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Mechanical (tensile, hardness and fatigue) behavior of the Al-Al_2O_3p composites fabricated by stir casting method

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Abstract: Aluminum–alumina particulate composites are a class of metal matrix composites which have high strength-to-weight ratio and low density. The most important mechanical property in industries is the fatigue behaviour. Hence, it is important to know more about mechanical properties of these composites. In this study, composite samples containing of different weight percent of 1%, 2%, 3% Al_2O_3 particles in size of 20μm were fabricated by stir casting method, extruded by reduction area of 1:20 and heat treated by T6 condition. Microstructure of these composite materials was characterized by using scanning electron microscopy (SEM). Then Hardness, tensile and fatigue properties of these composites were investigated. It is observed that by increasing in weight percent of Al_2O_3, the hardness, tensile strength and fatigue strength more increased.

Keywords: Al-Al_2O_3 Composite, Hardness, Low cycle fatigue properties, Microstructure, Tensile strength.

Introduction

In the recent years application of composite materials in aerospace, automobile and other depended industries increased. Among these, metal matrix composites (MMCs) have developed because of their high specific modulus, fatigue strength, strength-to-weight ratio, wear resistance and temperature stability [1–5].

MMCs can be reinforced by: (1) fibre or whisker reinforced, and (2) particle-reinforced. These materials in general have high modulus, high strength and thermal stability [6,7]. the improvement properties associated with particle-reinforced are higher than other reinforced types, shows isotropic properties[8] and secondary conventional processing such as extrusion, forging, rolling and even super plastic forming can be performed[9]. These particulate metal matrix composites (PMMCs) can be fabricated by powder metallurgy [10] squeeze-casting [11] pressure-casting [12] hot isostatic pressing [13], compocasting [14], stir-casting [15], and superplastic forming techniques [16].

A major problem of particle-reinforced composites is nonuniform distribution of particles in matrix, which can lead to the presence of clusters of particles, or regions without reinforcement [17-19]. This inhomogeneity can give a wide scatter in strength and ductility [20], wear resistance [21], fracture toughness [22] and also in the fatigue behaviour [23].

PMMCs Structural materials are subjected to static and cyclic loading. Therefore understanding of mechanical behaviour of these materials is important. The investigations of fatigue properties of this material are still limited.

Several studies have been concentrated on high-cycle fatigue strength and fatigue growth resistance [24-27], studies on their low-cycle fatigue behaviour is still limited [28, 29].

The aim of this study was comparison the tensile,hardness and the low-cycle fatigue behaviour of particle-reinforced aluminum matrix composites, containing of different weight percentages of alumina particles. Optical and scanning electron microscopy was used to characterize the initial microstructure and fracture surface.

Experimental Procedure

In the present study 1, 2, 3 wt% Al_2O_3p/A356 composites were fabricated by stir-casting method. Also the unreinforced A356 Al alloy was prepared by the same process. Table 1 shows the chemical compositions of the matrix aluminum alloy (A356 Al). The Al_2O_3 particles used as reinforcement material had a size range of 20μm.

Ingots of the A356 Al alloy were melted in a resistance furnace. The alumina particles were added to the molten alloy at 700°C while the molten alloy was stirring. After casting both of composite and alloy bars were extruded in a 25 tonne extrusion press at 500°C with an extrusion ratio of 20:1 to obtain 20mm diameter bars. Heat treatment of the both composites and unreinforced alloy samples consisted of solution heat treating the extruded samples at 540°C for 12h followed by quenching in warm water at 40°C. Subsequently, the samples were artificially aged at 150°C for 5 h and then cooled in furnace to get the peak-aged (T6) matrix condition. Then, the composites microstructures studied by optical and SEM microscopes.

Uniaxial cylindrical samples with a gauge section of 5mm diameter and 14 mm length were made, conforming to ASTM E466-07 [30]. The surfaces of the gauge sections of the specimens were mechanically polished to remove scratches and machining marks.

Tensile test and fatigue tests were performed on Zwick

Table 1. chemical compositions of the matrix aluminum alloy.

Al	Si	Fe	Mn	Mg	Zn	Ti	Cr	Ni	P
Bal.	6.104	0.18	0.013	0.43	0.063	0.009	0.001	0.006	0.002

Z250 and servo hydraulic valve testing system in air at room temperature according to ASTM B557[31], ASTM E466-07, respectively.
The low cycle fatigue tests were performed under a fully reversed load controlled(R=-1), cycling frequency was 20 Hz. The cyclic loading was carried out at three different stresses consisting of 50%, 70%, and 90% UTS strength and the fracture cycles were recorded.
Fracture surfaces of the tensile and fatigue test specimens for each volume fraction of alumina particles were examined by using a SEM to study the crack initiation locations.

Results and Discussions

The microstructure investigation of some composites showed segregation and clustering of the particles (fig 2).
As extruded 1wt%Al_2O_3p/A356 composite is shown in figure 1. The microstructure results showed that the Al_2O_3 particles were partially aligned along the extrusion direction and the matrix material flaw along the extrusion direction.
the hardness of the unreinforced alloy and the composites are shown in table 2. The hardness increased with increasing in the volume fraction of particles.

The hardness of the composites were more than of the unreinforced alloy due to the high hardness of alumina particles and decreasing the grain size of the matrix. Also higher alumina weight percent caused higher strain hardening in aluminum matrix.

Increasing the UTS strength in composites was attributed to the work hardening which was affected by the elastic properties of the ceramic particles and their barrier from plastic deformation of matrix. Also work hardening of aluminum matrix is an important factor to increase the tensile strength of composites.
Figure 3 shows the values of the UTS and percent elongation versus weight percent of Al_2O_3 particles. As can be seen all composites displayed an increasing of the UTS strength and decreasing of the elongation with respect to the matrix alloys.
This improved tensile strength can be explained by strengthening mechanisms in composites.

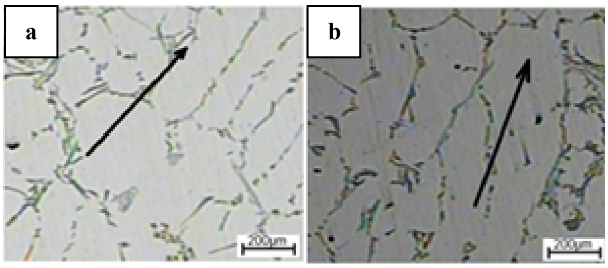


Fig 1. the microstructure of the (a) unreinforced alloy (b) A356-1wt %.Al_2O_3 composite.

Mechanisms such as grain refinement, load bearing, mismatch strengthening between particles and matrix strengthened the composites [32,33].
By increasing particle weight percent, inter particle distance decreased and the composite was strengthened.

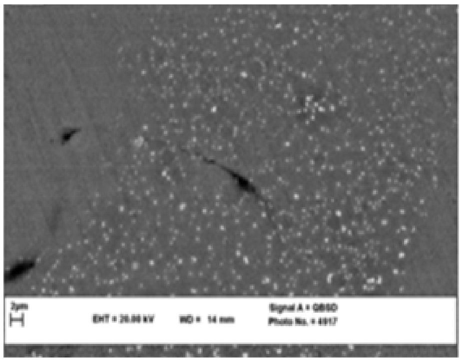
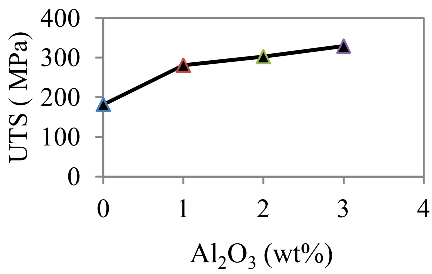


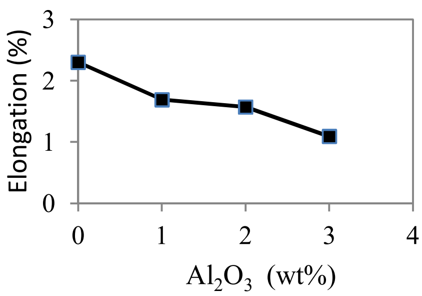
Fig 2. the particle clustering in the A356-3wt %.Al_2O_3 composite

Table 2. the hardness of the unreinforced alloy and the composites

Samples	Hardness (HBN)
A356	55.6
A356-1wt %.Al_2O_3 composite	63.1
A356-2wt %.Al_2O_3 composite	64.4
A356-3wt %.Al_2O_3 composite	66



a)



b)

Fig 3. (a) The different values of the UTS according to the weight percent of Al_2O_3 (b) The different values of the elongation according to the weight percent of Al_2O_3.

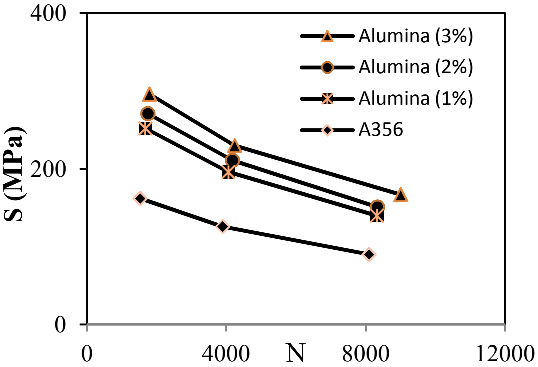


Fig 4. The S-N curves of the three composites and unreinforced alloy.

Particle reinforcement can rule the nucleation sites and refine grain size of matrix.
The S-N curves of the composites and matrix are shown in the figure 4. In this figure the endurance limit of the composite increased with increasing the particles and the endurance limit of the composites were more than the unreinforced alloy. In the constant load fatigue test the strength of the material is the important factor. As mentioned above the presence of rigid ceramic particles in the ductile metal matrix increased the strength of the composites.
In region of particle clustering, interlinkage between neighboring voids and cracks facilitated because of the presence of short interparticle distances.
Fracture in metal matrix composite is controlled by three main mechanisms: interfacials decohesion, fracture of reinforcing particles, and void nucleation and growth.
The interfacial decohesion is often due to the presence of undesired interfacial reaction products, such as $MgAl_2O_4$ spinel for Mg-rich aluminum alloy matrix reinforced with Al_2O_3 particles [34].
The local stress applying on the particles can generate fracture of the reinforcement particles. The large difference between the elastic modulus of the reinforcement particles and the metal matrix generated a deformation in the matrix and a stress concentration near the reinforcement particles. These stresses can generate cracking of the particles, fracture of the matrix and interfacial decohesion.
Fracture of the large particles and clusters was more feasible, where the stress concentration and the short distance between particles facilitated linkage between voids and cracks in the particles. The smaller Al_2O_3 particles cant generate cracks, but because of differences between the elastic modulus of matrix and particle, the matrix can fail by decohesion.
Void nucleation and growth was associated with ductile failure of the matrix alloy between the particles, where the local stress was not high enough to crack the particles or generate decohesion. The above mentioned mechanisms of fracture are evident in the fatigue fracture surfaces of figure 5(b), where fractured particles, surrounded by ductile regions with tear ridges mainly in

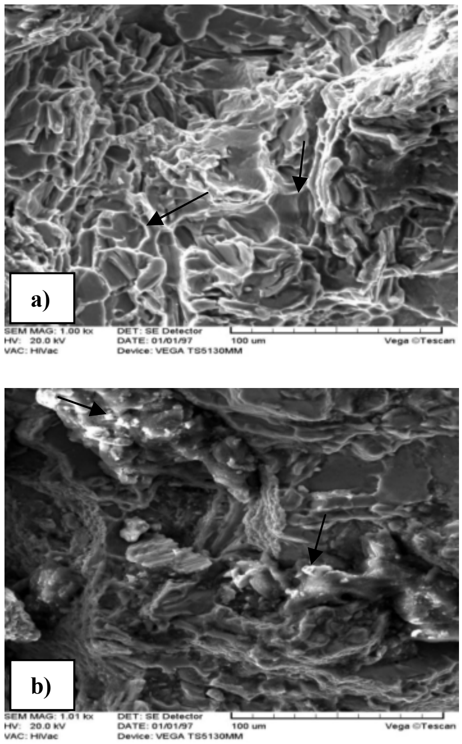


Fig 5. SEM micrographs of the fatigue fracture surfaces of the (a) unreinforced alloy (b) A356-3wt %. Al_2O_3 composite.

the composite.fracture of large Al_2O_3 particles or in regions with clusters occurred, while in the metal matrix the ductile fracture was more evident, Large voids and dimples are seen in figure 5(a),.
The $MgAl_2O_4$ spinel probably promoted voids nucleation, at the particles interface and failure of the particles. These effects were probably associated with the jagged interfaces generated by the spinel formation.

Conclusion

From this work, following conclusions can be reached:

- The hardness of the composites increased with increasing weight percent of alumina.

- The tensile tests showed an increasing of the tensile strength and a decreasing of the failure elongation in the MMCs, respect to the unreinforced alloys.
  The tensile ductility was strongly affected by the material inhomogenity, mainly related to the particles size and distribution.

- With increasing the weight percent of the reinforcement, the fatigue life at a given load was increased.
  The inferior fatigue-life of the unreinforced alloy can be attributed to the barrier effect of the particles on the dislocations movement.

- The fatigue fracture surfaces of composites fractured particles surrounded by ductile regions were evident,while in the fatigue fracture surfaces of metal matrix Large voids and dimples were seen.

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