Development of Aluminum Matrix Composite Through Microwave Stir Casting

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1 Introduction

Aluminum matrix infused with ceramic particles offers higher strength and better mechanical properties then monolithic metals. Aluminum matrix composites (AMCs) are popular composite materials used in the aerospace and automobile industry because of their superior mechanical properties. The methods for developing AMCs include centrifugal casting, stir casting, compocasting, rheocasting, infiltration, powder metallurgy, etc. Among the existing methods, stir casting is widely used because of its low investment cost.

A material processing route plays a vital role in developing defect frees AMCs. AMCs are being produced using a stir casting route employing conventional heating sources like resistance furnace or other furnaces, which consume more time and energy. The conventional stir casting methods have many drawbacks: long processing time, inferior microstructure and mechanical properties, non-uniform heating, wettability, porosity, etc. [1–6].

Attempts are being made to investigate material processing using microwaves to overcome the issues related to conventional processing methods. Microwave's popularity has been increasing due to its attributes, such as uniform and volumetric heating in short processing time. Processing of materials using microwaves is an attractive and alternate route because it is fast, eco-friendly, and economical. The fabrication route using microwaves enhances the physical and mechanical properties of metals. However, metals reflect microwaves at room temperature at 2.45 GHz. Research and development in the area of microwave material processing have made

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it possible to process bulk metal by applying microwave hybrid heating (MHH) principle. MHH technique employs susceptor material to accelerate the heating of the metal. MHH route has motivated several researchers toward its application in various processes: joining, sintering, cladding, heat treatment, melting, in-situ casting, and drilling [7–9].

The development of alloys and composites by employing microwaves is still at the development stage. MHH route has been explored to melt metals in powder form and to develop alloys and composites [10–13]. Metals in the bulk form are successfully melted by employing the MHH route [14–16]. An attempt to investigate the joining of alloys revealed that the joint was free from defects and showed better mechanical properties [17]. It was reported that cellular grain structure was observed at the joint using MHH [18]. Metal matrix composite (MMC) clads were developed successfully by varying exposure time using microwave irradiation at 2.45 GHz frequency [19]. The various processes using microwaves used fine particles [20]. It was observed from the studies that there exists a spot inside the microwave cavity, where heat generation is more in the microwave absorbing material [12, 21]. Coatings developed through microwave irradiations show better mechanical properties over the sprayed coatings. Microwave irradiation helps in achieving homogeneous structure and better metallurgical bonding between substrate and coating materials. Microwaves remove pores, cracks, and voids by remelting the particles, which remained unmelted through spray technique [22].

Several authors compared conventional sintering with microwave sintering and reported that the sintering by microwave irradiation consumes less time than conventional sintering. The fundamentals and applications of microwave sintering were discussed. The distinguishing attributes and future of material processing through microwaves sintering were markedly presented [8, 9, 23]. The uniform and rapid heating were observed during microwave irradiation when the temperature reaches nearly 50% of the melting point of bulk metal [24].

Compared to sintering, joining, cladding, and melting using microwaves, the development of metal matrix composites (MMCs) using microwave energy is at the immature stage. This provides an option to apply microwave energy to synthesis AMC through stir casting. This method could reduce the processing time and energy requirement. However, the development of AMCs via stir casting technique using microwaves as a heating source has not been reported [2, 7, 25]. The present work is an attempt to use microwave energy as a heating source for producing AMC using a stir casting route. The procedure and preliminary results of the development of AMC through the microwave stir casting route are reported in this paper.

Table 1 Chemical composition of as-received AA6061

S. No.	Elements	Weight (%)
1	Si	0.62
2	Fe	0.7
3	Cu	0.39
4	Mn	0.24
5	Mg	0.8
6	Cr	0.25
7	Zn	0.35
8	Ti	0.18
9	Al	Remaining

2 Experimentation

2.1 Material Details

In the present work, aluminum alloy 6061 (AA6061) in the bulk form was used as matrix material. Silicon carbide (SiC) particles (10–80 μm) were used as reinforcement. The chemical composition of the AA6061 is represented in Table 1.

2.2 Fabrication Process

The experiment was performed under atmospheric conditions in a 3.3 kW industrial microwave furnace at a frequency of 2.45 GHz. The schematic experimental setup of a microwave stir casting used in this study is shown in Fig. 1. Table 2 summarizes the processing parameters used in this study. A graphite clay crucible was filled with about 230 g of AA6061. The crucible, susceptor, and refractory brick were insulated and placed inside the microwave furnace. Alumina was used as an insulating material because it is transparent to microwaves. The MHH technique was applied to melt the AA6061, using SiC block as a susceptor material.

A K-type thermocouple was introduced into the crucible such that it touches the metal for temperature indication during the melting of the metal. The heat was generated rapidly within susceptor material by microwaves and transferred to the metal through the crucible wall. The AA6061 was melted within 1,200 s via the MHH technique. Figure 2 shows the arrangement for processing the material. After reaching 700 °C, the top layer of the slag was removed followed by stirring. About 1 wt.% of magnesium chips were introduced into the liquid metal for wettability between the matrix and reinforcement. Further, 2 wt.% of SiC particles were incorporated slowly while the slurry was solidifying, favoring mixing of all reinforcement in the slurry.

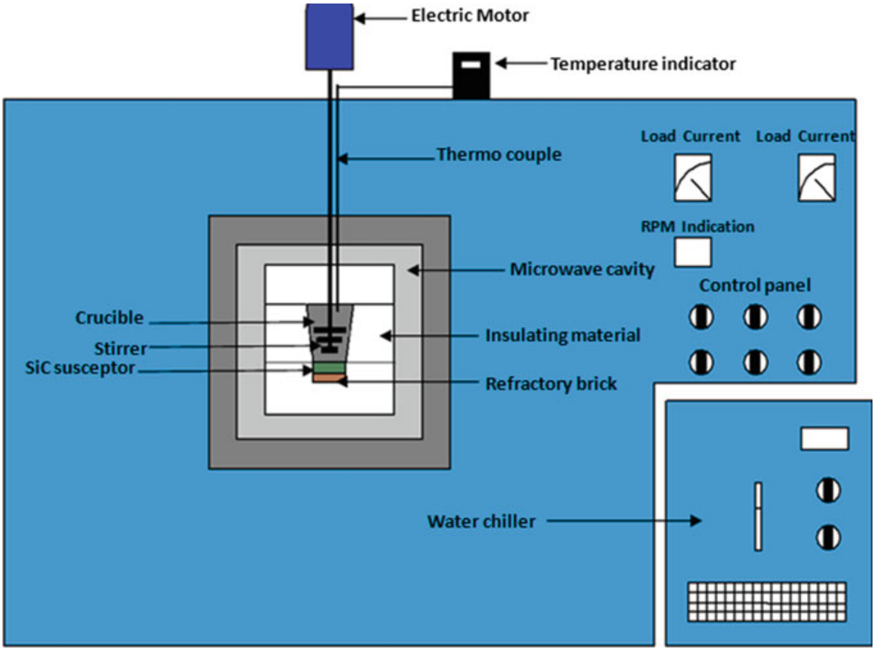

Fig. 1 Schematic diagram of the microwave stir casting setup

Table 2 Details of process parameters

S. No.	Parameters	Description
1	Furnace	Industrial microwave furnace
2	Power	3.3 kW
3	Frequency	2.45 GHz
4	Matrix	AA6061
5	Reinforcement	SiC particles (10–70 μm)
6	Susceptor material	SiC
7	Insulation	Alumina casket
8	Stirrer speed	30 RPM
9	Stirring time	300 s

The temperature of the slurry was increased to 730 °C, and subsequently, the liquid mixture was poured in a graphite mold and allowed for natural cooling. The casted AMC is shown in Fig. 3.

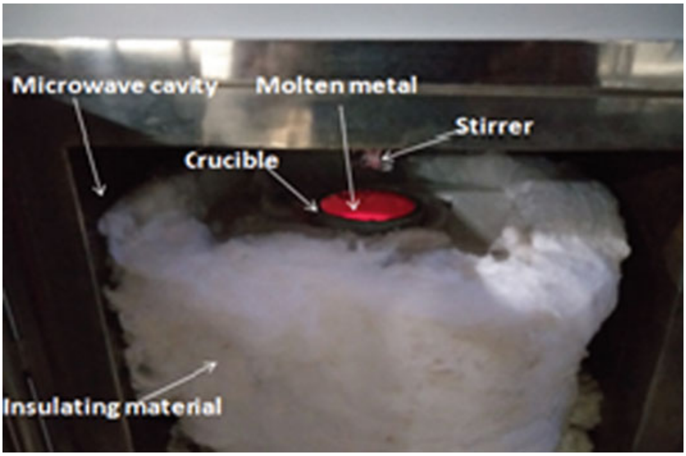

Fig. 2 View of the processing setup

Fig. 3 Developed as-cast AMC

3 Results and Discussions

3.1 Microstructural Study

In the present work, SiC particles were mixed into the AA6061 using the microwave stir casting method. Microstructural study was carried out on as-cast AMC samples to examine the presence and dispersion of SiC particles. The scanning electron microscopy (SEM) micrographs of the composite samples, which are prepared by metallographic procedures, are shown in Fig. 4. The gray area represents the AA6061 matrix. The dark-colored SiC particles are dispersed uniformly in the AA6061 matrix. The accommodation of SiC particles at the grain boundaries can also be observed.

Figure 5 shows dense microstructure, which could be attributed to uniform heating through microwaves. The energy dispersive spectroscopy (EDS) spectrum of the

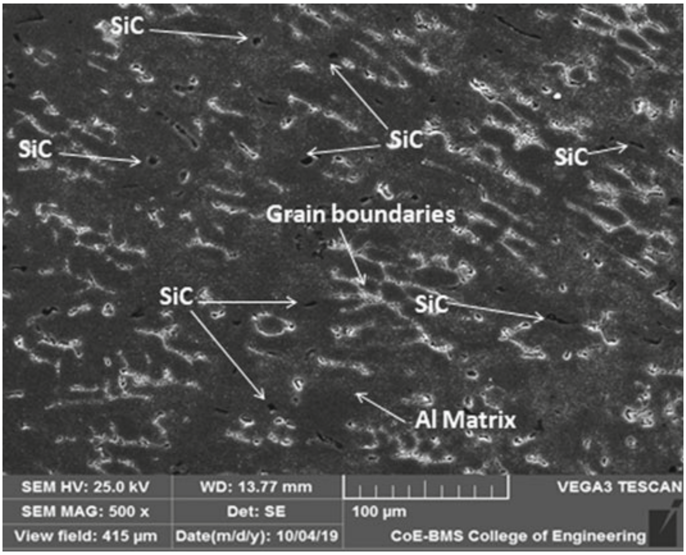

Fig. 4 SEM micrograph of as-cast AMC at 500 X

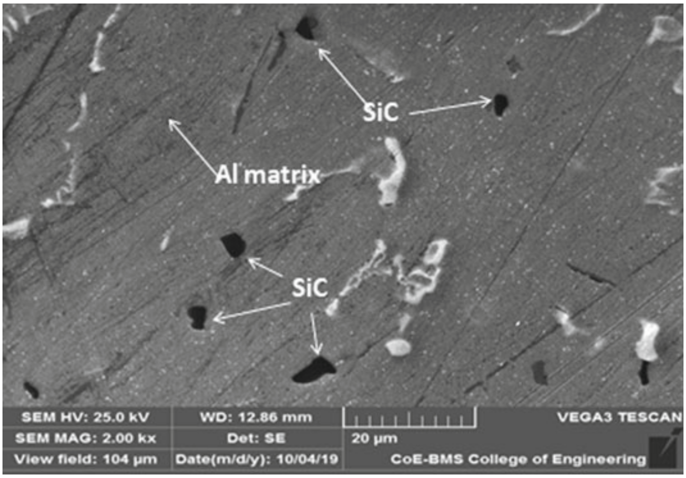

Fig. 5 SEM micrograph of as-cast AMC at 2.00 KX

developed composite is displayed in Fig. 6. The EDS pattern of the composite confirms the presence of the reinforcement in the dominant aluminum alloy matrix.

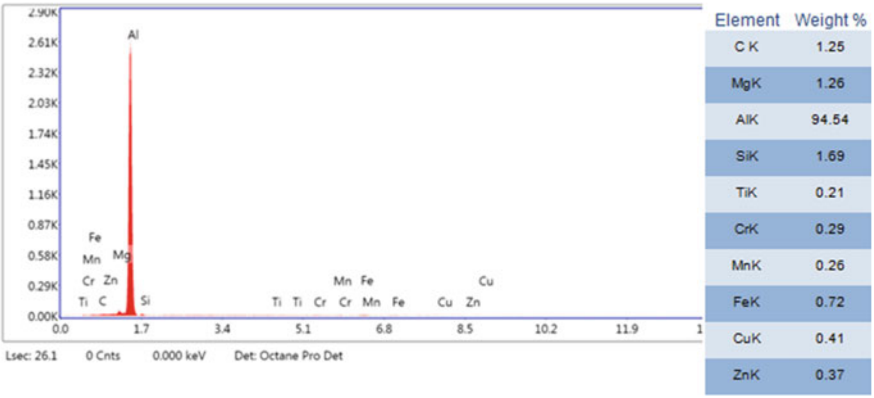

Fig. 6 EDS spectrum of as-cast AMC

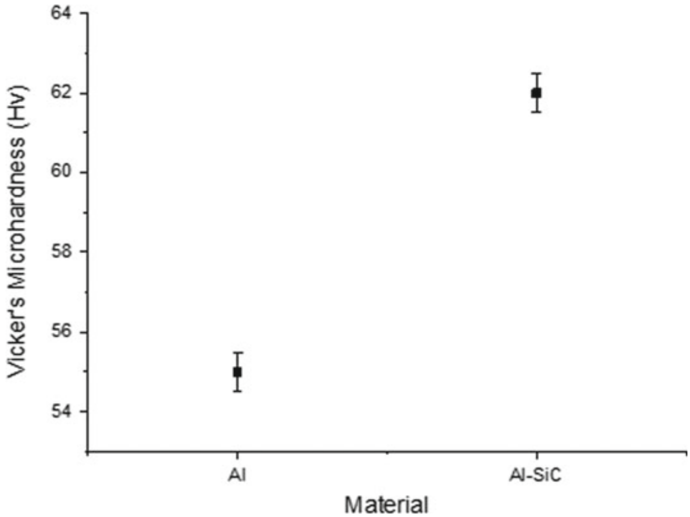

Fig. 7 Microhardness of the AA6061 and AA6061-SiC

3.2 *Vicker's Microhardness Test*

Vicker's microhardness test was performed using a hardness tester (HIGHWOOD HWMMT-X7). A load of 1 Kgf was applied for 10 s. Microhardness of the as-received AA6061 and the AMC is illustrated in Fig. 7. The average microhardness value of as-received AA6061 and as-cast AMC was found to be 55 Hv and 62 Hv, respectively. It was observed that the hardness value of base alloy increased by 12%, which could be due to microwave heating and the uniform dispersion of SiC particles in the composite.

4 Conclusion

Components of automobiles and aircraft are being fabricated by AMCs. AMCs are produced commonly through conventional stir casting methods. In the conventional stir casting process, the maximum amount of time is consumed in the melting of metals, and the developed composites have defects due to non-uniform heating and pollution. In the present work, the AA6061-SiC composite has been synthesized by a novel microwave stir casting route. The developed fabrication method consumes less time than the conventional stir casting process. The reduction in processing time is attributed to MHH. Moreover, the composite prepared through this method is free from defects due to uniform heating by microwaves. The SEM micrographs show the uniform distribution of reinforcements and dense microstructure. Further, the presence of reinforcement in the matrix was confirmed by EDS. The prepared AA6061-SiC composite is found to have a hardness of 62 Hv, increased by 12% compared with as-received AA6061. The illustrated microwave stir casting process is found to be promising and could be an alternative route for producing AMCs.

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