

PROCESSING AND CHARACTERIZATION OF SiC_p REINFORCED ZINC-ALUMINUM METAL MATRIX COMPOSITES AS BEARING MATERIALS

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ABSTRACT

Master alloy of Zn, Al, and Cu were used as matrix material and high purity SiC particles were used as reinforcing material. Three different metal matrix composites were produced with 2, 5, and 8 %SiC. After preparation, their microstructures were observed by means of Optical Microscope. Wear tests were performed in a unidirectional “pin on disk” apparatus. Thereafter, the worn samples were characterized with the help of Scanning Electron Microscope. The wear rates in an ambient air were calculated as a function of sliding distance. Results showed that wear rate decreased with increasing amounts of SiC. The compression tests at room temperature were carried out. It was found that, as the SiC content increased, the compressive yield strength decreased significantly.

Keywords: Zinc-Aluminium Alloy Composite, Metal Matrix Composite, SiC, Wear.

1. INTRODUCTION

Metal-matrix composites (MMCs) have recently become candidates for critical structural applications because of some superior mechanical properties such as higher elastic modulus, tensile strength, high temperature stability, fatigue and wear resistance in comparison to unreinforced alloys. During the past few years, zinc-aluminum alloys (ZA) have been subjected to considerable industrial use. Zinc-aluminum alloys (ZA), as an alternate alloy to aluminum, copper and cast iron, possess improved properties such as tensile strength, resistance to corrosion and wear, excellent castability. However, these alloys have some disadvantages such as high density and poor mechanical properties at elevated temperatures [2]. To increase the strength to weight ratio for these alloys, one of the best ways is to make a composite using low density, high strength and cheap fibers. For this purpose, in the present study ZA27 and SiC particles were chosen as matrix and reinforcement, respectively.

Compared to the continuous fiber reinforced composites, particulate reinforced MMCs offer several advantages such as improved isotropy, ease of fabrication, and the lower cost. Particulate reinforced MMCs can be fabricated by means of the foundry route or via the Powder Metallurgy (PM) process. The former technique has the advantage of lower fabrication costs, while the powder metallurgy route generally gives better mechanical properties. Zinc-based matrix composites are

most concerned in this literature. Zinc alloys are feasible matrix materials owing to their good bearing and wear properties, lower casting temperatures and lower cost.

Among the Zinc based foundry alloys, the Zinc-Aluminum (ZA) family of alloys has increasingly been used in past decades. ZA27 (26 to 28 pct Al, 2.0 to 2.5 pct Cu, and 0.01 to 0.02 pct Mg) alloy was originally developed as a high strength gravity casting alloy and is extensively being used in bearings and bushings for high-load low-speed applications and in automobile engine mounts and drive trains [3]. The additions of small amounts of copper and magnesium in ZA27 alloy are made to achieve the best combination of mechanical properties and castability. ZA27 alloy has the highest tensile strength compared to other Zinc and Aluminum based alloys.

It has been found that incorporating SiC in ZA27 alloy results in enormous property enrichment. The lower density and higher strength of the SiC particles compared with that of ZA27 give several important property enhancements. It combines higher strength to weight ratio as well as lower wear rates. In this study the reasoning behind these characteristic features were tried to investigate. The study emphasizes to improve the wear properties of Zinc-Aluminum (ZA) foundry alloy.

2. PROCEDURE

2.1 Processing of Composites

2.1.1 Starting Materials

For master alloy preparation commercially pure Zn (99.99%), Al (99.95%), Cu (99.95%), and Mg (99.99%) was used. The reason for using these high purity metals was to minimize the amount of impurities. As the tolerance limit for impurities is very low in ZA27 alloy the production process was so controlled to maintain it precisely.

For preparing composites, silicon carbide (SiC) particles of 200 meshes were used. In this study, three different composites were produced comprising of 2, 5, and 8 wt % SiC.

2.1.2 Preparation of Master Alloy (ZA27)

Preparation of zinc-aluminum alloy needs attention. The melting point and the specific gravity of both of the metals producing the alloy are very different. So it needs care to melt and solidify them. The specific gravity of Al is 2.7 g/cc and that of Zn is 7 g/cc. So there is wide discrimination in their densities. The melting point of Al and that of Zn is 660 °C and 420 °C. Moreover, the boiling point (907 °C) of Zn is not so far from that of the melting point. All of the above mentioned constraints impose greater precision of work to be performed. To overcome these limitations certain logistical improvement in techniques were done. In this study, pit furnace was used to melt the alloy. Aluminum was first melted. After it had been melted completely, preheated copper wires were added to aluminum. Copper has a higher melting point (1083 °C). Melting copper at around 800 °C is not an easy task. In fact, it is impossible. For this reason, it was added to Al, so the combination of them helps decrease the melting point. Afterwards, preheated zinc was added in small quantities into the crucible. Addition of Zn to the melt requires close control of temperature, because if it is above the boiling temperature of zinc then there will be a certain amount of zinc loss. This emphasizes to add zinc in quantity more than that is actually needed for maintaining the composition. The reason behind adding zinc in small quantities is that if a large amount of zinc is added, then there may be a risk of thermal shock in the crucible. The melt can get solidified in certain portions of the added zone. Also a drastic loss of temperature in those zones can occur. So in order to overcome this problem and to ensure a steady temperature in the melting unit Zinc was added in small quantities. After mixing the metals by stirring, the melt was taken out of the furnace into a ladle. At this point the slag layer existing on the upper surface of the melt was removed. Small amount of magnesium was added in the ladle for maintaining the composition of the desired alloy. Magnesium was added at the eleventh hour when it is time for the melt to be poured in the sand channels. The magnesium being in small amount was packed in a thin aluminum foil tied with nichrome wire, and sink to the bottom of the ladle.

2.1.3 Chemical Composition of Master Alloy

The composition of the master alloy was obtained by

a spark spectrometer. The master alloy sample was prepared by polishing on emery papers so that the both surfaces became parallel.

2.1.4 Preparation of SiC Composites

Here, SiC reinforced composites were produced by melt stirring method. The matrix alloy used in this study was ZA27 alloy. SiC particles with sizes of 200 meshes were preheated at 800 °C (1 hr) and added to the molten master alloy (ZA27). The weight percent of SiC were 2, 5 and 8 %. The preparation of this metal matrix composite is not a very easy task. As there is very sharp specific gravity difference between the SiC particles and the ZA27 alloy there arise a great probability of floating up of SiC particles during mixing. To overcome this problem and to mitigate the situation several prototypes of different additions of SiC were performed to ensure effective parameters for obtaining a good distribution of particles. In this study, SiC were added in the particulate form due to some advantages over the continuous fiber reinforced composite. Improved isotropic property, ease of fabrication and lower cost are the leading criteria for choosing particulate form of SiC. The whole process of manufacturing SiC reinforced composite is shown in Fig. 1.



Fig 1. Preparation of SiC reinforced composites (a) Mechanical mixing of particles with ZA27 and (b) Pouring of freshly prepared composite in metal mould

The master alloy was first melted at 750 °C and then it was brought towards a stainless steel shaft stirrer. The alloy was melted in a medium crucible and each time approximately 1 kg of sample was melted for the desired SiC particle addition. A thermocouple (chromel-alumel) was used to measure and control the temperature during the preparation. After doing several dummy test a reasonable conclusion was made for setting up the mixing time, the temperature for addition of SiC particles, and the pouring temperature of the viscous melt into the metal mold. For effectively setting up the parameters we have done several dummy tests. After we have concluded effectively all the important parameters mentioned above, SiC reinforced composites were made. The SiC particles addition was made slightly before the melt gets viscous enough to be solid. The time for each of the addition was about 4-6 minutes. After the addition of particles the melt was stirred for some time for the proper distribution of particles inside the matrix. The pouring temperature for the composites was around 520 °C. In this process, the molten metal was stirred to create a vortex to which SiC particles were added. It was then immediately poured into two metal moulds made of mild steel. The reason for

choosing metal mould is to ensure faster rate of solidification so that the distribution of SiC particles become uniform throughout the matrix. The other advantages of metal mould are better surface finish, good dimensional tolerance, and better productivity. Metal mould also possesses some disadvantages. The solidified product is more prone to blow holes etc.

2.1.5 Composition of the Composites

Chemical Analysis

In order to get the SiC content in the composite chemical analysis was performed. The composite bars obtained from the melt stirring method was analyzed by getting chips from the cast bar from different locations (top, middle and bottom of the bars) by a lathe machine and then 1 gm of sample for each of the composite was taken. It was dissolved in 20 ml hydrochloric acid diluted with 30 ml distilled water. It was heated to enhance the rate of reaction. Then it was filtered by two filter papers of equal weight. Afterwards, it was cleaned with warm water to remove the acid. It was then dried in an oven at 100 °C for 1 hour. The difference in weight of the two filter papers, one empty and the other containing SiC particles gives the weight of the SiC particles.

2.2 Characterization by Optical Microscope

The micro-structural characterization was performed by an optical microscope. The samples were prepared by polishing with emery papers 3, 2, 1, 0, 2/0, 3/0 and 4/0. After that, it was further polished in a fine grade wheel polisher. Afterwards, when the surface became scratch free, it was cleaned with acetone and investigated under optical microscope.

2.3 Rockwell B Hardness Test

In this study, we have measured Rockwell B hardnesses for the master alloy and all of the three composites with great care to minimize inaccuracies.

2.4 Wear Test

2.4.1 Wear testing apparatus

Wear tests were performed in a unidirectional pin-on-disc apparatus according to ASTM G 99 - 04. Fig. 2 shows the apparatus that is used in this study. The wear pin specimen is clamped in a holder which is attached to a loading arm. The load is applied directly on top of the pin holder. The sample and load containing arm is free to move in the horizontal plane. A force sensor just touches this arm to stop the movement of arm in the sliding direction during wear test. The force transducer is connected to an amplifier which is calibrated to display tangential force experienced by the pin directly. Counter body in the form of a disc which is fixed on a brass disc mounted on a vertical shaft. This shaft is connected to an AC. motor through a belt-pulley arrangement. The speed (rpm) can be varied by changing pulley-belt coupling.

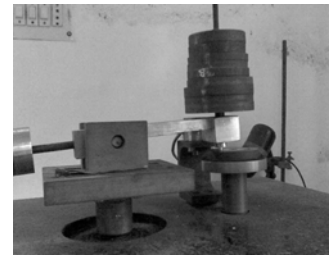


Fig 2. Wear testing apparatus

2.4.2 Preparation of Sample

The wear samples were prepared after the casting of bars had been performed. The bars were turned into the shape of the wear sample by a lathe machine. Fig. 3 shows the schematic view of the wear sample

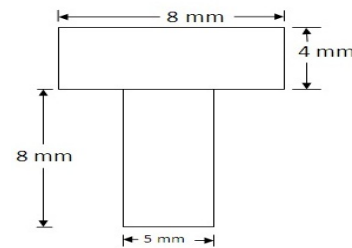


Fig 3. Schematic view of the wear sample

After the preparation of the sample into the desired shape, wear surfaces were polished in the 1, 0, 2/0 emery papers respectively. Then the samples were polished in a fine grade wheel polisher. After that, they were cleaned with acetone. The reason for polishing is to ensure a smooth surface and also an aligned surface. As wear test was performed on a "Pin on disk" apparatus. Here it needs extensive care for the surfaces of the wear samples. The surfaces should be very precisely aligned in order to ensure good contact between the surfaces and the disk rotating underneath the surfaces at a predefined velocity.

The overall contact between the surface and the cast iron disk rotating beneath it gives good results and ensures a parallel surface afterwards. So preparation of the wear samples surfaces is a very mandatory schedule.

2.4.3 Test parameters

The wear tests were carried out in a constant load condition and a constant sliding velocity. The duration of contact was also constant. The only variable was the composition of the metal matrix composite varying in its SiC content. The wear samples were made into contact with cast iron disks comprising hardness around RC 50 (equivalent to HRB 117).

The load which was constant throughout the experiment was 4 kg. The duration of contact for each sample was 35 minutes. The revolution of the disk rotating was 670 rpm, resulting in 1.37 m/s sliding velocity.

2.4.4 Wear rate

The wear rate was taken as weight loss as a function

of sliding distance. That is weight loss per unit sliding distance was taken for each of the composite. The sliding distance for each sample was same and was measured by the following formula:

$$\text{Sliding distance} = 2 \pi r N t$$

Where, r = radius of the sliding path

N = revolution per minute of the disk; which is 670 rpm

t = time of contact of each sample

By formulating the calculation with the above formula the sliding distance obtained was 2.874 km (2874 m). The rate of wear was calculated by dividing the weight loss with the sliding distance.

2.5 Characterization of Worn Sample

The samples after it had been wear tested were cleaned to remove any wear debris attached to them, so that no marks form on the worn surfaces. After that they were cleaned with acetone. The samples treated this way were put into an Scanning Electron Microscope to observe the surface features.

2.6 Compression Test

Compression tests were performed at room temperature according to ASTM E 9-89 a. The tests were done on cylindrical specimens (13 mm in diameter and 25 mm in height) using universal tensile testing machine. The desired dimension of specimens was made from as-cast composites by cutting and machining. The flat surfaces of the specimens were made very smooth with emery papers and then cleaned with acetone. Dry graphite powder was used as lubricant. Strain rate of 0.016 mm/mm.min was applied. Compressive stress-strain curves were plotted and from these graphs, 0.2% compressive yield strengths were measured.

3. RESULTS AND DISCUSSION

3.1 Composition Analysis

3.1.1 Spectroscopic Analysis

A sample was taken from the master alloy. The sample for this analysis was prepared with care. The surfaces subjected to spark were perfectly parallel and lustrous. The composition obtained in this analysis is shown in tabular form in Table 1.

Table 1: Result of spectroscopic analysis

Zn	Al	Cu	Mg	Fe
73.17	25.1	1.6823	0.00377	0.02738
Sn	Pb	Cd	Ni	Mn
0.00061	0.00468	0.00199	0.00662	0.00233

The chemical requirements for ZA-27 alloy according to ASTM B 86 – 03 is given in Table 2. According to ASTM B 86 – 03, ZA-27 may contain Cr, Mn or Ni in amounts of up to 0.01% each or 0.03% total. No harmful effects have ever been noted due to the presence of these elements in up to these concentrations.

Table 2: Chemical requirements for ZA-27 alloy

Al	Cu	Mg	Fe, max	Pb, max	Cd, max	Sn, max	Zn
25-28	2-2.5	0.01-0.02	0.075	0.006	0.006	0.003	Remainder

We can see that the zinc, aluminum, copper and magnesium content were 73.17, 25.10, 1.6823, and 0.00377 percent respectively along with the impurities Fe, Pb, Cd, Sn each below the maximum concentrations allowed for them. The amounts of Cu and Mg were lower than that mentioned in the ASTM standard.

Since the alloy was not completely in congruence with the ASTM standard, we will designate it as Zn-25Al-1.7Cu.

3.1.2 Chemical Analysis

Chemical analysis was performed on three composites. The composition obtained from this analysis was 2 wt% SiC, 5 wt% SiC and 8 wt% SiC.

3.2 Microstructure of the Composite

The microstructures obtained for different compositions of the composites are shown in Fig. 4.

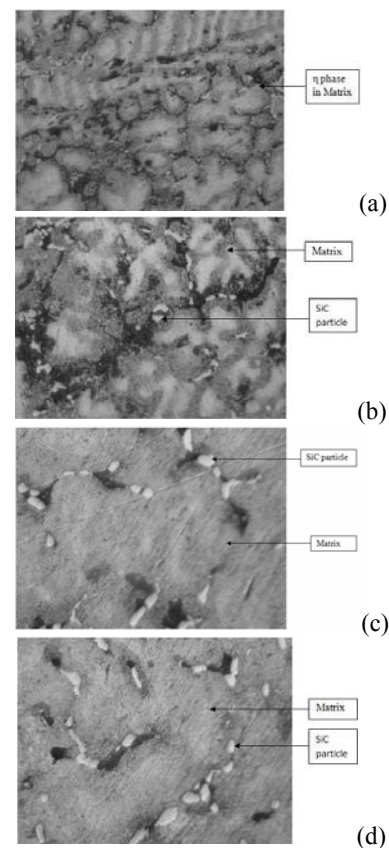


Fig 4. Microstructure (a) master alloy [$\times 400$], (b) 2 wt% SiC [$\times 400$], (c) 5 wt% SiC [$\times 400$], (d) 8 wt% SiC [$\times 400$]

In the case of master alloy, the bright white phase is η which is rich in Zn and the other is α phase which is rich in Al. In the composites as the percentage of the SiC increased in the composites, there appeared more SiC hard particle phases. The phases of the SiC particles are white in color and distributed in the matrix material. The distribution of the SiC particles in the metal matrix can be identified in the microstructure. In this study much care was taken for the right distribution of the SiC particles in the matrix.

3.3 Rockwell B Hardness

The Rockwell B hardness of the unreinforced and reinforced composites is shown in Fig. 5.

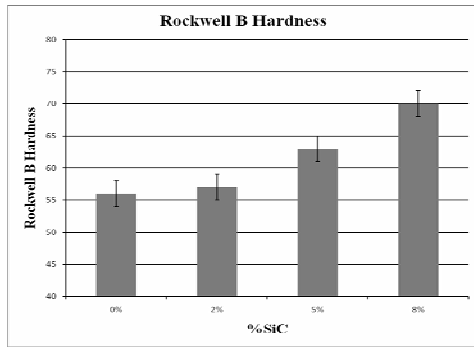


Fig 5. Effect of SiC content on the Rockwell B hardness of the MMCs

The hardness of the composites increased with increase of the amount of reinforcing particles. This was due to the grain refinement and also the hard SiC particles that were distributed. Hardness of composite with 2% SiC is similar to hardness of the matrix alloy (as-cast) while hardness of other two composites with 5 and 8 wt. % SiC was higher.

3.4 Wear Test Result

The dry sliding wear tests were carried out at a load of 4 kg, a speed of 670 rpm (1.37 m/s) and a sliding time of 35 minutes. The weight losses were measured after sliding for 35 minutes. Wear rates were calculated by using the weight loss data. Fig. 6 shows the graph of wear rates versus %SiC.

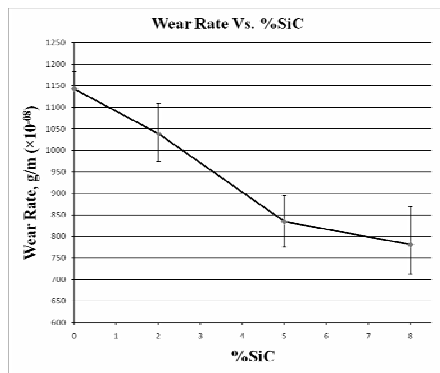


Fig 6. Variation wear rate with SiC content

From Fig. 6, it is clear that the wear rate decreased substantially with the increase of SiC particles content of the composites.

3.5 Morphology Of Worn Surfaces

For studying the characteristics of worn surfaces, Scanning Electron Micrographs of the worn surface of the samples were taken. In Fig. 7, the micrographs of the worn surfaces of the composites are shown.

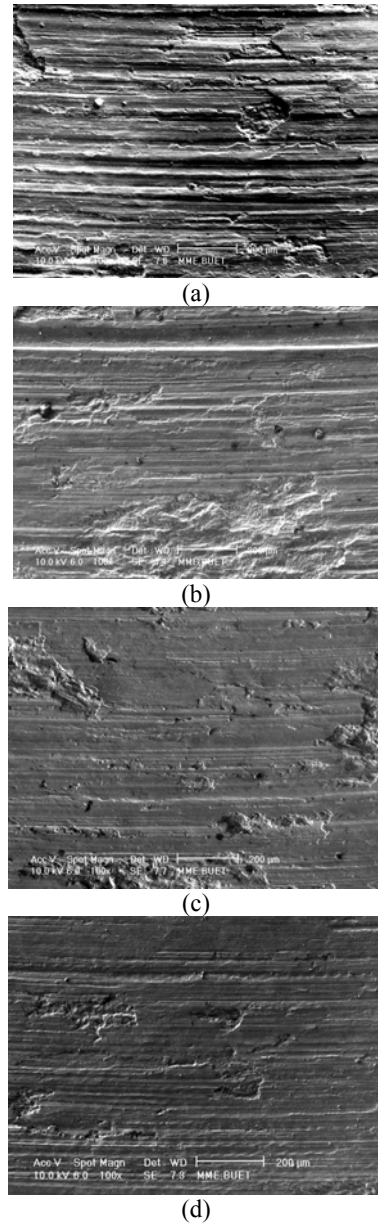


Fig 7. SEM image of the worn surfaces (a) Master alloy, (b) 2 wt% SiC reinforced composite, (c) 5 wt% SiC reinforced composite, (d) 8 wt% SiC reinforced composite

From Fig. 7, we see that the unreinforced alloy sample has deep and coarse grooves on the worn surface. The addition of SiC particles into the alloy increased the

hardness of the alloy. Also, the SiC particles hinder the ploughing during wear. The grooves became shallower as the content of SiC particles were increased in the composites.

3.6 Compression Test

Compression tests were carried out at a strain rate of 0.016 mm/mm.min. The 0.2% compressive yield strengths of master alloy and composites with varying amounts of SiC are shown in Fig. 8.

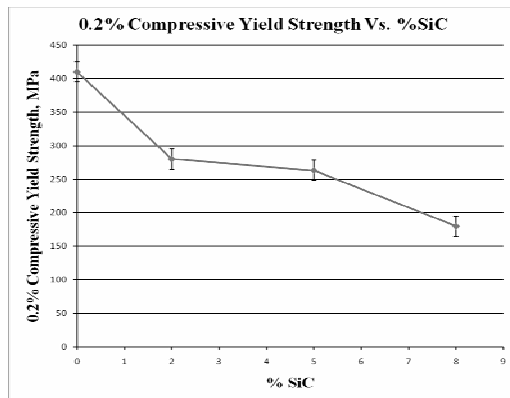


Fig 8. 0.2% Compressive yield strength Vs. % SiC

The compressive yield strength decreased with increasing SiC content. The lower compressive strength of composites may be due to the negative effect of microcracks formed due to the SiC particles [1].

4. CONCLUSION

(a) The alloy that was chosen for performance evaluation was ZA-27 foundry alloy. This alloy has very good bearing properties. In order to increase the bearing properties to a greater extent we have incorporated with a particulate form of high strength SiC. Zn-25Al-1.7Cu was produced by gravity die cast method in metal mold. Zn-25Al-1.7Cu/2% SiC, Zn-25Al-1.7Cu/5% SiC and Zn-25Al-1.7Cu/8% SiC composites were produced by melt stirring method successfully. The distribution of particles through the matrix is found fairly uniform.

(b) Hardness tests showed that the hardness of the Zn-25Al-1.7Cu alloy composite increased with the increase of SiC particle content.

(c) Wear rates decreased substantially with the increase of SiC particle content in the composites.

(d) Zn-25Al-1.7Cu alloy exhibit higher compressive yield strength with respect to Zn-25Al-1.7Cu alloy/SiC composites. For composites, compressive yield strength decreased with the increase of SiC particle content.

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