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Effects of B_4C Addition on the Laser Beam Welding Characteristics of Al/SiC MMCs Produced By P/M

T/M ile Üretilen Al/SiC MMK'lerde B_4C Katkısının Laser Işın Kaynağı Karakteristiklerine Etkileri

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ABSTRACT

Fusion weldability characteristics of metal matrix composites (MMC) produced by powder metallurgy (P/M) are usually insufficient due to unwanted micro-structural changes that occur during welding. This study aims to investigate the effects of B_4C addition as reinforcement on the weld quality of Al/SiC MMCs. After the production of Al/SiC MMCs by P/M with or without the addition of B_4C, laser beam welding (LBW) characteristics of the materials were investigated by focusing on the integrity of the welds. Optical microscopy (OM), scanning electron microscopy (SEM), and energy dispersive X-ray analysis (EDX) were utilized for the characterization of the welds. Results show that Al/SiC MMCs produced by P/M can not be easily welded by LBW, but weldability characteristics of the material can be improved by the addition of B_4C.

Keywords : *MMC, P/M, Aluminum, SiC, B_4C, Laser beam welding.*

ÖZET

Toz Metalurjisi (T/M) ile üretilen metal matrisli kompozitlerin (MMK) ergitme kaynak kabiliyetleri genellikle yetersizdir.Bunun sebebi kaynak işlemi sırasında oluşan istenmeyen mikro-yapısal değişimlerdir. Bu çalışma, Al/SiC MMK'lerde takviye elemanı olarak B_4C ilavesinin kaynak kalitesine etkilerini incelemeyi amaçlamaktadır. Al/SiC MMK'lerin, B_4C takviyesi yaparak ve yapmadan imal edilmesinden sonra, malzemelerin lazer ışın kaynağı karakteristikleri, kaynak bölgesinin bütünlüğü açısından incelenmiştir. Kaynakların karakterizasyonu için; optik mikroskobisi (OM), taramalı elektron mikroskobisi (SEM) ve enerji-dispersif X-ışını analizleri (EDX) kullanılmıştır. Sonuçta, T/M ile üretilen Al/SiC MMK'lerin lazer ışın kaynağı ile kolayca kaynatılamadığı, B_4C ilavesi ile malzemenin kaynak kabiliyetinin arttığı görülmüştür.

Anahtar Kelimeler : *MMK, T/M, Alüminyum, SiC, B_4C, Lazer ışın kaynağı.*

1. INTRODUCTION

Due to their excellent combinations of mechanical and physical properties and high temperature properties, metal matrix composites (MMCs) have attracted attention from material scientists. The MMCs can be produced in liquid state, in semi-solid state, and by powder metallurgy (P/M) techniques. Among these methods, powder metallurgy has important advantages compared to the others. The main advantage is the minimization of the undesirable interface reactions due to the low treatment temperature, which enables the P/M to produce MMCs with higher mechanical properties. Another advantage of the P/M is the more uniform distribution of the reinforcement in the matrix.

Its excellent properties such as low density, low cost (compared to Mg and Ti), high strength, high ductility and corrosion resistance have made the aluminum the most popular metal matrix material. Al MMCs, produced by reinforcing Al matrix with some ceramics are being considered as a group of new advanced materials.

With a density slightly higher than that of Al, SiC is the most widely used reinforcement due to its interface quality, low cost and wide range of

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availability (Torralba et al., 2003). Al/SiC MMCs have been well developed and applied especially in the automotive and aerospace industries due to their high specific strength, specific stiffness and wear resistance. Industrial applications of Al/SiC MMCs as structural components often require joining of the MMC to other components made of similar or dissimilar materials. Therefore, commercialization of Al/SiC MMCs depends on the development of economic and reliable joining techniques. However, joining of the MMCs especially those made by the utilization of powder metallurgy methods has been remaining as a difficult problem (Wang et al., 2000). Inevitable interfacial chemical reactions between reinforcement and the molten matrix and very large differences of physical and chemical properties between the aluminum matrix and the reinforcing SiC particles give rise to the problems that make the fusion welding of the MMCs difficult (Wang et al., 2000; Gomez de Salazar and Barrena, 2003).

Traditional arc welding methods (lower power density) such as Gas Tungsten Arc Welding (GTAW) and Gas Metal Arc Welding (GMAW) have been employed for joining Al/SiC MMCs. However, high viscosity of the melt pool, reinforcement particle segregation and agglomeration, and especially the serious SiC particle dissolution leading to the formation of large amount of coarse, needle-like deleterious Al_4C_3 or Al_4SiC_4, or Al_4 Si_2C_5 and the occluded gases during welding prevented the achievement of acceptable weld bead and their industrial applications (Ellis, 1996; Wang et al., 2000).

Welding of Al/SiC MMCs with high power laser beams has also been investigated. Formation of needle-like detrimental phases of Al_4C_3 following the partial or complete dissolution of SiC reinforcement particles in the fusion zone of the weld is still a serious problem. Recent studies about fusion welding of Al/SiC MMCs have focused on the prevention of the harmful aluminum carbide (Al_4C_3) formation, which deteriorates the ductility and reduces fracture toughness of the joint. Wang et al. (2000) used Ti as a strong carbide forming element for in-situ weld alloying. To decrease the interface reactions by decreasing the weld pool temperature, Garcia et al., (2002) utilized indirect arc in MIG welding (GMAW). Niu et al., (2006) concluded that interface reactions can be controlled by means of decreasing heat input of molten pool and increasing the content of Si in molten pool. Bassani et al. (2007) offered diode laser method which has a low energy density relative to CO_2 laser.

Since the mechanical properties of composite materials depend on the homogeneous distribution of the reinforcement, welding processes, which cause the formation of un-reinforced weld zones, will produce a loss in the joint strength of the composite material. Apart from the dissolution of reinforcements, the loss of the mechanical properties of the welded Al/SiC materials is also resulted from the formation of detrimental brittle phases, which are not observed in Al MMCs reinforced with Al_2O_3 or B_4C (Ellis, 1996; Gomez de Salazar and Barrena, 2003).

Weldability of Al matrix composites can be improved by using reinforcements with better interface characteristics than SiC. Despite its higher cost, with its better interfacial bonding and more uniform particle distribution (Kennedy, 2002; Shorowordi et al., 2003) B_4C seems to increase the fusion weldability of Al matrix composites.

This study aims to investigate the effects of small amount of B_4C addition as reinforcement on the weld quality of Al/SiC MMCs. After the production of Al/SiC MMCs by P/M with or without the addition of B_4C, laser beam welding (LBW) characteristics of the materials were investigated comparatively by focusing on the integrity of the welds.

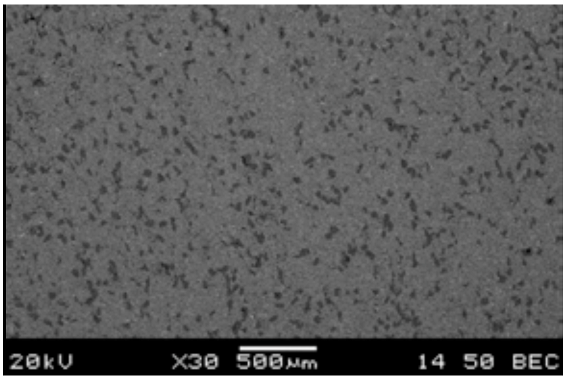
2. MATERIALS AND METHODS

The materials used in this investigation were aluminum powders with commercial purity as matrix material and SiC (10wt.%) and Ekabor (10wt.%) powders as reinforcement particles. The average sizes of the aluminum powders, SiC particles and Ekabor were; 83 µm, 63 µm and 80 µm respectively. Ekabor is a mixture of SiC and B_4C (5wt.%). Al/SiC and Al/SiC/B_4C (Al/Ekabor) MMCs were fabricated by P/M. Al/SiC and Al/SiC/B_4C powders and zinc-stearate as a lubricant and binder were mixed for 30 minutes in a V-type mixer to ensure uniform distribution of the ingredients. Die wall lubrication was applied by brushing a thin layer of zinc-stearate powder over the die cavity and punch face. Then, the mixed powders were cold pressed with a uniaxial press at 250 MPa. After compaction, composites were sintered in a furnace at 500 °C for 6 hours in argon atmosphere. All specimens were allowed to cool to room temperature in the furnace.

The weld samples were produced by slicing the sintered specimens with wire cutting and then grinding to the dimensions of 4x18x45mm. Bead on plate type welds were made by laser beam welding process. An Nd:YAG laser welding machine with a maximum power of 200W was utilized for the welding experiments. Laser welding processes were carried out under the shielding of pure argon. Welding speed was 120mm/minutes for all welds. The main variable of the joining process was the power of the laser beam. Laser welds were made at power values ranging from 20W to 180 W. A gas tungsten arc welding (GTAW) process was also carried out for comparison with laser beam welding. GTAW current, voltage and speed were 85Amperes, 13.5 Volts and 100mm/minutes respectively. Optical microscopy (OM) and scanning electron microscopy (SEM) with energy dispersive X-ray analysis (EDX) attachment were used for characterization of the MMC materials and welded specimens. After preparation of samples by cutting, embedding in polyester resin, grinding and polishing, the microstructure of MMCs and welds were investigated.

3. RESULTS AND DISCUSSION

As shown in Figure1, distributions of reinforcements in Al matrix are fairly homogenous. A few macro and micro pores and poor bonding at some particle-matrix interfaces can be seen.



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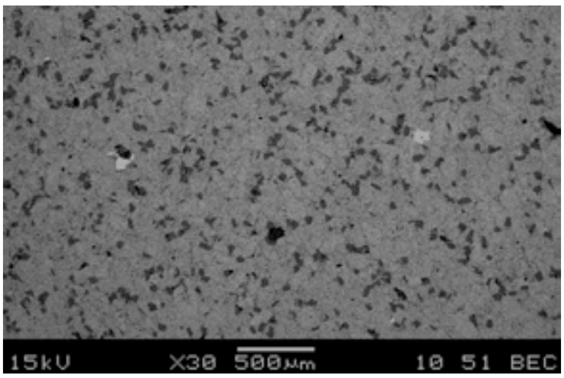

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Figure 1. SEM images showing the microstructures and particle distributions of a) Al/SiC and b) Al/SiC/B_4C MMCs.

The quality of the laser welds was unacceptable. Very large cavities (pores) on the weld bead and cracking through the bead-base metal interface, indicating very low weld strength, were observed in all welds (Figure 2).

Very steep temperature gradient and high cooling rates caused the formation of blow holes by entrapped gases, which can be interstitial gases or products of some chemical reactions occurred during welding. Very large gas pores generally in the form of worm holes were observed in all weld beads leading to volumetric increases in welds (Figure 2). EDX analysis of a weld metal and inner surface of a cavity is listed in Table 1.

Table 1. EDX analysis of a weld metal and cavity surface (Al/SiC, Power: 180W).

Elements (wt.%)	Weld metal	Cavity Surface
C	0.162	1.963
O	0.160	1.996
Al	97.140	94.455
Si	2.547	1.587

Higher amounts of oxygen and carbon on the surface of the cavity show that low density compounds in the form of gas formed in these regions during welding. Oxides on the surface of the Al matrix composite or moisture absorption through the pores of the material may explain the high amounts of oxygen found on the pore surface. Specimen preparation process might have also contributed to the increase in the oxygen content. Transformation from solid to gas form under the influence of high energy of laser causes large amount of gas emission from the fusion zone of the weld. Gas entrapment during the rapid solidification of the laser welds resulted in an increase of the weld volume.

Apart from cleanliness of the MMC material, preheating can be used to decrease the gas emission during welding. Preheating can also decrease temperature gradient across the weld, and decrease gas entrapments by the prolonged solidification and cooling period.

As shown in Figure 2 and Figure 3, concentration of the reinforcing particles in the weld bead is very low. Dissolution of reinforcements in the weld zone and segregation of the reinforcing particles at the weld-base material interface led to formation of an almost unreinforced weld. The slightly higher concentration of reinforcements at the weld-base material interface indicates segregation due to rejection of reinforcements by solidification front. Formation of needle-like phases of Al4C3 following the dissolution of SiC reinforcement particles in the fusion zone of the weld was not observed at the magnifications used in this study.

In order to investigate the effect of welding process on the weldability of the material, a GTAW process

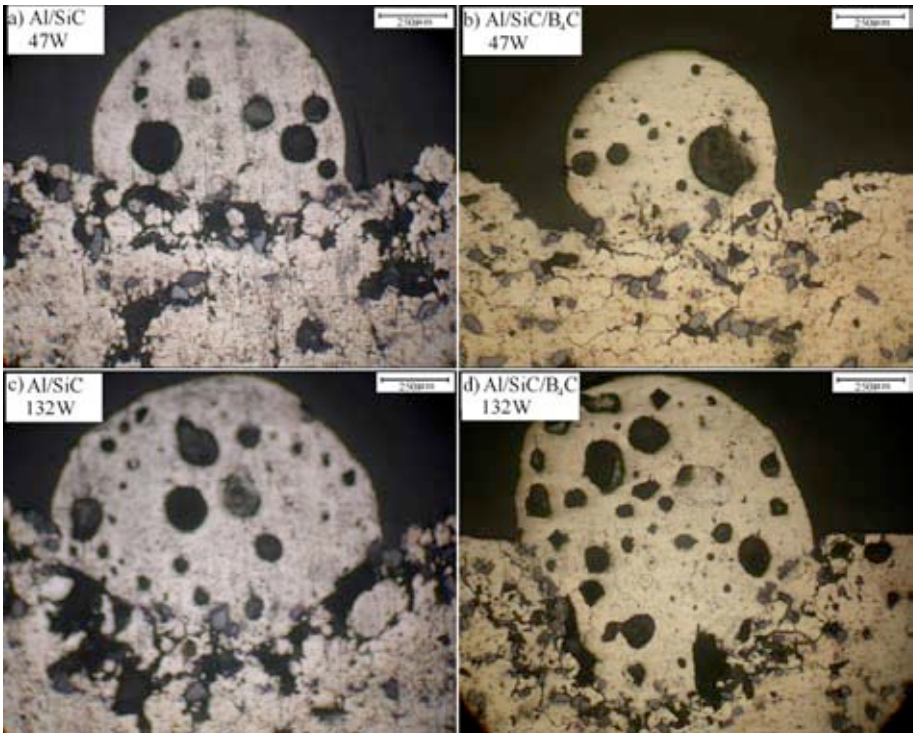
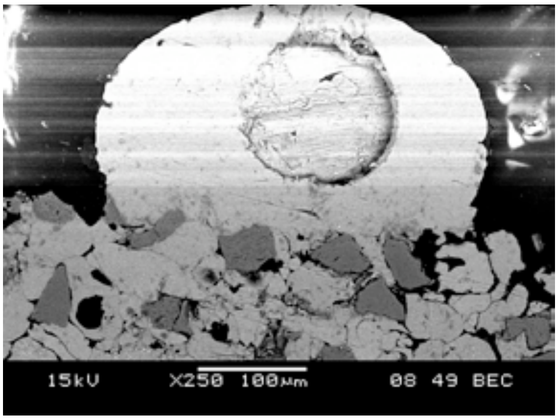


Figure 2. Optical micrographs of Al/SiC and Al/SiC/B_4C MMCs laser welded at different power levels.

was also carried out and welds made by LBW and GTAW were compared. Annealing effect of GTAW arc over a large area decreases the temperature gradient and cooling rate of the weld zone. GTAW, which has a lower power density than LBW, gave a homogenous and smooth weld bead with no porosity and without cracking at the base material-weld interface (Figure 4). After comparing the welds obtained from GTAW and LBW, it can be concluded that, excessive weld porosity and cracking can be attributed to the nature of the LBW. Energy of the laser beam, concentrated on a very small area, produces a tremendous temperature difference between the molten metal and base material immediately adjacent to the weld. Tensile stresses, generated between the cooling weld metal and surrounding material, combined with inherent residual stresses of the P/M give rise to the formation of cracks. Very high cooling rate of LBW has an important role in the formation of cracks and cavities (blow holes).

Tensile solidification stresses superposed with the residual stresses lead to cracking at the weld metal-base metal interface where the resultant stress exceeded local strength obtained by bonding of Al and reinforcement powders. The quality of welds is strongly dependent upon the strength of the matrix-reinforcement interface.



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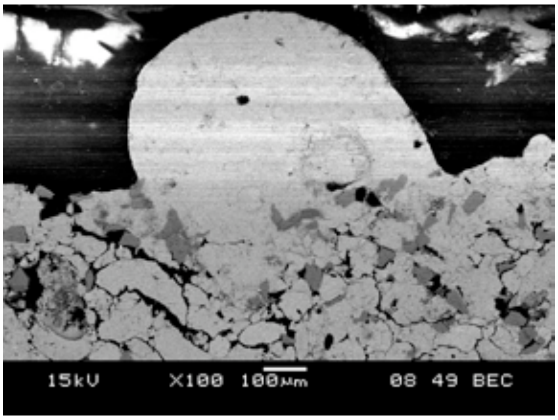

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Figure 3. Effect of laser power on the microstructure of the weld area of Al/SiC/B_4C a) 20W b) 47W.

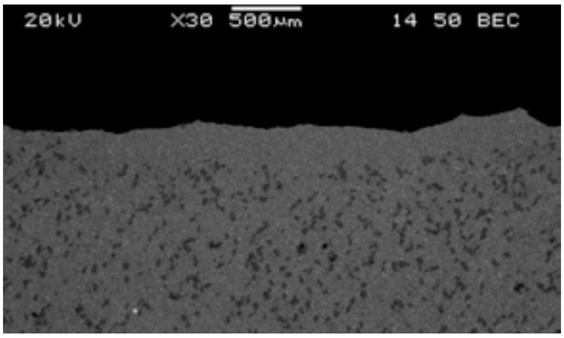
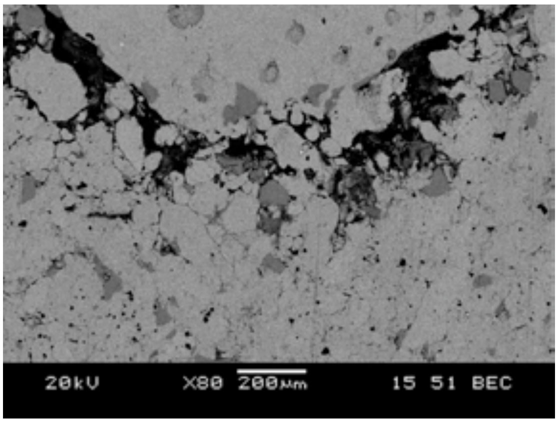


Figure 4. SEM image of GTA weld bead on the Al/SiC material.

In general, laser welds of Al/SiC and Al/SiC/B_4C MMCs had similar features and problems. But there were some differences on the quality of the welds. As shown in Figure 2 and Figure 5, the Al/SiC welds cracked through the interface almost continuously, while more continuous bonding zones and less cracking were observed in all welds of Al/SiC/B_4C materials.



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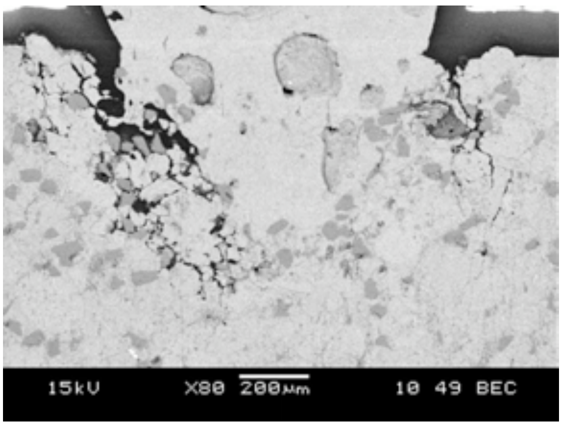

(b)

Figure 5. Weld-base material interfaces of a) Al/SiC and b) Al/SiC/B4C MMCs. (Power: 180W).

High temperatures imposed by the LBW process and unwanted reactions between Al matrix and SiC particles leading to formation of brittle deleterious compounds (e.g. Al_4C_3) caused more severe cracking and decreased strength of the welds in Al/SiC MMCs. A small addition of B_4C decreased cracking tendency due to higher interface strength of Al/B_4C compared to Al/SiC. The secondary phases produced at Al/B_4C interface are not detrimental like Al_4C_3 that is observed in Al/SiC MMCs (Shorowordi et al., 2003).

4. CONCLUSIONS

- Very high cooling rates of LBW have an important role in the formation of cavities and cracks, which made the quality of laser welds unacceptable.
- The quality of welds is strongly dependent upon the strength of the matrix-reinforcement interface.
- The poor bonding of interface give rise to the formation of crack initiation sites during the LBW of Al/SiC MMCs.
- Even a small addition of B4C improves weldability characteristics of Al/SiC MMCs produced by P/M.

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