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The Effect of Heat Treatment on the Dry sliding Wear Behaviour of as cast and Grain Refined and Modified, Gravity cast A356

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ABSTRACT: In this study, Al-Si alloy A356 grain refined and modified using Al-5Ti-1B and Al-10Sr respectively was cast in pre-heated permanent mold using liquid metallurgy route. They were further heat treated (T6) by solutionising at 540^{0}C, quenched in water at 70^{0}C and aged for 5 hours at 180^{0}C. They were tested for hardness and wear resistance as per relevant ASTM standards. A quantum rise in wear resistance was observed in Grain refined, Modified and heat treated A356 compared to as cast A356, Grain refined and modified A356. The improvement in wear resistance may be attributed to the refined microstructure, grain refinement and modification and improved hardness due to heat treatment.

KEYWORDS: Sliding wear behaviour Grain refined and modified A356, Tribological properties

I. INTRODUCTION

Aluminium-Silicon alloys are known for their excellent combination of characteristics namely, low density, excellent castability, formability, good mechanical properties, cryogenic properties and good machinability and have wide range of applications particularly in Automobile, Aerospace and Marine sectors on account of their light weight, good surface finish, resistance to wear and corrosion and high strength-to-weight ratio. As components with complex geometries can be produced cost effectively, they find enhanced utility particularly in Automobile Aerospace sectors. Large aluminium extrusion components can be produced with lesser number of joints, resulting in less welding. Reduction in weight due to low density leads to increased load capacity, increased mileage, reduced pollution of environment and higher profits to the manufacturers. The low melting temperature, ease of handling, easy formability, easy recycling has led to increased demand for aluminium alloy/composite components.

II. MATERIALS

Grain refined and modified A356 were cast in pre- heated permanent mold in the form of cylindrical rods of diameter 25 mm and length 250 mm and heat treated (T6).Test specimens required for Microstructure, hardness and wear were obtained by machining the rods and tested as per ASTM standards.

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Table 1: Chemical Composition of A356

Element	Weight %
Si	7.25
Mg	0.45
Fe	0.086
Cu	0.010
Mn	0.018
Ni	0.025
Zinc	0.005
Others	0.028
Al	Balance

III. METHODOLOGY

a. **Microstructure:** The specimens for microstructure were prepared as per standard metallurgical procedures, etched in etchant prepared using 90 ml water, 4 ml HF, 4 ml H_2S0_4 and 2g C_r0_3 and photographed using Optical Microscope.

b. **Hardness test:** The hardness tests were conducted as per ASTM E10 norms using Rockwell Hardness Tester, where the tests were performed at randomly selected points on the polished surface of samples by providing sufficient space between indentations and distance from the edge of specimen. The hardness values of as-cast A356, Grain refined and Modified A356 and Grain refined and Modified and heat treated A356 are shown in Table 2.

c. **Wear test:** Dry sliding Wear tests were carried out at room temperature using Pin-on-Disc apparatus for varied loads and sliding distances. The wear rates were evaluated using weight loss method by dividing the loss of weight of specimen by the sliding distance for a known sliding time. The loss of weight was measured using an Electronic balance to the accuracy of 0.0001gm. The wear rate was based on the average value of 5 test results. During test, the load was increased gradually till seizure, indicated by high temperature rise; abnormal wear and vibration in Pin-disc assembly were observed. The disc was thoroughly cleaned using acetone after every test. The worn surfaces were further analysed for type of wear.

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IV. RESULTS AND DISCUSSION

a. Microstructure (200x)

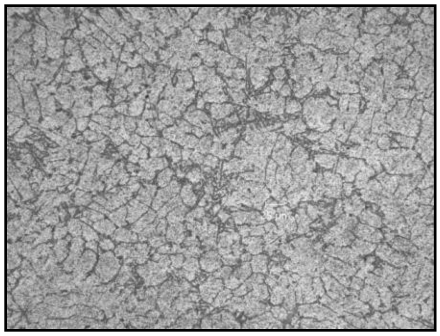

Plate.1: Microstructure of As-cast A356

Plate.1 shows the distribution of the primary dendrite alpha phase (aluminum rich phase) in as-cast alloy which is predominant in the matrix. Grey coloured needle shaped silicon particles seen in and around the inter dendrite regions resulted in increased aspect ratio.

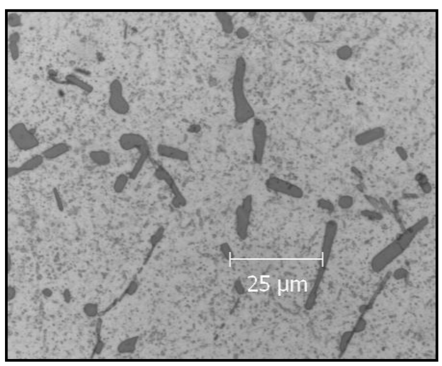

Plate.2: Microstructure of Heat treated A356 (A356-H)

In Plate.2 is shown, the microstructure of heat treated A356 (A356-H) showing spherodisation of Silicon particles leading to increased aspect ratio.

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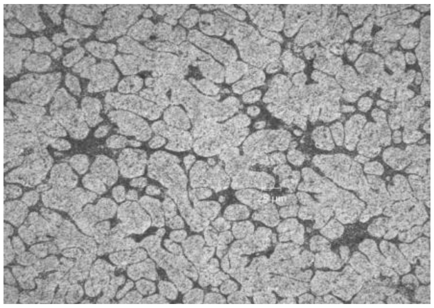

Plate.3: Microstructure of Grain refined and Modified A356 (A_{GRM})

Plate.3 shows the Microstructure of combined Grain refined and modified alloy. Grain refinement resulted in fine grain structure and reduction in size of primary aluminium grains. Grain modification produced fibrous and finely dispersed Si and promoted the formation of finer particles of Iron-rich inter-metallic compounds which are hard compared with as-cast material. Further, it led to refined porosity dispersion leading to increased hardness and wear resistance.

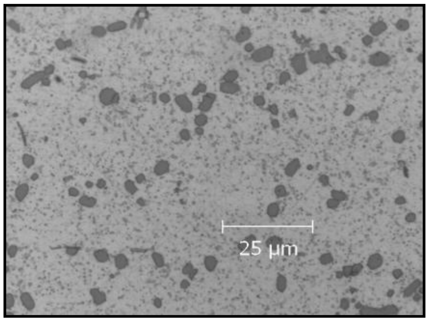

Plate.4: Microstructure of A_{GRM-H}

Plate.4 shows the microstructure of A_{GRM-H} in which complete spherodisation of Silicon particles with aspect ratio nearing 1 and uniform distribution of Si in the matrix.

b. Hardness Test Results:

Table 2: Hardness values of as-cast and Heat Treated A356, Grain refined and Modified A356

Sl No.	Alloy	Designation	Hardness (R_B)
1	A356	A356	60
2	Heat treatedA356	A356-H	88
3	A356 with Grain refinement and modification	A_{GRM}	65
4	Heat treated A356 with Grain refinement and modification	A_{GRM-H}	91

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Fig 1 shows the hardness values of A356, A_{GRM} and heat treated A356 (A356-H) and A_{GRM-H}. It is clear from the plot that A_{GRM} has higher hardness 65m BHN compared to A356 with hardness 60. A further incrase in hardness is obtained in both A356 and A_{GRM} after heat treatment. After heat treatment, 8.33% and 3.4% increase in hardness in A356 and A_{GRM} respectively were observed.

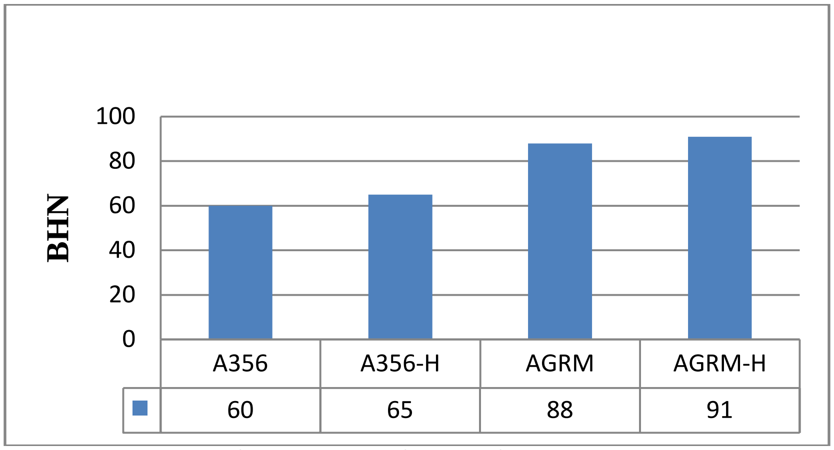

Fig 1: Hardness values of As-cast, Grain Refined Modified and Heat Treated alloys/composites

c. Wear test Results:

i. Effect of sliding distance on wear rate

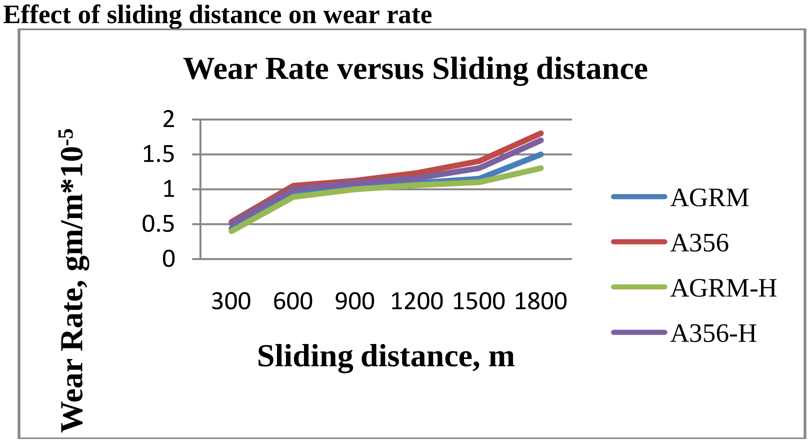

Fig 2: The effect of sliding distance on the wear rate of As-cast A356 and Grain Refined and Modified A356 (A_{GRM})

Fig 2 shows the plot of the effect of sliding distance on the wear rate of both as cast and heat treated As-cast A356 and Grain Refined and Modified A356. It is clear from the plot that the wear rate increases with sliding distance for both As-cast A356 alloy and A_{GRM}. The wear rate for A_{GRM} is comparatively smaller when compared to As-cast A356. Heat treatment has resulted in further increase in wear resistance. Grain refinement resulted in fine grain structure and reduction in size of primary aluminium grains. Grain modification produced fibrous and finely dispersed Si and promoted the formation of finer particles of Iron-rich inter-metallic compounds which are hard compared with as-cast material.

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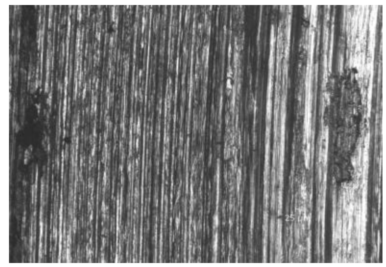
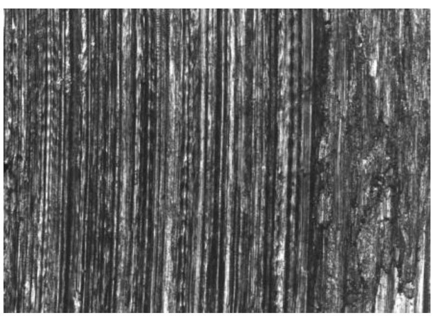
5(a)



5(b)

Plate 5: Optical micrographs of worn surfaces of As-cast A356 5(a) and Grain refined and modified A356 (A_{GRM}) 5(b)

Plate 5 shows the optical micrographs of the worn surfaces of A356 and Grain Refined and Modified A356 (i.e A_{GRM}) slid through 1500m under the normal load of 30N and velocity of 1m/s. It is obvious from plate 3 that wear grooves are wider and deeper in A356 compared to that of A_{GRM} which may be attributed to higher hardness in A_{GRM}.



6(a)

6(b)

Plate 6: Optical micrographs of worn surfaces of Heat Treated A356 and Grain refined and modified (A_{GRM-H})

Plate 6 (a) and 6 (b) show the Optical micrographs of worn surfaces of Heat Treated A356 and Grain refined and modified (A_{GRM-H}) slid through 1500m with load 30N and velocity 1m/sec. It is obvious from plate 6 that grain refined and modified, heat treated worn surface has almost fine surface with least wear.

ii. Effect of load on wear rate

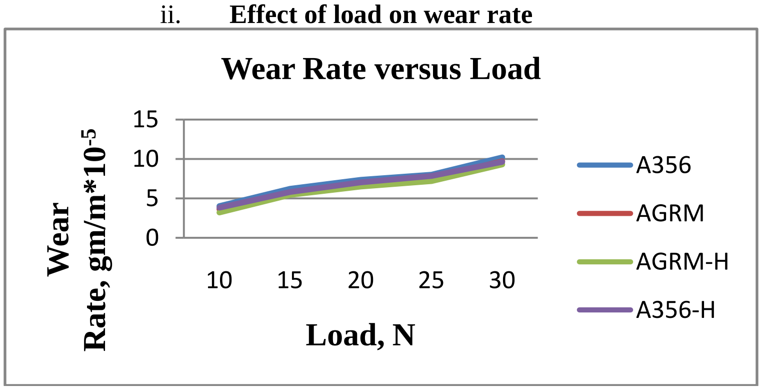


Fig.3: The effect of load on wear rate of As-cast and heat treated A356, Grain Refined and Modified and heat treated A356.

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Fig.3 shows the effect of load on wear rate of As-cast A356, Grain Refined and Modified A356 and Heat treated A356 where, an increase in wear rate is observed for both As-cast A356 and Grain Refined and Modified A356. An increased wear resistance is observed for Grain Refined and Modified A356 compared to As-cast A356. The increased wear resistance in heat treated A_{GRM} compared to heat treated A356 may be attributed to the increased hardness achieved by Grain Refinement, modification and Heat treatment.

iii. Effect of sliding distance on coefficient of friction (COF)

Fig 4 shows the plot of sliding distance on coefficient of friction of As-cast and Heat treated A356 and $A_{GRM.}$ For $A_{GRM,}$ the COF decraeses from 0.51 to 0.437 over a sliding distance of 300m. A steep decrease in COF is observed between 600m and 1200m where it decreases from 0.51 to 0.437. Beyond 1200m, the value of COF remains almost constant (0.3).

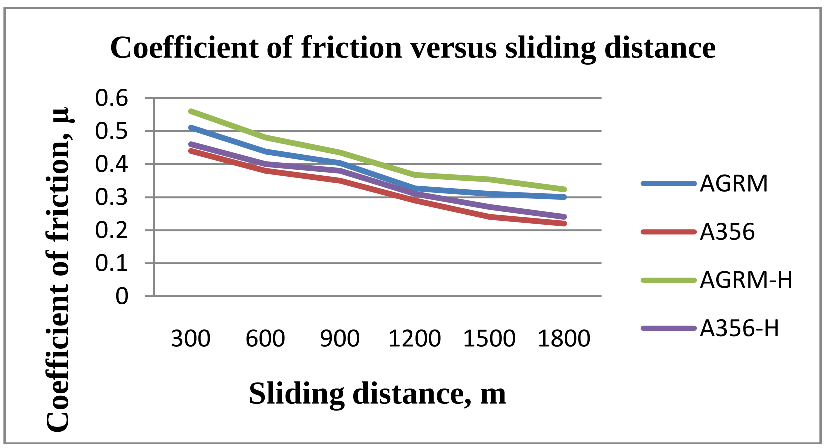

Fig 4: The Effect of sliding distance on coefficient of friction (COF), µ

Similarly, for As-cast alloy, COF decreases from 0.46 to 0.4 when slid through 300m. Further a decrease in COF is observed between 600 and 1200m when it decreases from 0.38 to 0.31.Heat results in further increase in COF in both As-cast and Heat treated A356 and A_{GRM}. The increase in COF in A_{GRM} compared to A356 may be attributed to the increased frictional force resulted due to increased hardness compared to $A_{GRM.}$

d. Analysis of wear Debris:

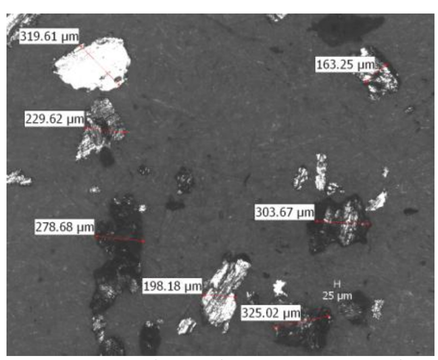

Plate 7: Photograph of Debris collected from Dry sliding wear of A356 for sliding distance of 1500m and load of 30N, sliding velocity 1m/s

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Plate 7 shows Debris collected from Dry sliding wear of A356 for sliding distance of 1500m and load of 30N, sliding velocity 1m/s. From Plate.7 it is clear that the size of Debris varies from 163.25 µm (minimum) to 319.61 µm (maximum). The dark particles are the Debris (Fe) removed from disc and white shining particle are the Debris of specimen (A356).

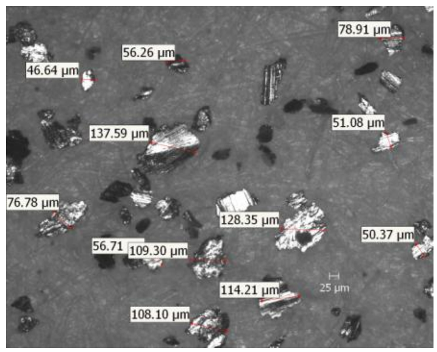

Plate 8: Photograph of Debris collected from Dry sliding wear studies of A_{GRM} for sliding distance of 1500m and load of 30N, sliding velocity 1m/s.

Plate 8 shows the Debris collected from Dry sliding wear of A_{GRM} for sliding distance of 1500m and load of 30N, sliding velocity 1m/s where the size of Debris is around 50 µm. The reduction in size and quantity of debris may be attributed to the increased hardness achieved through Grain refinement and Modification

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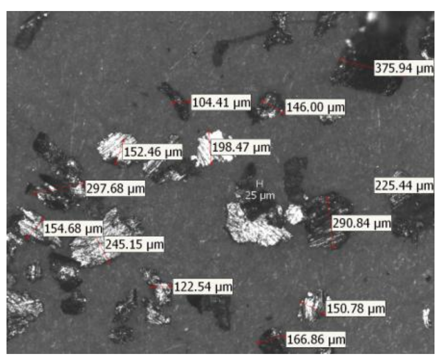

Plate 9: Photograph of Debris collected from Dry sliding wear studies of A356-H for sliding distance of 1500m and load of 30N, sliding velocity 1m/s.

Plate 9 shows the photograph of Debris collected and its size from Dry sliding wear studies of A356-H for sliding distance of 1500m and load of 30N, sliding velocity 1m/s.

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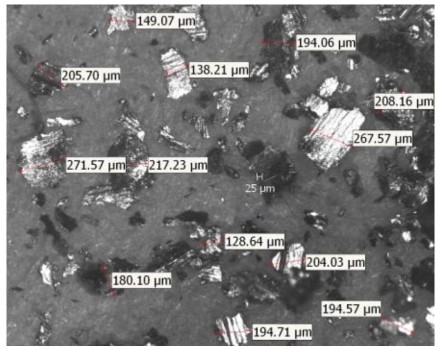

Plate 10: Photograph of Debris collected from Dry sliding wear studies of A_{GRM-H} for sliding distance of 1500m and load of 30N, sliding velocity 1m/s.

Plate 10 shows the size of Debris generated in Dry sliding wear behaviour of Grain refined and Modified A356 (A_{GRM-H}) subjected to T6 treatment.

V. CONCLUSION

1. Sound and dense castings were produced by Gravity casting using pre-heated permanent mold.
2. Grain refinement resulted in fine grain structure and reduction in size of primary aluminium grains. Grain modification produced fibrous and finely dispersed Si and promoted the formation of finer particles of Iron-rich inter-metallic compounds which are hard compared with as-cast material.
3. Heat treatment resulted in Spherodisation of needle shaped Silicon particles leading to reduced aspect ratio
4. Improved Hardness and wear resistance was achieved in A_{GRM} compared to As-Cast A356. Further, heat treatment resulted in improved hardness and wear resistance in both as cast and Grain refined, modified and Heat treated A356.

VI. ACKNOWLEDGEMENT

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