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# Effect of Heat Treatment on Mechanical Properties of A356 Reinforced With Boron Carbide Composites

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***ABSTRACT*** *- The effect of natural ageing on microstructure and mechanical properties of A356 reinforced with boron carbide, after and before heat treatment were studied in this article. The experimental results of microstructures of the alloy showed primary dendrite-delta phase rich in A356, upon grain refinement it resulted in fine grain structure and grain modification produced fibrous in the silicon phase of the alloy. Boron carbide reinforcement has led to in its uniform distribution thereby improving the mechanical properties mainly ultimate tensile strength (UTS), yield strength(YS), and ductility. Including the boron carbide reinforcement in the metal matrix displayed furthermore decreased in wear rate and thereby improving the wear resistance. The permanent mold, gravity cast* $A_{GRM}$ *(A356 reinforced with* $B_4C$*) alloys obtained from stir casting were heat treated for varied heat treatment parameters such as solutionising, and natural ageing, which spurred further improvement in the microstructure and the mechanical properties. The precipitation increased the hardness of the alloy/composite proportional to the solutionising temperature and natural ageing was found to enhance thehardness. Therefore, effect of heat treatment variables viz, solutionising temperature, natural ageing on grain refined, grain modified and boron carbide reinforced A356 alloys/composites has resulted in a more wear resistant material with improved mechanical properties.*

***Key words*****:** Aluminium alloy A356, Boron carbide, Natural Ageing, Mechanical strength, Heat treatment

## I. INTRODUCTION

For over a century Aluminium alloys are being profoundly used next to Steel and Iron in the metal market. The demand for Aluminium alloy has grown rapidly because of its exceptional combination of characteristics such as low density, ease of castability, formability and desirable mechanical properties, commendable cryogenic properties and favorable machinability. They become stronger with decreased temperature without significant losses in ductility and make them ideal for cryogenic fuel tanks for Rockets and launch vehicles.

Aluminium and its alloys outstretches its applications in the Automobile components, Aerospace and Marine industries on account of their durability, light weight, supreme surface finish, wear resistance and corrosion resistance and high strength to weight ratio. Complex geometries are produced with ease and are cost effective, they find enhanced utility in Aerospace sectors. Whereas in Automobile sector, due to its low density it can provide increased load capacity, superior mileage and concentrated pollution and higher profit to manufacturers. The low melting point, ease of formability, castability, handling and recycling has led to increased demand for aluminium composite components making more versatile for engineering and construction material.[9-10]

Mechanical, technological and microstructural properties of the casting made from this alloy depends on the correctly performed process of melting and pouring, casting and mold with their structures, as well as their heat treatment process which plays a vital role in improving the properties. Current investigations in this work with the improvement of mechanical properties and microstructure of aluminium alloy pertaining mostly to the advancement in selection of alloys, synthesis of alloys, improvement of selection of modifiers, additives and reduction of impurities and slag and implementing a modern heat treatment technology has spurred their application by further improvement in their properties. A standard heat treatment consists in holding the castings in the furnace with constant temperature for a predetermined period results thus improving the mechanical properties such as: Tensile strength and HB hardness; and in simultaneous worsening of plasticity, and natural ageing. The reduction of the plasticity accomplished after heat treatment influences the growth of alloy's strength, thus the given application of the alloy should be selected depending on their optimal relation.

Also in this work, the hardness of aluminium alloy A356-T6 was conducted by using precipitation hardening process. Enhancing the strength and hardness of metal Effect of Heat Treatment and Natural Agening on Microstructure and Mechaanical Properties of A3566 Reinforced with Boron Carbide Composites alloys by the formation of extremely uniformly dispersed small particle of a second phase within the existingg phase matrix is termed as Precipitation hardening. The diffusion of solute atoms into it from the matrix phase permits the precipitated particle to nucleate and grow. Na tural ageing will be accomplished in order to enhance the structure of the material, thereby increasing the yield strength and reducing the ductility which is attrib uted due to the formation of the clusters of Mg/Si. β" precipitates formed by ag eing at room temperature chiefly enhances the strength of The Al-Mg-Si alloy. Thee solute clusters formed reduces the nucleaation rate at β" phase and consequently p roduces a slow response during hardening of the material. Ageing (Age hardening) is the final stage in development of properties in the heat treatable alloys of aluminiium, during ageing the alloying elements trappped in solution (which are formed during Quenching) precipitate to form uniform distribution of very fine particles. Fine distribution of precipitates strengthens the alloy by creating obstacles to dislocation (a crystallographic defect) movement as shown in Fig.1

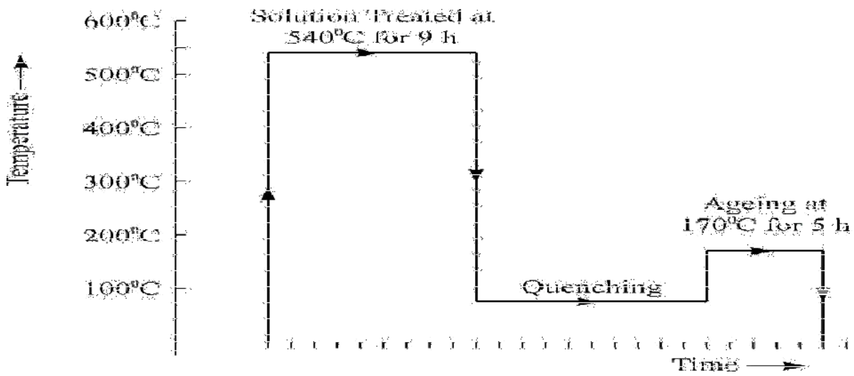



**Figure 1** Heaat treatment diagram for peak solution treated allooy

The aim of quenchi ng is to achieve maximum super saturation of alloying elements and keep the alloying elements trapped in solution. Age hardening or Ageing is final stage in the development of properties in the heat treatable aluminium alloys.

**1.1. The Need for Grain refinement and Modification:** The silicon content in most aluminium castings varies between 5 to 12%. When melts of these allloys have failed to modify, coarse platelet crystals of the aluminium silicon eutectic ph ase form in the casting during solidification which are brittle and tend to reduce thhe strength and ductility of the casting.

**1.2. Grain refining*:*** Grain refining is the addition of solid particles (in the form of Titanium and Boron master alloys) to a metallic melt to act as nucleant catalysts/ sites and result for the formattion of fine equiaxed, grains at the expensse of dendrites. Titanium (Ti) and Boron (B) are administered to refine primary Aluminium grains. When only Titanium is addded as the master alloy Titanium- aluminiu m, forms $TiAl_3$, which serves to nucleate primary Aluminium dendrites. larger num ber of smaller grains results when there is more frequent nucleation. Grain refininng efficiency is better with the presence of combinations of Titanium and Boron. C ommonly used additives for the master alloys of aluminium are 5% Titanium and 1% Boron (Al-5Ti-1B master alloy), they fo rm $TiB_2$ and $TiAl_3$, which together result in better effective grain refining than $TiAl_3$ alone.

**1.3. Need for Grain Mo dification*:*** Modifiers are added to Al-Mg-Si alloys to alter the morphology of the eutectic silicon phase. Modification of the silicon phase is done using modifier such as Al-10Sr master alloy which produces a silicoon phase that is fibrous and finely dispersed. Boron carbide (chemical formula approximately $B_4C$) is one of a promisingly hard boron–carbon ceramic material next to cubic boron nitride and diamond which are used in tank armor, bulletproof, engine sabotage powders, as well as numerous industrial applications, with a Mohr's hardness of about 9.497. Boron carbide, being one of the favorable ceramic material for its aesthetic properties which includes extreme hardness, high strength to weight ratio, comparatively low density, chemical stability and absorption of neutron ability.[11]

## II. EXPERIMENTAL DETAILS

The following section highlights the material, its properties and methods of composite preparation and testing.

**2.1. Materials Used:** The matrix material for present study is A356. Table.1 gives the chemical composition of A356. The reinforcing material selected is $B_4C$, grain refiner as alloys of aluminium are 5% Titanium and 1% Boron and grain modifier Al-10Sr

**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 |

## 2.2. Fabrication Process

Stir casting technique a paradigm liquid metallurgy route was adopted to prepare the cast mold composites. A batch of 500g of A356 was melted to 840°C in a graphite crucible using resistance furnace. The melt was agitated with the help of stirrer to form a fine vortex. At the temperature of 800°C the preheated B4C particles of various percentages were was added into the vortex with mechanical stirring at 300rpm for 5mins. Grain refiners and modifiers were added. Test specimens were obtained by machining the rods and tested as per ASTM standards for Microstructure, hardness and tensile. Before pouring the molten metal to mold, to reduce the atmospheric contamination, 2g of cover flux (NaCl 45% + KCl 45% + NaF 10%) was added to the molten metal. The molten metal at a temperature of 850°C was then poured into mold preheated to 300°C and allowed to solidify. Grain refined and modified A356 were cast of cylindrical rods of diameter 25 mm and length 250mm in a pre- heated permanent mold and heat treated to 500°C for 9 hours later subjected to water quenching and natural ageing.

## 2.3. Microstructure and Testing

To study the microstructure of the specimens that were cut and prepared as per the standard metallographic procedure. The specimens for microstructure were etched in etchant (Keller’s reagent) prepared using 90 ml water, 4 ml HF, 4 ml $H_2S0_4$ and 2g $C_r0_3$ prepared as per standard metallurgical procedures and photographed using



Optical Microscope. The specimen surfaces were finished by grinding through 600 to 1000 mesh size grit papers. The velvet cloth polishing is done for superior surface finish of the specimen. Th e microstructures of etched specimens were observed under Optical microscope (OM).

## 2.4. Hardness test

The hardness tests as per ASTM E10 norms were conducted using Rockwell Hardness Tester(RHB), where the tests were performed on the by indenting on a polished surface at randomly selected points of the samples by providing sufficient space between distance from the edge of specimen and indentations. Fig2 shows test samples of as-cast A356, Grain refined and Modified A356 and Grain refined and Modified, untreated and heat treated A356

**Figure 2** Hardness Test specimen

## 2.5. Tension test

The tension test specimen s (Fig 4) were tested at room temperature machined as per ASTM E8 standards in a c ompact Bench Tensometer interfaced with computer

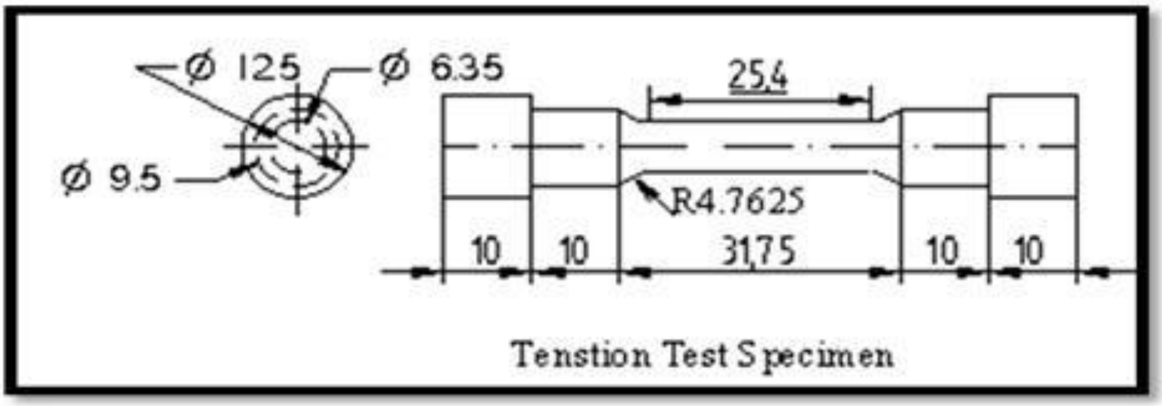



**Figure 3** Tension test specimen

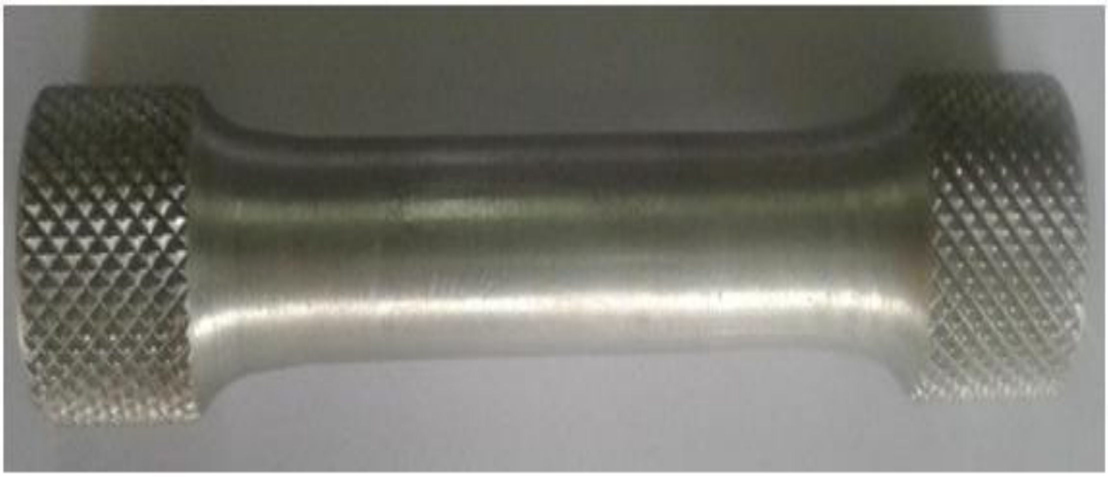


**Figure 4** Tensile Test Specimen Before fracture

The mechanical properties obtained from the data acquisition system of the machine were UTS (Ultimate tensile strength), and % Elongation (ductility) were. The average value of these results was based on 5 test results for each alloy/composites. To study the mechanism of fracture the fractured surfaces were photographed using LOM (Light optical Microscope).

## 2.6. Wear test

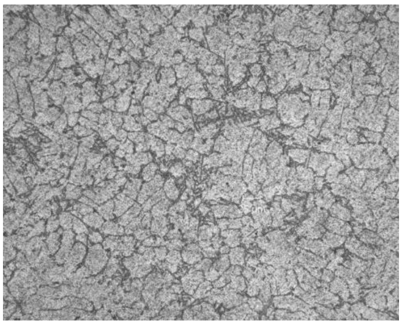
Dry sliding Wear tests were carried out for varied loads and sliding distances at room temperature using Pin-On-Disc apparatus. By using weight loss method by dividing the loss of weight of specimen by the sliding distance for a known sliding time, the wear rates were gauged. The loss of weight was measured by using an Electronic balance to the accuracy of 0.0001gm. The average value of 5 test results of wear rate was evaluated, during test, the load was increased gradually till seizure which were indicated by high temperature rise; abnormal wear and vibration were observed in Pin-disc assembly during the test. After which the disc was thoroughly cleaned using acetone after every test. [1]

**Figure 5** Wear Test Specimen



## III. RESULTS AND DISCUSSIONS

### 3.1. Evaluation of Mic rostructure



**P late 1** Microstructure of As-cast A356

Plate 1 shows the distribution in A356 (as-cast alloy), the primary dendrite alpha phase (aluminum rich phase) which is predominant in the metal matrix. due to the Grey colored needle sha ped silicon particles seen in and around th e inter dendrite regions which provides increased aspect ratio

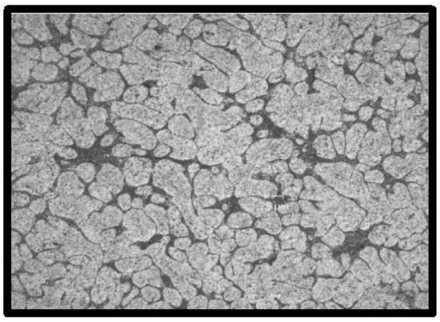
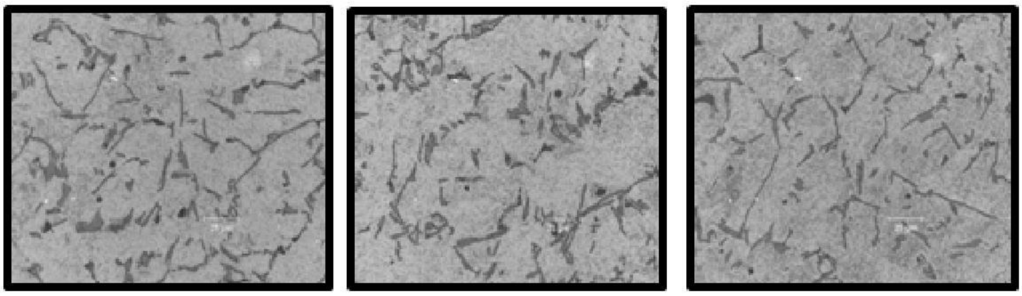


**Plate 2** Microst ructure of Grain refined and Modified A356 (AGRM)

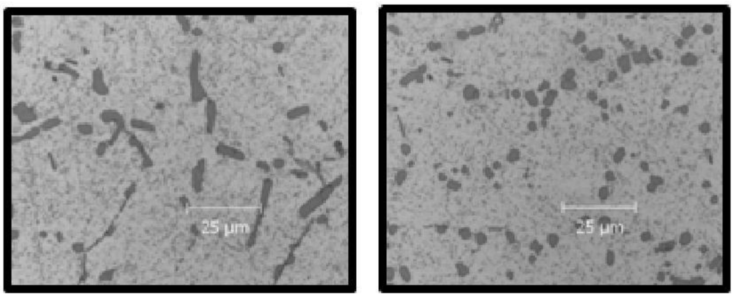
Plate 2 illustrates the combined Microstructure of Grain refinedd and modified alloy of $A_{GRM}$. Reduction in size of primary aluminium grains is ma inly due to the addition of Grain refinement resulted in fine grain structure fibrous and finely dispersed Si produced by the Grain modification and stimulated the forrmation of finer particles of Iron-rich inter-metallic compounds which are hard comparred with as-cast material. Additionally, improved hardness and wear resistance due to refined porosity dispersion.



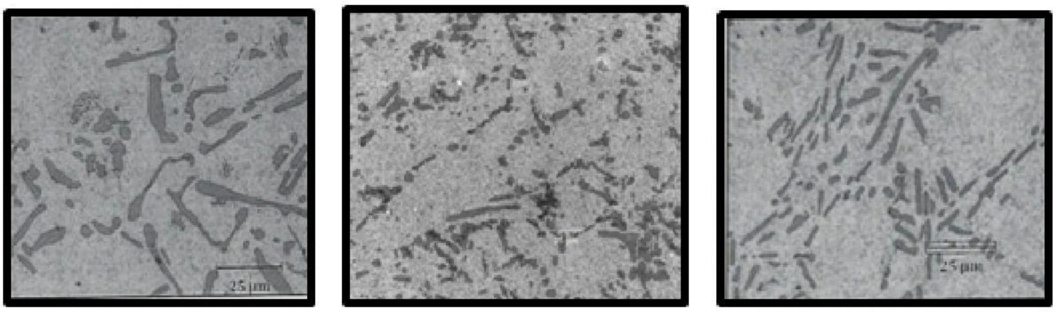
3(b) 3(c) 3(d)

**Plate 3** Microstructure of untreated A1 A3 A7

From plate 2(b) 2 (c) 2 (d) show the microstructure of AGRM reinforced with 1%, 3%, and 7% B4C demonstrating uniform distribution of $B_4C$ in the metal matrix.




4(a) 4(b)




4 (c) 4(d) 4 (e)

**Plate 4** Microstructures of Heat treated A356 AGRM A1 A3 A7

Plate 4(a), 4(b), 4(c), 4(d) and 4(e) show the microstructure of Heat treated and naturally aged A356, AGRM reinforced with 1%, 3% and 7% $B_4C$ demonstrating uniform distribution of $B_4C$ in the matrix, which displays in the microstructure by showing needle shaped silicon particles due to spherodization obtained by addition of Grain refiners and modifiers with heat treated at higher temperature.

## IV. EVALUATION OF MECHANICAL PROPERTIES

### 4.1. Hardness Test Results

**Table 2** Hardness values of As-cast and Grain refined and Modified Al-7Si-0.45Mg (AGRM) and B4C reinforced A356 (heat treated)

| **Sl No.** | **Alloy** | **Designation** | **Hardness ($R_B$)** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 1 | Al-7Si-0.45Mg | A356 | 60 |
| 2 | Al-7Si-0.45Mg with Grain refinement and modification | $^{A}$GRM | 66 |
| 3 | $A_{GRM}$ with 1% $B_4C$ | A1 | 68 |
| 4 | $A_{GRM}$ with 3% $B_4C$ | A3 | 79 |
| 5 | $A_{GRM}$ with 7% $B_4C$ | A5 | 75 |

Effect of Heat Treatment and Natural Ageening on Microstructure and Mechanical Properties of A356 Reinforced with Boron Carbide Composites

| **Sl No.** | **Alloy** | **Designation** | **Hardness ($R_B$)** |
|---|---|---|---|
| 3 | Al-7Si-0.45Mg with Grain refinement and modification heat treat @500deg and naturally aged | $^{A}$GRM | 88 |
| 4 | $A_{GRM}$ +1% $B_4C$ heat treat @500deg and naturally aged | A1 | 92 |
| 5 | $A_{GRM}$ +3% $B_4C$ heat treat @500deg and naturally aged | A3 | 97 |
| 6 | $A_{GRM}$ +7% $B_4C$ heat treat @500deg and naturally aged | A5 | 90 |

Table 2 shows hardness values of heat treated A356, AGRM and alloys reinforced with varying % of B4C. It is observed from the graph that hardness of the test specimens increased with an increase in the Grain Refined, Modification, heat treatment and natural ageing and further with % B4C.Addition of Boron Carbide reinforcement particles in the melt increases the nucleation rate and decreasing the grain that are provided by the additional substrate for the solidification to trigger there by size. The optimum value of reinforcement is 3% B4C giving hardness values of 97 indicates 23% increase in hardness compared to AGRM reinforced with 3% without heat treatment. Beyond 3% of reinforcement (i.e,5 %), a decreased value of hardness is observed, the decreased hardness beyond 3% may be attributed to the reduced solubility of B4C in the matrix.

Fig 1 shown below is the hardness values of Al-7Si-0.45Mg, AGRM and B4C reinforced AGRM and A1 A3 A7 along with heat treated and naturally aged. It is clear from figure that hardness increases with addition of grain refinement, modification, heat treatment and natural ageing and A3 indicating maximum hardness compared to A1 and A7 which may be attributed to the optimum percentage and uniform distribution of B4C in A3.The increase in hardness is attributed to the precipitation of Mg2Si in aluminium matrix, the changed morphology of silicon particles i.e. spherodization from needle shape, due to heat treatment reduction in its size and uniform distribution in the matrix. From the above analysis it is very clear that, natural ageing resulted in improved hardness of the alloy.

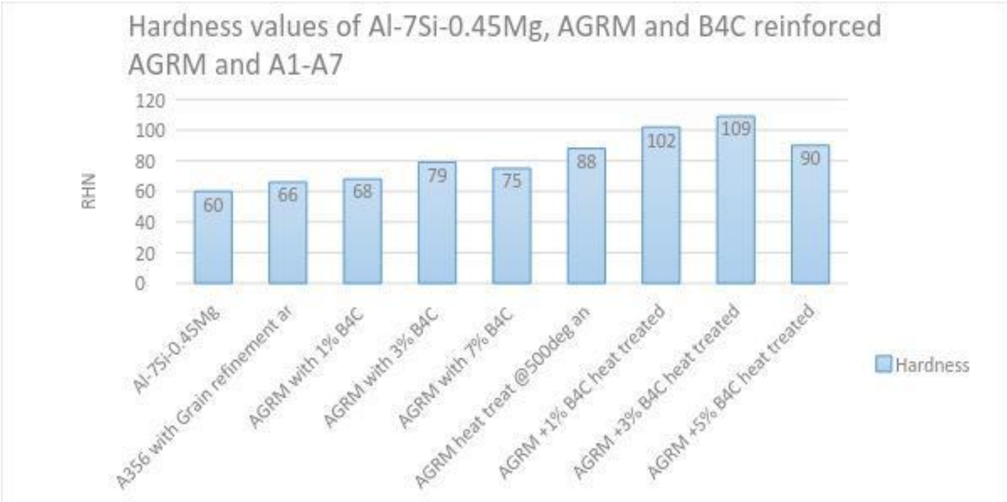



**Figure 6** hardness values of Al-7Si-0.45Mg, AGRM and B4C reinforced AGRM and A1-A7.

## 4.2. Tensile Test Results

**Table.3** Tensile Test result of As-Cast, AGRM, 1%, 3% 7% of Boron Carbide

| Sl. No | Alloy/Composite | UTS (MPa) | % Elongation (Ductility) |
|---|---|---|---|
| 1 | A356 | 119.83 | 1.71 |
| 2 | $^{A}$GRM | 130.23 | 3.2 |
| 3 | A1 untreated | 155.04 | 3.62 |
| 4 | A3 untreated | 164.0 | 6.05 |
| 5 | A7 untreated | 135 | 2.87 |
| 6 | A1 heat treated | 235.04 | 5.48 |
| 7 | A3 heat treated | 364.0 | 8.15 |
| 8 | A7 heat treated | 305 | 6.07 |

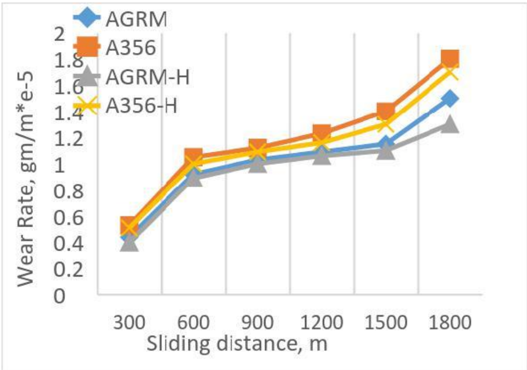
Closer examination of the fractured surfaces show larger and uneven distribution of dimples left by silicon particles during fracture in as-cast alloys compared to smaller and more evenly distributed dimples in peak solution treated alloys. A further reduction in size and better distribution of dimples is seen in peak aged alloys.

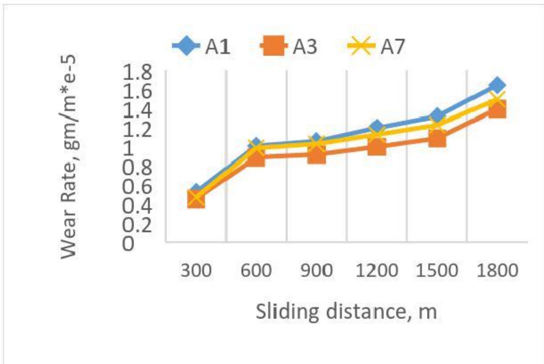
From Table 3 it is perceived that the mechanical properties such as UTS, Ductility and Fatigue strength increased after heat treatment

**Figure 7** Fractured Test Specime

## 4.3. Wear Test

**I) Effect of sliding distance on wear rate:** Fig 8 shows the plot depicted for the effect of sliding distance on the wear rate of as cast A356, $A_{GRM}$ and $B_4C$ reinforced with varying percentage of $B_4C$ such as A1, A3, and A7 with A3 demonstrating maximum wear resistance compared to A1 and A7. The wear rate for $A_{GRM}$ and increased addition of various percentage of $B_4C$ is comparatively smaller when compared to As-cast A356 also heat treatment and natural agening has resulted in further increase in wear resistance. Grain refinement resulted in decrease in size of primary aluminium grains and gave rise to fine grain structure and, grain modification further enhanced by providing fibrous and finely dispersed Si and hence promoted the formation of finer particles of Iron-rich inter-metallic compound.




ffect of Heat Treatment and Natural Agening on Microstructure and Mechanical Properties of A356 Reinforced with Boron Carbide Composites

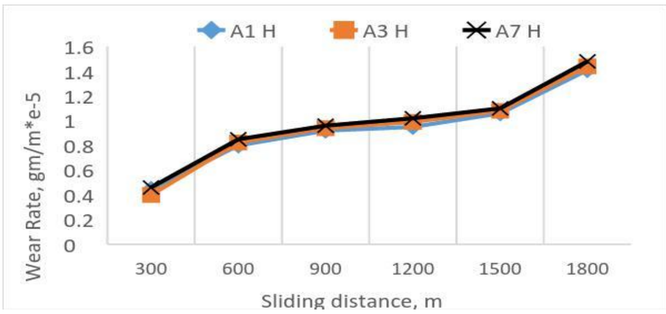



**Figure 8** The plots of effect of sliding distance on the wear rate of gravity cast Al-7Si-0.45Mg, Grain Refined and Modified alloy AGRM, and B4C reinforced composites (Untreated and Heat treated)

## II) Effect of load on wear rate

Fig.9 depicts the plot of Wear rate versus Load for as cast AGRM reinforced with B4C and heat treated and naturally aged AGRM where the wear rate increases with load. Beyond 25N load, a steep rise in wear rate is observed in the heat treated composites. This may be ascribed to the softening of pin material due to excessive heat produced at the pin disc interface.

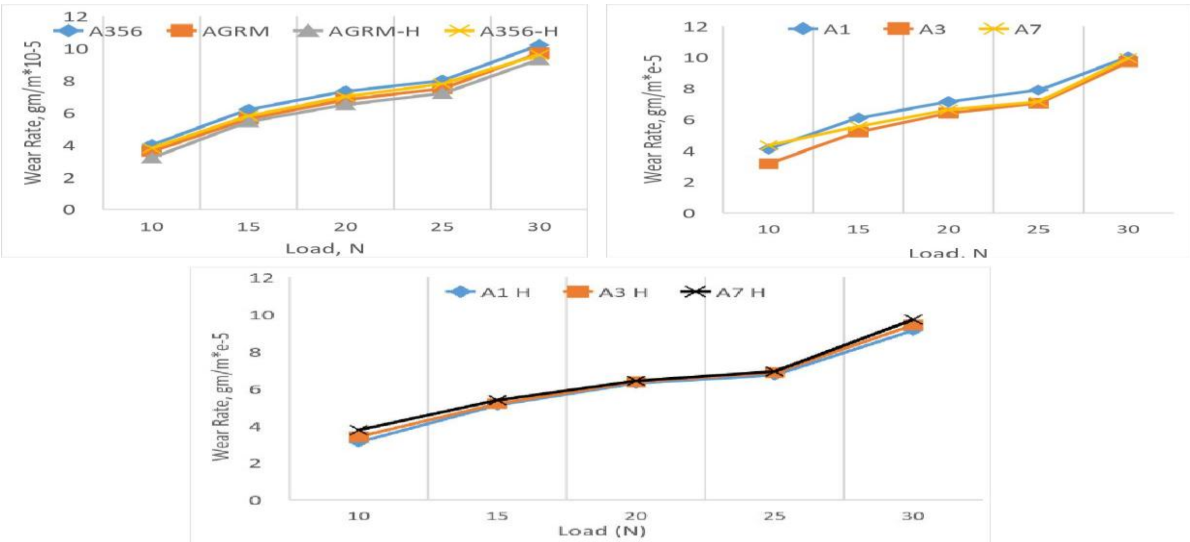
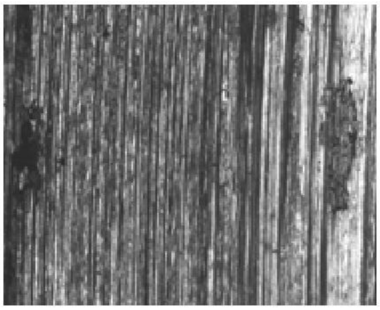


**Figure 9** The plots of effect of load on wear rate of gravity cast Al-7Si-0.45Mg, AGRM and composites reinforced with B4 (untreated and heat treated)

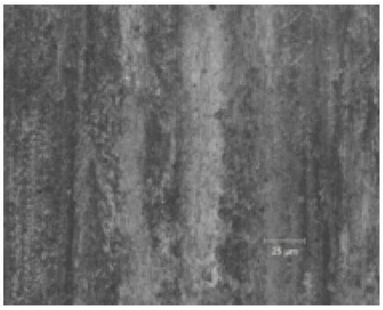
An improved wear resistance is observed for Grain Refined and Modified A356 compared to As-cast A356. In the plot A1, A3 and A7 exhibit enhanced wear resistance compared to A356 and $A_{GRM}$ with A3 exhibiting minimum wear or maximum wear resistance.

### 4.4. Analysis of Worn surfaces of gravity cast Al-7Si-0.45Mg, $A_{GRM}$ and A1 to A7

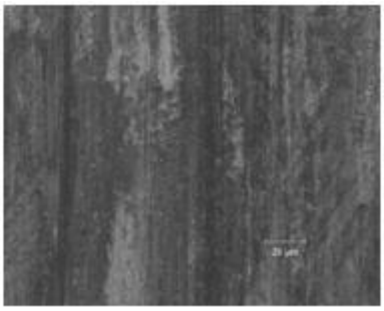
Plate 5 and plate 6 shows the optical micrographs of the worn surfaces of A356 and Grain Refined and Modified (i.e. $A_{GRM}$) untreated and heat-treated slid through 1500m under the normal load of 30N and velocity of 1m/s. It is obvious from plate 5 and Plate 6 that wear grooves are wider and deeper in A356 compared to that of $A_{GRM}$ both in untreated and heat treated condition which may be attributed to higher hardness in $A_{GRM}$.



5(a)

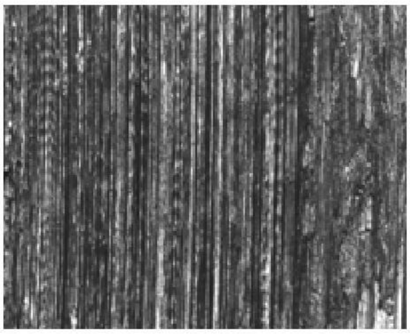


5(b)



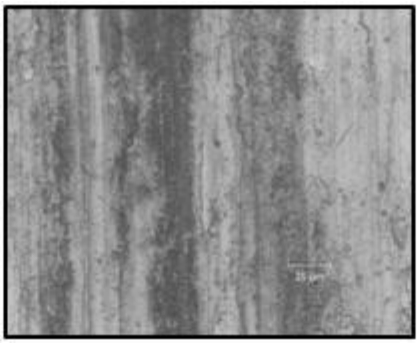
5 (c)

**Plate 5** OM of worn surfaces of A356 AGRM and reinforced with 1%, 3% and 7% B4C with heat treated and naturally aged

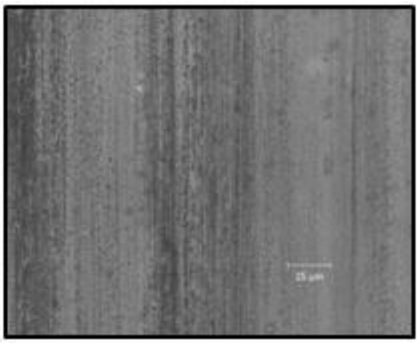


6(a)

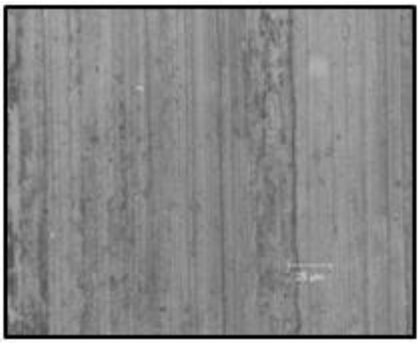
6(b)



6(c)



6(d)



6(e)

**Plate 6** OM of worn surfaces of A356 AGRM and reinforced with 1%, 3% and 7% B4C with heat treated and naturally aged

Plate 5(untreated) and plate 6 (heat treated and naturally aged) shows the Optical micrographs of worn surfaces before heat treated and naturally aged $A_{GRM}$ reinforced with 1%, 3%, and 7% $B_4C$ respectively with A3 showing shining worn surface, signifying a hard surface with least wear compared to A1and A7 in both untreated and heat treated conditions.

## V. CONCLUSION

1. Sound and dense castings were produced by Stir casting by means of pre-heated permanent mold.
2. Heat treatment to a higher temperature resulted in Spherodisation of needle shaped Silicon particles leading to decreased aspect ratio, also natural ageing spurred further improvement in the microstructure and the mechanical properties
3. Grain refinement resulted in fine grain structure and decrease in size of primary aluminium grains. Grain modification produced fibrous and finely dispersed Si and promoted the development of finer particles of Iron-rich inter-metallic compounds which are hard compared with as-cast material. Heat treatment enhanced wear resistance and fine dispersion of second phases resulted in blocking dislocation slip leading to improved wear resistance
4. Improved Hardness, high strength to weight ratio, tensile and wear resistance was achieved in $A_{GRM}$ and reinforced $B_4C$ from heat treatment and natural ageing thereby providing vast applications in Aerospace, automobile and missile sectors

## ACKNOWLEDGEMENT

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