Jurnal Teknologi

Full Paper

INFLUENCE OF MILLING TIME ON GROWTH MORPHOLOGY AND MECHANICAL PROPERTIES OF ALUMINUM-SILICON-CARBIDE COMPOSITES

Article history
Received
13 November 2014
Received in revised form
2 March 2015
Accepted
1 August 2015

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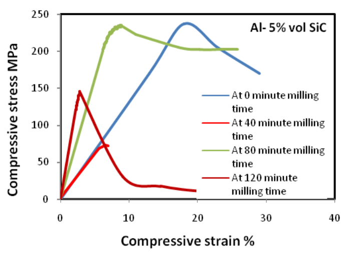
Graphical abstract



Abstract

Achieving improved mechanical properties of aluminum (Al) in the composite structures by mixing ceramics is ever-demanding for sundry applications. We synthesize aluminum-silicon-carbide composites via ball milling of aluminum which is reinforced with 5% of the silicon carbide (SiC) powders having particles size of 20 µm. Microstructures of powdered composite is characterized via XRD, EDX, and FESEM measurements. These mixtures are grinded at the speed of 200 rpm in a planetary ball mill for 0, 40, 80, and 120 minutes using zirconium balls as milling media. The ratio of the ball to powder is selected to be 10:1. At room temperature and pressure of 10 ton the mixed powders are die-pressed in a cylindrical stainless steel mold having internal diameter of 12.7 mm. The impact of milling time on the growth morphology (microstructures) and mechanical properties of the prepared Al–SiC (5 wt %) composite are scrutinized. The method mechanical alloying (MA) is comprised of milling, cold pressing, and sintering. The increase in milling time is demonstrated to enhance the hardness of the composites. Furthermore, the highest hardness and superior strength is achieved for 80 minutes of milling. Both the hardness and strength of such composites are decreased beyond this milling time. The excellent features of the results suggest that Al–SiC (5 wt%) composite with the present composition may be potential to fortify the structural network in terms of strength and stiffness.

Keywords: Milling time, particles size reduction, reinforcement dispersion

Abstrak

Penambahbaikan properti mekanikal aluminium di dalam struktur komposit dengan mencampurkan seramik adalah sangat dikehendaki di dalam pelbagai aplikasi. Dalam penyelidikan ini kami mensintesis komposit aluminium-silikon karbida menggunakan kaedah penghancuran melalui mesin bebola aluminium yang diperkuatkan dengan 5% serbuk silikon karbida (SiC) dengan ukuran saiz zarah 20 µm. Pengukuran mikrostruktur serbuk komposit ini pula telah dicirikan dengan menggunakan pengukur XRD, EDX, dan FESEM. Bahan bahan campuran ini kemudiannya telah dikisar pada kelajuan 200 rpm didalam pengisar bebola planetari untuk tempoh selama 0, 40, 80, dan 120 minit menggunakan bebola zirkonium sebagai media pengisaran. Jumlah nisbah bebola terhadap serbuk yang dipilih adalah pada kadar 10: 1. Pada suhu bilik dengan menngunakan tekanan sebanyak 10 tan, serbuk campuran kemudiannya ditekan padat secara hidraulik di dalam acuan selinder keluli tahan karat yang mempunyai diameter kedalaman 12.7 mm. Impak sewaktu tempoh pengisaran terhadap pembiakan morfologi (struktur mikro) dan properti mekanikal terhadap komposit Al-SiC (5 wt%) kemudiannya dikaji dan diteliti. Kaedah mengaloi secara mekanikal terdiri daripada proses penghancuran, proses, proses penekanan secara hidrolik dan pensinteran. Didapati bahawa peningkatan terhadap masa penghancuran dapat meningkatkan tahap kekerasan komposit. Hasil kajian juga mendapati bahawa tahap kekerasan dan kekuatan tertinggi dicapai apabila tempoh penghancuran dilakukan selama 80 minit. Lanjutan dari hasil kajian ini juga mendapati bahawa tahap kekerasan dan kekuatan pada komposit mula menurun selepas had tempoh tersebut. Hasil daripada kejayaan kajian yang amat memberansangkan ini mencadangkan bahawa tambahan komposit Al-SiC (5 wt%) ke dalam komposit gunapakai yang sedia ada mempunyai potensi yang amat baik dari penambah baikan kekuatan dan kekerasan.

Kata kunci: Masa pengilangan, pengecilan saiz zarah, pengukuhan sebaran.

1.0 INTRODUCTION

Composites are materials made by mixing two or more constituent materials with considerably dissimilar properties than their individual counterparts when combined. More specifically, it is the mixture of a combination of two or more macro or micro constituents that differ in chemical composition, form and are essentially insoluble in each other. For instance, aluminum-matrix composites are the group of materials whose density, strength, stiffness, electrical and thermal properties can be tailored. Interestingly, the volume and shape of the reinforcement, matrix alloy, reinforcement material, fabrication method, and location of the reinforcement can all be varied to achieve desired properties. We take an attempt to prepare metal-matrix-composites (MMCs) with the desirable attributes of ceramics and metals in terms of hardness, wear resistance, and strength. One of the major challenges in processing MMCs is to achieve a homogeneous distribution of reinforcement in the matrix because it strongly impacts the quality and properties of the composites. [1]

As aforementioned, a composite material having completely new features is made by combining two or more materials, where often ones have very different properties. The two materials function together to give the composite unique properties. However, within the composite different materials distinctively exist and remain apart because they do not dissolve or blend into each other. Composites are the combination of two or more materials or phases of the same material, insoluble in one another, possessing properties which are superior to any of the component materials. [2] For example, compressive strength of aluminum based composite powders is higher than Al itself. Usually, the green density (more than 90% of the theoretical) can get the advantage of low pressure compression (about 200MPa) allowing the use of smaller capacity presses. Sintering of Al-SiC composite parts is more efficient than most other materials particulate matter energy due to relatively lower sintering temperatures. Furthermore, low density Al-SiC composite materials with more than double the number of parts can be manufactured from the weight of the powder compared to iron or copper based powders.

In the past two decades, synthesis and microstructures characterizations of Al-SiC composites in terms of their strength, hardness, and wear resistance are intensively carried out. [3] Powder processing including mechanical alloying is identified as a promising technique for the production of effectively dispersed particles of submicron size distribution. This method also provides more flexibility in the choice of alloy matrix chemistry than the melt casting technique. Thus, mechanical milling became attractive for integrating fine ceramic particles in promoting ductile metal matrix composite materials production. Other notable advantages of milling include its ability to refine the particle size ensuring the uniform distribution [4]. Based on traditional melting methods, high quality Al-SiC composite is difficult to achieve because of the poor wetting between the molten Al and SiC. Moreover, these methods usually lead to an undesirable reaction between SiC and molten Al, which produces fragile stages of Al4C3 and Si. To overcome this shortcoming, mechanical alloying method is proposed.

Mechanical alloying (MA) is widely exploited for the production of fine particles of metal or ceramic composite powders. This process includes repeated welding and fracture of a mixture of powders to produce finer particles. Recently, using the method of mechanical alloying several efforts are dedicated towards the production of composite materials. The main aspiration is to determine the impact of milling time on the mechanical properties of the products and to optimize the milling parameters [5]. In fact, the evidence regarding the considerable effect of time of milling on the properties and morphology of the milled powder tempted us to examine the milling time dependent structural evolution of composite powders. We report the effects of milling time on microstructures morphology, compactness, reinforcement phase distribution, and mechanical properties of Al–SiC composite prepared via MA. The enhancement of composites hardness and strength with the increase of milling time is analyzed and attributed. The significance of Al-SiC composites towards automotive and aerospace applications is emphasized.

2.0 EXPERIMENTAL

Following MA, Aluminum powder is reinforced with 5 wt% of SiC having particles sizes of 20 μm. During milling, the shape, size, and chemical composition of Al and SiC particles are characterized via scanning electron microscopy (SEM), energy dispersive X-RAY analysis (EDX) and X- RAY diffraction (XRD). At room temperature and 10 ton of pressure, the mixed powders are die-pressed in a cylindrical stainless steel mold of internal diameter 12.7 mm using manual hydraulic press. First, the pressed samples are sintered at 550° C for 5 hours in a furnace under atmospheric condition and then cooled down at room temperature. Figure 1 illustrates the hydraulic press equipment and cylindrical mold consisting of two pellets. The powdered sample is mounted on one pellet at the base and covered with the other pellet and pin to press the powder.

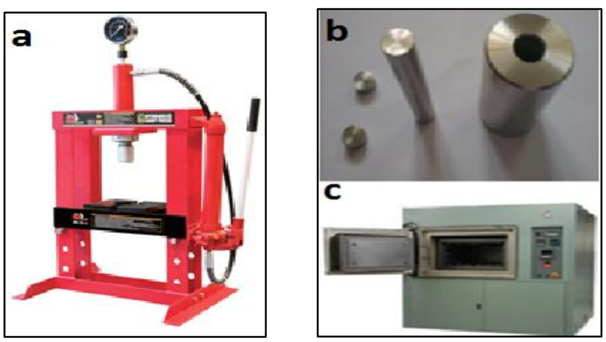


Figure 1 (a) Hydraulic press, (b) cylindrical mold with two pellets and pin and (c) pressure-less sintering furnace

Table 1 enlists the milling parameters used to mix Al with SiC. The type of balls and jar materials is appropriately selected for the speed of 200 rpm and beyond. However, an increase milling speed above 200 rpm or time more than 120 minutes may have some impact on the jar wear without any effect on the zirconium balls. It is well known that high hardness of zirconium is capable of withstanding towering milling speed and time.

Table1 Milling parameters for mixing Al with SiC

Planetary ball mill	Conditions
Ball to weight ratio	10: 1
Material of the balls	Zirconium
Rotating speed	200 rpm
Milling times	0, 40, 80 and 120 minutes
Powder weight for each sample	2.5 gram
Atmosphere	Air
Milling machine	Planetary ball mill PM 400

3.0 RESULTS AND DISCUSSION

3.1 Powder Morphology

The Milling times for mixing Al powder with SiC (5 wt%) are varied to 0, 40, 80, 120 minutes. Figure 2 illustrates the milling time dependent SEM images of the composites. The influence of milling time on the particles size and distribution is clearly evidenced. The particles size is found to decrease with the increase of milling time accompanied by good dispersion of SiC particles in the aluminum matrix. The pre-milled (0 minute) sample revealed flake-shaped aluminum particles and non-uniform distribution of SiC particles with sharp edges. Furthermore, upon milling the SiC particles disappeared due to their superior dispersion in aluminum matrix [6, 7].

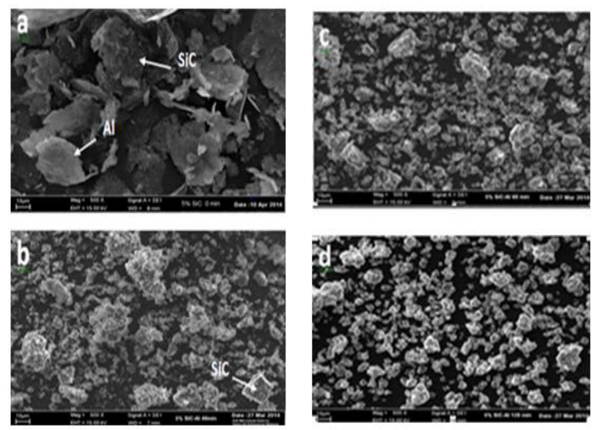


Figure 2 The SEM micrographs (magnification 500x) of 5% SiC-Al powder composites at different milling time of (a) 0 minute, (b) 40 minute, (c) 80 minute, and (d) 120 minute

Figure 3 displays the EDX spectra of milled powder composite with precise detected elemental traces. Chemical elements including aluminum, silicon, carbon, and oxygen are detected. The occurrence of oxygen is due to oxidation (atmospheric effect) of composite powdered at high milling time. Interestingly, an increase of milling time caused an increase in the oxygen content [8].

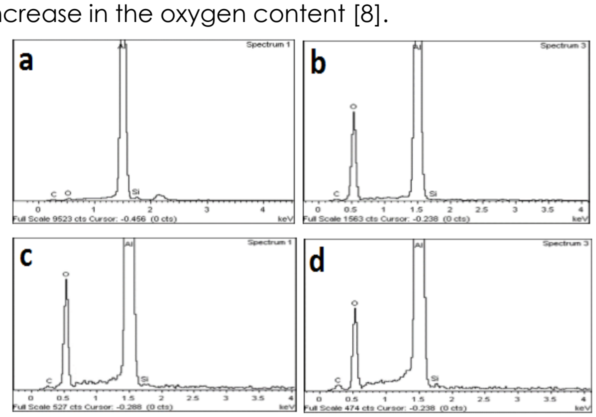


Figure 3 EDX spectra of 5%SiC-Al powder composites at different milling time of (a) 0 minute, (b) 40 minute, (c) 80 minute, and (d) 120 minute

Figure 4 reveals the XRD pattern of the powdered composites. The peaks marked with circles refer to crystal lattices of Al while the squares indicate the lattice planes of SiC. For 40 and 80 minutes of milling time the presence of SiC particles are clearly evidenced. However, for 120 minutes milling, the SiC peaks are completely disappeared and Al peaks became prominent.

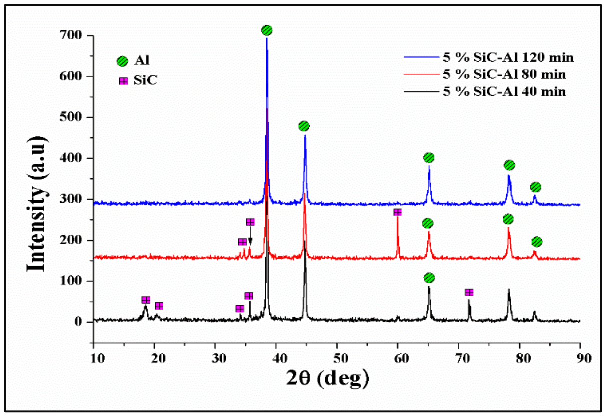


Figure 4 XRD patterns of 5%SiC-Al powder composites

3.2 Microstructures Of Cold Pressed And Sintered Samples

Figures 5 (a) and (b) depicts the optical microscopic images of the 5%SiC- Al composites. High porosities near the silicon carbide regions are evidenced. Complete disappearance of SiC grain structure from the matrix with the increase of milling time from 80 and 120 minute is ascribed to the deformation of the lattice. Furthermore, the porosity is observed to decrease with the increase of milling time. The prepared 5%SiC-Al composites displayed good dispersion of SiC in the Al matrix [9, 10, 11]. This observation is consistent with the XRD and EDX data.

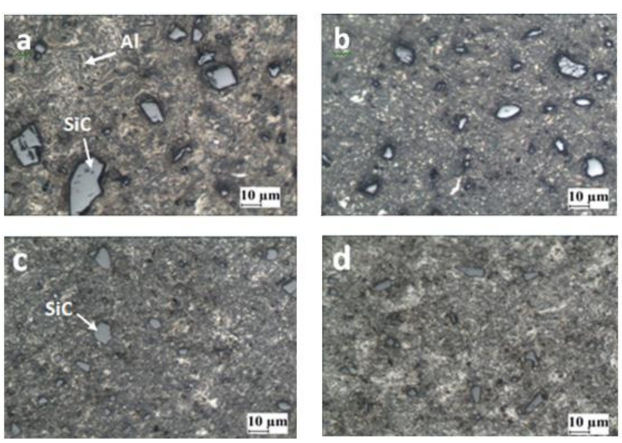


Figure 5 Optical microscopic images of pressed and sintered (550˚C for 5 hours) 5%SiC-Al composites at different milling time of (a) 0 minute, (b) 40 minute, (c) 80 minute, and (d) 120 minute

3.3 Hardness Test

Figure 6 shows the variation of composites hardness as a function of milling time. Vickers hardness test of the synthesized composited is performed using Matsuzawa, DVK-2. Samples hardness is measured with a load of 10 kg, where the dimension of composite is 4.5 mm in height and 12.7 mm in diameter. The observed maximum hardness at 80 minutes of milling time is attributed to the response from the Al matrix to the deformation. This hardening is majorly attributed to the presence of lattice distortion in the Al matrix that resulted strain and increased the dislocation. Conversely, the reduction of hardening at higher milling time (120 minutes) is ascribed to the elongation of the grain size within the matrix material and their subsequent segregation [9, 12].

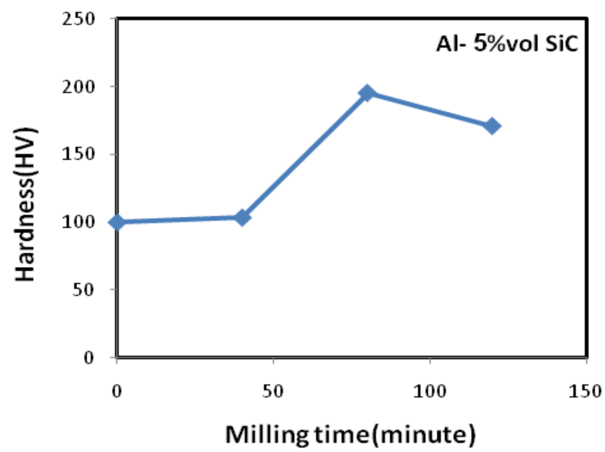


Figure 6 Milling time dependent hardness of 5% SiC-Al composites

3.4 Compression Test

Figure 7 displays the composites compressive stress versus strain relationship. Samples strength is recorded using Universal testing machine (Instron 600 DX). Composites are prepared by hydraulic press (cold pressing) with dimensions of 15 mm in diameter and 10 mm in height followed by sintering at 550˚C for 5 hours. Samples produced with 0 and 40 minutes of milling time are found to contain cracks as observed by naked eyes. The appearance of such cracks may be due to the sudden reduction of thermal conductivity of the composites at increased silicon carbide contents and less dispersion in the matrix. However, for 80 and 120 minutes of milling time the scenario is reversed. The increased deformation of the grains caused enhanced segregation between the Al and SiC.

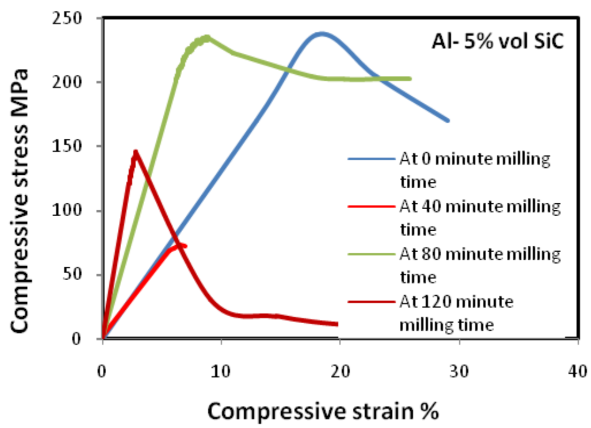


Figure 7 Stress-strain correlation of 5%SiC–Al composite

Pre-milled samples revealed very high compressive stress even in the presence of cracks. This is due to the horizontal orientation of the cracks with respect to the applied load. For 40 minutes of milling the occurrence of lowest ultimate stress (73 MPa) is attributed to high ductility of samples aroused from the presence of cracks and their vertical orientation with respect to the applied load. Finally, at 120 minutes of milling the ultimate stress is significantly reduced due to the decrease in composited ductility. A detail study on the mechanism of crack propagation and their estimation will be reported elsewhere.

4.0 CONCLUSION

The milling time dependent improvements in the growth morphology and mechanical properties of 5% SiC-Al powders composites are inspected. The microstructures evolution and strength enhancement of these composites are determined and explained via different mechanism. Samples are prepared using MA method, which consisted of milling, cold pressing, and sintering. The hardness and compressive strength of the composites are shown to increase with the increase of milling time. Composites milling time of 80 minutes is discerned to be optimum with highest hardness and outstanding strength. With increasing milling time (from 0 to 120 minutes) the SiC powders are found to stuck within Al flakes before they are gradually fragmented and dispersed. The fracture mechanisms and cold welding caused the formation of homogeneous structure faster with the increase of the weight ratio of the reinforced particles. The milling time dependent stress–strain behavior exhibited a decrease in the composites ductility, size, and initial density of the porous sample. A drop in the compressive stress and hardness beyond 80 minutes of milling is attributed to the increased deformation of the grains and subsequent segregation between Al and SiC. The present composition may be nominated for potential applications.

Acknowledgement

We are grateful for the UTM scholarship to Author 1.

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