Construction and properties of Al/SiC composites using nano silicon carbide by powder metallurgy technique in pure aluminum alloy

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Abstract— Aluminum matrix composites are widely used in aerospace, military and automotive industry. Furthermore silicon carbide powder is one of the best and common material used to reinforce the aluminum matrix composites. High strength-to-weight ratio, abrasion resistance and desired corrosion resistance of Al/Nano SiC composites are the most important of specifications of this group of composites. In this research, Al/Nano SiC composites with pure Aluminum as matrix with 0,1.5,2.5,5,10,15 and 20 volume percent of SiC were made by powder metallurgy technique (cold pressing and sintering)as reinforce used to study the effect of volume percent of SiC on mechanical properties and microstructure of the composite. Considering the electron microscope images, it is possible to understand nano SiC particles existence and their uniform distribution. Mechanical properties such as tensile strength will increase with increasing particle fraction to optimum percent, also with increasing of volume percent of SiC; the hardness of composite will be increase. In these types of composites, unlike studies using micron particles, the flexibility will not be reduced with increasing of volume fraction of Nano SiC particles. The overall results of the study show that the best outcomes are related to the sample containing 10% powder with heating at the temperature of 650° C.

Index Terms— Aluminum matrix composite, Al/ Nano SiC, Composite properties Powder metallurgy, Silicon carbide.

1 INTRODUCTION

IN In recent decades, the major efforts of designers of composite materials are directed to select the light weight metals which have a high strength-to-weight ratio [1, 2]. Among these materials, aluminum-based metal matrix composites (MMCs) are appropriate materials for structural applications in the aircraft and automotive industries. Metal matrix composites (MMCp) are engineering materials in which a hard ceramic component is dispersed in a ductile metal matrix in order to obtain characteristics that are superior to those of conventional monolithic metallic alloys[3,4]. Metal matrix Nano composites (MMNCs) are a class of metal matrix composite in which the size of matrix or fiber is in the Nano scale (usually 1 to 100 nanometers)[5].

It should be noted that Al-SiC composites are difficult to obtain by conventional melting-based methods due to the poor wettability between molten Al and the SiC. In addition, these methods usually lead to an undesirable reaction between the SiC and molten Al, which produces brittle phases of Al4C3 and Si. Mechanical alloying (MA), as originally developed by Benjamin, has been widely utilized to produce metal or ceramic- based composite powders with fine microstructures[3,7].

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There are some other benefits of composites such as the ability to control the mechanical and physical properties by appropriate selection of matrix, second phase, and volume fraction of fibers. Production of composites is a low-cost process with respect to their high performance [8, 9].

Since the ceramic particle in the Nano scale, cause increasing of strength of the matrix without significant reduction in ductility, so the construction of the composites is much-considered. On the other hand the surface area of Nano particle size is much bigger than the micro particle size surface area that lead to unique specifications for Nano particles. Nano SiC particles are widely used to improve the mechanical and thermal properties of metal matrix composites specially aluminum matrix composites [5].

2 EXPERIMENTAL PROCEDURE

Nano-sized Al/SiC powders were prepared by mechanical alloying method. nano-sized SiC particles was dispersed in aluminum powder uniformly after ball milled for 2 h. The bulk Al/SiC nano composite was fabricated by hot pressing technique at temperature about 723 K under pressure of 100 MPa.

Effects of the particle size and agglomerate state of SiC, as well as the microstructure of Al/SiC nano composite were studied by SEM. For these purposes, a pill-shaped sample was made from each set of samples prepared in the same conditions. Sandpapers NO. 100, 400,600, 1000, 1500 and 2000 respectively were used to smooth down the samples. Also the samples were polished with one micron size alumina solution. The Keller reagent was utilized for 45 seconds to etch the samples. Then the samples were cleaned by alcohol and

coated by platinum in order to achieve high resolution pictures before placing the samples inside the SEM machine.

Tensile test was performed in order to study the tensile strength of the samples. The Samples prepared using ASTM E8 standard. Finally the mean values obtained were considered.

Brinell hardness tests were performed to assess stiffness. For this purpose the samples were polished after using the abrasive. Finally hardness tests were done with the power of 31.25 kgf by Brinell hardness tester. The metal ball indenter had a diameter of 2.5 mm. In order to obtain an accurate hardness value of each series, three samples were selected. Hardness of each sample was measured three times. The mean values obtained were considered.

3 Results and discussion

3.1 Study of SEM images

In order to observe the phase's morphology, phase particle size and their distribution in aluminum, scanning electron microscopy was used. Fig.1(a) to Fig.1(f) are related to samples containing 1.5, 2.5, 5, 10, 15 and 20 volume percent of SiC which heated at 650°C.

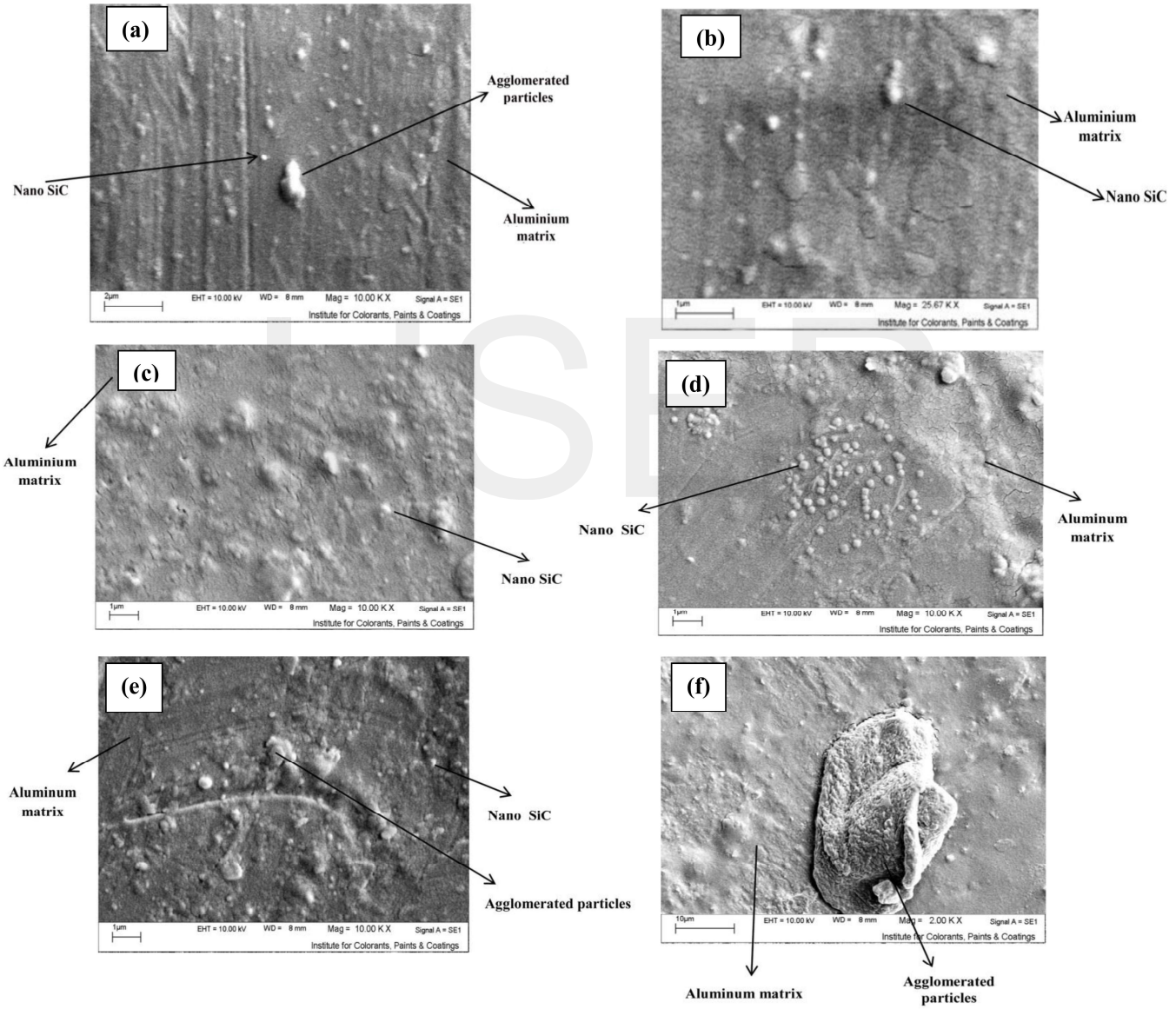

Fig.1. SEM micrograph of the sample containing (a)1.5 % (b) 2.5 % (c) 5 % (d) 10% (e) 15 % of SiC and (f) 20 % of SiC.

In the Figures, 1(a), 1(e) and 1(f) agglomeration phenomena are seen clearly. It seems that the best distribution of nano SiC particles is related to Fig.1 (d) which is related to the sample containing 10% nano SiC. Analysis of the images shows that the matrix which consists of pure aluminum is gray and SiC particles seem bright colors. The purpose of preparation of SEM images is to evaluate the size of SiC particles and the quality of distribution of these reinforcement particles in the matrix. The scale of each photo indicates nonometric size of particles.

In the composite microstructure, accumulation of nanoparticles in a particular area will avoid uniform distribution of these particles. When particles agglomerated more, their distribution will be more heterogeneous. As a result of agglomeration phenomenon, some particles stick together and increased the diameter size of agglomerated particles bigger than nanoscale; so the percentage of nanosize particles decreases. When the percentage of the SiC particles increases, the possibility of formation of the agglomerated particles would increase too. Regarding to the scale of figures, it is concluded that the size of majority of these particles have about 80 nanometer.

The authors in this research are trying to find the optimum amount of nano particles in the samples. For this purpose, it was necessary to study the microstructure of samples.

Fig.2 shows Map images obtained from all samples. The Map images describe dispersion of Silicon element in the samples.

In these figures, bright spots depict the existence of silicon element. As the matrix is pure aluminum, so it is concluded that the bright spots are nano silicon carbide particles and the map image could show distribution of these particles. The amount of nano particles increases from Fig.2 (a) to Fig.2 (f). The best uniformity of distribution is seen in fig.2 (d) which is related to the sample containing 10% nano SiC and Fig.2 (f) shows agglomeration phenomenon in the sample containing 20% nano SiC. Moreover, the scale of images would prove nonometric size of distributed particles in the matrix. If the nano particle distribution is more uniform, mechanical properties would be more desirable.

When these figures are compared with each other, Agglomerated particles can be seen in some area and this problem causes in the manufacturing process. In the case of finer particles, this problem will be intensified. It is clear that a large number of nano SiC particles, are agglomerated that may be harmful to the mechanical properties of composites.

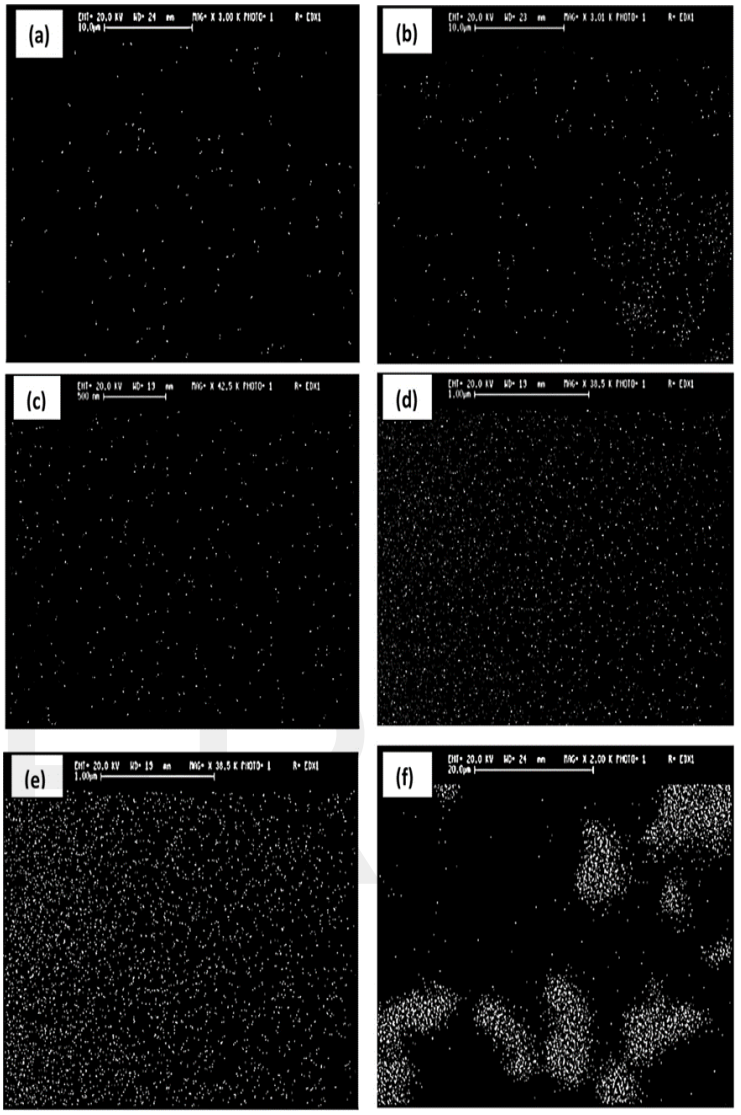

Fig. 2. Map images which describe dispersion of nano SiC in the samples containing (a) 1.5% (b) 2.5% (c) 5% (d) 10% (e) 15% and (f) 20% nano SiC.

3.2 The results of mechanical properties

Fig.3 shows the ultimate tensile strength of the samples versus volume percent of fibers at 650°C temperature. As shown in this figure, with increasing the amount of particles up to 10 volume percent, the ultimate tensile strength (UTS) of the composites would increase continuously. The UTS value of the sample without any nanoparticles is 81.7 Mpa, on the other hand, the UTS value of the sample containing 10 volume percent of fiber is 232.7 Mpa. In fact, the UTS values are improved about 180%. This behavior is attributed to high strain hardening rate of composites at low strain. Strain hardening would increase because of elastic effect of nano SiC particles. In other words these particles act as barriers which prevent plastic deformation of the matrix. Nano SiC particles only have capability of elastic deformation, although, the aluminum matrix has

capability of plastic deformation. It seems that there is a strong interface between the nanoparticles and matrix which would ban the plastic deformation that lead to strain hardening phenomenon.

It is obvious that the coefficient of thermal expansion for ceramic particle and matrix are different; so when the composite is heated, the matrix is stressed and density of dislocations will be increased. This is another reason for strain hardening and improvement of strength and hardness of the composite.

A decreasing trend of tensile strength is observed, while the volume percent of fibers increase from 10% to 20%. When the number of nano particles grows, the agglomeration event will happen severely and the interface between particles and matrix will weaken. Finally, the particles segregate from matrix. These parameters are the most important reason that the UTS of the sample containing 20 volume percent nano SiC is less than the sample containing 10 volume percent ones. Also some defects such as porosities are the source of crack initiation which could affect on the strength of samples produced by powder metallurgy technique. With increasing of volume percent of nano SiC particles at a constant temperature the porosities would increase and this is harmful to the mechanical properties of the samples. Among all samples prepared in this research, the sample containing 10 volume percent of Nano SiC has the best microstructure and mechanical properties. The mechanical properties of this sample such as tensile strength and hardness in comparing to the other samples, is much better. In fact, uniformity of dispersion of nano particles in matrix is the most important reason for good mechanical properties.

The impact of strengthening of the fiber particles can be described by a theory known Orowan strengthening mechanisms. According to this theory, a lot of stress is needed to move the dislocation to cross the fiber particles [10].

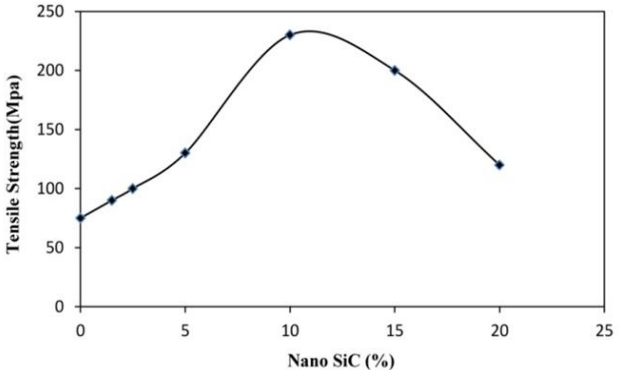

Fig.3. The ultimate tensile graph of samples prepared by powder metallurgy technique and heated at 650°C.

Fig.4 shows the changes of Brinell hardness versus volume percent of Nano SiC particles. A logical connection is established between the hardness of samples and volume percent of fiber particles. It is clear that the hardness of fiber particles is much higher than Aluminum matrix. So with increasing of SiC particles, Brinell hardness of the samples would improve naturally.

In the samples containing 20 volume percent nano SiC, the opposite trend can be observed. It seems that due to high amount of SiC, the porosity number would rise and distribution of nano particles in the matrix is not uniform and Brinell hardness would decrease.

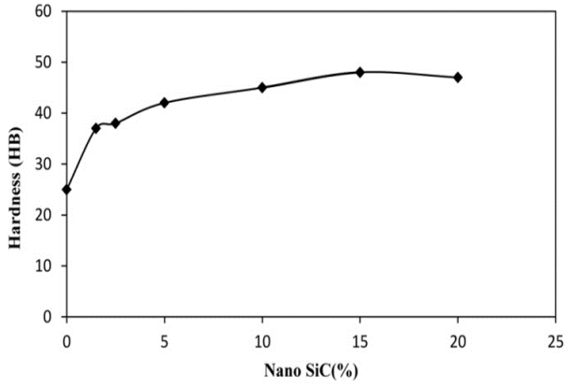

Fig. 4. The changes of Brinell hardness of samples heated at 650°C versus volume percent of Nano SiC.

Fig.5 shows a graph which represents the relationship between percent elongation and volume percent of nano SiC particles. It is expected that with the addition of hard particles to aluminum matrix, toughness reduces, because these particles act as crack initiation and reduce flexibility. Furthermore, the motion of dislocations allows plastic deformation to occur and Nano SiC particles are barriers to movements of dislocations. But as a result of nanometric size of particles, not only toughness would not reduce but also it would not change or even may improve. In fact, it can be related to nanotechnology and nanometric particle size which causes strength and hardness improvements without reduction of flexibility.

According to the results obtained from this research, it is not certainly concluded that by adding the nano¬particles to the matrix, flexibility improvement will happen because there are some porosities and agglomerated particles in the samples in experimental conditions.

In the sample containing 20 volume percent of SiC, as seen in fig.2 (f), agglomeration of nano particles is a problem because this phenomenon causes unsuitable dispersion of nano particles and reduction of flexibility. It seems that the optimum amount of nano particles in the samples is 10%, so the sample containing 10% nano SiC is the most flexible among all samples.

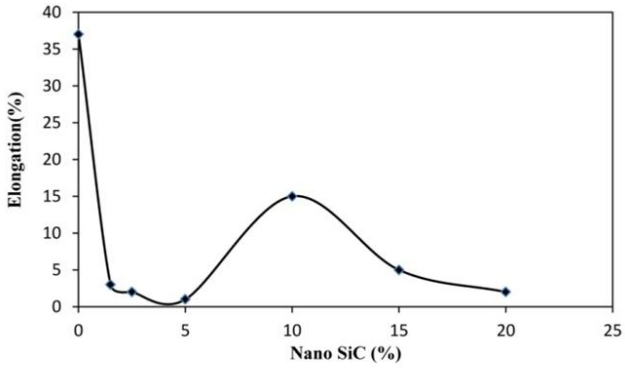

Fig.5. Elongation behavior of samples.

4 Conclusion

1-The scale of each figure represents nanometric size of SiC particles and uniform distribution of these particles in the matrix.

2-There were some agglomerated particles which this issue was normal in powder metallurgy technique in the samples with high amount of SiC particles and with very minor sizes.

3-The agglomeration phenomenon was mostly seen in the sample containing 20 volume percent of nano particles and heated at 650°C.

4-The ultimate tensile strength results indicated that with increasing the volume percent of nano silicon carbide up to 10%, the UTS increased and after that started to decrease.

5-The Brinell hardness of the samples would increase with raising the amount of nano silicon carbide.

6-The results of flexibility show that a downward trend was observed up to 5%SiC and at the amount of 10% nano SiC a sudden increasing were seen.

7-There is an optimum amount of nano particles,which the best mechanical properties occurred in 10% nano SiC.

8-The uniformity dispersion of nano particles in the matrix is the most important reason for good mechanical properties; also agglomeration of nano particles has harmful effect on mechanical properties.

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