THE EFFECT OF Sr AND SiC ADDITION ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF 319 ALUMINIUM ALLOY

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ABSTRACT:- 319 type of Aluminium alloy is a high strength heat treatable alloy having wide range of engineering applications such as automotive and aerospace industry for the complicated castings which must complies of high strength requirements. The most common chemical treatment consists of modifying the morphology of silicon eutectic phase from acicular to fibrous form resulting in an increase of mechanical characteristics and microstructure. In practice common elements with the modifying effects are strontium and antimony etc. Addition of SiC particles characterized by good physical and mechanical properties such as high strength, hardness, resistance to high temperature, wear resistance and abrasion into the metal matrix alloy improves their properties and makes it much more useful in different applications. This experimental program is undertaken to explore the effect of addition of strontium and silicon carbide on chosen mechanical properties and the microstructure of the investigated alloy. Analysis by optical microscope and scanning electron microscope reveals the evolution of the microstructure and the intermetallic compounds of Al-319. The Brinell hardness test was used to determine the hardness of the alloy thus produced. Experimental works have showed that the addition of strontium and silicon carbide results in similar or even higher mechanical properties than the conventional 319 alloy.

Keywords – Al 319, Eutectic Silicon, Grain refinement, Aluminium metal matrix, metal composite

1. INTRODUCTION

Al-Si cast alloys have been widely used in automotive and aerospace industries due to their high specific strength, excellent castability and recycling possibility. The lightweight materials, such as Al alloys applied in these industries are favourable to reduction of the greenhouse gases emission. An increase emphasis on the weight reduction promotes the use of these alloy in automobile and aerospace industries because the density of the Al alloy is less than that of iron and steel. Nowadays, since the industrialization leads to excessive consumption of Aluminium resources, more and more secondary Al alloys have been developed and utilized to replace virgin Al. Al-Si-Cu-Fe commercial alloy is one of the recycled Al alloys, which is low cost, heat treatable and possesses relatively excellent mechanical properties. In addition, it is deemed as a prominent substitution for steel in automotive industry. However, an extensive application of this alloy in structural parts is restricted by its relatively low ultimate tensile strength because of the presence of needle-like phases in the microstructure.

2. EXPERIMENTAL PROCEDURE

For the present study we use different equipment from different laboratories. For testing and studying the properties of the specimen we needed different machines like UTM, SEM analysis, XRD analysis, Brinell hardness test and pin on disk wear test equipment.

The first tests conducted were tensile strength and hardness test. Both the tests were conducted in a testing facility at Trivandrum. Tensile test is conducted using UTM machine and hardness is conducted using Brinell hardness machine. For both tests the test specimen were machined to standard size of 88mm long and 9 mm dia. specimen for tensile test and 10mm dia. and 10mm height for Brinell test. Tensile strength is found by breaking the specimen by applying tensile force axially. The specimen is placed in the machine between the grips and an extensometer if required can automatically record the change in gauge length during the test. If an extensometer is not fitted the machine itself can record the displacement between its cross heads on which the specimen is held. However, this method not only records the change in length of the specimen but also all other extending/elastic components of the testing machine and driving systems including any slipping of the specimen in the grip. Once the machine is started it begins to apply an increasing load on specimen. Throughout the test the control system and the associated software record the load and extension or compression of the specimen.

The harness is found out by applying a predetermined test load to a carbide ball of fixed diameter which is held for a predetermined time period and then removed. The resulting impression is measured with a specially designed brinel microscope or optical system at least two diameters-usually at right angles to each other and these result are averaged. Although the calculation below can be used to generate the brinell number, most often a chart is then used to convert the averaged diameter measurement to a brinell hardness number. Brinell testing often use a very high test load (3000 kgf) and a 10mm diameter indenter so that the resulting indentation averages out most surface and sub-surface inconsistencies.

The next test was XRD analysis using X-Ray diffraction technique. It is done by using powder XRD method of both specimen and corrosion precipitate. Different compounds diffract X-Ray in different angle by collection of the angle and intensity of compounds we can identify the intensity of different compounds present in the alloy. The vary trace number of compounds is difficult to identify by this method.

Wear study is done using pin on disk apparatus. Pin on disk wear testing is a method of characterizing the coefficient of friction, friction force and rate of wear between two materials. As a particularly versatile method for testing ear resistance, pin on disk can be configured in multiple scenarios depending on the goal of our project. The test is done by rotating a counter face test disc against a stationary test specimen pin. The alloy samples were held stationary in the sample holder and the normal load is applied through a lever mechanism. An electron weighing balance is used to measure the weight loss of the sample.

2.1. DESIGN OF COMPONENTS

The casting is commenced using a green sand cast mould which is preheated. The base alloy is melted down in a pit furnace to which 15 % Sr master alloy is added after which SiC is added and stirred well and then casted out in the preheated mould in the right proportions as shown in the calculations below

Volume of the pattern =12 x 12 x 3.5 cm^3

Mass of the specimen =1400 g

Extra allowance provided =20 %

Total mass to be taken =1690 gAmount of Sr to be added is 2 wt% in alloy Amount of Sr to be added =37 g Amount of master alloy (Al-15 Sr) =244 g

-to be added

Amount of SiC to be added is 10 wt %

Mass of SiC to be added is =255 g Mass of 319 Al alloy to be taken =1191 g

Initially the 319 aluminium alloy of calculated amount is taken in the crucible and placed inside the pit furnace and is heated. The temperature variations are noted down using the help of a thermocouple and a control unit in the furnace. The crucible is heated to a temperature of 750 C and held at that temperature with the help of thermocouple. Sr metal alloy which is being pre heated near the furnace is now added to the crucible along with flux. After which SiC is added with agitated stirring. The stirring is continued for some time for proper blending of the material to the metal matrix complex. The temperature is to be maintained at the same point throughout the process.

Now from the completely molten metals the slag is removed from the top of the crucible. Then the molten metal is poured into the preheated mould. Then the mould is set for hardening of the alloy after that the metal is taken out and placed on the ground for cooling.

2.3. METHODOLOGY

Enhancement of the mechanical properties of the specimen was considered as the main objective of the project. Change in microstructure of the 319 Al alloy and addition of metal matrix composite to the aluminium matrix was found as a way to accomplish this. Addition of rare earth metals was the key way of improving the microstructure of the alloy. Addition of SiC to the metal act as a reinforcement to the metal matrix of the 319 Al alloy. It works in such a way that when acted upon by a load, metal matrix transmit the load to reinforcements and then then the loads are carried by the disperse reinforcement bonded with the matrix. Strong interface bond between the reinforcement and the metal matrix is needed for high strength of composites. An optimum amount of 10 % of SiC was added on account of its increase in hardness and other mechanical properties alongside with increase in porosity level in the metal.

2.4. MOULDING

The moulding operation which was the primary step was conducted using a wooden pattern. The wooden pattern was furnished to a dimension of 12x12x3.5 cm block with finished faces. Tapers was provided in all lateral faces for the easy withdrawal of the pattern from the mould after moulding.

The pattern was kept in the female box and green sand was added and rammed all around the box to get a rigid structure holding the pattern well, so that the exact replica is formed on the sand. Now the male box is placed on the female box and after adding a separator the male box is also filled with green sand and packed well. Later the two boxes are separated and the wooden pattern is taken out. The runner, raiser and channel is cut on the pattern for smooth flow of the molten metal into the mould. Holes are provide on the male box so that the vapour emanating from the mould due to the moisture content on contact with the molten metal may flow through these holes so that, they will not produce any blowholes or any deformation in the sample. It is further kept for drying and is preheated to a temperature of 250 C alongside the furnace before commencing the casting operation.

2.5. SEQUENCE OF CASTING OPERATION

1.190 kg of 319 alloy is weighed using a weight balance. The pit furnace is heated to 700 $^{\circ}C$ to become red hot and the alloy is charged in the crucible. Hexa-chloro ethane tablets were added to degas the melt after 319 ingots gets completely melted. 2%wt Sr is added in to the melt. Heat treated SiC particle were added in the crucible through the funnel at 730$^{\circ}C$ After the additions are over the molten metal is poured in to the preheated mould while pouring the temperature of the melt should be at 720 C. After solidification of the molten metal in air the casting is removed from the mould. Later the specimen which is casted out is machined out in a lath into various sizes needed for each testing.

2.6 TESTING

The XRD analysis is done by using X-ray diffraction technique. In the test small powder of the specimen are taken and analysed. X-ray powder diffraction (XRD) is a rapid analysis technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions.

The optical microscope, often referred to as the light microscope, is a type of microscope that commonly uses visible light and a system of lenses to magnify images of small objects. The image from a optical microscope can be captured by normal, photosensitive cameras to generate a micrograph. Most microscopes are compound microscopes, which means they contains at least two lenses.

The hardness of the alloys were measured using Intendec hardness machine for Brinell hardness, measurements with a load of 62.5 kgf with a dwelling time of 30 sec and the ball indenter diameter of 2.5 mm on polished round specimens. The specimen used for hardness test is prepared with 10mm diameter and 10mm height and smoothed both the surfaces for conducting Brinell hardness test. The harness is found out by applying a predetermined test load to a carbide ball of fixed diameter which is held for a predetermined time period and then removed. The resulting impression is measured with a specially designed brinell microscope or optical system at least two diameters-usually at right angles to each other and these result are averaged. Although the calculation below can be used to generate the brinell number, most often a chart is then used to convert the averaged diameter measurement to a brinell hardness number. Brinell testing often use a very high test load (3000 kgf) and a 10mm diameter indenter so that the resulting indentation averages out most surface and sub-surface inconsistencies.

The specimen for tensile test is prepared as per ASTM E8 specifications in the shape of a cylinder of 9mm diameter and 88mm length. The test was performed in Instron UTM (Universal Testing Machine) at crosshead speed of 2 mm per minute and at a strain rate of 1.3 x10^{-3}/s. The specimen is placed in the machine between the grips and an extensometer if required can automatically record the change in gauge length during the test. If an extensometer is not fitted the machine itself can record the displacement between its cross heads on which the specimen is held. However, this method not only records the change in length of the specimen but also all other extending/elastic components of the testing machine and driving systems including any slipping of the specimen in the grip. Once the machine is started it begins to apply an increasing load on specimen. Throughout the test the control system and the associated software record the load and extension or compression of the specimen.

The Wear study of the specimen is conducted using a computerized pin-on-disk apparatus (Model type TR-20, DUCOM). Pin on disk wear testing is a method of characterizing the coefficient of friction, frictional force and rate of rate between two materials. The specimen is machined to a cylinder of 6 mm diameter and a height of 30 mm. The specimen is thoroughly cleaned and burns are removed from the surface using fine emery paper of 600 grit SiC paper. After which the weight of the specimen is measured very accurately using highly accurate weighing balance. Now the specimen is tested in the machine for a definite amount of time. The disc used was EN-32 steel having hardness value HRC 65, diameter of 160 mm and a thickness of 8 mm. wear test were carried under varying loads of 1,2,3 and 4 kg and with a sliding speed of 1 m/s and a constant sliding distance of 1500 m.

3. RESULTS AND DISCUSSIONS

3.1 XRD ANALYSIS

The XRD analysis of Al 319 alloy added with Sr and SiC is shown below along with the table showing the percentage composition of the material after casting. The first two are results of the two samples and third one include the XRD analysis results of unmodified Al-319 alloy and modified Al-319 compared to each other. Both of their grain size and phases are analysed and recorded. The below results were calculated using Optical Emission Spectroscope to confirm that the percentage addition was correct which shows that the addition was correct. So XRD was conducted. Confirmation of various phases in the microstructure is obtained from the X-ray diffraction of the Al alloys is show in figure. As expected, the principal phase in the XRD profile is the α-Al for before casting and their crystallite size of 21nm. Due to the casting and resultant crystallographic texture after solidification, the observed intensity distribution of the α-Al phase is non-random for the dendritic alloys (319

+ Sr), which is not unexpected. The second major phase in the Al-Si-Sr or Al-Si alloys is the eutectic Si phase, which unlike α-Al phase possesses a greater crystallite - size of 25 nm and a more random orientation

Components	Percentage composition (in %)
Si	5.87
Sr	2.07
Cu	2.42
Al	88.1

Table 5.1: composition of sample

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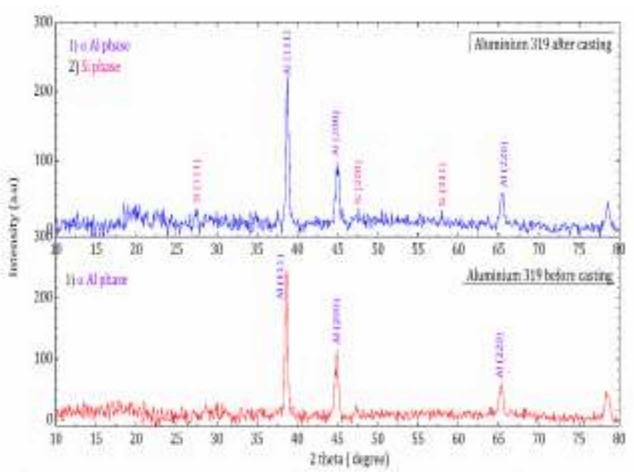


Fig 5.1 XRD analysis results

FWHM values before casting and after casting are .006353 rad and 0.005152 rad respectively. Scherrer formula was used to calculate crystal size. From the XRD analysis it can be inferred that the crystalline size of 319 aluminium alloy has increased by 4nm.

3.2 OPTICAL ANALYSIS

Optical microscope was used to analyse the microstructure of the specimen. Magnified micrograph was taken from etched specimens of Sr and SiC modified Al 319 for the analysis of the microstructure.

The results obtained are shown below. The images are of a resolution of 100μm. A decrease in the microstructure can be seen in the images from unmodified to Sr and SiC modified Al 319.By analysing both the image in Fiji software the average grain size of pure 319 aluminium was calculated to be 31.43μm. Similarly the average grain size of modified Al-319 was calculated to be 16.146μm which points towers the decrease in average grain size of the alloy.

The decrease in the average grain size can be attributed to the addition of Sr addition to the alloy. Sris responsible for the grain refinement changing the coarse eutectic silicon to fine fibrous form. It is also evident from the optical images that the grain size is considerably being reduced on addition of SiC and Sr. As the grain size decrease according the Hall-Petch equation the mechanical properties of the material will increase

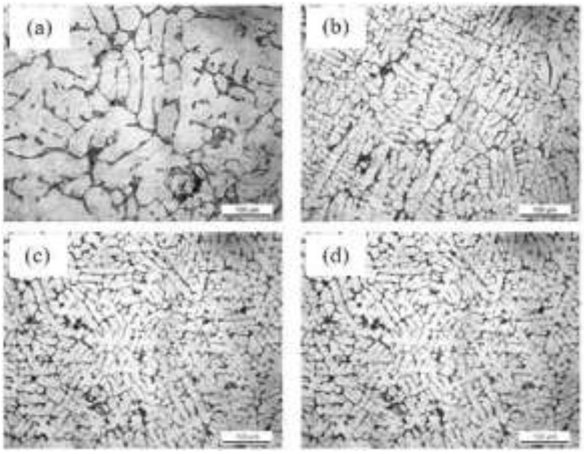


Fig 5.2.a: Optical image of pure 319 alloy **b**: Al 319+Sr, **c**: Al 319+SiC, **d**: Al 319 +SiC+Sr

3.3 HARDNESS TEST

Hardness test is performed using Brinell hardness test. In this test a small inundation is produced at a smooth surface of the alloy and its diagonal length is measured and its hardness is found out using the above mentioned equations

The hardness of the element added alloy is seen to be increasing. The presence of harder and well bonded SiC particles in Al matrix that impede the movement of dislocations increases the hardness of AMCs and the refinement of eutectic phase silicon also attributes to it.

The tensile strength is conducted using the universal testing machine. Two specimens were machined out with a length of 88 mm and a maximum diameter of 9 mm. For testing the specimen, the sample is clamped between two jaws of the machine and stretched till break point. And the load is noted. The point of break is known as the tensile point of the specimen.

The tensile strength of the elemental alloy is seen increasing because of modification of the eutectic silicon from coarse needle shape to fibrous one and the addition of SiC to the metal matrix composite which leads the distribution of load throughout the metal matrix uniformly when acted up on by force.

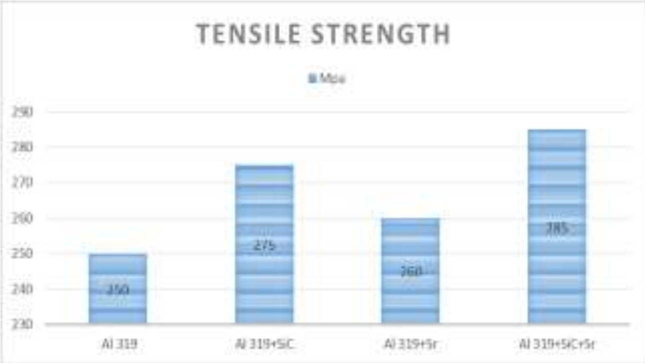


Fig 5.4 Tensile strength of sample

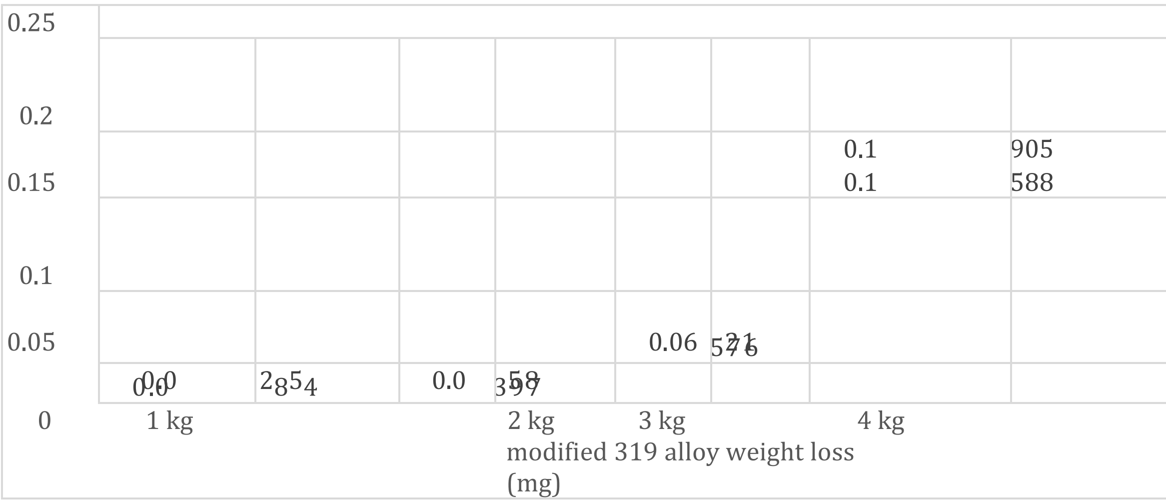
3.5 WEAR ANALYSIS

Wear is the removal of material from the metal surface on contact with another surface. The graph shows the cumulative metal removal rate of the modified 319 aluminium alloy as a function weight acting up on it. It is seen from the graph that mass loss for unreinforced Al 319 is greater than SiC reinforced AMCs.

Fig 5.3 Hardness results

3.4 TENSILE STRENGTH

The decrease in wear rate can be attributed to the SiC addition. SiC act as a reinforcement over the aluminium .During loading the softer Al matrix is worn away first from sample's surface during wear test leaving the hard SiC particles on worn surface. These exposed SiC particles protect the Al matrix from further wear. Hence the wear resistance is improve compared to unmodified alloy.



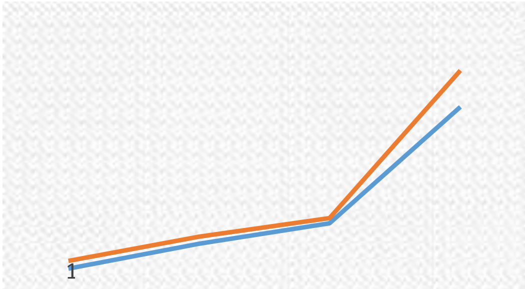


Fig 5.5 wear results of Al 319+SiC+Sr and unmodified Al 319.

4. CONCLUSION

In this study the effect of Sr and SiC addition on 319 Aluminium alloy was performed to improve the mechanical and microstructural properties of the alloy.

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The addition was carried out by a casting operation. Different tests and analysis were performed on the modified cast alloy to obtain the expected results. And from the results that we have received it can be inferred that both the mechanical properties and the microstructure of the base alloy, ie 319 Aluminium alloy have changed. Both tensile strength and hardness test has given promising results on addition of Sr and SiC into the alloy. The wear analysis shows a slight increase in wear resistance in the new modified alloy

The XRD and optical tests also conform that there have been morphological changes in the modified alloy which when analysed with the mechanical results infers that the coarse grain eutectic silicon has changed its form to fine fibrius form and the presence on reinforcement of SiC over the aluminium metal matrix. The only unexpected results was an increase in grain size only up to a very small extend which in turn should affect the mechanical properties but the other two effects to dominate this effect and nullify it. So with increased mechanical properties and a better microstructure modified 319 alloy can be used as a potential substitute for material used in engine blocks which can in turn increase efficiency.

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