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WELDING OF ALUMINUM METAL MATRIX COMPOSITES (AL/SiC-MMCs)

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ABSTRACT

Due to their high specific-strength, SiC reinforced aluminum metal matrix composites (Al/SiC-MMCs) are becoming popular for wide range of applications including vehicles, aircraft, rockets and shipbuilding. It is difficult to fusion weld such material due to porosity and aluminum carbide (Al4C3) formation in weld zone (WZ) which result in degradation of mechanical properties of the welded joints. In this study, several sets of Al/SiC-MMCs samples having 0, 5, 15 and 20 vol.% SiC particulates were fabricated by powder metallurgy technique using hot compaction of Al and SiC powders followed by hot extrusion. Effect of welding conditions such as heat input, filler wire type (AA4043 and non-commercial AlTi5B1) and without filler using AC-GTAW (TIG) process was studied to find out appropriate conditions to get sound welded joints. Microstructure was examined using optical and SEM. Phases were identified and analyzed using XRD and EDX analysis. It was found that porosity and AL_4C_3 formed in WZ during welding without filler and with AA4043 filler. Using non-commercial AlTi5B1 filler, porosity and Al_4C_3 were reduced and suppressed at 20 vol.% SiC and 5.86Kj/cm heat input. Whereas, hardness values in WZ remain as high as base metal when using non-commercial AlTi5B1 filler, but drastically reduced when welding without and with AA4043 filler. The new filler wire of AlTi5B1, was examined for the first time and proved as promising filler in welding Al/SiC-MMC.

تستعمل المواد المركبةالمعدنية المصنوعة من حبيبات الألومنيوم والمقواة بحبيبات كربيد السليكون فى متطلبات صناعية عديدة وذلك لارتفاع المتانة النوعية لها. وتعانى تلك المواد من انخفاض كبير فى الخواص الميكانيكية بعد اللحام بطرق الانصهار المعروفة و منها اللحام بالقوس الكهربى بالكترود التنجستين الغير مستهلك فى وجود الارجون كغاز حماية. و ذلك بسبب تكون المسامات و تحول حبيبات كربيد السيليكون الى كربيد الالومنيوم. يتناول هذا البحث دراسة التوصل الى أنسب الظروف للحام تلك المواد للحصول على وصلات لحسام ذات جودة عالية بأقل مسامات و أقل كربيد الومنيوم. وقد تم دراسة تأثير ظروف اللحام مثل كمية الحرارة المعطاة و نوع سلك اللحام (سلك الومنيوم --٥% سليكون ٤٠٤٣ القياسى و سلك غير قياسى الومنيوم--٥% تيتانيوم-١% بورون) و كذلك بدون استخدام سلك لحام و ذلك على عينات تم تصنيعيها معمليا بطريقة ميتالورجيا المساحيق تحتوى على نسب مختلفة من كربيد اسليكون ٠ و ٥ و١٥ و ٢٠%. و قد خلصت الدراسة الى تحسين فى الخواص الميتالورجية و الميكانيكية مع امكانية منع تكون كربيد الالومنيوم وتقليل المسامات و ذلك بأستخدام سلك الومنيوم-٥% تيتانيوم-١% بورون غير قياسى و قد تم تجربته لاول مرة كسلك لحام.

Keywords: Metal Matrix Composites, Al/SiC, GTAW, Filler wire, Hardness, Heat input.

1. INTRODUCTION

At present, there is a great interest in the application of metal matrix composites (MMCs). Potential uses of these materials are numerous, in industries such as aerospace, defense, sports goods, and marine structures. When compared with the un-reinforced matrix alloys, MMCs have superior properties, especially increased stiffness, high strength, good wear resistance, and excellent elevated temperature properties can be tailored to satisfy a number of requirements. Despite the potential advantages of using MMCs, at present they have not reached widespread industrial application. There are several reasons for the limited use of MMCs. The major one being that their production costs are significantly higher than traditional alloys and that joining is not a trivial matter. In the latter regard, fabrication of virtually any complex structure requires joining to be made. The disparate nature of most matrixes and reinforcement materials greatly affects the ease with which welding can be performed. Reflecting the various material development studies carried out; there is an emphasis on Al-based materials. Where metal matrix composites (MMCs) are becoming more popular as structural materials, and joining them is, therefore of a paramount importance [1]. Concerning fusion welding of MMC, a number of difficulties have been identified specifically, in particular:

1. High viscosity of MMC melts above the melting point when compared with un-reinforced melts.
2. Segregation effects on re-solidification.
3. Reinforcement-matrix interactions.
4. Evolution of gases.

During fusion welding, the matrix will be heated to a temperature above its melting point, but the particular will remain solid. In sequence, particle reinforced Al-alloys have melts with high viscosities, making the mixing of the molten parent melt metal and filler difficult to a chive [2]. This can, however be alleviated by employing Si-rich Al-filler wires such as AA4043 or AA4047 and may be less marked when welding MMC based on Si-rich matrixes. The use of Si-rich Al-filler increases the wetability of SiC in an Al matrix enhancing mixing of the plate and filler materials [2]. Nevertheless, the rejection of SiC during solidification tends to give un-reinforced regions of particulate-free Al alloy. For Al203 reinforced Al MMC, the use of high Mg containing wires (ER5356) is preferable, preventing the Al_2O_3 from dewetting and "clumping" [2]. In principle, fluidity of the weld pool might be increased by increasing its temperature, but this can load to further problems because of detrimental reactions between reinforcement and matrix materials. The reaction between Al & SiC in SiC reinforced Al MMC during welding and casting has been well-documented [3,4] and occurs as follows;

$$3SiC+4Al \longrightarrow Al_4C_3+3Si$$

The Al_4C_3 is detrimental to the properties of the weld for two reasons. First, the platelets are brittle, reducing fracture toughness, and second, the weld corrodes due to moisture attack of the Al_4C_3 to give acetylene, resulting in a weld life expectancy in the atmosphere of only days [4-6].

Therefore, the objective of this work is to investigate effect of welding conditions such as heat input, filler wire type (AA 4043 and the new non-commercial AlTi5B1) and without using filler on porosity and Al_4C_3 formation in order to fiend out appropriate welding conditions to get sound welded joints using AC-GTAW process.

2. EXPERIMENTAL WORK

Al/SiC MMCs produced form aluminum pow with size less than 8oμm and SiC powder with less than 30μm. Al/SiC MMCs with different volu fractions of SiC 0, 5, 15 & 20 vol.% samples we fabricated by hot compaction and hot extrusion using powder metallurgy technique. Hot compaction is the step in which the blended pure powders (Al & SiC) heated and pressed into primarily shape using press that are hydraulically activated. The hot compaction process was made in order to produce prefabricated samples with 35mm ϕ and height 50 to 60mm according to the amount of powder filling. The hot pressing process is the step where the pressure applied to the hot powder at a temperature of 530-550°C. Hydraulic press unite with maximum pressing capacity of 75 tons, the selected pressure was 420 MPa which is higher than the pressure required for aluminum (70-275) MPa [7]. The pressing process for the powder continued for 7 min. the samples were extruded at 500°C with extrusion ratio of 8:1 to the required shape (rectangular shape with 300x30x4mm).The physical properties and Vickers hardness measurements of the produced composites were determined.

Prior to welding, samples were cleaned using acetone to remove oils and then mechanically cleaned using stainless steels wire brush to remove surface oxides. Bead on plate welding was performed using AC-GTAW (TIG) process with pure tungsten electrode having 2.4mm□ , arc length 2.4mm and argon flow rate 10 lit/min. Heat input used ranged from 5.4 to 7.75 kj/cm Heat input calculated using the equation:

heat input = 60 (E*I/S) (Joule/cm) [8]

Where: I: welding current (amp), E: arc voltage (volt), S: welding speed (cm/min), Welding was done autogenously and with two different filler wires, standard AA4043 (2.4mm □) and non-standard new wire AlTi5B1 (2.0mm □). Welding conditions are given in Table 1. Cross-section samples were cut from both base metals and the welded joints at specific weld locations, for examination using optical and scanning electron microscope (SEM) The sections were prepared by polishing and etching with a modified Keller's reagent consisting of 85ml distilled water , 3ml HF,3ml HCl and 1.5ml HNO3. Specimens immersed for 5 sec, and then water washed and blows dry. Phases identified using X-ray diffraction (XRD) and analyzed using SEM equipped with energy dispersive X-ray analyzer (EDX). Hardness measured using Vickers hardness (Hv) machine operated at 10kg load.

Table 1 Welding conditions used in this study

Specimen No.	A (amp)	V (volt)	Heat I/P (kj/cm)	SiC%	Filler
1	150	15.4	6.93	5	----
2	170	15.2	7.75	5	----
3	170	15.2	7.75	5	----
4	170	15.2	7.75	15	----
5	135	16	6.78	5	----
6	115	17	5.86	20	----
7	135	16	6.48	15	----
8	115	19	6.55	5	AA4043
9	115	19	6.55	15	AA4043
10	115	17	5.86	20	AA4043
11	135	17	6.88	5	AA4043
12	135	17	6.88	15	AA4043
13	135	17	6.88	20	AA4043
14	135	17	6.88	5	AlTi5B1
15	135	17	6.88	15	AlTi5B1
16	135	17	6.88	20	AlTi5B1
17	115	17	5.86	5	AlTi5B1
18	115	17	5.86	15	AlTi5B1
19	115	17	5.86	20	AlTi5B1
20	90	20	5.4	5	AlTi5B1
21	90	20	5.4	15	AlTi5B1
22	90	20	5.4	20	AlTi5B1

Table 2 deviation from theoretical density

SiC, vol.%	0	5	15	20
The deviation from theoretical density (kg/m3)	-0.001	-0.028	-0.061	-0.071

3. RESULTS AND DISCUSSION

Results of deviation between theoretical and experimental densities of the fabricated Al/SiC-MMCs base metal with 0, 5, 15 and 20 vol.% SiC are given in Table 2. It is obvious that the void content and porosity decreased as SiC vol. % decreased.

3.1 Microstructure Investigation

3.1.1 Base metals

Microstructure of the as-fabricated Al/SiC-MMC with 20 SiC vol.% is shown in Fig. 1 This microstructure show that, SiC particles uniformly distributed within the aluminum matrix. Aluminum matrix and SiC particles have been Cleary labeled in fig.1, the dark regions are voids and porosity as shown in microstructure.

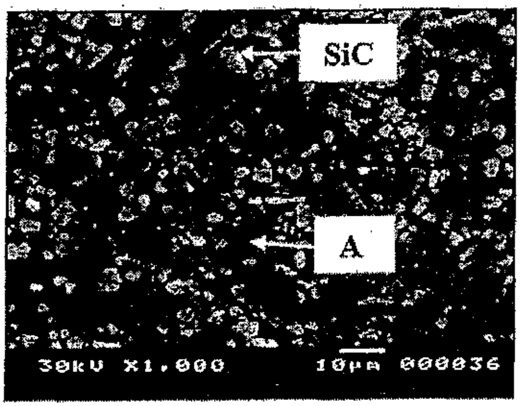

Fig. 1 Microstructure of AL/SiC-MMC, containing 20% SiC.

3.1.2 Autogenous welding (without filler)

Optical micrograph of autogenously welded specimen reveals existence of porosity in weld zone, Fig. 2. It is to be noted that porosity was formed in weld zone at the range of heat input used (5.86~7.75 kj/cm). At both low and high heat input, porosity was high, but at intermediate heat input (6.93kj/cm) it was the lowest. The increase in porosity content at low heat input attributed to high solidification rate of the weld pool, therefore there is no opportunity for escaping the pores. At high heat input the increase in porosity in weld zone could be attributed to the vigorous agitation and turbulence effect of the arc, thus it allow air to react with molten metal.

Fig. 2 Microstructure at weld zone for specimen No. 1, containing 5% SiC autogenously welded.

3.1.3 Welding with filler wires

Optical micrographs of welded joints using AA4043 and AlTi5B1 wires are shown in Figs. 3-5. Porosity was formed in joints welded using AA4043 filler, Fig. 3, as similar to autogenously welded joints, Fig. 2. It is obvious that porosity increased with using AA4043 filler wire compared with welding without filler. Using AlTi5B1 wire as filler resulted in reducing porosity in weld zone (Fig. 4) and it nearly eliminated porosity at high SiC content, Fig. 5. Porosity is formed due to hydrogen existed in aluminum matrix. The aluminum powder raw material is easily oxidized and it reacts with moisture to form hydrated aluminum oxide (Al2O3.3H2O). When filler melts it reacts with Al-base matrix in weld zone, resulting in breaking the bond between Al_2O_3 and H2O, then hydrogen evolved [9], with Ti-Al alloy filler, stable molten pool is gained with improving its fluidity [10], resulting in hydrogen easily escaping from weld deposit.

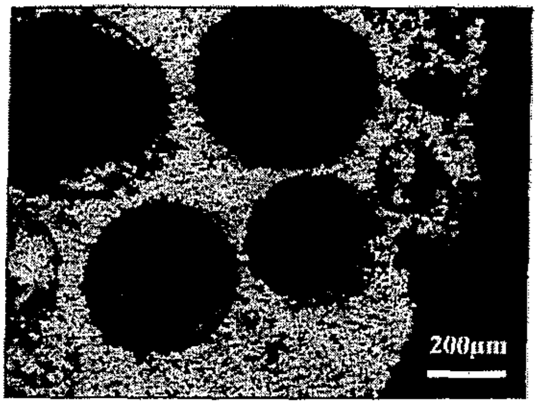

Fig. 3 Microstructure at WZ for specimen No. 8, containing 5% SiC welded using AA4043 filler.

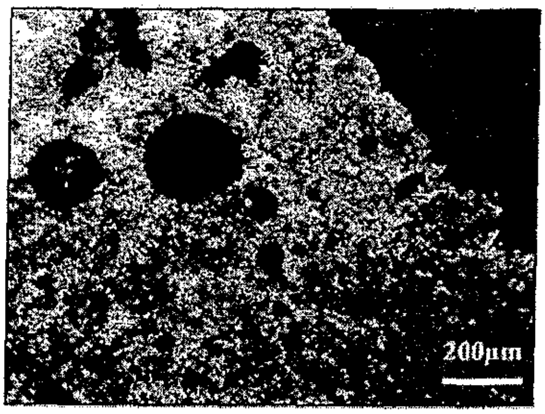

Fig. 4 Microstructure at WZ for specimen No. 18containing 15% SiC welded using AlTi5B1.

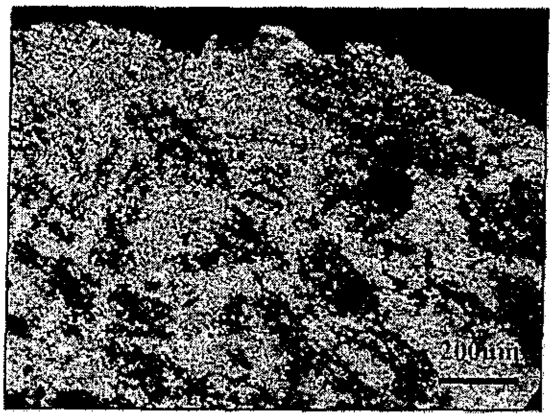

Fig. 5 Microstructure at WZ for specimen No.19 containing 20% SiC welded using AlTi5B1.

SEM Micrograph at WZ of specimen contains 20% SiC welded autogenously is shown in Fig. 6. It is obvious that microstructure consists of lamellar Al_4C_3 phase and aggregates of Si formed in Al matrix. SEM micrographs in weld zone of Al/20%SiC welded with AA4043 and the new filler AlTi5B1 are shown in Figs 7 & 8, respectively. It can be clearly seen that both lamellar Al_4C_3 and Si aggregates are formed when using AA4043 filler. However, their volume fraction is higher than that formed in the same specimen welded without filler, Fig. 6. Microstructure in WZ of Al/20% SiC base metal welded with AlTi5B1 reveals in existence of SiC, TiC, Al_3Ti and TiO_2. These phases were identified using XRD analysis, Fig.9.It is evident that welding of Al/SiC- MMCs either autogenously or using AA4043 filler, reaction between Al & SiC occurs resulting in formation of the detrimental Al_4C_3 and Si aggregates. This results in SiC particulate-free zones formation. When using the non-standard AlTi5B1 filler wire to weld Al/SiC-MMCs, chemical reactions occurred in WZ resulting in formation of TiC and the intermetallics Al_3Ti in addition.

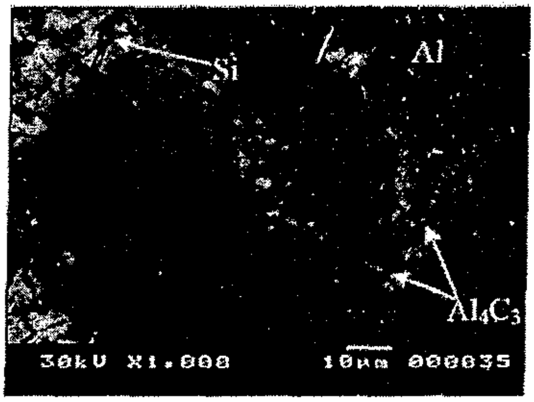

Fig.6 SEM micrograph at WZ of autogenously Weld spec. No. 6 having 20% SiC.

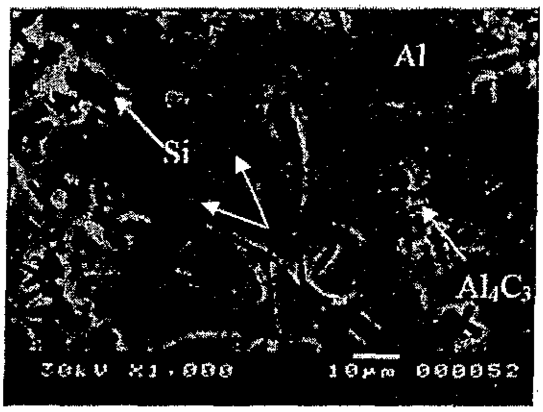

Fig 7 SEM micrograph at WZ of 20%SiC spec. No.10 welded with AA4043.

Since, Ti has higher affinity than Al to react with C to form TiC and so suppresses the formation of the detrimental Al_4C_3 phase. Formation of TiO_2 in WZ, Fig.8 synchronized with the nearly elimination of porosity from WZ (Fig.5) when using the new AlTi5B1 filler. Based on the results of XRD analysis and microstructure evolution, the reactions occur in weld zone; resulting in hydrogen escaping, thus nearly eliminate porosity.

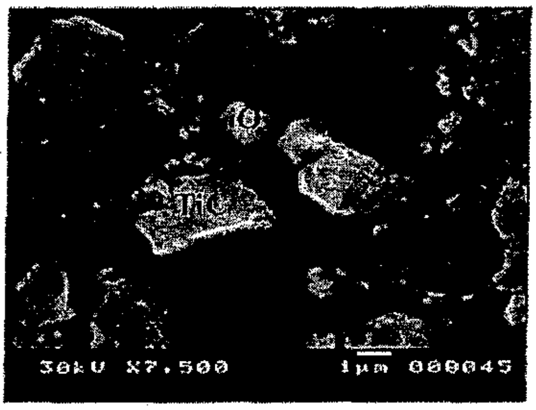

Fig. 8 SEM micrograph at WZ for spec.No.19 containing 20% SiC welded using AlTi5B1.

3.2 Hardness Measurement

Results of hardness of Al/SiC MMCs contain 0, 5, 15 and 20% SiC reinforced particles clarify increasing hardness of base metal with increasing vol.% of the SiC reinforced particles, Table 3. Results of hardness measurements of BM, HAZ and WZ of Al/SIC-MMCs containing 20% SiC welded without and with AA4043 and AlTi5B1 filler are given in Table 4. While, drastic decrease in hardness values in WZ when welding without filler (22Hv) or using AA4043 filler (30Hv), it remain unchanged when using the new AlTi5B1 filler (53Hv). These results are in good agreement with microstructure Fig. 8 and XRD analysis Fig. 9. Using the new AlTi5B1 wire as filler in welding Al/SiC-MMC is beneficial due to formation of TiC, Al_3Ti reinforced phases as well as eliminating formation of the determinately Al_4C_3 phase and reducing porosity in welded joints. The Al_3Ti intermetallics phase formed in weld zone posses high specific strength, high specific modulus, and excellent properties both at ambient and elevated temperatures [10-15]. As compared to most other aluminum-rich intermetallics, Al3Ti is very attractive because it has a higher melting point (~1623K) and relatively low density ($3.4 g/cm^3$). Furthermore, Ti has low diffusivity and solubility in aluminum ; hence, Al_3Ti formed in weld zone can be expected to exhibit a low coarsening rate at elevated temperature. In addition, the Young's modulus of Al_3Ti phase has been determined to be 216 GPa [13]. Therefore, the presence of Al_3Ti phase is very effective in increasing the stiffness of welded joints.

Table 3 Results of measured average hardness of fabricated Al/SiC MMCs at different SiC.%

Specimen SiC %	0	5	15	20
Average hardness (HV)	29	43	49	55

Table 4: average hardness (HV) of welded joints at base metal (BM), heat-affected zone (HAZ) and weld zone (WZ)of Al/SiC-MMC having 20% SiC

Specimen No.	Average Hardness Vickers (HV)		
	BM	HAZ	WZ
6	50	45	22
10	57	34	30
19	53	51	52

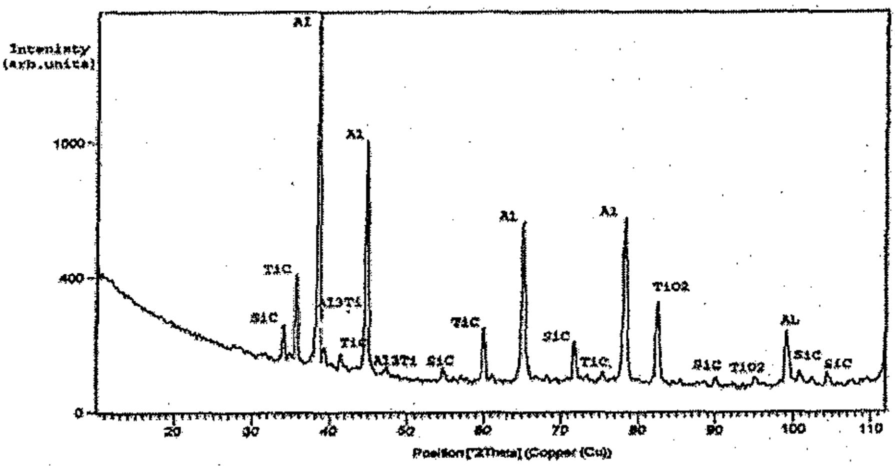

Fig. 9 X – ray diffraction pattern (XRD) at WZ of Al/20% SiC MMC specime No.19 welded using the new AlTi5B1 filler.

4. CONCLUSIONS

Based on the results of this study the following conclusions are submitted:

1- New filler wire of AlTi5B1, was examined and proved promising filler in welding Al/SiC-MMC using TIG process.

2- Using the new AlTi5B1 filler resulted in nearly eliminating porosity and suppresses the formation of the detrimental Al_4C_3 phase in weld joint comparing with autogenously welding or using the conventional AA4043 filler.

3- Whereas, drastic loss in hardness at WZ of autogenously or welding using AA4043 filler, it remain as high as base metal with using the new AlTi5B1 wire.

4- The AlTi5B1 filler enhanced hardness of welded joints due to formation of TiC, Al3Ti and TiO2 reinforcing phases.

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