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Production and characterization of SiC reinforced aluminum alloy matrix composites from waste beverages cans

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Abstract

In the study; SiC reinforced (1-12 wt. %) aluminum matrix composites from waste beverage cans were fabricated by stir casting method. The effect of reinforcement ratio on the experimental density, hardness, the compressive and tensile strength of the composites was investigated. The crystal structures and microstructure of the composite materials were analyzed by X-ray diffraction (XRD) method and scanning electron microscopy (SEM). From the results, the hardness of composites increased from 70,81 HV (pure Al alloy) to 89,80 HV (for 9 wt. % SiC). The compressive and tensile strengths were performed as 763,69 MPa (for 5 wt. % SiC) and 201,79 MPa (for 1 wt. % SiC) compared with pure aluminum alloy (620,35 MPa and 154,71 MPa).

1. Introduction

The conventional materials used in space, aerospace and automotive sectors have been insufficient due to technological developments. Instead of these conventional materials, composites with superior properties have been produced and their use has increased rapidly. The composites can be defined as is a material made from two or more materials for various physical and chemical properties which produced a material with characteristics different from the individual materials. According to matrix materials, the composites can be classified as polymer, ceramic and metal matrix. In recent years, the composite form of metal matrix composites (MMC) is a good candidate for industrial applications due to their extraordinary hardness, tensile/compressive strength, corrosion resistance and abrasion resistance [1-3].

The MMC consists the reinforcing element which homogeneously distributed in the matrix phase. The commonly used matrix elements such as Al, Mg, Ti, Co, Fe, Cu, Mo and Ni and their alloys have great importance mentioned industries. Among them, aluminum and its alloys are the most widely used matrix element because of its lightweight, easy to cast, efficient mechanical properties, high thermal conductivity and electrical conductivity. On the other hand, the reinforcement element as Silicon carbide, Silicon nitride, Aluminum oxide, Boron carbide, Magnesium oxide, Tungsten, Carbon, Titanium carbide, Titanium DiBoride and carbon based particulates are widely used in composite fabrication. The SiC provides to composites higher hardness, compressive behavior and tribology features due to its high wear resistance, low friction coefficient, high thermal shock resistance, adequate thermal expansion and thermal conductivity coefficient [4-6].

In the composite fabrication, the method should be cost-effective and suitable the large scale production. The powder metallurgy (PM) and stir casting (SC) methods are the most commonly used methods in the production of MMC. The production cost of SC method is less than PM method because SC method allows the use of recycled and scrap materials. Moreover, recycling can reduce natural resources and reduce the rapid increase in environmental pollution. Considering the energy and cost spent on the production of materials from ore, scrap and waste production is gaining importance. One of the most widely used places in aluminum is beverage cans. Recycling of aluminum beverage cans will reduce both cost and environmental pollution. Although the waste Al beverage cans have been collected in the reproduction of the traditional materials, there is no effort for using these waste aluminum beverage cans to develop cost-effective advanced composites [7,8].

Hindi et al. produced the SiC reinforced Al 6063 composites using the SC method. It was reported that ductility decreased and hardness and tensile strength increased with the SiC reinforcement [9]. Saenpong et al., aimed to investigate the SiC distribution and hardness of the A356-SiC composite produced by casting. The results showed that SiC was homogeneously distributed in A356 under all conditions. SEM micrographs showed that the interface between the matrix and the SiC particles exhibited good binding. However, the small cracks in the intermediate interface between the reinforcement element and the matrix phase were found for 20 wt.% SiC. The maximum hardness value of the composite material was found as 74 HB in 15 wt.% SiC [10]. Kumar et al. were presented that SiC reinforced Al6063 matrix composite produced using SC method. According to the results, SiC was homogeneously distributed within the matrix and the tensile strength was increased for 12.5 wt% reinforcement ratio [11]. Microstructure, Vickers hardness, tensile strength and wear performance analysis of SiC reinforced Al composite

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materials prepared in wt. 0, 5, 10 and 20 wt% were performed by Rahman et al. According to their results, the hardness and tensile strength increased as the reinforcement rate increased and the maximum values reached for 20 wt% reinforcement [12]. Singla et al. developed a low-cost method for the production of SiC-reinforced Al composite materials. In the experiments applied to the materials prepared at a ratio of 5, 10, 15, 20, 25 and 30 wt%, the SiC particles were homogeneously distributed in the matrix. It was observed that the hardness and impact strength increased as the SiC weight percent increased. The best results were obtained with a 25% weight supplement. By increasing this weight ratio, hardness and impact strength values decreased due to the agglomeration of SiC particles [13]. Sujan et al. conducted this study to evaluate the physical and mechanical properties of SiC and Al_2O_3 particulate reinforced AMCs. 5, 10, 15 wt% of Al_2O_3 and SiC were added to the Al356 alloy composite materials were produced by SC. The results showed that composite materials exhibit improved physical and mechanical properties such as high tensile strength, high impact strength, high hardness and low thermal expansion coefficient. They also found that the rate of reinforcement was significantly reduced by increasing the rate of reinforcement in composite materials [14]. Although given studies have valuable results on SiC reinforced Al matrix composites, they have not been used cheaper raw materials as scrap or waste beverage cans. They generally preferred highly expensive raw materials as alloys or ultra-pure metal powders. Because of these considerations, the cost-effective advanced Al composites were fabricated from waste beverage cans maybe for the first time. We purpose that fabrication and characterization of SiC reinforced (1-9 wt%) aluminum matrix composites from waste beverage cans.

The effect of reinforcement ratio on the experimental density, hardness, the compressive and tensile strength of the composites was evaluated in detail.

2. Experimental

In this study, instead of primary aluminum materials or aluminum powders, waste beverage cans and SiC (Nanografi Co., 99,9% purity, 44 µm in average size from particle size analyzer with laser diffraction) have been used as Al matrix and reinforcement element. SiC reinforced aluminum composites with 1, 3, 5, 7, 9 and 12 wt% have been produced under vacuum (10^{-2} Pa) and argon atmosphere by stir casting method in a graphite crucible. Before the casting, the SiC particles were heat-treated at 1100°C for 5h to enhance the wettability of the SiC-Al interphases. The schematic representation of the method is given in Figure 1. The codes of casted composites are given in Table 1. In the first step, waste beverage cans have been melted at 850°C and cast in an ingot form. While the temperature of the furnace was between 800-900°C, aluminum ingots have been placed in the crucible. After the aluminum has been melted in the argon atmosphere, to perform wettability of SiC and obtain coherent interface, the temperature of furnace has been decreased to 630°C. After that, the liquid has been mixed at 400 rpm for ten minutes by a mechanical mixer. At the next step, the temperature has been increased step by step to 850±10°C and the mixing process has been continued for two more minutes to obtain a homogeneous mixture. Before the composite melting has been poured into the mold which was heated to 400-450°C, the dross was removed from the surface of the liquid before casting. Finally, after waiting at the room temperature for the solidification of the melting the casted composites have been removed from the stainless steel mold.

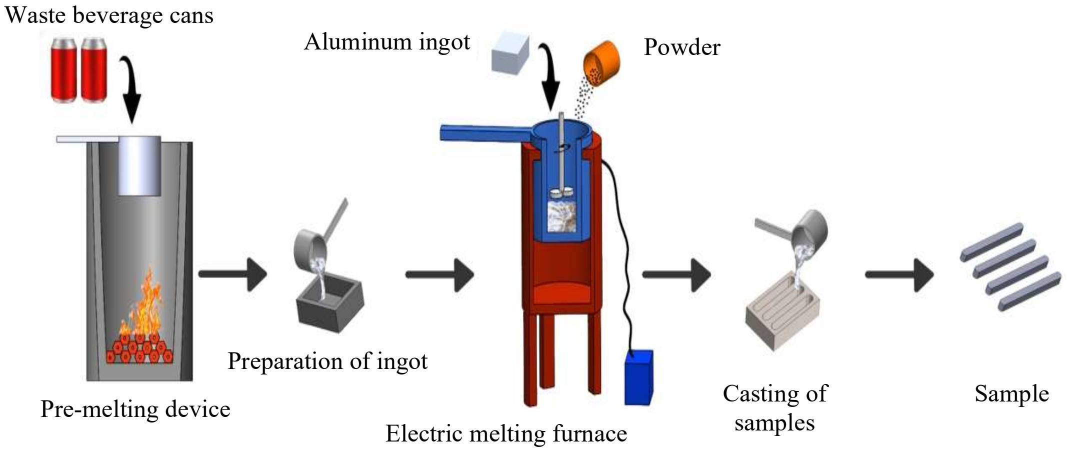

Figure 1. The schematic illustration of composite fabrication.

Table 1. Sample code of the materials.

Material	Code
Pure Al	Al-0SiC
Al- 1% SiC	Al-1SiC
Al- 3% SiC	Al-3SiC
Al- 5% SiC	Al-5SiC
Al- 7% SiC	Al-7SiC
Al- 9% SiC	Al-9SiC
Al- 12% SiC	Al-12SiC

The microstructures of composites have been analyzed by scanning electron microscope (SEM, Jeol JSM-6610LV) and X-Ray diffraction device (XRD, Rikagu Rint 2200). The experimental density of the specimens has been measured by using Archimedes' principle. The hardness of the specimens determined by using TMTECK-HV-1000B device using 1.96 N (200 g) load. The average value of hardness after six measurements were evaluated at the polished surface. Hardness was calculated using Eq. (1):

$$Hv= 1.854\frac{W}{d^2} \tag{1}$$

Tensile and compressive strengths were performed by the universal test machine (Mares Test-10 tons).

3. Results and discussion

3.1 Density

In Figure 2, the highest experimental density (2.66 g·cm^{-3}) among Al-SiC composites were measured for 5 wt.% SiC content. The improvement of experimental density with SiC addition can be explained that homogeneous dispersion of the powder, higher experimental density of SiC particles than aluminum alloy. Increasing experimental density can be explained with homogeny distributed SiC for low content, the higher experimental density of SiC particles.

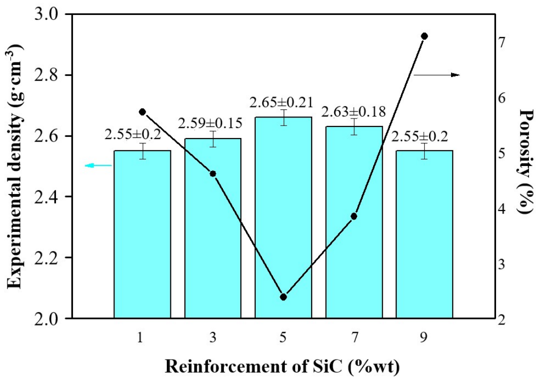

Figure 2. Experimental density and open porosity results of SiC reinforced composites

3.2. Hardness

Figure 3 gives the micro Vickers hardness of Al-SiC composites. The highest hardness (89.8 HV) is observed for Al-9SiC composites. Increasing SiC content has a positive effect on hardness due to its homogeny particle dispersion in a matrix and its outstanding hardness compared al alloy. Theoretically, the hardness increase can be explained with the rule of mixtures by Eq. (2) [15].

$$H_c = H_m f_m + H_r f_r \tag{2}$$

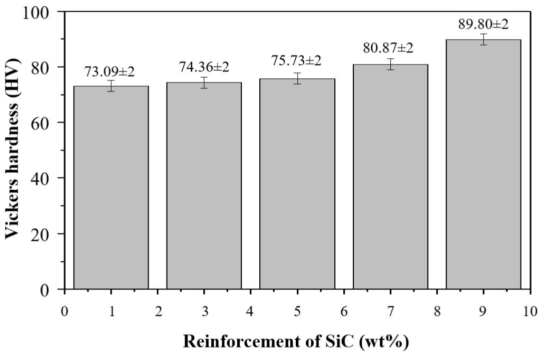

Figure 3. The Vickers hardness of SiC reinforced composites.

3.3 Tensile and compressive strength

Figure 4(a) to 4(b) illustrates the tensile and compressive behavior of the Al-SiC composites. The best tensile property (201.79 MPa) is observed for Al-1SiC composites compared with pure alloy (154.71 MPa). With increasing SiC content, the ultimate tensile strength is decreased due to the dispersion problem and agglomeration tendency of ceramic particles. On the other hand, the highest ultimate compressive strength (763.69 MPa) is observed for Al-5SiC composites. Above this ratio, the compressive strength is deteriorated with increasing SiC ratio due to agglomeration which creates the open porosity in structure. It can be explained that the higher load was required to plastically deform the composites. The high strength can be explained with a load transfer mechanism during the mechanical test. SiC particles existed along Al grain boundaries and the dispersion of SiC particles suppress the grain growth. If the grain boundaries suppress the dislocation during deformation, the strength of the fine-grain materials is increased [16, 17].

3.4 Characterization of the composites

Table 2 gives the EDX analyses of the fabricated aluminum alloy ingot from waste aluminum which includes the Si, Mg, Mn instead of Al. These alloying elements positively affect the mechanical properties of the composites.

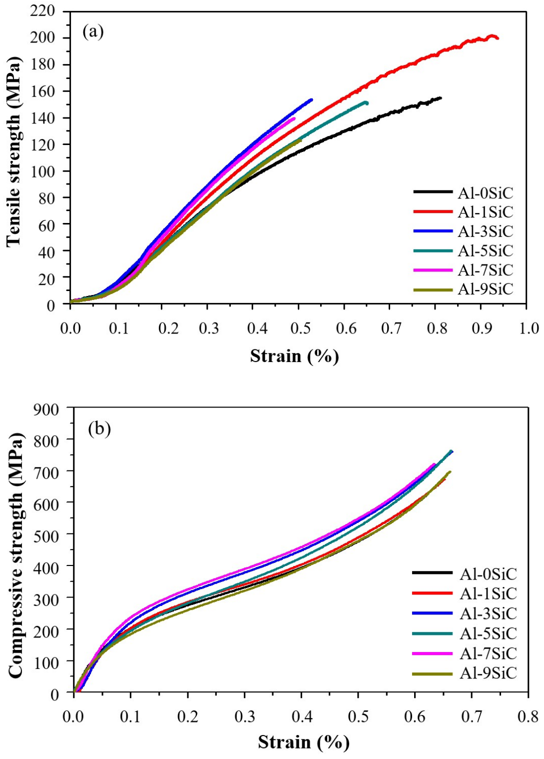

Figure 4. The tensile (a) and compressive (b) strength of SiC reinforced composites.

Table 2. EDX analyses of pure beverage cans and casted aluminum alloy.

	Al	Si	Mg	Mn
Pure beverage cans (wt%)	94.72	3.62	0.78	0.88
Casted samples (wt%)	93.85	4.18	0.76	1.21

The SEM images (500X for main images and 2000X for small images) of Al-SiC composites are represented in Figure 5(a) to 5(d). As given in the figure, SiC particles between 1-9 wt% are homogeneously distributed in the matrix. From the high magnification images, aluminum grain and SiC particles has good interphase for 1 wt% SiC content. However, the dispersion of SiC and interphase between SiC and aluminum is deteriorated above 9wt.% SiC content due to the excess amount which led to nonhomogeneous particle agglomeration. It is clearly seen that from high magnification images the bonding between both SiC and aluminum was significantly weak above the 9 wt% SiC content (Figure 5(c) to 5(d). Both agglomeration and weak interphase between the particles led to a decrease in the mentioned mechanical properties

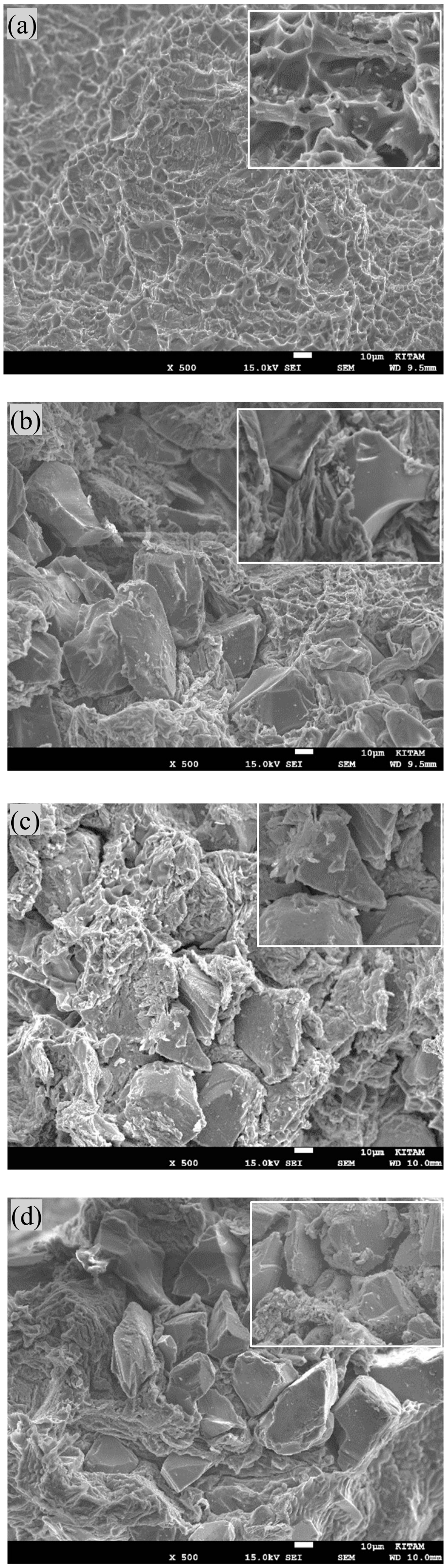

Figure 5. SEM images of pure Al0 (a), Al-1SiC (b), Al-9SiC (c) and Al-12SiC (d).

Figure 6(a) and 6(b). presents the EDX mapping analyses of composites for 1 wt% SiC and 9 wt% SiC content. As shown, dispersion of the SiC (violet color from Si, red color from C) in an aluminum matrix (blue color) is very homogeneous for 1 wt% SiC. However, an increasing amount of SiC particles (9 wt% SiC) causes the local agglomeration in structure (Al, Si and C are yellow, brown and red color, respectively).

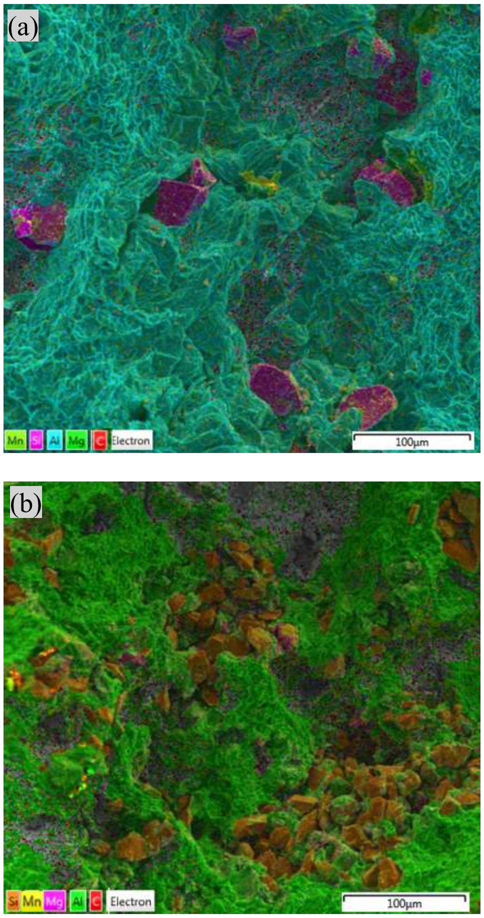

Figure 6. EDX mapping analyses of Al-SiC composites Al-1SiC (a), Al-9SiC (b).

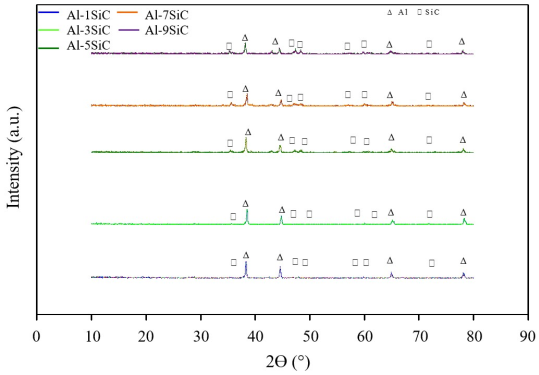

Figure 7. XRD analysis of the SiC reinforced Al composites.

Also, the XRD patterns of SiC reinforced aluminum composites are given in Figure 7. As clearly seen, all diffractions possess pure Al and SiC. In addition, second phases such as aluminum carbide (Al_4C_3) peak is not detected for all Al-SiC samples due to the low-temperature casting which is not activated to react Al with Si-C.

4. Conclusions

In this study, SiC reinforced aluminum composites were prepared by stir casting method. Experimental density, hardness, tensile/compressive strength and microstructure of the composites were evaluated. According to the results, the highest experimental density (2.66 $g \cdot cm^{-3}$) among Al-SiC composites were measured for 5 wt% SiC content. The highest hardness (89.8 HV) is found for Al-9SiC composites. The maximum tensile strength was measured at 1 wt% SiC (201.79 MPa). The best compressive strength was determined at 5 wt% SiC (763.69 MPa). In SEM and XRD analysis, homogeneously distributed SiC and secondary phases were not formed.

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