Tribological studies and Microstructural characterisation of SiC and Fly Ash Particles Based Aluminium 2024 alloy Composites Prepared through Stir Casting Route

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Abstract. Aluminium and its alloys have excellent characteristics such as low density, high ductility and appropriate strength. In the marine, automotive and high-speed train sector, they find extensive applications. The volume percentage of metal matrix and reinforcement material and also the method of manufacturing the composites are the vital factors in making composite product. Composites of a metal matrix (MMCs), such as SiC and Al strengthened fly ash particles, are most widely used because of their excellent high hardness, high strength, corrosion resistance, stiffness and wear properties. The high strength and rigidity of AA 2024 alloys are well known. The high specific strength of such alloys with suitable reinforcement gives better yield properties and finds various applications at a reasonable cost. This article includes the study on mechanical and microstructural behaviour of AA 2024 metal matrix composites by reinforcing SiC and fly ash particles.

Keywords: Stir Casting, Metal Matrix Composites, Fly Ash, Silicon Carbide (SiC), Microstructure, Hardness

1. Introduction

Now a days the traditional heavy materials components have been replaced by modern lightweight composite materials which are economical, high specific strength used in various applications. The stiffness, strength and hardness of composite materials are highly dependent on the type of reinforcement and percentage volume in the base matrix. In the modern era throughout the globe, different structural and vehicle manufacturers are concentrating on innovative wear resistance component and replace the cast iron by aluminium based composite material in various uses [1-2, 15-17]. Composites materials based on Al as base matrix and reinforced by various secondary particles like; B2C, SiC and fly ash had been done by various scientists and researchers. It is found that the Al-based composites have low wear rate, high thermal conductivity as per requirement, low density and higher heat capacity potential comparing with traditional steel [3-5]. The effect of 20 vol. % SiC reinforced AA359 aluminium amalgams has shown higher wear resistance in an arid sliding environment [6].

The production of green components has been used to accumulative responsiveness environment worldwide. Fly ash generally obtained from the pulverized coal burning at various coals based thermal power plants, the waste by-product of shows a very low density, therefore, very useful in producing high strength and low weight hybrid metal composites. Reprocessing Fly Ash saves energy and comparatively cheaper. Several researches have established and shown that Al-Fly Ash hybrid composites can enhance the rigidity, tensile strength, shock-absorbing capacity, and wear resistance but at the same decreasing the density of base matrix alloy [7, 8]. Fly Ash comprises mostly of Al2O3, SiO2, Fe2O3, and oxides such as P, Mg, and Ca, comprises less volume fraction of particles like; mullite, hematite and crystalline quartz [9].
Fig. 1. Simple schematic stir casting process diagram [10]

Usually, micron-level ceramic reinforcement is used to advance the MMCs properties. As known ceramic materials have very low thermal expansion coefficient (CTE) properties than other metal alloys, but because of amalgamation of such ceramic constituent may cause interfacial incompatibility among reinforcement and matrix. Amongst the several dispersions used, Fly Ash is found to be reasonable and lower density reinforcement existing in huge amounts as dense waste by-product through coal combustion at power plants [11].

2. Materials

2.1. Matrix Material

Al-Cu-Mg (AA2024) alloy with a theoretic density of 2.78 g / cm³ is used as metal matrix constituents in this study with excellent corrosion resistance. The alloy, however, has a relatively high thermal expansion coefficient and lower yield power, resulting in dimensional unpredictability in adverse environments such as thermal stress and various fluctuating stress [12]. This is one of his family's most prevalent alloys. Table 1 describes the chemical structure or composition of AA2024.

|         | Cu   | Mg   | Si   | Fe   | Mn   | Ni   | Sn    | Pb    | Ti    | Zn    | Al     |
|---------|------|------|------|------|------|------|-------|-------|-------|-------|--------|
| Present | 4.41 | 1.77 | 0.053| 0.664| 0.132| 0.073| 0.028 | 0.013 | 0.012 | 0.12  | balance|

2.2. Reinforcement Materials Used

The reinforcement used in the present work is Fly ash and SiC. Also known as carborundum is the SiC. This contains the SiC compound equation of carbon, silicon. Particles of SiC used in the 62 μm average particle size experiment [13]. Whereas, as coal combustion products, fly ash is usually termed as fuel ash of pulverized type, which incorporates ultra-fine elements that come with the flue gases.
from the plant that produces. For this study, 53 μm is used for the usual particle size of fly ash [14]. Table 2 indicates the usual constituents of fly ash.

Table 2. Main compositions of fly ash by wt. %

| Silicon oxide | Alumina oxide | Ferric oxide | Copper oxide | Calcium oxide | Titanium oxide | Magnesium oxide | Potassium oxide |
|---------------|---------------|--------------|--------------|---------------|----------------|-----------------|----------------|
| 51.41         | 29.64         | 5.38         | 4.87         | 2.83          | 2.53           | 1.71            | 1.53           |

Fig.2. SEM microstructure of AA2024+ (5% fly ash+5% SiC)

Fig.3. SEM microstructure of AA2024+ (5% fly ash+10% SiC)

3. Metal Matrix Sample Preparation

The stir casting process is utilised for producing the various hybrids metal composites materials. In this study Al2024 with secondary phase particles of Fly Ash and SiC are used in molten form by means of a mechanical automatic stirrer. Figure 1 has shown the typical stir casting arrangement. The newly developed hybrid composite is primed by two different reinforcing material by weight percentage. During the processing of fly ash and SiC in Al metal composites, the AA2024 block had kept in the furnace and permissible to melting at 750 ºC, till the constituents into the crucible were melted, consequently bypassing argon gas as an inert gas. Particularly, the SiC and fly ash both
mixtures are mixed to the preheated sample and the whole slurry was stirred at 600 rpm for 15 minutes. Sample casting was done at various fractions of secondary particles at a temperature of 725 °C (AA2024, 5% SiC + 10% SiC + 5% fly ash). Samples are processed according to the ASTM standard for the study of strength, wear and micrographs.

4. Experimental Details

4.1 Microstructural Analysis (SEM)

The generic metallographic technique is used for the analysis of the preparation microstructure. The sample was sensitively mechanized on a belt grinder to obtain a well-polished surface, free of scratches and deformation, after which it was polished using different grit size emery paper. Consequently, the polishing process is carried out using alumina powder for mirror finishing and graded for improvement contrast through Keller's reagent. The secondary electron microscope (SEM) was used to analyse these samples.

4.2 Energy Dispersive Spectroscopy Analysis (EDS)

Of newly formed composites, the EDS analysis is performed. The existence of Al, Cu, Mg, O and Fe in the composites is shown in figure 4. In addition, Figures 2 and 3 clearly show the presence of fly ash and SiC materials. Oxygen traces have also been detected which may or may not be due to the composites being fully covered with argon gas.

![Fig.4. EDS Spectrum of composite](image)

4.3 Hardness Test

The Vickers hardness test was conducted on the newly formed composite samples. An average load of 3kgf was applied. A Diamond indenter was used for indentation. Dwell time was retained at 20 seconds and speed of indentations was 50 µm/s. Tests were conducted at five different positions and taken the average of all value. The diamond indenter marks the deep and wide indentation to obtain the result of the hardness over a wider material surface, which gave a precise value for structures with several particles and any indiscretions in the consistency of the material. Among all these are the best methods to obtain micro-hardness of materials and is most beneficial for materials with structures that are dissimilar.
4.4 Wear Test

The wear test sample is 8 mm in diameter and 28 mm in height. Aside of the workpiece is required to perform a completely smooth wear test on the pin-on-disc tester device. Finishing was done manually using emery paper. Use three separate emery papers 1/1000, 2/1000 and 3/1000. Using 1/1000 grit size emery first in this process, thereafter 2/1000 grit and then with 3/1000 to complete the test. During the entire process, the specimen must be held straight. In order to test the wear, a pin-on-disc type device has been used. The spinning disc consists of 32EN steel materials with the HRC 60 hardness rating. Sliding wear tests were conducted with load 1 kg on track diameter 100 mm, sliding speed held 640 rpm for 5 minutes. The wear rate was conducted on a dry sliding wear tester that is defined by weight loss rate measurement. The pin’s weight loss is converted by sample size into volume loss.

![Vicker Hardness (HV)](image)

Fig.5. Hardness variation of fly ash and SiC in hybrid composites with weight fractions.

5. Results and Discussion

5.1 Analysis of Micro-structure

Analysis of materials has been done using a Scanning Electron Microscope (SEM) microscope, which has objectives to obtain different magnifications i.e. 50X to 1000X. SEM is used for highly magnified sample analysis. It can be perceived from the SEM images that the SiC and fly ash comprises of particles with various size and shapes. The mean particle size obtained is around 62 μm for SiC and 53 μm for fly ash respectively. The SEM images have shown that there is homogenous dispersal of SiC particles shown in figure 2 and 3. The fly ash distribution is rather non-homogenous dispersal and this is because of the lower density of fly ash particle.

5.2 Hardness Measurement

The measurement of hardness composite material with fly ash and SiC particles reinforced were executed by means of Vickers microhardness tester. The hardness value results in different reinforcement's volume fractions is revealed in Figure 5. The results showed that the increase in hardness as the SiC weight fraction increases as well. This is the fact that in the matrix composites, rigid SiC particles add more stiffness relative to fly ash. The main cause of that hardness is the hard SiC reinforcement particle which acts as a dislocation obstruction within the base alloy matrix.

5.3 Wear Testing

In order to test the wear rate a pin-on-disc sliding wear tester device has been used. During the testing, ASTM G99 has been followed. Specimen of 8 mm diameter, has a length of 28 mm has been prepared, then polished and etched metallographically so that a very smooth surface can be achieved. Wear tests were conducted with loads of 10, 20, 30 and 50 N, and sliding distance of 500, 1000, 1500, 2000 m at a constant sliding speed of 650 rpm at ambient temperature. Tests have been performed at rack diameter of 80mm on the 32EN steel hardened disc with 60 HRC by putting above-mentioned
load. The surface finish of the counterface is 2 µm. At room temperature, both tests were performed. Due to the specified sliding speed and sliding distance, the time interval for the test is deliberated. The weight loss during wear testing can be measured by taking into account the sample weight before and after the wear test, as well as the volume loss. The results of the wear test are displayed in Figure. 6(a) and 6(b). From the figure, it is concluded that by cumulative the wt. % of SiC particles the wear rate is decreased. Moreover, the same result was obtained for increasing the sliding distance also.

![Wear rate V/S % Reinforcement](image)  
**Fig.6 (a)** Wear rate variation for various sliding distance at constant sliding speed.

![Wear rate V/S % Reinforcement](image)  
**Fig.6 (b)** Wear rate variation for different loads at constant sliding speed.
6. Conclusion

The stir casting process has used to manufacture metal composites with reinforcement as SiC and fly ash. Samples of composites are formulated in two separate fractions of reinforcement weight. The hardness measurement; wear rate testing and microstructural examination were performed. The SEM results exposed that there is homogeneous dispersal of SiC element and rather a random dispersal of fly ash constituent part in AA2024 matrix composites. The wear resistance and hardness increases by increasing the reinforcement weight fraction. For automotive and aerospace system applications, the assessed outcomes in this investigation are helpful. The findings of this paper can also be used as a basis for industrial waste application such as fly ash for the development of hybridized composites in aluminium.

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