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Microstructure and Mechanical Properties of Al-4wt. %Cu – (2.5-10) vol. % SiC Nanocomposites Produced by Powder Compact Extrusion

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Microstructure and Mechanical Properties of Al-4wt. %Cu – (2.5-10) vol. % SiC Nanocomposites Produced by Powder Compact Extrusion--*Amro A.K Gazawi, Ahmad Albloush, Sadi Taha, Majid Kindi*-- Palarch's Journal Of Archaeology Of Egypt/Egyptology 17(6). ISSN 1567-214x

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ABSTRACT

Ball milling is used to produce Al-4wt. %Cu- (2.5-10) vol. % SiC nanocomposites, in which Al, Cu and nano-powder SiC used to produce the nano-powder. The produced nano-powder was consolidated by using powder compact extrusion process. The characterization of the produced bars was done by using tensile testing and electron microscopy. The ultimate tensile strength and hardness was enhanced significantly from 104HV and 168MPa to 153HV and 400 MPA when SiC nanoparticles volume fraction increased to 5% from 2.5%. On other hand, due to the agglomerate of the SiC nanoparticles the ductility decreased from 6.8% to 2%.

1. Introduction

Powder metallurgy for Al Alloy matrix composites have been examined widely for the past decades and that's due to the great potentials of having better mechanical properties such as high strength and low density especially for space applications[1-13].

When the size of Aluminium matrix composite reduced to less than 100 nm, the strength and fracture toughness will increase. One of the challenges for Aluminium composites is the dispersion of the ceramic particles homogeneously within the matrix, to overcome this issue high energy mechanical milling is introduced[3,6,8]. To consolidate nanocomposites powders severe plastic deformation (powder compact extrusion and forging) is used to produce near net shaped components[2, 7-9].

Hesabi et al.[11] used powder compact extrusion after mechanical milling to produce the Al-5vol.%Al_2O_3 powders and convert them into bars. The results showed a strength of 356 MPa. In agreement Ogel et al.[13] results showed with

increasing the amount of SiC particles the strength was improved and the ductility was decreased as a result of SiC particles were heterogeneously in Aluminium composite.
In this research paper, we synthesized Al-(2.5-10)%SiC composite powders using high energy mechanical milling, followed by consolidating the milled powder by pressing at room temperature and severe plastic deformation (extrusion) to try to produce composites with homogeneous SiC particles within the matrix.

2. Experimental Procedure

The nanocomposite powders of Al (99.7% purity), Cu (99.7% purity), and SiC powder (99.5% pure, size less than 100nm) were all mixed using a PM100 planetary ball mill for 6 hours and a rotational speeds of 100 rpm with adding 1wt% of stearic acid and sealed in an argon environment. After completing the mixing, the powder was milled for 12 hours/400rpm with 30 minutes intervals of milling and stopping. The milled powder was compacted for 5 minutes under a 1000MPa pressure using a uniaxial press at room temperature. The green compacts were heated up to 500 ºC using induction heating under argon. After heating the compacts were extruded with 8mm in diameter and cylindrical shape. Tensile test specimens with 20mm gauge length were cut. The mechanical properties were tested by using an Instron 4204 testing machine with a strain rate of 1.8x10-4 s^{-1}. The microstructure of the samples were characterized using the following machines; electron microscopy and X-ray diffractometry.

3. Results and Discussion

The relative density of both compacts and extruded bars shown in Figure 1. The rule of mixture and theoretical density of the materials was implied to calculate the relative density for the green compacts and the bars. The powder compacts relative density was reduced with the volume of SiC nanoparticles changed from 2.5 to 5 vol.%., as a result of increasing the hardness of the nanocomposites produced. Figure 2 below shows the SEM graphs for the extruded bars. From the Figure below it is obvious that the extruded bars are dense. This discrepancy of density proved by using SEM and measured using Archimedes is a result of the error from the calculation of theoretical density. The energy dispersive X-ray for Si in Al-4wt%Cu-(2.5 and 10) vol.%SiC extruded bars shown in Figure 3. From the figure below it was obvious that SiC nanoparticles were dispersed uniformly within the aluminium matrix and that small volume fraction of SiC is shown as agglomerates.

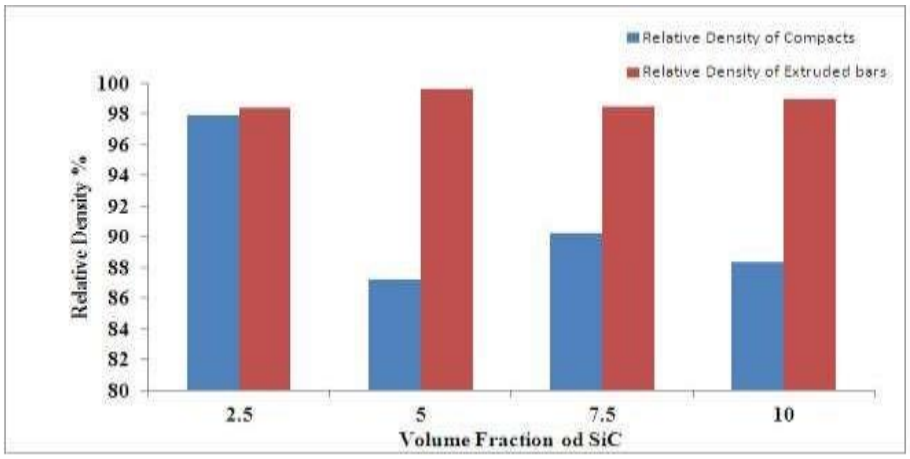


Figure 1: Relative density for compact and extruded bars.

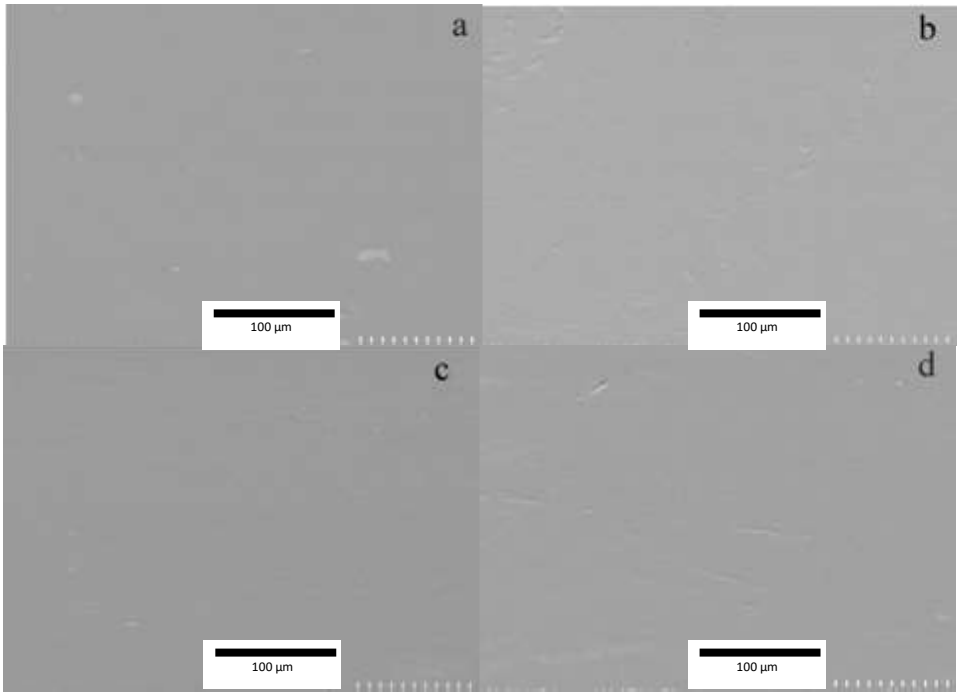


Figure 2: SEM of Al composite bars: (a) 2.5; (b) 5; (c) 7.5; and (d) 10

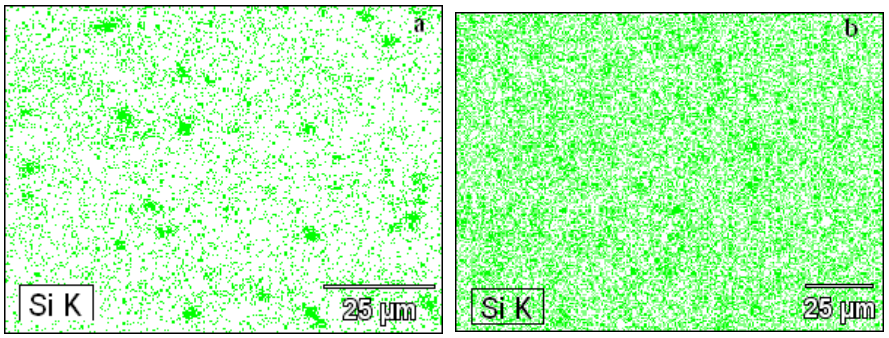


Figure 3: EDX mappings of Si in the extruded bars of the Aluminium composites: (a) Si in the 2.5vol.% ; (b) Si diin the 10vol.%SiC

The XRD of were shown in Figure 4. The Williamson-Hall method was used to estimate the lattice strains and the average grain size (0.36-0.42% and 250-1000 nm) of the Al nanocomposite. Figure 5 shows the typical TEM bright field images of the Al composites extruded bars. As shown in Figure 5, the particle sizes of the Al matrix were in the ranges of 100-600 nm, 50-600 nm, 50-500 nm, and 50-400 nm for the nanocomposites with changing the volume fractions of Silicon carbide from 2.5 up to 10 vol. %. Dislocations is shown in the aluminium matrix. The SiC particles were not clear in bright field images due to the small size of the particles and the dislocations in the aluminium grains. Stress-strain curves of the bars is shown in Figure 6. The extruded bar showed a tensile strength of 168MPa, plastic strain of 6.8% for the 2.5vol.% . While the 5vol.% showed a substantial increase in the ultimate tensile strength of 400MPa and a reduction of 1.2 % in plastic strain to fracture. The Specimens with volume fraction over 5% SiC fractured prematurely before any clear yielding. The hardness increased from 104 to 205HV as the SiC volume fraction increased.

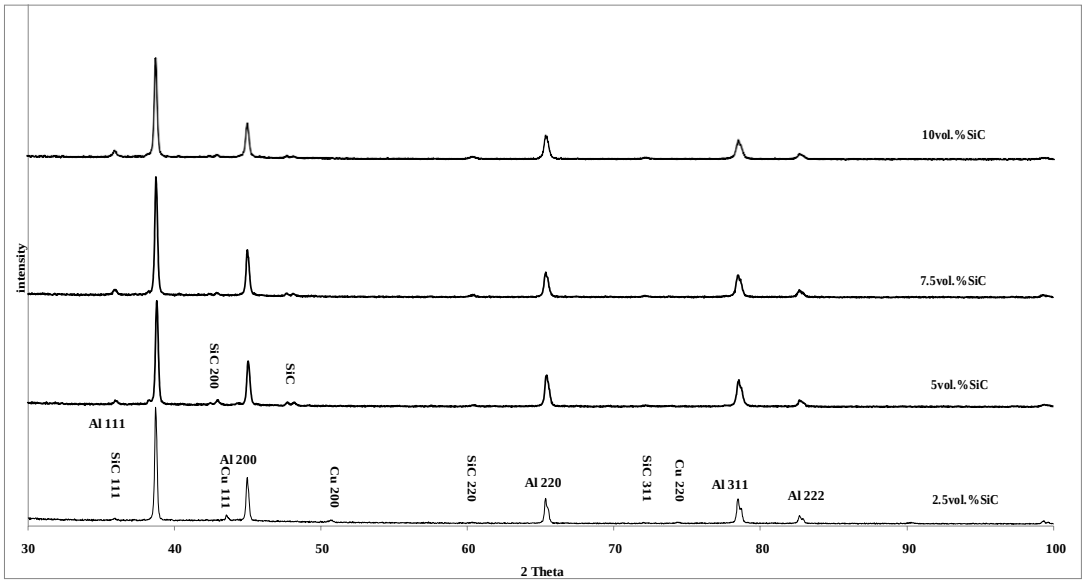
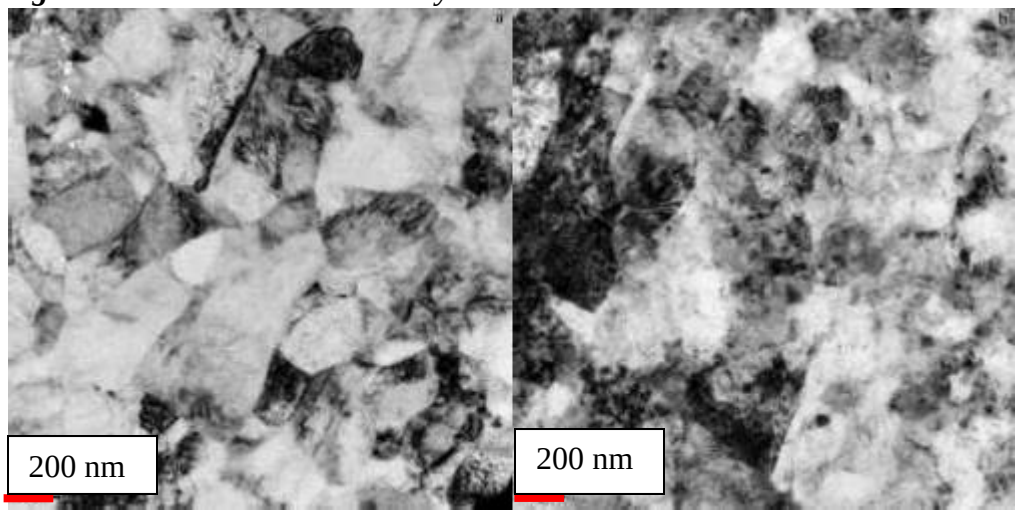


Figure 4*: The extruded bars X-ray*



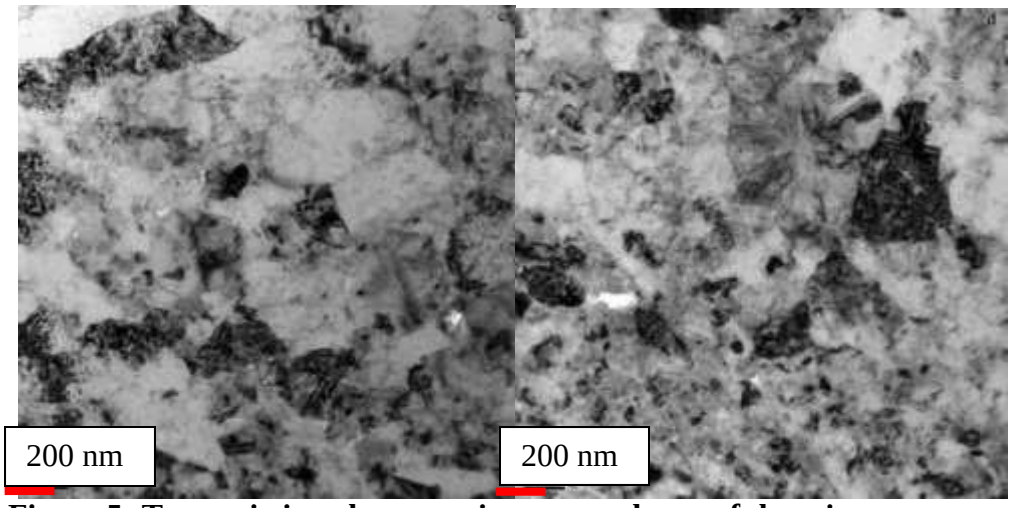


Figure 5: Transmission electron microscope photos of the microstructure for the samples produced by powder extrusion: (a) 2.5% (b) 5 % (c) 7.5v% (d) 10%

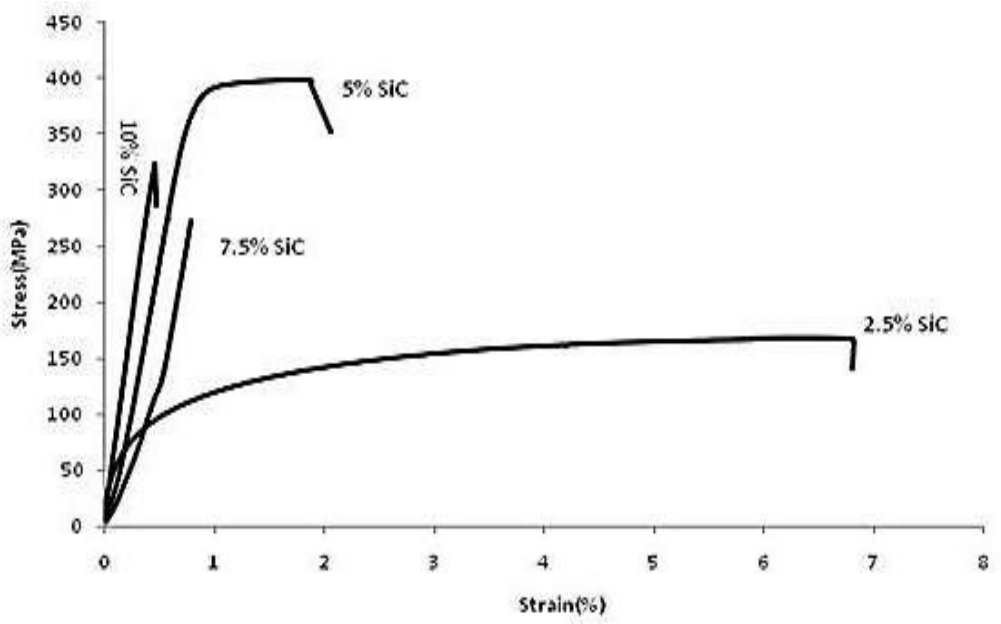


Figure 6: The Stress-strain results for the extruded samples

Figure 7 below shows the fractured area of the test specimens. Ductile fracture is obvious for specimens up to 5vol.%, with the fracture surfaces showing dimples. It showed the depth of dimples became smaller with increasing the content of SiC from 2.5 vol. % to 5%. The fractured surfaces for both samples containing more than 5vol.% were macroscopically flat, as a clear indication of the cracks propagated under tensile stress and fracture prematurely.

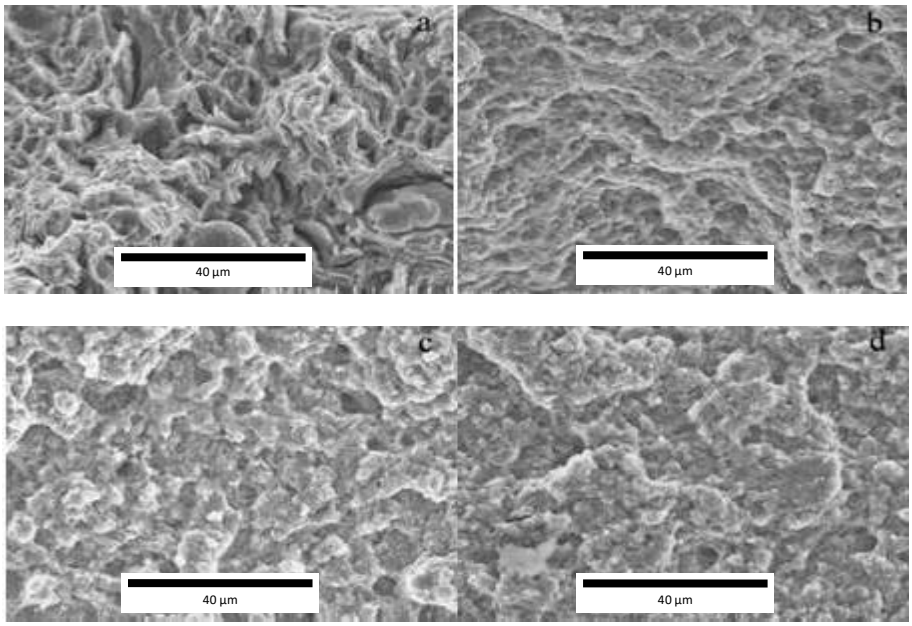


Figure 7: SEM micrographs for fractured surfaces composite: (a) 2.5% (b) 5 % (c) 7.5%(d) 10%

Through this work it has been shown that the microstructure became fine with increasing the volume fraction of SiC. This can be explained by increasing the volume fraction of SiC in which increased the effectiveness of high energy milling which was proved by TEM [14], also due to stop the movement of grain boundaries due to Zenar-drag effect of nanoparticles. The SiC nanoparticles plays an effective role in strengthening the materials and increasing the yield strength. Strength increase is clearly shown by the observing Figure 6 that the strength with 5% volume fraction is almost three times higher than the composite with 10vol.% [15].

Changing the volume fraction of SiC to 5% from 2.5% the ductility decreased and that can be explained by the following: as the Al composite get refined and causing stability loss under deformation and cavity formation from subjected to tensile stress due to SiC particles agglomerations [16]. The SiC agglomerates in Al-4wt%Cu-(7.5 and 10)vol.%SiC may be the reason behind the premature fracture under tensile test and make the formation and initiating of the cracks to be at ease, causing fracture to occur before macroscopic yielding.

4. Conclusions

High energy mechanical milling was the starting step to make alumimium powder followed by powdewr consolidation. The ultimate tesnile strength and hardness has a positive relation ship with increasing the volume fraction of SiC particles in the aluminium matrix from 168MPa to 400MPa from 2.5 to 5vol.% and the ductility decreased to less than 2% because of SiC nanoparticle agglomerates. Both extruded bars with 7.5 and 10 vol.% SiC experienced premature fracture and that also relates to the aggloemration of SiC.

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