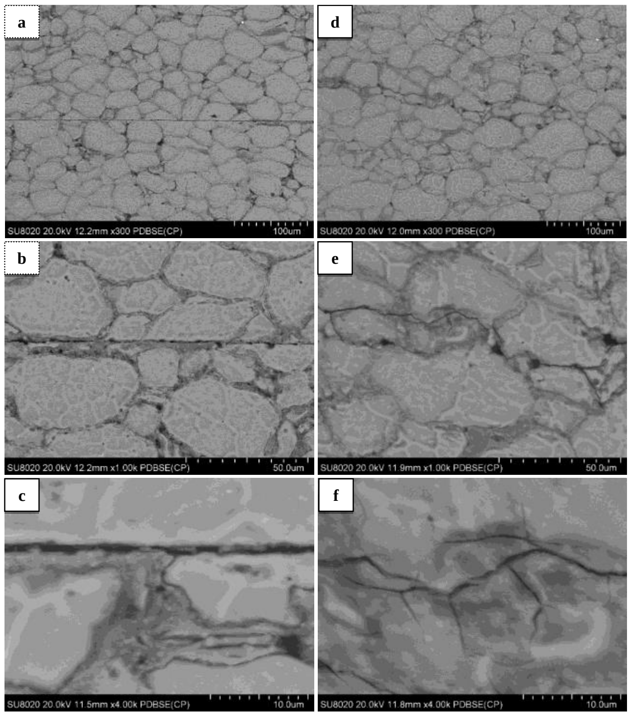

Figure 3. SEM micrographs of weldment reinforced with: (a); 7.5 and (b); 13 wt.% of SiCp with different magnification; (b-c of a) and (e-f of d)

EDS analysis in Figure 4 confirms the homogeneous distribution of SiCp in the matrix and in the joint, the EDS analyzes focused on three areas of the welded joint. The first zone corresponds to the bonding line; on the other hand, the second zone and the third zone correspond to a grain boundary which binds the Al particles in base material. Based on the EDS spectra and chemical composition, the two elements Si and C exist in both zones, which confirms the high concentration of SiC in these areas. However, the presence of fluorine is due to the etching process by the HF agent. There were also in the composite the elements Al, Si, Mg and Cu, which are major elements of the composite.

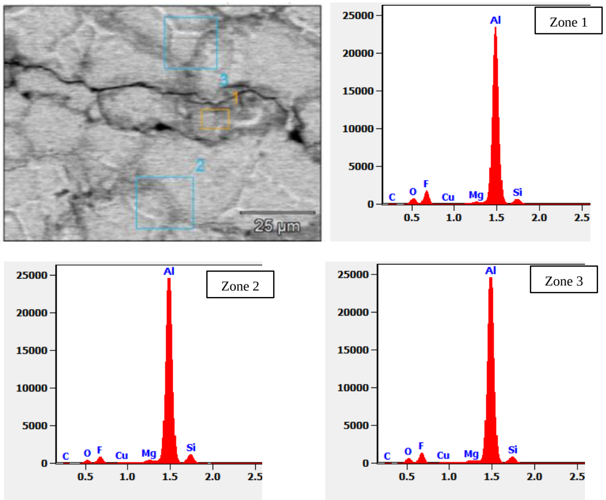

Figure 4. SEM electron image and its EDS analysis of welded AA6061/SiCp composite

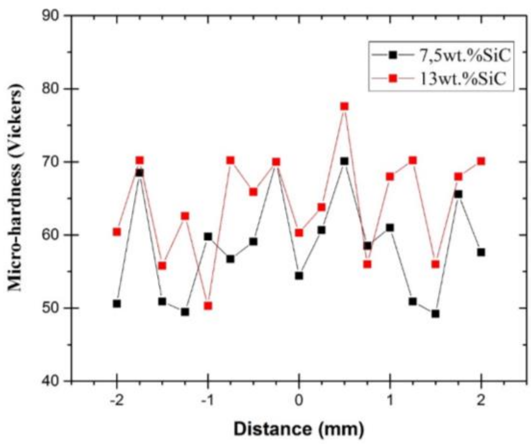

Figure 5. Vickers microhardness profiles across the weldments

3.2 Microhardness

The quality of the weld was assessed with Vicker microhardness measurement in transverse plane for AMCs welded by diffusion, from the centre of the weld to either side of the welds is spread as shown in the Figure 5. The microhardness values of AA6061- 13wt.% of SiC composite welded by diffusion are greater than the microhardness values of AA6061-7.5wt.% of SiC composite.

From the curve it is clear that diffusion bonding resulted in an increase in micro hardness of AA6061/SiCp composite with increasing SiCp percentage. We conclude that increasing SiCp reinforcement percentage contributes to the improvement of micro- hardness

The microhardness near center of a weld was similar to that of the parent material, but it increased near the joint interface. A low hardness value at the weld center also indicated the absence of Al_4C_3 precipitates in that area, the XRD results confirm the absence of new phases in the composite. Mitul [13] reported that a higher SiC particle density would form high dislocation density in a smaller dendrite by residual strains due to thermal mismatch between the aluminum matrix and ceramic reinforcement, which in turn increased the matrix hardness and matrix strength at this location. Other researchers [8,14] explained the hardening phenomenon by the mechanical properties of SiC particles, which are unbreakable dispersoid that definitely add to the hardness of the composite.

4. Conclusions

The main importance of this study focused on the bonding by diffusion of AA6061-SiC nanocomposites fabricated by powder metallurgy technique. The main highlights of this research can be summarized as follows:

- The metal matrix nano-composites were fabricated by powder metallurgy method and successfully joined using diffusion welding processes.
- The XRD diffraction peaks of welded Al6061/SiCp composites confirm the presence of Al and SiC, no other phases are formed during welding.
- Microstructural examinations revealed the uniform distribution of SiC particles in the base composite and in bonding joint.
- The AA6061–SiC composite with 13 wt. % SiC has high microhardness compared with the composite reinforced with 7.5 wt.%.

Acknowledgments

The authors would like to thank WBI and MESRS of Algeria for their support. We thank also all the team of metallurgy service, university of Mons, for their technical support and encouragement.

Author contributions

Wafa Melik (PhD student): investigation, funding acquisition, writing the original draft

Zakaria Boumerzoug: methodology; supervision, review & editing

Fabienne Delaunois: resources, visualization, reviewing

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