FRACTURE BEHAVIOR OF ALUMINA PARTICLES REINFORCED WITH DIFFERENT MATRIX ALUMINIUM ALLOYS

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Abstract: Al/Al_2O_3 metal matrix composites exhibits lower ductility than the matrix alloy. The ductility decreases with increasing amount of reinforcement in Al/Al_2O_3 metal matrix composites. The larger ceramic particle size is detrimental to composite strength. The decrease in the particle size increases the ultimate tensile strength. The fracture surfaces of fractured Al/Al_2O_3 MMC specimens reveal dimple morphology. The tensile fracture behavior of Al/ Al_2O_3 metal matrix composites is observed to be ductile in nature.

Keywords: alumina, metal matrix composites, low pressure die casting process, fracture.

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1. INTRODUCTION

Metal matrix composites usually consist of a continuous phase called the matrix and discontinuous phase in the form of fibers, whiskers or particles called the reinforcement. The addition of ceramic particles into light alloys would guarantee exceptionally high specific elastic modulus, strength-to-weight ratio, fatigue strength, wear resistance [1]. These important characteristics have made the reinforced aluminium alloy based metal matrix composites an attractive and viable nominee for automobile and aerospace applications [1-21].

2. THE MOTIVATION AND OBJECTIVES

The need for satisfying high fuel-economy goals in the automobile and ground transportation industries is a major challenge. The metal matrix composites based on lightweight alloys will play a significant role. Classes of MMCs which have grown in stature to emerge and attract attention are both the magnesium and aluminium alloy metal matrices discontinuously reinforced with silicon carbide and Al_2O_3 particulates. While few studies have focused on establishing an understanding of the influence of particulate reinforcements on matrix microstructure and concurrent fracture behavior for particulate reinforced metal matrix composites is limited and there does a critical need to examine and understand this aspect of mechanical consideration.

The main objectives of this work are to characterize fracture behavior of Al/Al_2O_3 metal matrix composites. In this research work, the effect of type of aluminum alloy matrix and type of reinforcement materials, and volume fraction and particle size of the reinforcement on the mechanical behavior have been evaluated. The fracture mechanisms in Al/Al_2O_3 metal matrix composites have also been characterized. The schematic representation of the current research work is shown in figure 1.

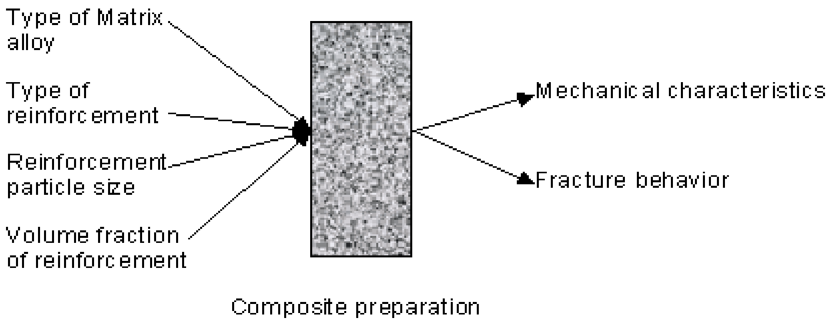

Figure 1: Schematic representation of the current research work

3. EXPERIMENTAL PROCEDURE

Al/Al_2O_3 metal matrix composites were prepared by low pressure die casting process. Several test samples of these composites were prepared with reinforcement content of 12, 16 and 20% volume fraction, different type of aluminum matrix Al6061, Al6063 and Al7072, and different particle sizes (such as 10, 20 and 30 μm) of Al_2O_3 reinforcements.

The mechanical behavior of the metal matrix composites was evaluated in terms of ultimate tensile strength, and ductility (in terms of tensile elongation). The microstructural examination of the test samples was carried out to reveal and study the distribution of reinforcement particles, grain structure, the matrix-particle interfaces, and the formation of intermetallics in the metal matrix composites. The fractured surfaces of the tested specimens under tensile loading were examined using scanning electron microscope (SEM). The dimensions of tensile specimens are shown in figure 2.

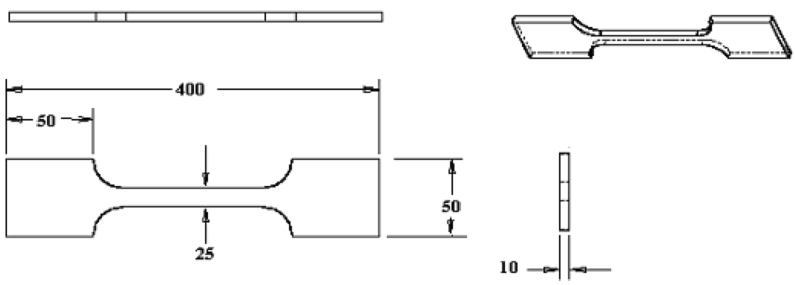

Figure 2: Tensile specimen, all dimensions are in mm

4. RESULTS AND DISCUSSION

The effects of matrix microstructure and reinforcement (in terms of % volume fraction and particle size) are focused on the properties of alumina (Al_2O_3) and SiC reinforced Al-alloy composites. Type of fracture occurred in these composites is also addressed. Suitability of manufacturing automobile components is also presented.

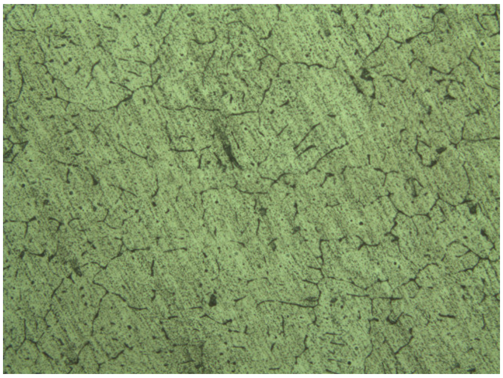

Figure 3: *M*icrostructure of MMC (Al 6061 matrix, 12% Al_2O_3, 10µm particle size), 200X

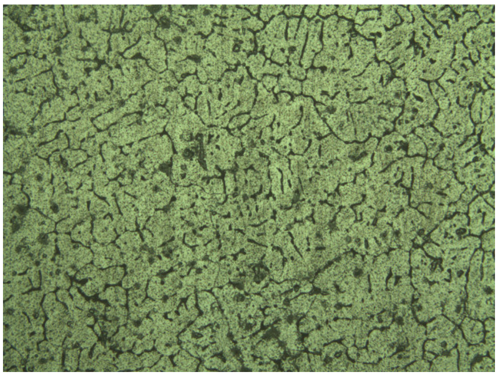

Figure 4: *M*icrostructure of MMC (Al 6063 matrix, 20% Al_2O_3, 10µm particle size), 200X

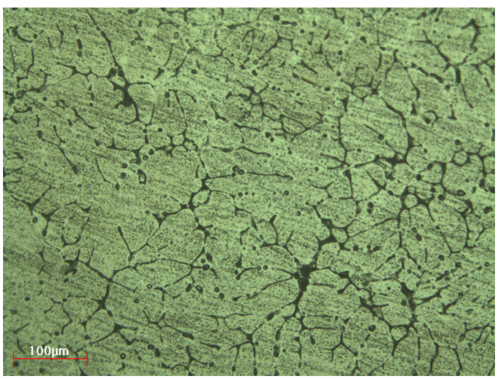

Figure 5: *M*icrostructure of MMC (Al 7072 matrix, 16% Al_2O_3, 10µm particle size), 200X

4.1 Undefomred Microstructures of Al-alloy/ Al_2O_3 composites

The various intermetallics can be revealed in the microstructures shown in figures 3-5. In the as-cast condition, Al is present both in solid solution with the matrix and precipitated as $Al_{12}Mg_{17}$ phase that is present at and along the grain boundaries. A non-uniform distribution of Al_2O_3 particulates through the Al-alloy metal-matrix with evidence of clustering, or agglomeration is observed. MgO and $MgAl_2O_4$ are also seen along the grain boundaries. The phases Al_2Cu, Mg_2Si, $Al_5Cu_2Mg_8Si_6$ and $Al_4CuMg_5Si_4$ are also observed in the microstructures.

4.2 Effect of % Volume Fraction on Mechanical Properties

Figure 6 illustrate the influence of % volume fraction of Al_2O_3 (reinforcement) on the ultimate tensile strength of Al-Al_2O_3 metal matrix composites. The graphs indicate that the ultimate tensile strength increases with increase in % volume fraction of reinforcement in the composite. With increasing volume fraction, more load is transferred to the reinforcement which is results in a higher ultimate tensile strength.

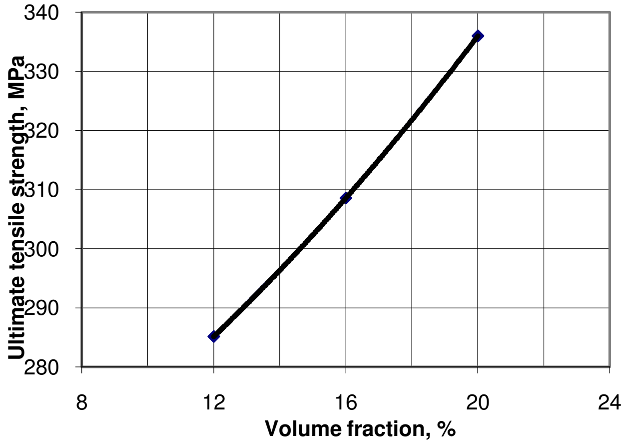

Figure 6: Influence of volume fraction on the ultimate tensile strength of Al/ Al_2O_3 composite

The effect of volume fraction on the ductility of the composites is shown in figure 7. The decrease in ductility can be attributed to the earlier onset of void nucleation with increasing amount of reinforcement. The high stress concentration at the tip of the cracked particles can also contribute to a decrease in the ductility (tensile elongation) in the composite.

4.3 Effect of particle size of reinforcement on the mechanical properties

Figure 8 illustrates the effect of particle size on the ultimate tensile strength. The decrease in the particle size increases the ultimate tensile strength. This is because, the small particle size means a lower inter-particle spacing so that nucleated voids in the matrix are unable to coalesce as easily. Also, the larger ceramic particle size is detrimental to composite strength. This is on account of the strength distribution of a ceramic particulates population obeys weibull statistics. The agglomeration could contribute a reinforcing effect in the aluminium matrix. The inhomogeneous distribution of reinforcement reduces the effective amount of particulates for strengthening.

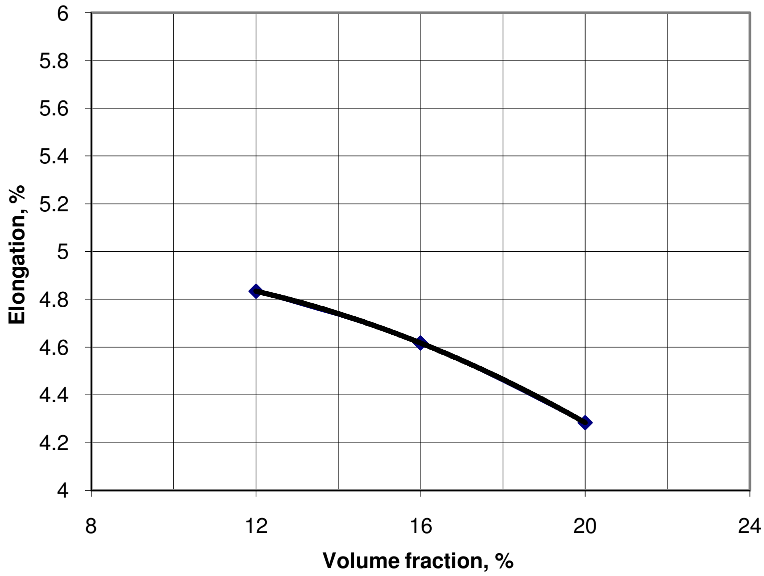

Figure 7: Influence of volume fraction on the ductility of Al/ Al_2O_3 composite

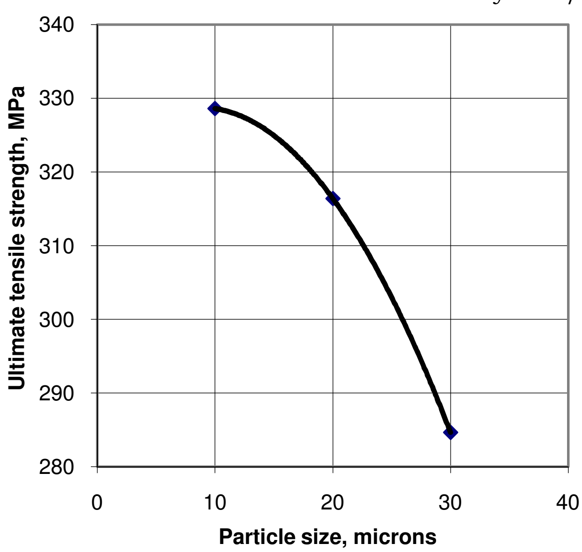

Figure 8: Influence of particle size on the ultimate tensile strength of Al/ Al_2O_3 composite

There is an increase in the ductility with a decrease in the particle size of the reinforcement (figure 9). At relatively large particle sizes, a significant amount of particle cracking takes place during tensile testing of the composites. Cracked particles do not carry any load effectively and can be effectively thought of as voids, so the ductility is decreased.

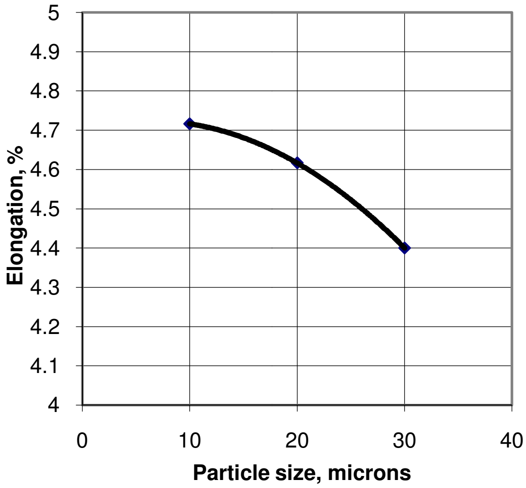

Figure 9: Influence of particle size on the ductility of Al/ Al_2O_3 composite

4.4 FRACTURE MECHANISM IN Al/Al_2O_3 COMPOSITES

Study of the fracture surface of fractured MMC specimens by scanning electron microscope (SEM) reveals dimple morphology (figures 10-12). In fact, it is very difficult to detect any major change in dimple morphology in different samples because both in size and distribution of the dimples in the dimple-dominated areas are mainly governed by the size and distribution of the reinforcing particles. In addition, there is a minor fraction of fracture surface that is dominated by smaller dimples (figures 10 and 12) that is mainly distributed at the boundaries between the larger dimples, probably due to ductile rupture of the matrix. Occurrence of the dimple morphology certainly leads to the conclusion that these types of materials fail mainly via a void nucleation and growth mechanism.

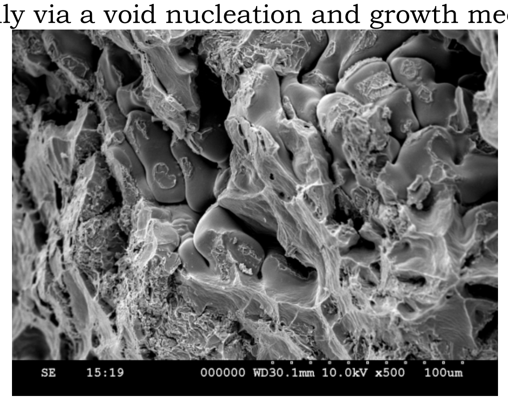

Figure 10: SEM of fracture surface of Al_2O_3/Al6061composite (V=20% and P =30μm); 1000X

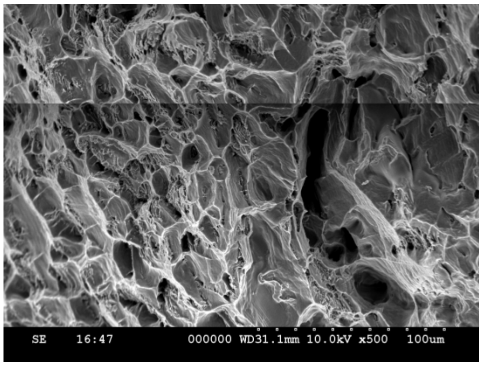

Figure 11: SEM of fracture surface of Al_2O_3/Al6063composite (V=20% and P=10μm); 1000X

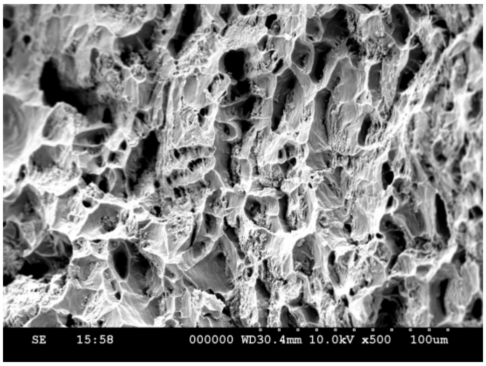

Figure 12: SEM of fracture surface of Al_2O_3/Al7072composite (V = 6% and P =10μm); 1000X

5. CONCLUSIONS

The major conclusions drawn from the current research work are as follows:

1. The ductility of Al/Al_2O_3 metal matrix composites is much lower than that of un-reinforced Al-alloy.
2. The ultimate tensile of Al/Al_2O_3 metal matrix composites is only marginally higher than yield strength indicating that the work hardening rate past yielding is low.
3. In the as-cast condition, Al is present both in solid solution with the matrix and precipitated as $Al_{12}Mg_{17}$ phase along the grain boundaries. MgO and $MgAl_2O_3$ are also formed along the grain boundaries.
4. The ductility decreases with increasing amount of reinforcement in Al/Al_2O_3 metal matrix composites.
5. The decrease in the particle size increases the yield strength, ultimate tensile strength, bending force, hardness, and ductility (tensile elongation). The larger ceramic particle size is detrimental to composite strength.
6. Al_2O_3 particles aggregated to form coarse clusters in the matrix. The degree of agglomeration increases with the particulate volume fraction in the case Al 6063 and Al 7072 matrix alloys.

7. The tensile fracture behavior of Al/ Al_2O_3 metal matrix composites is observed to be ductile in nature.
8. The fracture surfaces of fractured Al/Al_2O_3 MMC specimens reveal dimple morphology. There is an occurrence of interface or near interface debonding in the Al/Al_2O_3 composites.

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