Production of Al-4.5% Cu Alloy Reinforced Fly Ash and SiC Hybrid Composite by Direct Squeeze Casting

G.N.Lokesh, M.Ramachandra, K.V.Mahendra

Abstract*— Today the use of composites will be a clear choice in many instances especially in automobile and aerospace sector. Material selection in others will depend on factors such as working life span necessities, number of items to be produced, convolution of product shape, possible savings in assembly costs and on the experience & skills of the designer in drumming the optimum potential of composites. Composites produced using waste as reinforcements helps not only clearing environmental issues but also helps in increasing mechanical properties of the composites. One of the inexpensively available and also coming as waste form thermal power plant is fly ash. In the present investigation fly ash and SiC reinforced Al-4.5% Cu composites containing 2%fly ash with 2,4,6% SiC and 4%fly ash with 2,4,6% SiC fabricated by direct squeeze casting technique. The composites was analysed by measuring the hardness, tensile, compression, impact and wear behaviour. Microstructure of the composites was observed by scanning electron microscope (SEM). The results indicate that the hardness, tensile, compression, impact and wear resistance increases with increase in percentage of fly ash and SiC. Microstructure shows better bonding between matrix particle interface and no fracture observed.

***Index Terms*— Squeeze Casting, Fly Ash. Tensile Strength, Compression Strength, Wear.**

I. INTRODUCTION

Aluminium-based alloys are widely used in automotive aerospace and industries because of their low densities and good mechanical and tribological properties [1]. However, the relatively poor convulsion resistance of aluminium alloys has restricted their uses in such engineering applications [2]. Conventional monolithic materials exhibit lower strength and stiffness and hence composites substitute and dominant for the past four decades [3]. Liquid metallurgy processes have some difficulties including the uniform dispersion of the ceramic particulates, extensive interfacial reactions, and particulate fracture during mechanical stirring, whereas powder metallurgy processes make easy, the uniform dispersion of the reinforcements and the control of interfacial reaction [4]. However, the liquid-phase processes have lower manufacturing cost and are nearer net shape than solid-phase processes [5].

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Particulates or discontinuous-fiber reinforced Metal Matrix Composites (MMCs) present an opportunity for automotive manufacturers to improve performance and to reduce costs [6]. In liquid metallurgy, squeeze cast process is simple, economical and it can be automated easily [5]. The pressure infiltration process exhibit highest mechanical properties in cast products [7], whereas effect of squeeze pressure refines fine microstructure, low Coefficient of Thermal Expansion (CTE) [8], higher hardness, tensile strength [9], superior wear resistance [10], higher flexural strength and fatigue resistance [11], with higher fracture toughness and bending strength [12]. Fly ash particles are discontinuous dispersoids in the form of hallow spherical in shape used in MMCs, since they are low density and low-cost reinforcement available in large quantities as a waste in thermal power plants [13]. Fabrication of MMCs by casting processes is very promising for manufacturing near net shape components at a relatively low cost [14]. Al-fly ash MMCs are widely used in automobile applications due to its higher tensile, hardness, compression and wear resistance [15]. Al-alloy reinforced fly ash reveal superior damping characteristics [16] and increases mechanical properties [17]. Addition of fly ash decreases erosive wear but increases corrosion [18]. Squeeze cast of Al-fly ash is limited by many authors and J.Bienia et al. [14] compared gravity cast with squeeze casting of Al-fly ash reinforcement and stated that advantageous of squeeze cast for obtaining higher structural homogeneity with minimum porosity level, uniform distribution of fly ash and good interfacial bonding between matrix and fly ash. Al-alloy reinforced SiC particulates by squeeze casting is a promising composite accelerates hardness [19], tensile and fracture toughness [12], fatigue strength [20], flexural, stiffness and wear resistance [21] with low CTE and higher thermal conductivity [22]. The majority work reported in literature has been devoted to aluminium alloy with single reinforcement and not much work has been reported on the use of Al-alloy with two reinforcements casted by squeeze casting. Y. Q. Wang et al. [23] reinforced Al_2O_{3f} and SiC particulates in Al-alloy hybrid MMCs by squeeze cast and stated higher wear resistance and mechanical properties. In the present study an attempt has been made to squeeze cast Al-Cu alloy with two reinforcement fly ash and SiC to form hybrid MMCs with different weight percentage. The hardness, tensile, compression, impact and wear behaviour of hybrid MMCs were investigated. Microphotographs were taken by SEM to know the distribution of reinforcements.

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II. EXPERIMENTAL PROCEDURE

In this study, direct squeeze casting system was constructed for production of specimens. A stir casting setup which consisted of a resistance furnace and a stirrer assembly is used to synthesis the combination of matrix and reinforcements before squeeze. Al-4.5wt%Cu alloy commercially prepared was melted in a resistance heated muffle furnace and casted in a crucible. Table 1 shows the chemical composition of base alloy, analysed by optical emission spectrometer. The density of fly ash measured is 2.1 g/cm^3 with the particle size varying between 49 and 60µm. SiC particle size which is used to fabricate the composite had an average of 60µm and density is 3.2g/cm^3. Fig.1 shows the SEM micrographs of fly ash particulates.

Table 1. The chemical composition of the base alloy (wt. %)

Cu	4.51
Mg	0.061
Si	0.52
Fe	0.59
Mn	0.13
Ni	0.06
Pb	0.03
Sn	0.02
Ti	0.012
Zn	0.12
Al	Balance

Initially, Al-4.5wt%Cu alloy which is widespread commercial applications was charged into the crucible and heated to about 750°C till the entire alloy in the crucible was melted. The fly ash particles were preheated to 210°C for two hours to remove moisture. The SiC particles were heated at 400°C temperature for 2 h before addition into the melt. The cast iron mold of size 50mm diameter with 200mm length was used for the preparation of cast blanks. After the molten metal was fully melted, solid dry hexachloroethane degassing tablet was added to reduce the porosity. The stirrer was lowered into the melt slowly to stir the molten metal at the speed of 450 rpm. Various stirrer speeds, tilt angles and movement of stirrer from top to bottom in the crucible were used to obtain vortex strong enough to disperse the reinforcements into the melt [16]. The preheated fly ash and SiC particles were added to the vortex between liquidus and solidus temperatures at the rate of 25g/min during the stirring time with Mg (0.6wt %) were also added to ensure good wettability of particles[24]. The stirring was continued for another 1minute even after the completion of particle feeding. The temperature was also monitored simultaneously during stirring. Split cast iron die and tool steel ram were preheated to 400°C to avoid premature chilling. After through mixing of matrix and reinforcements, the melt was poured into preheated die cavity and solidification was carried out with a squeeze pressure of 110MPa for a period between 120 and 180 seconds [12]. The chemical composition of samples casted is shown in Table 2. As the matrix alloy is age hardening, the composites produced were subjected to T6 heat treatment [6, 25]. The castings were heated to 450°C for 12 hours, quenched in 100ºC water and reheated to 170ºC for 16hours and cooled in the furnace temperature. Hardness measurements were performed using a Brinnel hardness tester with a load of 10kgf as per ASTM-E10-01. Hardness values were averaged over eight measurements taken at different points on the cross-section. Tensile tests were carried out using samples prepared according to ASTM-E-8M-09 standard. These tests were conducted using a computerized universal testing machine (UTM) with 60KN capacity. Similarly compression strength were determined using a computerized UTM with an electronic extensometer as per ASTM-E9-89A standards. Online plotting of load versus extension was done continuously through a data acquisition system. Impact specimen was cut as per ASTM-E23 by diamond blade using CNC machine. Wear test was carried out using a computerized pin on a disc wear testing machine under ambient temperature conditions. Wear pins of 8mm diameter and 30mm heights were prepared and subsequently the weight loss of the materials was determined. Micro photographs were taken after wear test of each sample for SEM to examine the effect of the percentage of particle distribution.

Table 2. Measured chemical composition of squeeze cast samples (wt.%)

Sample		Composition
Sample 1	Base alloy	Al-4.5wt%.Cu alloy
Sample 2	Composite 1	2wt%Fly ash, 2wt%.SiC,
Sample 3	Composite 2	2wt%Fly ash, 4wt%.SiC
Sample 4	Composite 3	2wt%Fly ash, 6wt%.SiC,
Sample 5	Composite 4	4wt%Fly ash, 2wt%.SiC,
Sample 6	Composite 5	4wt%Fly ash, 4wt%.SiC,
Sample 7	Composite 6	4wt%Fly ash, 6wt%.SiC,

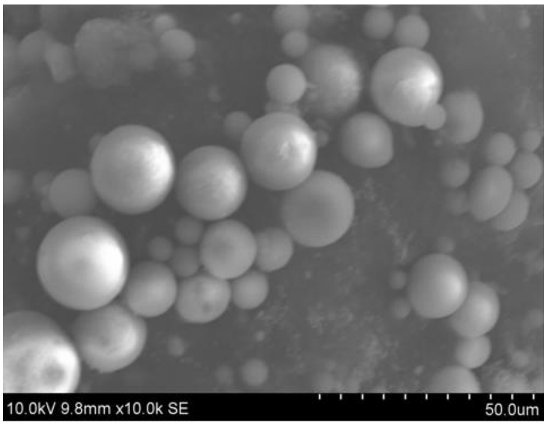

Fig.1 SEM of fly ash particulates

III. RESULTS AND DISCUSSION

A. Hardness

From Fig.2, the hardness of squeeze cast composite is higher than that of matrix alloy by about 5.5% approximately. The hardness increases with increase percentage of reinforcements which is in par with literature [24]. The application of pressure during solidification in squeeze casting minimizes porosity and makes the metal denser, making the matrix to resist surfacial plastic deformation, rendering higher hardness to the matrix.

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The dispersion of fly ash and SiC particles enhances the hardness, as particles are harder than Al alloy. The materials render their inherent property of hardness to the soft matrix. The hardness in squeeze casting conditions may be due to combined effect of denser matrix and hard ceramic particles [27]. The peak hardness of 114BHN was found to be for an addition of 4wt.% fly ash and 6wt% SiC particles in squeeze cast condition.

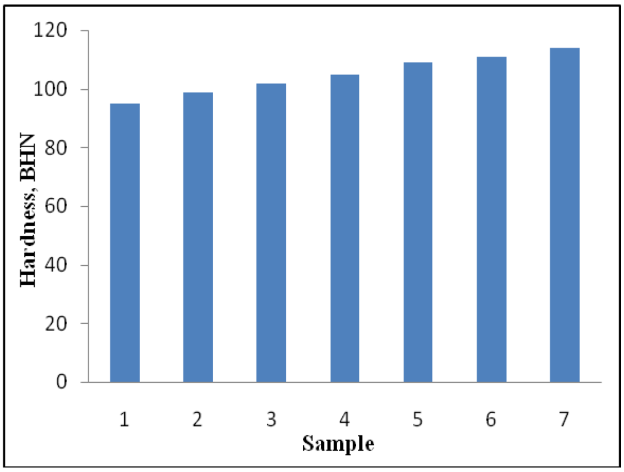

Fig. 2 Hardness of squeeze cast of base alloy and composite

B. *Tensile strength*

The influence of fly ash and hard SiC particulate content on the Ultimate tensile strength (UTS) of the MMC is shown in Fig.3. It is noted that the UTS increases with the addition of reinforcements. The UTS shows the peak value of 160MPa for 4wt.%. fly ash and 6wt.%. SiC and shows an increase of strength to 45.5% when compared to squeeze cast of base alloy. This is due to the hard and lighter microsphere of fly ash, which act as barriers to the movement of dislocation and refines the structure of matrix [28].

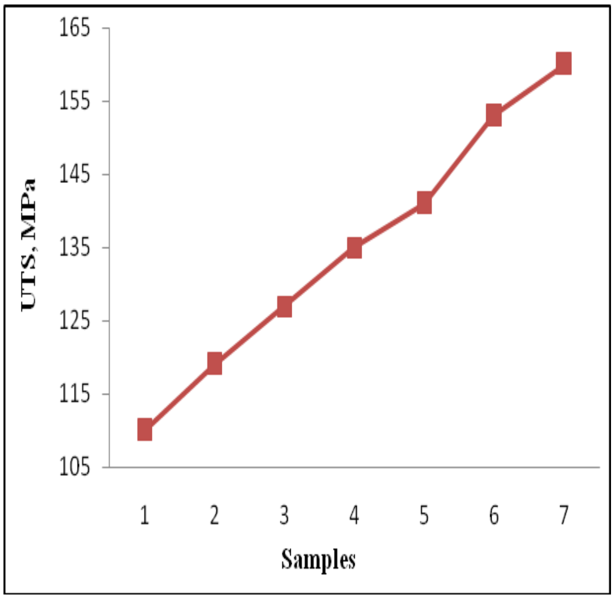

Fig. 3 Ultimate tensile strength of squeeze cast base alloy and composite

C. *Compression strength*

Fig.4 shows the results obtained from uniaxial compression as a function of fly ash and SiC particulate. Increase in percentage of fly ash and SiC increases the compression strength of composites. This is due to the hardening of the base alloy by fly ash particulates.
The SiC reinforcement has highest weight percentage and this may increase the density of the material which cause in increase in compressive strength. The squeeze cast exhibit higher compression strength and this may be due to compaction pressure applied during squeeze made the casting finer grain size and low porosity. The compression strength of squeeze cast base alloy is 564MPa and that of 4wt.%. fly ash and 6wt.%. SiC is 778MPa.which is 38% increase in strength. This could be due to the applied pressure while squeezing. The applied pressure attributed to eliminating of micro-pores in the alloy and microstructure refining enhancement of solubility of solute [29].

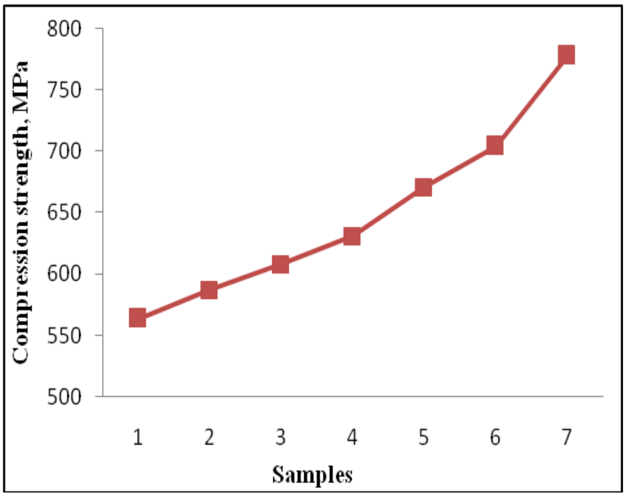

Fig. 4 Compression strength of squeeze cast base alloy and composite

D. *Impact strength*

From Fig. 5 the impact strength also increases with increasing fly ash and SiC content.

Fig. 5 Impact strength of squeeze cast base alloy and composite

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This may be due to the presence of hard fly ash and SiC particulates. The impact strength shows higher values for higher percentage of reinforcements. This is due to the applied pressure during squeeze which gives homogeneous crystal structure and dendrite arms were broken down and fine-grained equiaxed microstructure will obtained by squeeze casting.

E. Wear behaviour

Fig. 6 shows the weight loss during wear test for different weight percentage of Al-4.5wt.%Cu alloy and Al-4.5wt.%Cu alloy reinforced fly ash and SiC MMCs for 10N load. Dry sliding wear behaviour of matrix alloy reinforced fly ash and SiC shows reasonable increase in wear resistance.

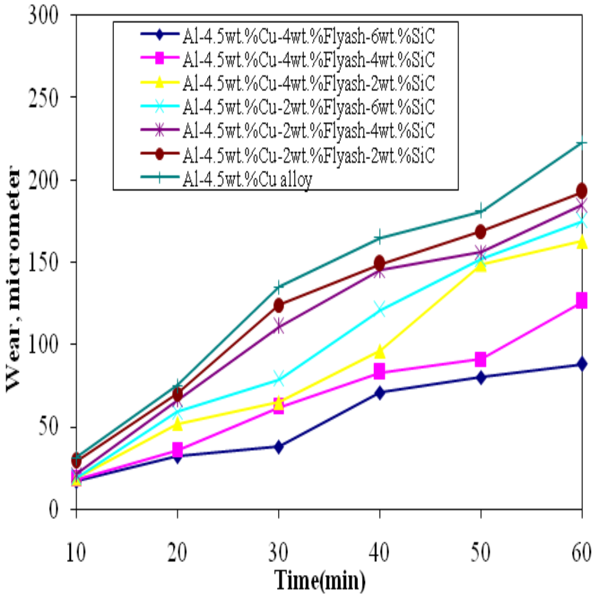

Fig. 6 Wear vs. time at various percentages of fly ash and SiC at 10 N load of casting

It is observed that addition of 4wt. % fly ash and 6wt. %.SiC shows lesser wear than other composites. The highest weight loss is distinct for matrix alloy and linearly the weight loss decreased by increasing the percentage of reinforcements. The wear resistance of the composites is considerably improved due to the addition of 6wt.% SiC particle. Also presence of 4wt.% fly ash strengthen the matrix and hence more wear resistance is observed and therefore volume of wear debris decrease with increasing percentage of reinforcements.

F. Microstructure

It can be seen in Figures (7 and 8) that, the presence of grooves of varying sizes was observed frequently on the worn surface. The worn debris particles are likely to act as third body abrasive particles. The fly ash and SiC particles trapped between the specimen and counterface cause microploughing on the contact surface of the composite [30]. The wearing surface is characterized by a significant transfer of material between the sliding surfaces. Fly ash and SiC could be dispersed inside the matrix alloy with better bonding due to which the wear resistance occurred. Also it is observed that matrix alloy reinforced up to 4wt. %fly ash and 6wt. % SiC for a load of 10N, there is no fracture initiation at matrix particle interface.

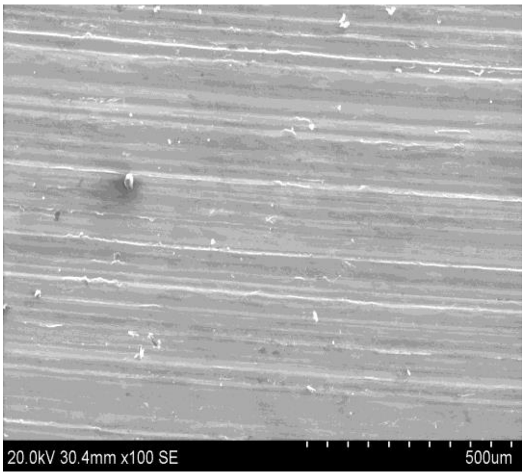

Fig. 7 SEM micrograph of worn sample of matrix reinforced 2%flyash, 6%SiC at 10N

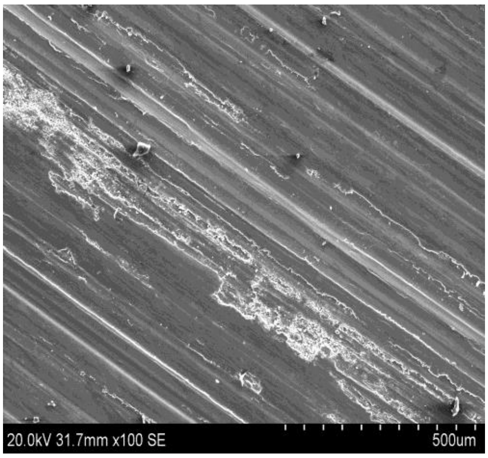

Fig. 8 SEM micrograph of worn sample of matrix reinforced 4%flyash, 6%SiC at 10N

IV. CONCLUSION

Effect of squeeze cast and addition of reinforcements on mechanical properties of fly ash and SiC particulates reinforced Al-4.5wt.%Cu composite have been investigated in this paper. The test results showed that the fly ash up to 4% and SiC up to 6% by weight can be successfully added to Al-4.5wt.%Cu alloy by squeeze casting route to produce composites. Addition of flyash and SiC improves the hardness of the composite. Ultimate tensile strength, compression and impact strength also increases with an increase of fly ash and SiC particulates. The wear resistance increases with an increased percentage of flyash and SiC particulates. Microphotographs shows better bonding between matrix, fly ash and SiC with no fracture observed at matrix particle interface. Overall, Al-4.5wt.%Cu alloy can be considered as a suitable matrix for the development of fly ash and SiC reinforced aluminium based composites by squeeze casting.

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