Processing and testing of Aluminium composites with flyash and SiC as hybrid reinforcements

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Abstract. The current project work lays emphasis on the manufacturing and mechanical testing of an aluminium, Silicon Carbide, fly ash hybrid composite. The metal matrix selected were aluminium and fly ash, Silicon Carbide constituents in different percentage composition were reinforced in it to manufacture the required hybrid metal matrix composite (MMC). Stir casting method was used to manufacture the MMC with (0, 2.5) (2.5, 0) (2.5, 2.5) % weight of fly ash and Silicon Carbide constituents in aluminium. Tribological analysis of the tribopairs formed between the smooth surfaces of cast iron disc and smooth MMC pin has been taken into consideration, friction force and wear of the MMC were evaluated by using a Pin-on-disc setup. Furthermore the morphological study and mechanical properties were evaluated as per ASTM standards. It was observed that the MMC with (2.5, 2.5)% weight of fly ash and SiC content in aluminium matrix results in higher hardness value and it is also noticed that the hybrid MMC shows very superior wear resistant properties and can be used in applications of disc brakes of two wheeler automobiles.

1. Introduction
Aluminium based metal matrix composites have significant potentials in the area of structural, aerospace, automobile and shipbuilding applications due to its good strength to weight ratios. A metal matrix composite is composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramic or organic compound. The project involves the comparative study of addition of heat treated flyash (F class) in pure Al and Magnesium metals along with traces of Silicon Carbide. Aluminium is the world’s most abundant metal and it is the third most commonly found element and thus comprises of 8% of the earth’s crust. For this project Aluminium-H30 also called as 6082 aluminium alloy has been used. The alloy belongs to the wrought aluminium-magnesium-silicon family which is one of the most commonly used alloy in this series. Fly ash is one of the residues formed post the combustion of coal. It is an industrial byproduct which is recovered from the flue gas of coal burning electric power plants. Background study by government of India states in its article that “Generally one acre land is needed per M.W. of power production. The Ministry of Power, Govt. of India estimates 1800 million tons of coal use every year and 600 million tons of flyash generated by 2031-2032. Hence these facts suggest that there is flyash in abundance which is not being fully used to its potential of being developed as a cost saving material. Depending upon the source and makeup of the coal which is being burned, the constituents of the fly ash produced may vary considerably, but all fly ash includes substantial amounts of silica (silicon dioxide, SiO2) comprising of both amorphous and crystalline and calcium oxide. Generally, fly ash consists of SiO2, Al2O3, and Fe2O3 as major constituents and oxides of Mg, Ca, Na, K etc. as minor constituents. Several researchers made different trails with the
varying compositions of aluminium and flyash in their studies. M.Ramachandra.et.al in their study suggested that with inclusion of flyash as the reinforcement in matrix of aluminium, good wear behaviour was observed. The resistance to wear was found to be increasing with the raise of weight percentage of fly ash content. Production method was used was stir casting method [1].

Sharma VK et al [2] in their study published in 2017, revealed that inclusion of fly ash as reinforcement in matrix of aluminium a comparative raise in coefficient of friction was observed in the resulting MMC. The production method used was stir casting. P Garg et al [3] in the study published in 2019. Concluded that when alumina reinforcement in matrix of aluminium. MMC was produced by stir casting and powder metallurgy method. Also the resulting composites exhibited that the in-situ metalized reinforcement stages are thermodynamically balanced, free of surface impurity and dispersed more uniformly in matrix. Resulting in the more steady in the particle matrix bonding. K A Babu et al [4] in their study published in 2018, proposed that SiC/Flyash reinforced with aluminium results in composites with greater mechanical characteristics having lesser porosity as well as densities. Production method used was stir casting. Shanmughasundaram et al [5] in their study published in 2011, indicated with the increase in Flyash content the density of the composite was reduce , weight reduction high proportion of fly ash reinforcement shows the poor resistance to corrosion, the production method used was stir casting.

Silicon Carbide (SiC) is the only Chemical compound formed between carbon and Silicon. It is originally manufactured by the high temperature electro-chemical reaction between Sand and Carbon. [6] Silicon Carbide due to its excellent abrasive properties has been used in grinding wheels and other abrasive products for a long time. It finds its application in abrasives, refractories, ceramics and numerous high performance uses. The material has potential to be developed into a polymer with high wear properties. The major benefits of SiC usage are lighter weight and higher strength, precision surface treatment, cost effectiveness in production. The basic need of the project is seen to minimize the wastage of industry which is frittered away and there is little but scope of reuse. This project aims to manufacture a two wheeler disc break with the use of Aluminium H30 matrix, Fly ash F-class and SiC as hybrid reinforcements. Disc brakes in two wheelers require highly strengthened materials with good wear resistance, hardness, heat dissipating and low coefficient of thermal expansion. Usage of a hybrid composite ensures the presence of suitable properties with much inexpensive solution.

2. Experimentation

2.1. Raw Material procurement

The matrix material used in the experiment investigation was aluminium H30. The fly ash (F class) was obtained from NTPC-Simhadri situated in Vishakhapatnam. The particle size of the fly as received condition lies in the range from (0.1-100 μm). Silicon Carbide was procured for the experimental proceedings. Pure magnesium metal is used for improving wetting property. With the above materials six samples were prepared with different composition as shown in table 1.

| Sample Number | Sample Designation                          |
|---------------|---------------------------------------------|
| S1            | Pure Al                                     |
| S2            | Al + Fly ash(5%/w)                          |
| S3            | Al+ SiC(5%/w) (0hr)                         |
| S4            | Al+ SiC(5%/w) (3hr)                         |
| S5            | Al+SiC(2.5/w)+flyash(2.5/w)(0hr)            |
| S6            | Al+SiC(2.5/w)+flyash(2.5/w)(3hr)            |
2.2. Experimental Procedure

Single batch of hybrid metal matrix composite was prepared by stir casting method using 500gms of H30 grade aluminium and desired amount of fly ash particles and SiC. The fly ash and SiC particles were preheated to 300°C for three hour to remove moisture. Aluminium H30 grade was melted in a clay graphite crucible using electrical resistance furnace. The melt temperature was raised up to 720 OC and it was degassed by purging hexachloroethane degasser powder. The melt temperature was adjusted to 720°C when the melt was taken out from the furnace for stirring during addition of fly ash particles and Magnesium. Then the melt was stirred with the help of a stainless steel stirrer. The stirring was maintained between 5 to 7 minutes at 1200 rpm. The dispersion of fly ash particles were achieved by using the vortex method. The melt was poured into the preheated metallic mould to get the desired shape. The pouring temperature was maintained at 700OC. The melt was then allowed to solidify in the moulds for further extraction as shown in figure 1.

Figure 1. A. Hot melt in furnace, B. Stirring process, C. Scrap removal, D. Pouring in die, E. composite rods.

The composites were made with a different amount of fly-ash and SiC. Magnesium was added to increase the wettability of fly ash particles to achieve proper homogeneity. This process was repeated with Silicon Carbide instead of using Flyash and a second sample was taken after 3 hours from the first casting. Subsequent samples were done by following same process with the required compositions.

3. Results and discussions

3.1. Morphological study

The prepared composites was evaluated under an optical microscope to define the microstructure. A cylindrical portion was machined from the prepared composites and samples were made using lathe machine later polishing was done using different grids of emery paper. Afterwards it was cleaned and polished in fine velvet clothes(with diamond paste) and then cleaned, afterwards when the moisture is removed and it is etched with Keller’s reagent and then it is observed under an optical microscope for magnification of 100X and 200X and the images were shown in figure 2.
Figure 2. Microscopic images of S1, S2, S3, S4, S5 and S6.

Same procedure is followed for subsequent samples. In S1 micro-structure shows a complex grainy structure of aluminium which is a typical characteristic of an aluminium microstructural image. Sample two S2 microstructure confirms the presence of flyash in matrix of aluminium .This can be observed by the presence of black dots flyash within matrix of dendrite shape structure (Aluminium). S3 mixture of aluminium and SiC is poured immediately after stirring, the sample procured has a presence of SiC which is seen as a black flack structure (SiC) in matrix of Aluminium. When the sample S4 is put under an optical microscope the holding time and further stirring caused even distribution of SiC particles in the melt which is clearly observed compared to the image in S3. Among all the samples S5 shows very even distribution of SiC and fly ash particles in the aluminium matrix. In S6 after holding for 3hrs also there is no appreciable results observed.

3.2 Mechanical properties
3.2.1. Density comparison. The cylindrical samples made for microstructure were reused in density calculation. First the weight of each sample was taken (measured till fourth decimal). The height and diameter of the sample were measured. The theoretical volume of the cylinder was calculated using the formula \( V = \pi r^2 h \).

| Sample Number | Density (gm/cc) |
|---------------|-----------------|
| S1            | 2.85*           |
| S2            | 2.72            |
| S3            | 2.81            |
| S4            | 2.85            |
| S5            | 2.48            |
| S6            | 2.54            |

The density of each sample is the calculated respectively by dividing each individual mass by the volume and the results are shown in the table 2. Density of a material needs to be lower if the desired weight needs to be less. In this study it has been found out that the least density out of the tested samples is of the S5 sample which makes it optimal material for lesser weight. The explanation for this is the presence of a hybrid reinforcement which acts as a weight reduction factor. When compared to all the composites S5 shows minimum value.
3.2.2. Vickers hardness. From the experimentation done on samples of various compositions it is observed that the hardness values fluctuates on addition of only flyash or SiC. But a composition with higher hardness is obtained by mixing of a hybrid reinforcement. In our study the Aluminium melted with hybrid reinforcement and left to condensed in to a sample at zero hours without holding (S5) shows the highest hardness among the casted samples which is shown in the figure 3.

![Figure 3. Hardness values for prepared composites](image)

3.3. Tribiological Properties
Wear is described as the shift of the material generated by rigid particles. When these rigid particles are pressed over and move along a solid surface. Two body sliding wear tests was experimented on the various casted samples. The test was conducted on computerized pinion- disc wear test machine in dry condition at a uniform sliding velocity of 1m/sec-320R.P.M at load of 15N. A cylindrical pin of size 0.9 cm diameter and 2.5cm was machined from casted samples was fixed to a vertical specimen holder over horizontal rotating disc. Prior to conducting the test, the levelled surface of the sample was rubbed by using 1000 grade emery paper. The revolving disc was constructed of carbon steel of (D=60 mm). Wear tests was done at ambient temperature with no use of lubrication for 30 min. The primary aim of experiment was to analyse the coefficient of friction and wear properties. The result of the samples having been undergone pin on disc wear behaviour test shows that S5 is the optimal composite. The reason for it being optimal is the least resistance to wear which is studied using its coefficient of friction which is the least, meaning the composite is optimal to wear resistance and the results were shown in the figure 4.

![Figure 4. Hardness values for prepared composites](image)
The result of the samples having been undergone pin on wheel wear behaviour test shows that S5 is the optimal composite. The reason for it being optimal is the least resistance to wear which is studied using its coefficient of friction which is the least meaning the composite is optimal to wear resistance.

3.4. Structure Property correlation
By analysing the morphological study it observed that the reinforcement was not distributed homogeneously and by comparing all the structural and mechanical properties it is observed that density increases with addition of SiC, decreases with addition of flyash and hardness increases with the addition of hybrid reinforcement, coefficient friction decreases with the addition of hybrid reinforcement.

4. Application of Composite
Due to higher hardness optimal wear and less weight the composite chosen to manufacture a two wheeler disc brake is S5. Exploration of new composites in the area of manufacturing of disc brakes is much needed as most of the commonly used disc brakes are manufactured using cast iron example disc break of pulsar 150cc these cast iron disc breaks even though providing high strength it have some defects like low corrosion resistance and slightly higher weight.

4.1. Model Calculation for Disc
A suitable model for the disc brake testing setup was found in the Automobile department. The dimensions of the disc brake used in the test setup was calculated. According to further plans a similar disc will be manufactured using the optimal Composition found out. The disc will have the following volume. Volume of a disc \( V = \pi r^2 \Delta x \) Where, \( r \) = radius, \( \Delta x \) = Thickness of plate = 5mm.

4.2. Fabrication of Disc Brake
Composite S5 is taken in to account for casting disc brake. First trial was fail due to insufficient quantity and poor flow ability of melt. Different stages of casting is shown in figure 5. A wooded pattern is prepared according to the existing pulsar 150 disc brake. The process of making the casting is depicted in the figure 5. CAD model developed for manufacturing wooden pattern using Solid Works software. Finally pattern was made by wood carpentry leaving approximate 2% casting allowances from the actual dimensions. The foundry sand is refined using fine strainer.

![Figure 5](image)

**Figure 5.** A. Arrangement of patters, B. Pouring S5 melt, C. first trail casting, D. Second trail casting, E. machining, and F. Final disc brake.

The refined sand is moisturized by sprinkling water and through pressing and mixing of the sand. The wooden die is placed in the metal die and the graphite powder is sprinkled along with fine sand. The refined foundry sand is rammed on the die till all the sand is uniformly distributed and no space is left between. After that the wooden die is removed. Next the cope is placed and the riser, runner are
installed. Similar ramming is done on the cope. The molten composite is carefully poured into the die till it fills the chambers and rises up. The die is left to cool and then once cooled it is opened and the disc is extracted. The extra parts of the disc are then cut and the cast disc is sent for machining. In machining the cast disc is subjected to turning, milling and drilling. The disc is then cleaned and prepared for testing.

5. Conclusion
Aluminium flyash/SiC hybrid MMC were manufactured using stir casting method with different compositions. Among all the hybrid composites prepared sample S5 show optimal mechanical and tribological properties. From optical microscopy also it is clear that even distribution of reinforcement is obtained in the aluminium matrix. It was observed that the MMC with (2.5, 2.5) % weight of fly ash and SiC content in aluminium matrix results in higher hardness value and it is also noticed that the hybrid MMC shows very superior wear resistant properties. Based on results the composition with the optimal properties is chosen to manufacture a two wheeler disc brake which is tested for further usage.

6. References

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