# INFLUENCE OF PARTICLE SIZE DISTRIBUTION ON MECHANICAL PROPERTIES AND MICROSTRUCTURAL EVOLUTION OF AL-CU/FLY ASH COMPOSITE

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**Abstract:** *In the present work the combined effects of particle size and distribution on the mechanical properties of the fly ash particle reinforced Al–Cu alloy composites is investigated. It has been shown that small ratio between matrix/reinforcement particles sizes resulted in more uniform distribution in the matrix. The particles distributed more uniformly in the matrix with increasing in mixing time. The results also showed that homogenous distribution of the fly ash particles resulted in higher hardness, ultimate tensile strength, yield strength and elongation. Fracture surface observations showed that the dominant fracture mechanism of the composites with small fly ash particle size (27µm) is ductile fracture of the matrix, accompanied by the "pull-out" of the particles from the matrix, while the dominant fracture mechanism of the composites with large fly ash particle size (77µm) is ductile fracture of the matrix, accompanied by the fly ash particle fracture.*

**Keywords:** *Powder Metallurgy, Fly Ash, Mechanical Properties, Particle Size*

## 1. INTRODUCTION

Composites are the most successful and extensively used materials in modern industries compared with alloys or some other metals as these materials hold significantly improved mechanical properties. Tailoring the mechanical, physical and thermal properties that consist of lower density, higher specific strength, higher specific modulus, greater thermal conductivity and better abrasion and wear resistance gives advantage for metal matrix composites in their performance. Among the various discontinuous reinforcement used, fly ash is one of the most inexpensive available. The fly ash reinforced aluminum alloy composites are the typical candidates for engineering applications due to their enhanced mechanical properties over the corresponding aluminum alloys [1]. Among different shaped reinforcements, the composites reinforced with particulates offer relatively isotropic mechanical properties compared to the composites reinforced with short fibers or whiskers, and can be produced using conventional metal manufacturing process with low cost [2, 3].

It is commonly recognized that both the particle distribution and particle size have obvious effects on the mechanical properties of the composites. In general, particle size has a significant effect on the dislocation strengthening mechanism, but has almost no effect on the load transferring strengthening mechanism [4, 5]. Slipenyuk et al. [6] studied the effect of matrix-to-reinforcement particle size ratio (from 2.9 to 12.9) on the microstructures and mechanical properties of SiCp reinforced Al–6Cu–0.4Mn composites. Zhangwei Wang et al [7] studied effects of particle size and distribution on the mechanical properties of SiC reinforced Al–Cu alloy composites. In addition, a detailed study on the effects of the process parameters on the reinforcement particle distribution fabricated by powder metallurgy technique is very important to obtain the enhanced mechanical properties. Thus, in this paper, composites containing 20% fly ash particles with the size of 27 and 77µm were fabricated using powder metallurgy technique with different mixing time. The purpose of this paper was to reveal the relationship between the mechanical properties of the composites and the fly ash particle size and distribution.

## 2. EXPERIMENTAL WORK

The matrix alloy used in the present work is an Al–4.5Cu alloy with the total impurities in the matrix being less than 0.7 wt%. The Al–Cu powders were produced by inert gas atomization, and have an average size of about 40μm after sieving. The volume fraction of the fly ash particles in the composites is 20%. The fly ash reinforcements are in the form of particulate with an average diameter of about 27μm and 77μm respectively. Al–Cu alloy with fly ash powders was ball mixed for 5 h, 15 h and 25 h using a V-shaped powder rotator mixer with the rotation speed of about 35 rpm. The balls are made by hard metal, and the mass and diameter of each ball are about 20g and 8mm respectively. The ball to powder weight ratio was 1:4. The mixed powders were die-pressed at the room temperature under a pressure of 250MPa in a cylindrical steel die with the diameter of 25mm and 75mm length. The specimens were sintered for 1hour at 420°C. Then the specimens were heated to 570°C with a heating rate of 10°C per minute. At 570°C, the specimens were further sintered for varying mixing time of 5, 15 and 25h. The hardness measurements were performed using a Brinnel hardness tester with a load of 10kgf as per ASTM-E10-01. An average of 5 measurements was taken at different locations for each sample. Tensile test samples having 6mm diameter with a gauge length of 25mm, were prepared for testing in universal Testing Machine as per ASTM E-8 standards.

## 3. RESULTS AND DISCUSSION

### 3.1 Hardness

The Brinell hardness of the composites is illustrated in Fig. 1. The hardness of the Al-Cu/fly ash composites increases with the mixing time and particle size and it is in par with literature[8]. A maximum hardness of 101BHN appears at 25h mixing time and 77μm particle size. This might be associated with the changes in the microstructure with the mixing time. Increasing mixing time gives higher hardness due to improved sinterability as a result of inherent residual stresses which acts as driving force for sintering. The minimum hardness of 85 BHN is seen at 5 hours mixing time and 27μm particle size. The gradual increase of hardness is observed as evident from Fig. 1. With increase in mixing time and particle size of 77μm, it enhances the diffusion of atoms across the particle interface due to transient eutectic phase [9] formed at sintering temperature of 570°C results in higher hardness.

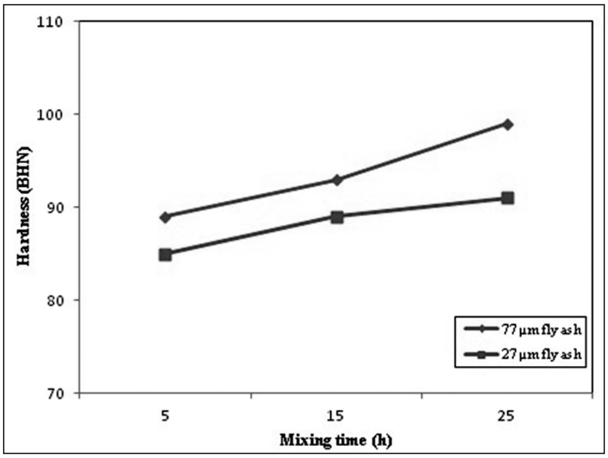


**Fig 1. Hardness of the Composites Containing 20% Fly Ash Particles with Different Mixing Time**

### 3.2 Tensile Behaviour of the Composites

Fig. 2, 3 and 4 shows the mechanical properties of the composites. The, ultimate tensile strength, yield strength and elongation of the composites containing small fly ash particles (27μm) and large fly ash particles (77μm) generally increase with increasing the mixing time. This increase is due to the decrease in the clustering degree of the fly ash particles in the matrix with increasing the mixing time. With the increase of the mixing time, the fly ash particles distribute more uniformly in the matrix, resulting in higher strength and ductility. However it should be noted that, ultimate strength, yield strength and elongation

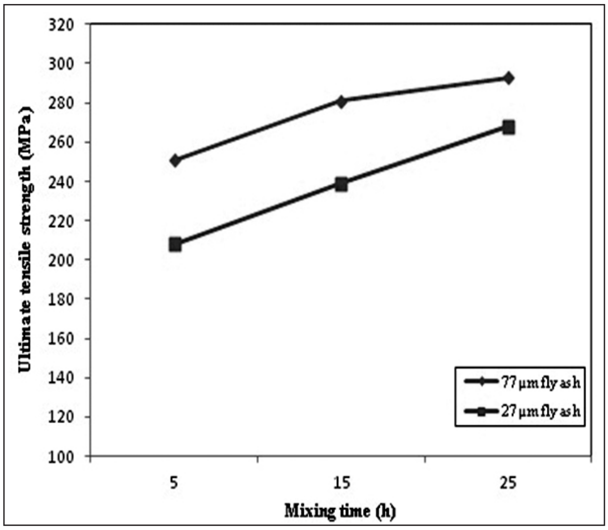


**Fig 2. Ultimate Tensile Strength of the Composites Containing 20% Fly Ash Particles with Different Mixing Time**

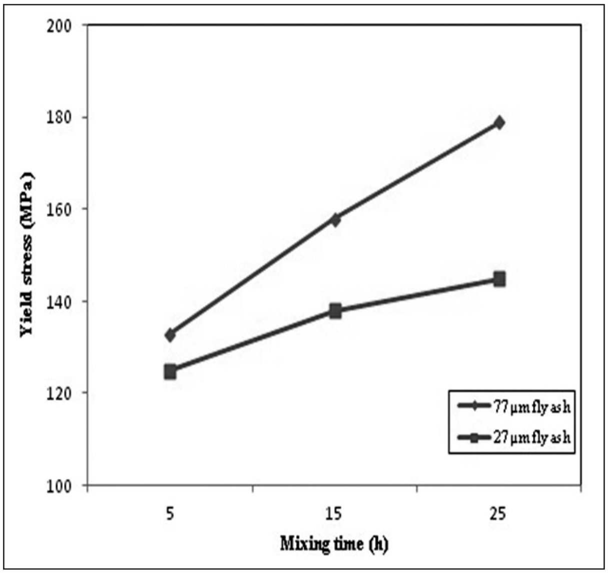


Fig 3. Yield Strength of the Composites Containing 20 % Fly Ash Particles with Different Mixing Time

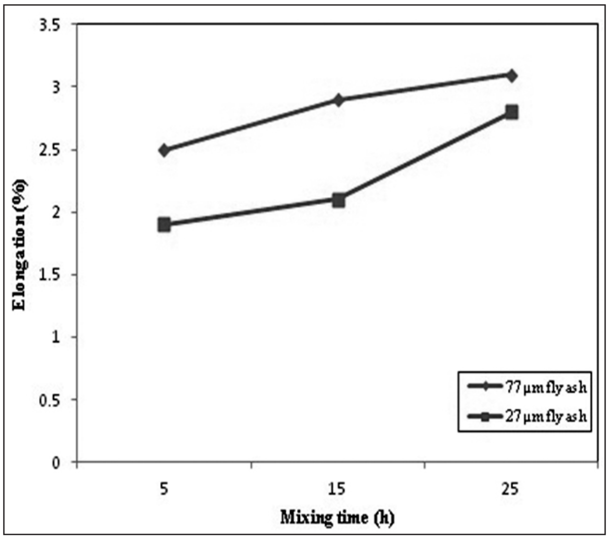


Fig 4. Elongation of the Composites Containing 20% Fly Ash Particles with Different Mixing Time

of the composite containing 27µm sized fly ash particles with the mixing time of 5h are unusually low. It may be due to a large number of the pores exist in the composite, and these pores substantially decrease the strength and ductility of the composite [10].

## 3.3 Fracture Mechanisms

Figs. 5 and 6 show the SEM fracture surfaces of the composites with the fly ash particles size of 27µm and 77µm respectively.

It can be seen from fig. 5 that the fracture surfaces of composites reinforced by 4.7µm sized fly ash particles after mixed for different periods

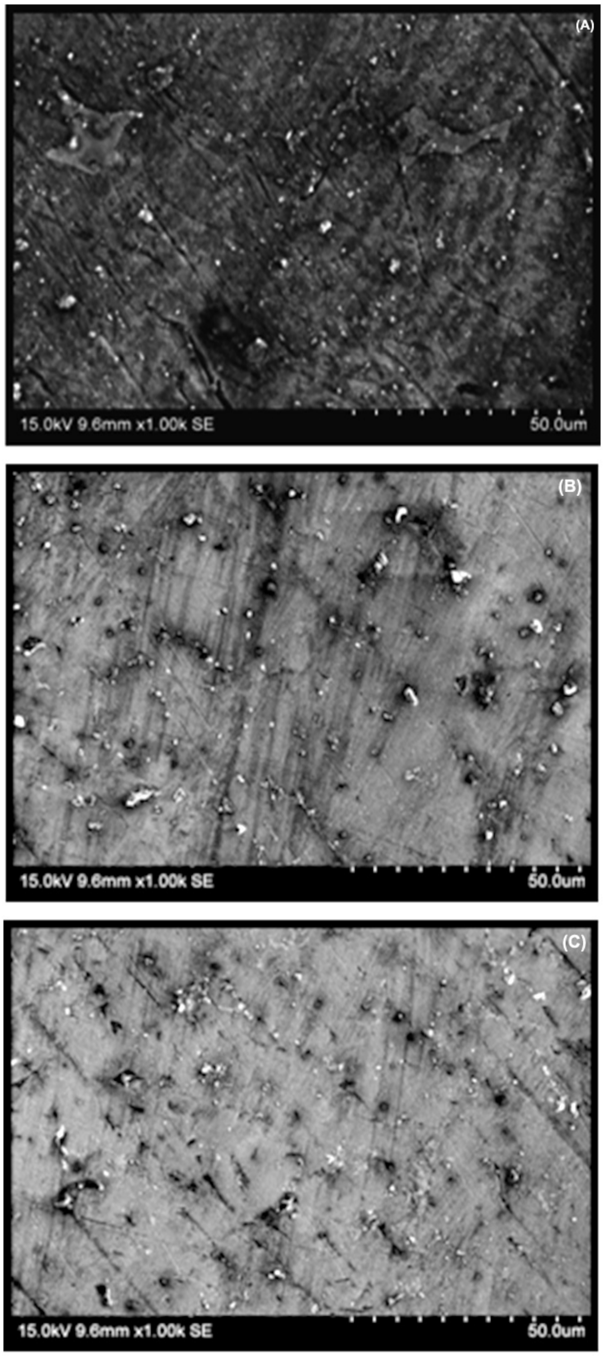


Fig 5. SEM Tensile Fracture Surfaces of the Composites Containing 20 vol.% Fly Ash Particles with the Particle size of 27µm. The Mixing Time is (a) 5 h, (b) 15 h, and (c) 25 h, Respectively

show similar characteristics, including both ductile and brittle fracture features. The fracture surfaces consist of numerous dimples on the matrix and decohesion of the fly ash particles from the matrix.

Fig. 6 shows that the fly ash particles with the size of 77µm, the composites exhibit typical brittle fracture, surrounded by the ductile dimples of the surrounding matrix. The main difference of fracture surfaces between Figs. 5 and 6 is that the "pull-out" of the fly ash particles from the matrix can be clearly observed in the composites with small particles (27μm), while the dominant fracture mechanism for the composites with large fly ash particles (77μm) is particle fracture. The relationship between the particle strength and particle/matrix interfacial bonding strength is the critical criterion to determine the fracture mode of the composites during deformation [11]. If the particle/matrix interfacial bonding strength is high, particle fracture usually happens during deformation.

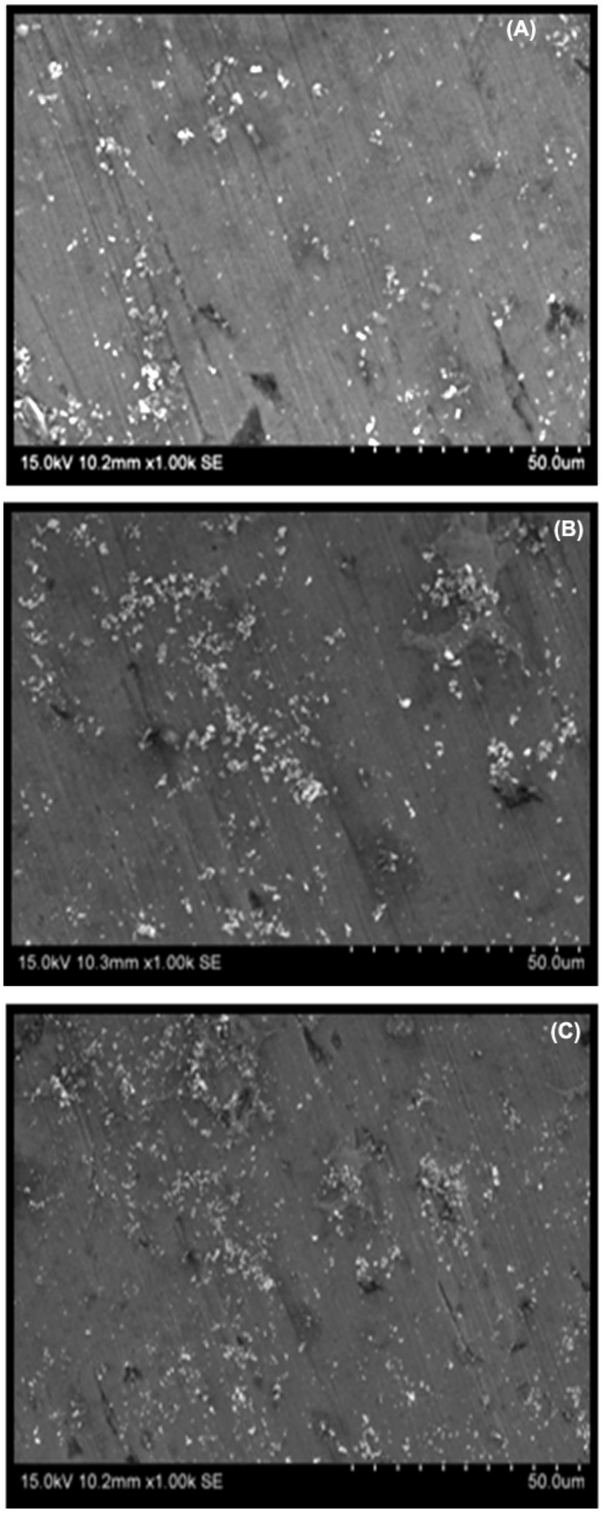


**Fig 6. SEM Tensile Fracture Surfaces of the Composites Containing 20 vol.% Fly Ash Particles with the Particle Size of 77μm. The Mixing Time is (a) 5 h, (b) 15 h, and (c) 25 h, Respectively**

On the other hand, if the particle/matrix interfacial bonding strength is weak, decohesion between the fly ash particles and the matrix will occur prior to the particle fracture. The above mentioned phenomena result in the fracture mode changing from particle "pull-out" from the matrix for the composites with small fly ash particle size (27μm) to particle fracture for the composites with large fly ash particle size (77μm).

## 4. CONCLUSION

In this paper, the combined effects of particle size and distribution on the mechanical behaviour of the composites have been studied. It is evident that small ratio between matrix/reinforcement sizes results in more uniform distribution of the fly ash particles in the matrix. The fly ash particles distribute more uniformly in the matrix with increase in the mixing time. Homogenous distribution of the fly ash particles results in higher yield strength, ultimate tensile strength and ductility. Yield strength and ultimate tensile strength of the composite reinforced by 27μm sized fly ash particles are lower than those of composite reinforced by 77μm sized fly ash particles. The fracture surface of the composites changes from particle "pull-out" from the matrix for the composites with small fly ash particle size (27μm) to particle fracture for the composites with large fly ash particle size (77μm).

## Acknowledgment

The work described in this paper was supported by Research Centre of Acharya Institute of Technology, Bangalore and BMS College of Engineering, Bangalore, India. A support from the Amruta Institute of Engineering & Management Sciences, Ramanagara, is also acknowledged.

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