Study of age hardening process on Al/SiC/Al2O3 hybrid composite

Kolli Balasivarama reddy¹, Chiguluri shaivinay¹, Jeevan naidu T¹, Shri Lekhaz¹ and Nived Akula¹
¹Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur campus, Chennai-603203.

E-mail: akulanived@gmail.com

Abstract. Versatile properties of aluminium make it the most common metal used now a days and it is used in various sectors like automobile, aerospace, civil etc. When mixed with other materials, properties like high tensile strength with high strength to weight ratio, high wear resistance low density and low coefficient of thermal expansion can be obtained. Aluminium with SiC, B4c, etc. forms a wear resistance hybrid. Its application is mostly in the brake drum of the automobile sector. Brake shoe of the brake drum is manufactured of cast iron so therefore a detailed study is done on both the properties of cast iron as well as the Al/SiC/Al2O3 composite. These hybrids are also used in sectors like construction to construct light weight racks, claps etc. The Composition of the manufactured composite is varied and tested to get the best fit for brake drum. Various tests performed are tensile test, tribology test and scanning-electron microscope to analyse properties of hybrid composite. Performance of the manufacture composite is evaluated on the basis of wear test as wear resistance is the most effective property that a brake shoe should possess. The method used here for manufacturing the composite is stir casting.

1. Introduction
Automobiles have become a necessity for everyday commute of people and people who travel longer distances prefer vehicles with better performance and fuel efficiency. There are various parts in a vehicle where weight can be reduced to achieve better performance and mileage. In order to do so a composite is used to manufacture light parts which replace the conventional heavy parts. The fabricated composites have better performance and high wear resistance. Hence, a shift in focus onto composites from pure metals, can be observed in the past few decades. Our study is on Aluminium composite Al/SiC/Al2O3 [3-5]. There are various grades of Aluminium which are used for different purposes. Aluminium6063 has some traces of Mg which provides more strength. Al6063 has good mechanical properties and is heat treatable [7-10]. Our composite contains SiC and Al2O3. SiC can be mixed with various metals to attain high endurance and high abrasive strength. Al2O3 is used as a reinforcement which is used to increase the wear resistance of the brake shoe [11-13]. While applying brakes various parameters like moisture content, speed, braking load, the surface temperature are also considered for safety purpose [15].

2. Literature survey
AM Rajesh et al [12] did an investigation on the effect of addition of SIC and Al2O3 on wear behaviour of hybrid aluminium Matrix composites and concluded that the increased wear resistance is
due to the increment in the weight fraction of reinforcements. It was observed that by raising sliding speeds there is a reduction in rate of wear and it reduces with increment in the sliding distance.

Md Habibur Rahman et al [10] investigated the characteristics of silicon carbide reinforced aluminium matrix composites. Various mechanical properties, microstructures and wear characteristics of aluminium with varying SiC content was studied. Pin-on-disc wear test was conducted and it was concluded that addition of SiC increased wear resistance.

Siva Kumar B et al [2] in this paper an attempt was made to study the different combinations of reinforcing materials used in the processing of hybrid aluminium matrix composites and how it affects the wear performance and microstructure of the materials.

Rohit Sharma et al [6] did a research on metal Matrix composites with reinforcement materials like graphite, fly ash, red mud, etc which when added improve the properties of base alloy. The work realised that the aluminium metal matrix composites can be replaced with conventional metals for better performance and longer life.

3. Experimental work

3.1. Synthesis of the Al/SiC/Al2O3 hybrid composite:
The Aluminum hybrid is manufactured through Stir casting. Stir casting is a type of casting in which reinforcement is homogeneously distributed in matrix. Synthesis of Aluminum hybrid MMC to have better mechanical properties then cast iron at lower price.

3.2. Composition of manufactured samples:
Four samples are manufactured using Stir Casting process. Samples are studied for analysis of mechanical properties and physical properties like tensile strength, tribology test and FESEM analysis. Aluminium 6063 used as a matrix as presence some traces of magnesium present which provides extra strength to the composite. Samples were named as 1H, 2H (heat treated) and 1WH, 2WH (without heat treatment). Composition of samples 1H and 1WH are as following. Aluminium 6063 has a weight of 500gms to which 5% of Silicon carbide weighing 25gms is added during the stirring process. 5% of Aluminium oxide which also weighted 25gms was added during the ongoing process of stirring. Composition of samples 1WH, 2WH are as following. Aluminium 6063 weighted 500gm to which 6% of Silicon carbide weighing 30gms is added. 4% of Aluminium oxide weighing 20gms was added during the stirring process. Various compositions are shown in the table 1.

| S.no. | Aluminium | Sic | Al2O3 |
|-------|-----------|-----|-------|
| Specimen 1 | 500gms | 25gms 5% | 25gms 5% |
| Specimen 2 | 500gms | 20gms 6% | 25gms 4% |

3.3. Particle size of the reinforcements:
The particle size of reinforcement affects the strength of composite. Finer the particle size of the reinforcement more will be the strength composite. Increasing the particle size increases impact strength whereas hardness decreases. With increase in size of reinforcing particles of red-mud, the value of tensile strength decreases but increases again for 250micron particle size. The reason lies in the boundary formed i.e. finer the grain particle more grain boundaries are formed. More grain boundary layer higher will be the strength of the material. The particle size of silicon carbide reinforcement is 50 micrometers whereas the particle size of aluminium oxide reinforcement is 60 micrometers. Particle sizes are given in table 2.

| S.No | SiC | Al2O3 |
|------|-----|-------|
| Particle size | 50 µm | 60 µm |
3.4. Heat treatment of samples
Heat treatment process (Quenching) is performed on the two samples in order to increase the strength. Samples are heated for four hours at 450°C. Then the specimens are water quenched. Quenching is done to increase hardness of a specimen. Quenching process increases the density of the material. Thus, the material become harder and stronger. Material density increase as the atoms comes closer to each other thereby increasing the density of the material and the changes obtained are described in the result.

3.5. Tests performed on the samples
Specimen produced through stir casting went through test to analysis mechanical and physical properties. All specimen produced went through destructive testing.

3.5.1. Hardness test on the samples
Hardness is basically how the metal or specimen can avoid its molecules and atoms undergoing a permanent change called plastic deformation. It also includes other behaviors of metal like resistance to scratching, indentation on the surface of the metal. The hardness test comprises of two types i.e, Rockwell hardness test and Vickers hardness test.

3.5.2. Tensile test
Tensile test is performed to gain the knowledge of the limit to which the manufactured samples or product can resist the load. Tensile test is carried on a machine called as Universal Testing Machine (UTM) which uses hydraulic force to apply load on the samples while carrying out the testing. Tensile test enables us to know how the material will perform or respond when force is varied. The dimensions of the specimen for the tensile test are shown in the figure 1.

3.5.3. FESEM (Field emission scanning electron microscopy):
In SEM a very significant feature which makes it different is that instead of light beam it uses electron beam to get the microstructure of the specimen. For testing the specimen, the samples needed to be of some specific dimension. The samples were manufactured of cubical shape of dimensions as follows: length, breadth, height = 1mm. The samples were then finely polished to have clear image of the specimens. The SEM experimental setup is liable to produce an image of nanometer particle size.

3.5.4. Wear test
Wear test is performed on the samples in order to find the wear rate when the brake shoe rubs against the brake drum when the force is applied on it. Coefficient of friction plays an important role in determining the wear rate of the specimen. Addition of SIC and Al2O3 adds to the wear property i.e. it decreases the wear rate of the samples and samples can withstand for longer duration. Figure 2.1
shows the tribometer used for testing of wear test. A tribometer is an instrument used to measure the wear rate of the specimen using a pin and disc. The samples were machined in the form of pin with the diameter of 8mm and length 30mm.

4. Results
All the samples manufactured were tested for their different properties and then those were compared. As already discussed four samples were manufactured of different grades and composition and two of them were heat treated with water quenched. These four samples went through various test and results were obtained as follows:

4.1. Microstructure analysis
Microstructure view of the particle were obtained through the SEM analysis which can be seen in the figure 2. Microstructure and distribution of particles play an important role in the physical and chemical properties of the composite and accordingly the materials are used in different sector and industries. The microstructure of the particles are obtained by optical microscope. Firstly, the samples were finely polished using emery papers of different grades and then it was etched using an etchant called as Keller’s reagent. Small dark spot can be seen which are the traces of reinforcement i.e. silicon carbide and aluminium oxide.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Figure 2. (a) Without heat treated sample 1 (1WH), (b) Without heat treated sample 2 (2WH), (c) Heat treated sample 1 (1H) (d) Heat treated sample 2 (2H).}
\end{figure}
4.2. Results of tensile test

| Specimen Shape       | Solid Round (ASTM E 8)        | Output Data        |
|----------------------|--------------------------------|--------------------|
| Specimen Type        | Aluminium                      | Load At Yield      |
| Specimen Description | SiC                            | Yield Stress       |
| Specimen Diameter    | 12.56 mm                       | Load at Peak       |
| Initial G.L. For % elong | 100 mm                      | Elongation at Peak |
| Pre Load Value       | 0 kN                           | Tensile Strength   |
| Max. Load            | 400 kN                         | Load at Break      |
| Max. Elongation      | 200 mm                         | Elongation at Break|
| Specimen Cross Section Area | 12.23 mm2             | % Reduction Area   |
| Final Sp Diameter    | 12.2 mm                        | % Elongation       |
| Final Gauge Length   | 103 mm                         |                    |
| Final Area           | 117.47 mm2                     |                    |

**Stress Vs. Strain**

Figure 3. Specimen 1 without heat treatment

| Input Data            | Solid Round (ASTM E 8)        | Output Data        |
|-----------------------|--------------------------------|--------------------|
| Specimen Type         | Aluminium                      | Load At Yield      |
| Specimen Description  | SiC                            | Yield Stress       |
| Specimen Diameter     | 12.56 mm                       | Load at Peak       |
| Initial G.L. For % elong | 100 mm                      | Elongation at Peak |
| Pre Load Value        | 0 kN                           | Tensile Strength   |
| Max. Load             | 400 kN                         | Load at Break      |
| Max. Elongation       | 200 mm                         | Elongation at Break|
| Specimen Cross Section Area | 12.9 mm2             | % Reduction Area   |
| Final Sp Diameter     | 12.2 mm                        | % Elongation       |
| Final Gauge Length    | 102 mm                         |                    |
| Final Area            | 116.9 mm2                      |                    |

**Stress Vs. Strain**

Figure 4. Specimen 2 without heat treatment.
Figure 5. Specimen 1 with heat treatment.

Figure 6. Specimen 2 heat treated.
In all the figure 3 to figure 6, it can be seen that firstly there is proportional increase in the graph for x-axis to y-axis which describes the Hooke’s law.

4.3. Results of hardness test

Hardness test also performed on all specimen in order to find which composite will have high resistance to surface deformed i.e. scratch, indentation etc. when the load is applied. The specimens manufactured were indented with ball indenter under the 100kgf force and results were obtained. Three readings of each sample were taken and at different spots on the surface and average value of all the three reading was taken and considered for comparison. The readings for specimen 1WH are 27.8HRB, 32.1HR, 33.1HRB and after taking their average it came to be 31.01 HRB. For the specimen 2WH the readings for the test are 33.0HRB, 33.4HRB, 33.8HRB and their average came to be 33.4HRB. For the specimen 1H which is heat treated the three readings are 36.2HRB, 33.2HRB, 38.5HRB and their average came to be 35.96HRB. For the specimen 2H which is also heat treated the three readings are 39.5HRB, 36.9HRB, 41.0HRB and their average came to be 39.13HRB. After taking all these readings they are compared with each other and a graph was plotted between them to have a better idea of their property.

4.4. Results of FESEM (Field emission scanning electron microscopy)

A FESEM is microscope that works with electrons instead of light. These electrons are liberated by using a area emission source. The object is scanned by electrons. A FESEM is used to visualize very small details on the surface or entire or fractioned objects. FESEM analysis was performed on fractured part of the specimen after the tensile test in order to get the structural view of the composition as shown in the figure 7.

4.5. Results of wear test

Wear test results were obtained from the tribometer and their respective results were compared. Four samples were manufactured and their results were extracted to get the better analysis
of the specimen in terms of wear resistance. Higher the wear resistance lower the wear rate. During the process of wear test different graphs plotted are as follows: (1) Coefficient of friction vs time (figure 8), (2) Frictional force vs time (figure 9) and (3) Wear rate vs time (figure 10) shows the different graphs plotted for specimen 1WH which is heat treated just for reference. All the graphs plotted were done under the condition of speed of the disc as 500RPM and load of 20N. The speed was chosen as 500RPM because it’s an average revolution of the brake drum in the cars.

![Figure 8. Coefficient of friction vs time.](image)

![Figure 9. Frictional force vs time.](image)
5. Inference
After obtaining the results from different tests of the manufactured specimen a comparative study has been made to find the which specimen is best suited and can be used as brake shoe in the brake drums. From the hardness test performed using Rockwell hardness test machine and results obtained were compared. From the bar chart shown in the figure 11, it can be seen that the specimen which are heat treated have more hardness value as compared with those of which are not heat treated. For heat treated specimens the hardness values are 35.9HBR and 39.13HBR and those which are not heat treated are 31.2HBR and 33.4HBR. Among the specimen the specimen which is heat treated and having a composition of 4% SiC and 6% Al2O3 has the highest value of hardness.

From the data obtained from the tensile test,a bar chart is plotted for the tensile strength. The chart can be seen in figure 12. From the figure it can be seen that the specimens which are heat treated have higher value of tensile strength as compared to the onece without heat treated. The specimen 1H with composition of 5% SIC and 5%Al2O3 have the highest tensile strength of 106.52kN.

Figure 10. Wear rate vs time.
Figure 11. Hardness of specimen.

Figure 12. Comparison of tensile strength.

Figure 13. Graph showing variation of wear rate of the specimen.
6. Conclusion
Aluminium when heat treated and reinforced with SiC and Al2O3 will have increased wear resistance and strength. Cast iron used as brake shoe has more weight and has high cost of manufacturing as compared with heat treated aluminium. The low cost, light weight and high wear resistance of aluminium makes it more viable to be used as brake shoe material instead of cast iron. Even though in this project the strength of aluminium composite is low as compared with cast iron it can be overcome by addition of some other metals like magnesium. Therefore the heat treated aluminium reinforced with SiC and Al2O3 can be used as a substitute for cast iron in brake shoes.

7. References
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