Study of Strontium Modification in Aluminium Alloy

Gautam Krishnan.R¹, Dr E. M. Somasekharan Nair²

¹MTech Production and Industrial Engineering SCMS College of Engineering, Ernakulam
²HOD Mechanical department SCMS College of Engineering, Ernakulam

Abstract— The morphology of eutectic silicon in Al 319 alloy has a strong influence on the mechanical properties of the casting. The silicon particle morphology can be controlled by the addition of strontium. The addition of strontium results in a fine and fibrous silicon structure during solidification. The strontium modification can improve ductility, fracture and impact properties. Strontium modification of 319 alloys has significant role on the presence of porosity in the casting.

Keywords—Al 319 alloy, Strontium, Pit furnace

I. INTRODUCTION

Aluminium is a silvery white and ductile member of the boron group of chemical elements. It has the symbol Al and its atomic number is 13. It is not soluble in water under normal circumstances. Aluminium is the most abundant metal in the Earth's crust, and the third most abundant element there in, after oxygen and silicon. It makes up about 8% by weight of the Earth's solid surface. Aluminium is too reactive chemically to occur in nature as a free metal. The chief source of aluminium is bauxite ore.

Aluminium is remarkable for its ability to resist corrosion and for the metal's low density. Structural components made from aluminium and its alloys are vital to the aerospace industry and very important in other areas of transportation and building. Its reactive nature makes it useful as a catalyst or additive in chemical mixtures, including being used in ammonium nitrate explosives to enhance blast power.

Aluminium is a relatively soft, durable roughness. It is nonmagnetic and does not easily ignite. A fresh film of aluminium serves as a good reflector of visible light and an excellent reflector of medium and far infrared radiation. The yield strength of pure aluminium is 7–11 MPa, while aluminium alloys have yield strengths ranging from 200 MPa to 600 MPa. Aluminium has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded, lightweight, ductile and malleable metal with appearance ranging from silvery to dull gray, depending on the surface.

A unique combination of properties puts aluminium and its alloys amongst our most versatile engineering and construction materials.

All alloys are light in weight, yet some have strengths greater than that of structural steel. The majority of alloys are highly durable, and no coloured salts are formed to stain adjacent surfaces or discolour products with which they come in contact, as they have no toxic reaction. Aluminium and most of its alloys have good electrical and thermal conductivities and high reflectivity to both heat and light. Aluminium and most of its alloys can easily be worked into any form and readily accept a wide variety of surface finishes. Light weight is perhaps aluminium's best known characteristic having a density of approx. 2.7 x 103 kilograms per cubic metre at 20°C as compared with 7.9 x 103 for iron and 8.9 x 103 for copper. Commercially pure aluminium has a tensile strength of about 90 mega Pascals. Its usefulness as a structural material in this form is thus somewhat limited. However, by working the metal, as by cold rolling, its strength can be approximately doubled. Much larger increases in strength can be obtained by alloying aluminium with small percentages of one or more other metals such as manganese, silicon, copper, magnesium or zinc. Aluminium has a high resistance to corrosion on surfaces exposed to the atmosphere A thin transparent oxide skin forms immediately and protects the metal from further oxidation. Unless exposed to some substance or condition, which destroys this protective oxide coating, the metal remains protected against corrosion. Aluminium is highly resistant to weathering, even in industrial atmospheres that often corrode other metals. It general direct contact with alkaline substances should be avoided as these attack the oxide skin and ore therefore corrosive to aluminium. Some alloys are less resistant to is also corrosion-resistant to attack by many acids, but general direct contact with alkaline substances should be avoided as these attack the oxide skin and ore therefore corrosive to aluminium. Some alloys are less resistant to corrosion than others, particularly certain high-strength alloys. In accordance with sound design principles, direct contact with certain other metals should be avoided in the presence of an electrolyte, as galvanic corrosion of the aluminium may take place in the vicinity of the contact area. The fact that aluminium is non-toxic was discovered in the early days of the industry.
It is this characteristic, which enables the metal to be used in cooking utensils without any harmful effect on the body and today a great deal of aluminium equipment is used by food processing industries. The same characteristic permits aluminium foil wrapping to be used safely in direct contact with food products.

The morphology of eutectic silicon in Al 319 alloy may have a strong influence on the mechanical properties of the casting. The silicon particle morphology can be controlled by the addition of strontium containing master alloy to the melt. The addition of Strontium results in a fine and fibrous silicon structure during solidification and produces several benefits. The Strontium modification may improve the ductility, fracture, and impact properties. Further more Strontium modification can effectively be used to reduce the solution treatment time of the alloy. Despite these benefits there is a degree of apprehension associated with modification primarily because of the apparent increase of porosity in the casting. The Sr addition can reduce the rejection rate and improves the casting quality. Approximately 0.02% of Sr will refine platelets into fibrous form.

Under modification and over modification can occur with modification process. The excessive amount of Sr (0.12 to 0.2%) will result in the formation of undesirable compounds such as Sr Si2 and Al2 Si2 Sr. As a general rule slight over modification is preferable if control of the Sr level is not good enough to achieve optimum Sr content.

II. EXPERIMENTAL PROCEDURE

In the present study, experiments are conducted in order to make castings of Al 319 Alloy with 0.02% Strontium and heat treatment of castings using various techniques

The following data consists of the quantity of materials used.

Weight of Al 319 alloy – 8.5kg
Coverall Flux – 1% of Al 319 alloy = 85 gm
Degasser for Al – 2% of Hexa-Chloro Ethane
Strontium Addition – 0.02% weight of Strontium
= 8500 * 0.02 = 1.7 gm
Weight of Al – 10% Sr = 1.7 * 10 = 17 gm

Prior to the change the ingots into the crucible they have to be cleaned by abrasive and chemical solvent (acetone). This is done to make the casting free from casting defects caused by impurities in the metal and to make it free from moisture to prevent corrosion. Cast Iron moulds are used throughout the experiments.

Graphite coatings are provided inside the mould for easy separation of the castings from the mould after solidification. The moulds are then preheated to a temperature of 250°C. Crucible was used to melt the Al 319 alloy. The crucible is a large sized one to prevent overflow of molten alloy.

Electrically operated pit furnace was used to melt the alloy. The pit furnace consists of nine resistance coils. The heat is transferred to the metal through convection coils and radiation.

8.5 kg of 319 alloy is weighed using a weight balance. The pit furnace is heated to 700°C to become red hot and the 319 alloy is charged in the crucible. Coverall flux of 85gm is also added into the crucible while charging the 319 alloy. The purpose of adding the flux is to prevent the melt surface from oxidation and contamination. The addition of hexa - chloro ethane was to degas the melt alloy i.e, to drive away the dissolved hydrogen, which will otherwise be present in the solidified ingot as porosities. To remove further the dissolved hydrogen and nitrogen gas is bubbled through the molten metal. Here nitrogen gas is bubbled for about 45 minutes. This will ensure that all the hydrogen present in the molten metal is removed.

17 gms of Al-10% master alloy was added into the crucible and complete melting is ensured. After Sr addition nitrogen gas is again bubbled for about 15 minutes as mentioned above. The molten metal is poured into the preheated moulds at 720°C. Then the moulds are allowed to solidify. The drying of the mould is shown in the figure. After solidification, the casting is removed from the mould.
To improve the mechanical properties of Al 319 S heat treatment process is done. Heat treatment process comprises mainly of two steps.

1. Solution Treatment & Quenching.
2. Artificial Ageing / Precipitation Heat Treatment.

The machined samples were placed inside the resistance furnace. The temperature of the furnace was maintained at 500°C. The temperature is kept constant and frequent checking is done. This process is continued for a period of 10 hrs. After 10 hrs the samples were taken out and were quenched in water. The temperature of the water was measured by the thermometer as 60°C before quenching. After Solution treatment the samples were subjected to natural ageing for 12 hrs. The artificial ageing was carried out in an air oven at 150°C. The ageing period was varied from 3-6 hrs. Set of samples were withdrawn from the ageing oven in every one hour duration and air quenched.

The as-cast as well as aged samples were polished for microstructure study. Initially the samples were polished using different grades of Silicon Carbide papers of progressively fine grades of 220, 400, and 600 grits. During paper polishing water was used as the cleaning agent. The samples were turned through 90° while polishing from one paper to the next one. Hand polishing was followed by machine polishing. The polishing machine consists of a rotating disk covered with polishing cloth. Diamond paste was used as the polishing compound. Diamond pastes with particle size 6µm, 3µm, 0.25µm were progressively used.

Samples were gently pressed against the rotating wheel. The machine speed was set at 350 rpm. Filtered kerosene was used as the lubricant during the operation. After fine polishing samples was cleaned using soap solution. The polished samples were chemically etched using 0.5% HF solution to reveal the microstructure. After etching and thorough cleaning in running water the samples were dries using hair drier and observed under optical microscope.

Tensile testing was carried out using computer controlled INSTRON 1195-5500R UTM. The required dimensions of the specimen were measured and noted. Then the specimen is loaded onto the UTM.

Ultimate tensile strength, yield strength and % elongation were obtained directly from the computer interface with the machine. An extensometer was used to measure the % elongation. Both As - cast and the aged samples (3hrs, 4hrs, 5hrs, and 6hrs) were tested as above and the stress-strain graph was plotted.
III. RESULTS AND DISCUSSION

The chemical composition and physical properties of AlSi19 alloy are given in table no: 1 and no: 2 respectively. As melt treatment Sr of the order of 0.02wt% was added to the alloy during melting in the form of AI-Sr10% master alloy in order to modify the eutectic Si morphology to achieve better mechanical properties. The alloy cast in permanent mould was cut to make samples for evaluating mechanical properties and metallographic studies. The samples were then subjected to T6 heat treatment.

In the present study Sr of the order of 0.02wt % was added to the alloy after degassing, allowed around 10 minutes to complete the reaction and the melt was poured into permanent mould. The results of the mechanical properties (table no:3) and the microstructure (fig 4.1) indicate that Sr was effective in modifying the eutectic Si. In the unmodified alloy the Al2Cu phase appears in the blocky form (fig 4.1) and distributed very non uniformly. But in the Sr modified alloy the blocky form of Al2Cu has reduced considerably and the distribution was also found to be better (fig 4.2), indicating that Sr addition was effective to some extent in distributing the Cu atoms in the matrix. As regards porosity in the casting is concerned, it has been observed that less than around 1% porosity was present in both unmodified and modified alloy casting indicating that Sr addition has no effect on the porosity content on the casting.

The as cast microstructure of Al 319 alloy consists of Al dendrites, needle shaped eutectic Si, plate shaped Al5FeSi intermetallic and equilibrium Al2Cu. The morphology of eutectic Si, namely the size and shape, plays an important role in determining the mechanical properties of this alloy. Under normal cooling conditions the eutectic Si appears as long acicular needles which act as stress raisers, thereby decreasing the mechanical properties. It has been reported that addition of elements such as Sr/Na can modify the morphology of eutectic Si from needle shaped one to fibrous one [6]. The modified eutectic Si in fibrous form will not act as stress concentrator and hence the mechanical properties of the alloy will be improved. However, the Sr modification results in segregation of Cu phase (Al2Cu) which makes it difficult for them to dissolve during solutionising heat treatment. The possibility of incipient melting of the undissolved Al2Cu during solutionising heat treatment, thus, cannot be ruled out. On the other hand, it has been reported that Sr addition improves the Cu distribution in the matrix which will lead to the better distribution of the hardening Al2Cu precipitate on heat treatment.

The selection of proper solutionising conditions (temperature and time) the Cu phase can be evenly distributed which will further improve the mechanical properties.

The alloy samples both for the evaluation of tensile properties and metallographic studies were subjected to the following T6 heat treatment:

- Solutionising at 500°C for 10 hrs
- Hot water quenching
- Natural aging for 12 hrs
- Artificial aging at 170°C for 3,4,5and 6 hrs

The microstructural studies showed that the eutectic Si morphology has changed from acicular/fibrous to rounded one indicating that the heat treatment was effective (fig 4.6). Artificial aging of the alloy was carried out for different periods. It was observed that with the increase of aging period the mechanical properties also found to increase.(table no: 4) and the maximum mechanical properties (UTS,YS \% elongation ) was obtained for an aging period of 6hrs. Thus aging at 150°C for 6hrs can be considered as optimum aging conditions which are well comparable to that reported in the literature.

The T6 heat treatment of 319 type alloy involve solutionising heat treatment at higher temperature (around 500°C) followed by quenching to near room temperature and artificial aging at higher temperature (around 150-155°C). The solutionising treatment dissolves the Al2Cu phase in the Al matrix and on quenching to a lower temperature a supersaturated solid solution of Al2Cu in Al matrix is obtained. Artificial aging at higher temperature and sufficient long period will result in the fine precipitation of Al2Cu which are fine and coherent with matrix are distributed uniformly in the matrix. This fine hardening precipitate of Al2Cu, which cannot be resolved under optical microscope, will hinder the movement of dislocations thereby hardening the material. In the peak aged conditions the precipitated particles are maximum, extremely fine and distributed uniformly in the matrix. It was reported that during heat treatment the Al2Cu phase undergoes necking which takes at several points along the length of the particle and further it leads to its breaking into smaller fragments and is followed by the diffusion of Cu atoms into the surrounding matrix.

In the present study as the aging time was increased from 3 to 6 hrs a gradual increase in the mechanical properties were observed, indicating that the precipitation process is on. After 6hrs of aging it appears that the precipitation process is complete since the mechanical properties obtained at this aging condition was maximum.
Thus the optimum aging conditions of 150°C for 6 hrs. may be considered as optimum one.

Strontium has the effect of segregating Al2Cu in the matrix. But the segregated Al2Cu can be dissolved in the matrix by the proper choice of the solutionsing conditions (temperature and time). In the present investigation considerable reduction of Al2Cu segregation was observed after heat treatment, which shows that the solutionsing conditions adopted in the study was sufficient for the dissolution of Al2Cu to a great extent.

The as cast microstructure of the alloy without the addition of Sr consists of mainly α Al dendrites, needle shaped eutectic Si and blocky Al2Cu segregated at eutectic Si and β Al. Fig shows the microstructure of the alloy with Sr addition, indicating that morphology of Si has changed from needle shape to fine fibrous one or the modification was effective with the Sr addition. Also the distribution of Al2Cu and the level of porosity in both the samples were found to be similar which indicates that Sr addition has little effect in Al2Cu segregation and increasing the porosity content in casting.

Microstructure of the alloy containing Sr and aged at different periods are given in fig. It may be noted that the morphology of eutectic Si has changed from fibrous one to rounded one due to heat treatment in all the samples. Although the three different aging treatments have caused considerable changes in the mechanical properties, no observable changes in the microstructure could be noticed. The improvement in the mechanical properties with the increase of aging time could be due to the increase in the amount of precipitation of the fine hardening phase of Al2Cu which could not be resolved by optical metallography. This demand for better micro structural analysis using SEM/TEM and EDAX, which is beyond the scope of the present studies.
Figure VII Microstructure of heat treated Al 319 S 3 hrs aged

Figure VIII Microstructure of heat treated Al 319 S 4 hrs aged

Figure IX Microstructure of heat treated Al 319 S 5 hrs aged

Figure X Microstructure of heat treated Al 319 S 6 hrs aged
The mechanical properties of the material both in the as cast and after heat treatment conditions are given in table.

### Table 1
Strength Test Results

<table>
<thead>
<tr>
<th>Ageing Period (hrs)</th>
<th>Ageing Period (hrs)</th>
<th>UTS (MPa)</th>
<th>Tensile Stress at yield (offset 0.2%) (MPa)</th>
<th>E – Modulus (MPa)</th>
<th>% Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>As-cast</td>
<td>186.94</td>
<td>120.8 – 123.4</td>
<td>37141.2 – 42896.6</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>243.2 – 300.6</td>
<td>157.5 – 171</td>
<td>51276.5 – 56771</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>282.6 – 310.7</td>
<td>156.1 – 175.5</td>
<td>55131.1 – 59586.1</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>274.2 – 320.1</td>
<td>165.6 – 185.5</td>
<td>57123.2 – 63397.4</td>
<td>10.5</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>312.2 – 316</td>
<td>177.1 – 185.3</td>
<td>58033.6 – 59938.7</td>
<td>11</td>
</tr>
</tbody>
</table>

It is clear that the UTS, YS and percentage elongation showed considerable improvement when the material is subjected to the heat treatment. Also, as the aging period is increased from 3-6hrs. The percentage increase in UTS, YS and percentage elongation was found to be 316 MPa, 185 MPa, 11% respectively. The tensile properties obtained at 6hrs of aging treatment are comparable to that reported in the literature for similar type of alloy, indicating that peak aging is achieved. The improvements in the mechanical properties after T6 heat treatment are due to (i) the presence of fine and evenly distributed Al2Cu particles and (ii) change in the morphology of Si. Strontium modification has the added advantage of improving the ductility (% elongation) by modifying the eutectic Si morphology in the as cast condition. Typical stress-strain diagrams of the as cast and heat treated samples are given in fig.

**Figure XI Stress strain curve of as-cast Al 319 S**

**Figure XII Stress strain curve of 6 hrs aged Al 319 S**

### IV. CONCLUSION

The addition of Sr of the level of 0.02% to Al319 alloy was effective in modifying the morphology of eutectic Si from needle shapes to fibrous one. The solutionising and aging conditions adopted are effective in improving the mechanical properties of the Sr modified 319 alloy. However, the effects of varying the solutionising conditions need further investigations. The tensile properties can be used for deriving the aging curve for the alloy. Though the microstructural analysis gives good assessment of the alloys, both unmodified and modified, in terms of eutectic Si and Al2Cu particle size, shape and morphology, the presence of porosity level, etc. It cannot be used to understand the aging behaviour of the material.
REFERENCES