

Research Article

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Tennur Gülşen Ünal, Ege Anıl Diler

Properties of AlSi_9Cu_3 metal matrix micro and nano composites produced via stir casting

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Abstract: The effects of micro and nano sized reinforcement particles on microstructure and mechanical properties of aluminium alloy-based metal matrix composites were investigated in this study. AlSi_9Cu_3 alloy was reinforced with micro and nano sized ceramic reinforcement particles at different weight fractions by using a stir casting method. The mechanical tests (hardness, three point bending) were performed to determine the mechanical properties of AlSi_9Cu_3 alloy-based microcomposites (AMMCs) and nanocomposites (AMMNCs). The experimental results have shown that the size and weight fraction of reinforcement particles have a strong influence on the microstructure and the mechanical properties of AlSi_9Cu_3 alloy-based microcomposites and nanocomposites. The relative densities of all AMMC and AMMNC samples are lower than unreinforced AlSi_9Cu_3 alloy due to porosity formation with the increase of weight fraction of reinforcement particles. As weight fraction increases, hardness values of AMMCs and AMMNCs increase. Maximum flexural strength can be obtained at 3.5wt.% for the AMMC sample with micro-sized Al_2O_3 particles and at 2wt.% for the AMMNC sample with nano-sized Al_2O_3 particles. After the weight fractions exceed these values, flexural strengths of both AMMCs and AMMNCs decrease due to clustering of Al_2O_3 particles.

Keywords: Metal matrix composites; Nanocomposites; Stir Casting; Microstructure; Mechanical Properties.

1 Introduction

Ceramic reinforcements in the form of particle are prevalently used in metal, ceramic and polymer matrix

composites [1-3]. Especially aluminum alloy-based metal matrix composite studies for automotive, aerospace and other industrial applications are quite popular since mechanical properties of aluminum alloys can be improved through the addition of micro and nano-sized ceramic reinforcement particles [4-6]. Ceramic reinforcements such as particulate boron carbide, alumina, silicon carbide, etc. in metal matrix composites (MMCs) and metal matrix nano composites (MMNCs) can be added into metal matrix by using various manufacturing methods [7-9].

The microstructure and mechanical properties of metal matrix composites are strongly influenced by microstructural factors such as distribution, size and weight fraction of micro and nano sized reinforcement particles. Among these factors, the distribution of reinforcement particles determining the microstructure and mechanical properties of metal matrix composites is affected by the parameters due to material and production method. There are two major problems to be cautious of adding micro and nano-sized particles into the aluminum matrix during the stir casting process: wettability and distribution of particles; because these two parameters can cause detrimental effects on the mechanical properties of both MMCs and MMNCs if they are not taken care of during the process. The wettability is poorer for nano reinforcement particles due to larger surface area of nano-sized reinforcement particles [10-12]. Also, it is difficult to obtain uniform distribution of nano-sized reinforcement particles in a matrix in stir casting method [13-14]. In literature, there are many studies that investigate the influence of micro and nano sized reinforcement particles on the mechanical properties of aluminium-based AMMCs at various sizes and weight fractions of ceramic-based reinforcement particles. In these studies, the parameters' optimum values that indicate the best mechanical properties of the composites could be different from each other because of the fact that the chosen size and weight fraction of reinforcement particles were different from each other and the composites were not produced at the same production conditions (temperature, etc.). Therefore, it is difficult to compare the composites with micro and nano-sized particles each other. For this

*Corresponding author: Tennur Gülşen Ünal, Ege University, Interdisciplinary Division of Materials Science and Engineering, Izmir, Turkey, E-mail: tennurgunal@gmail.com

Ege Anıl Diler: Ege University, Department of Mechanical Engineering, Izmir, Turkey

reason, this study has been conducted to investigate the effect of micro and nano sized reinforcement particles on the microstructure and the mechanical properties of aluminium-based AMMCs and AMMNCs reinforced with different weight fractions of micro and nano-sized Al₂O₃ particles by using stir casting method.

2 Materials and methods

2.1 Materials

Nano-sized (40 nm) and micro-sized (50 µm) Al₂O₃ reinforcement particles at various weight fractions were used to reinforce AlSi₉Cu₃ alloy. Figure 1 shows nano-sized Al₂O₃ reinforcement particles. The weight fractions and particle sizes of Al₂O₃ reinforcement particles are given in Table 1.

2.2 Production method

AMMC and AMMNC samples were reinforced with micro and nano-sized Al₂O₃ particles by using stir casting method. The AlSi₉Cu₃ alloy was heated up to melting temperature of 700°C. The nano-sized Al₂O₃ reinforcement particles were added to the melt at the weight fractions of 1, 2 and 3% while the micro-sized Al₂O₃ particles were added at the weight fractions of 2.5, 3.5, 5 and 10% under argon atmosphere. The stirring process was continued for 10 minutes at a speed of 300 rpm and then the mixture was poured to the mold to manufacture AMMC and AMMNC samples.

2.3 Experiments

Archimedes' principle was used to measure the experimental densities of unreinforced AlSi₉Cu₃ alloy, AMMC and AMMNC samples. The relative density indicating the porosity level in the samples was calculated by proportioning the theoretical and experimental densities of the samples.

The hardness tests of the samples were performed using Brinell hardness tester with a 2.5 mm diameter ball indenter and 62.5 kgf load test.

Three-point bending test was carried out in order to determine the flexural strength of the composite samples. These samples were supported by the rollers and tested at a cross head speed of 0.25 mm/min.

Ethical approval: The conducted research is not related to either human or animals use.

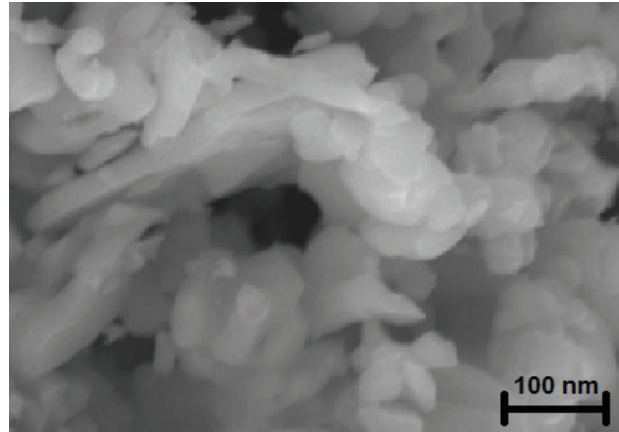


Figure 1: SEM image of nano-sized Al₂O₃ reinforcement particles.

Table 1: Weight fractions and particle sizes of Al₂O₃ reinforcement particles in AMMC and AMMNC samples.

Sample No	Al ₂ O ₃ (Weight fraction) (%)	Al ₂ O ₃ (Particle size)
1	AlSi ₉ Cu ₃ alloy (Unreinforced)	
2	1	40 nm
3	2	40 nm
4	3	40 nm
5	2.5	50 µm
6	3.5	50 µm
7	5	50 µm
8	10	50 µm

3 Results and discussion

The microstructure of AMMNC sample reinforced with 1 wt.% Al₂O₃ nano-sized particles is seen in Figure 2(a). Micro-sized Al₂O₃ particles in the microstructure of AMMC sample having 3.5 wt.% reinforcement particles are shown in Figure 2(b) by the dashed white arrows. Both nano-sized and micro-sized Al₂O₃ particles are uniformly distributed in the microstructure of AMMNC with 1 wt.% and AMMC with 3.5 wt.%. Uniform particle distribution can be obtained at higher weight fraction for the composites having micro-sized Al₂O₃ particles when compared to the composites with nano-sized Al₂O₃ particles.

The value of relative density of a MMC indicates porosity level in the microstructure. The relative densities of all composite samples are lower than that of AlSi₉Cu₃ alloy, and as seen in Figure 3, the relative density decreases with the increasing of weight fractions of both nano and micro-sized Al₂O₃ particles. This can be attributed to the problems of wettability and clustering of reinforcement particles [10]. Moreover, the relative densities of the

AMMNC samples having nano-sized Al_2O_3 particles are less than those of the AMMC samples with micro-sized Al_2O_3 particles for the weight fractions close to each other.

Hardness values of unreinforced AlSi_9Cu_3 alloy, AMMCs and AMMNCs are given in Figure 4. The hardness values for both AMMCs and AMMNCs reinforced with Al_2O_3 particles are higher than unreinforced AlSi_9Cu_3 alloy. Hardness values of AMMCs and AMMNCs increase as the weight fraction of Al_2O_3 reinforcement particles increases. Hardness of AMMNC having nano-sized Al_2O_3 particles at weight fraction of 3% is close to that of AMMC sample with micro-sized Al_2O_3 at weight fraction of 5%, which means that higher hardness can be achieved at smaller weight fractions for metal matrix composites which are reinforced with nano-sized reinforcement particles compared to those with micro-sized particles. Although the weight fraction of nano-sized reinforcement particles in AMMNC with 3wt.% is less than that of micro-sized reinforcement particles in AMMC sample having 5wt.%, strengthening mechanisms (load transfer effect, Hall-Petch strengthening, Orowan strengthening, mismatch of coefficient of thermal expansion and elastic modulus [15-18]) for nano-sized reinforcement particles are more effective than those for micro-sized reinforcement particles. As aforementioned, hardness values of both AMMCs and AMMNCs increase as weight fraction of reinforcement particles increases in this study. Similar results were obtained at the studies of Sajjadi et al. and [19] Shivakumar et al. [20] for the composites with nano-sized reinforcement particles and at the studies of Nagaral et al. [21] and Singh et al. [22] for the composites with micro-sized reinforcement particles.

Highest flexural strength is achieved at weight fraction of 2% for the AMMNC sample with nano-sized Al_2O_3 particles as seen in Figure 5. However, weight fraction of reinforcement particles more than 2% causes formation of clusters that prevent the homogeneous distribution of particles within the aluminium matrix. Maximum flexural strength can be achieved at 3.5wt.% for the AMMC sample with micro-sized Al_2O_3 particles. Among both AMMC and AMMNC samples, the highest flexural strength is obtained for the AMMNC sample having 2wt.% nano-sized Al_2O_3 particles. The flexural strength of AMMC sample having 3.5wt.% micro-sized Al_2O_3 particles is almost equal to that of AMMNC sample with 1wt.% nano-sized Al_2O_3 particles. It should be also noted that AMMC sample with 5wt.% micro-sized Al_2O_3 particles has a lower flexural strength than those of all AMMNC samples while the flexural strength of AMMC sample with 10wt.% micro-sized Al_2O_3 particles is far lower than that of unreinforced AlSi_9Cu_3 alloy. Flexural strength of a metal

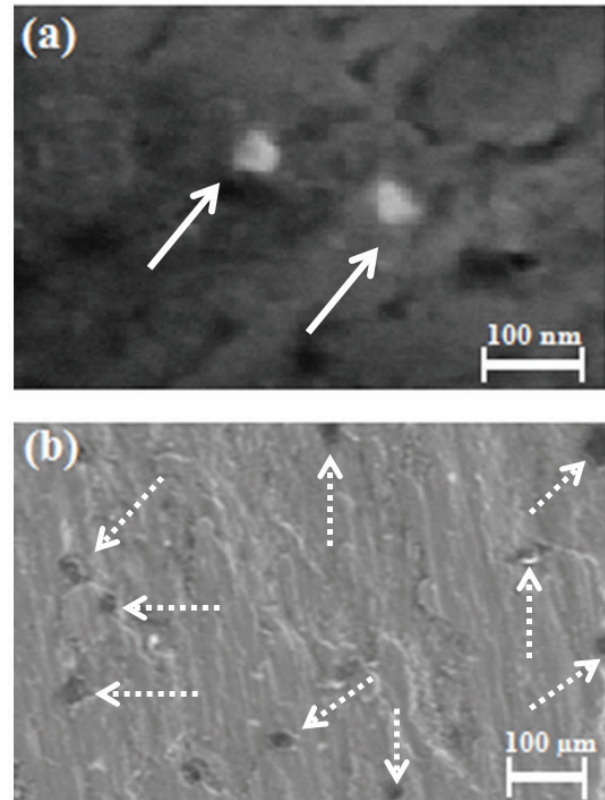


Figure 2: SEM images of the microstructures of (a) AMMNC sample with 1wt.% nano-sized Al_2O_3 particles and (b) AMMC sample having 3.5wt.% micro-sized Al_2O_3 particles.

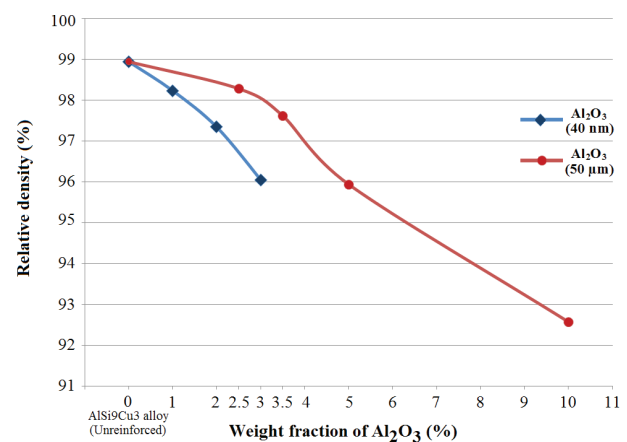


Figure 3: Relative densities of unreinforced AlSi_9Cu_3 alloy and the composite samples with micro and nano-sized Al_2O_3 particles.

matrix composite is improved compared to a metal alloy; however, after starting of agglomeration of nano-sized particles at lower weight fractions and clustering of micro-sized particles at higher weight fractions, fracture of metal matrix composites can be observed earlier. The reason is the particle clusters behaving as stress points and crack

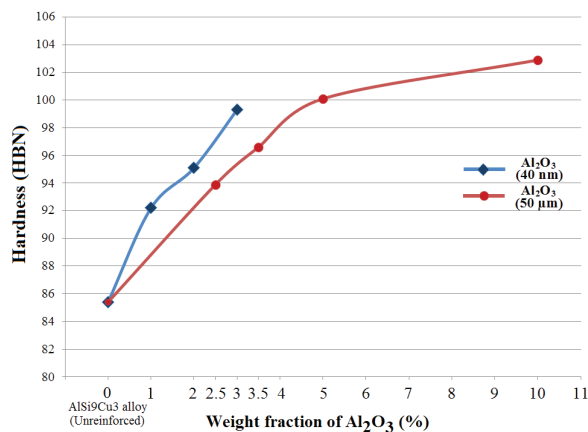


Figure 4: Hardness comparison of unreinforced AlSi_9Cu_3 alloy and the composite samples with micro and nano-sized Al_2O_3 particles.

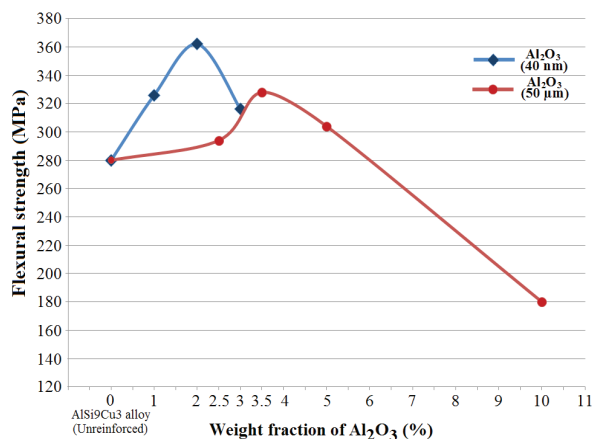


Figure 5: Comparison of flexural strengths of unreinforced AlSi_9Cu_3 alloy and the composite samples with micro and nano-sized Al_2O_3 particles.

initiator in the microstructure, which are detrimental for the mechanical properties of MMCs and MMNCs [23-25].

Figure 6 shows the fracture surface of the AMMC sample with 10wt.% micro-sized Al_2O_3 particles while fracture surface of AMMNC sample having 3wt.% nano-sized Al_2O_3 particles is seen in Figure 7. White arrows show the voids forming due to particle removal from the regions of reinforcement particle clusters on the fracture surface, which clearly indicates that reinforcement particle clusters are detrimental influence on the mechanical properties of MMCs. It should be also noted that these regions can cause a decrease in relative density. When the sizes of the void regions for AMMNC sample having 3wt.% nano-sized Al_2O_3 particles and AMMC sample with 10wt.% micro-sized Al_2O_3 particles are compared with each other, the void size of the regions forming due to clusters of micro-sized Al_2O_3 particles is larger than that of the

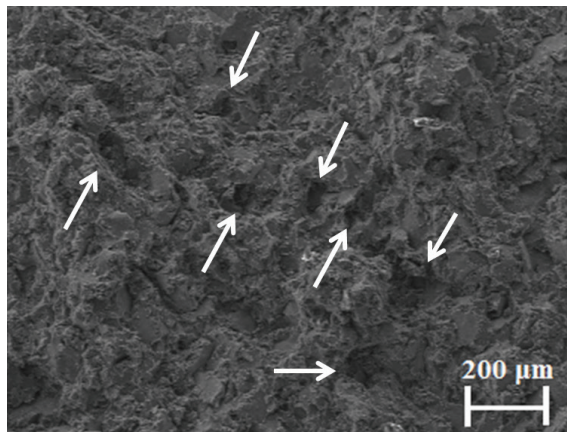


Figure 6: SEM image of fracture surface of AMMC sample with 10wt.% micro-sized Al_2O_3 particles.

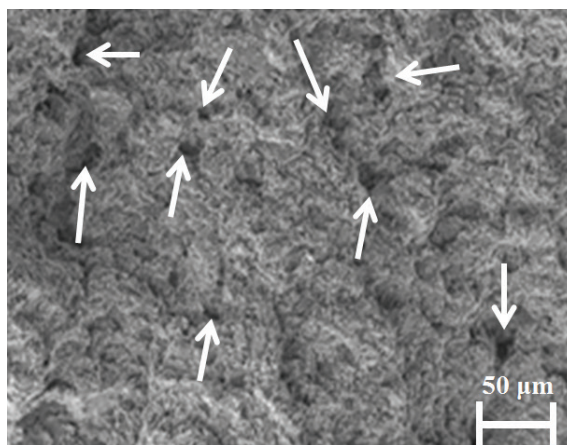


Figure 7: SEM image of fracture surface of AMMNC sample having 3wt.% nano-sized Al_2O_3 particles.

regions formed by clustering of nano-sized Al_2O_3 particles. Therefore, the clusters formed by micro-sized Al_2O_3 have a more detrimental influence on the flexural strength of MMCs than those formed by nano-sized Al_2O_3 particles.

4 Conclusion

The relative densities of all AMMC and AMMNC samples are lower than unreinforced AlSi_9Cu_3 alloy due to porosity formation with the increasing amount of reinforcement particles. Compared to micro-sized Al_2O_3 particles, nano-sized Al_2O_3 particles have a more negative influence on the relative density due to higher wettability and clustering problems of nano-sized Al_2O_3 particles.

The hardness values for both AMMCs and AMMNCs reinforced with Al_2O_3 particles are higher than unreinforced

AlSi₉Cu₃ alloy. Hardness of AMMCs and AMMNCs improves as the weight fraction of Al₂O₃ particles increases due to strengthening mechanisms.

Flexural strengths of AMMCs and AMMNCs reinforced with Al₂O₃ particles are improved when compared to AlSi₉Cu₃ alloy. Maximum flexural strength can be obtained at 3.5wt.% for the AMMC sample with micro-sized Al₂O₃ particles while highest flexural strength is achieved at weight fraction of 2% for the AMMNC sample with nano-sized Al₂O₃ particles. Weight fraction of reinforcement particles more than 2% for AMMNC and 3.5.% for AMMC causes formation of clusters that prevent the homogeneous distribution of particles within the aluminium matrix. After starting of agglomeration of nano-sized particles at lower weight fractions and of clustering of micro-sized particles at higher weight fractions, fracture of AMMCs and AMMNCs can be observed earlier due to clusters behaving as crack initiator in the microstructure. Uniform distribution of reinforcement particles in the metal matrix is essential to obtain MMCs and MMNCs that have better mechanical properties. In addition, the percentage of reinforcement particles and processing techniques are the effecting factors which should be optimized for the next study.

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Conflict of interest: Authors state no conflict of interest.

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