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EFFECT OF Mg ENHANCEMENT IN THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AC2A ALUMINIUM ALLOY

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ABSTRACT

For last several decades aluminium and aluminium alloys are widely used in automotive industries because for their favorable properties like low density, good malleability, high formability, high corrosion resistance and high electrical and thermal conductivity. High machinability and workability of aluminium alloys are prone to porosity due to gases dissolved during melting processes. However, in the engineering application pure aluminium and its alloys still have some problems such has relatively low strength, unstable mechanical properties and low wear resistance. AC2A alloy posse's better mechanical properties, machinability, wear resistance and are suitable for heat treatment. Now it is used for automobile application like brake calipers, piston rods etc. The microstructure can be modified and mechanical properties can be improved by alloying and heat treatment. In this regards, the present paper reports the presence of magnesium on the mechanical properties and microstructure of AC2A Aluminium Alloy.

KEYWORDS: AC2A Aluminium Alloy, Heat Treatment, Mg Modification, Mechanical Properties, T6 Condition

INTRODUCTION

Aluminium castings have played an integral role in the growth of the aluminium industry since its inception in the late 19th century. The first commercial aluminium products were castings, such as cooking utensils and decorative parts, which exploited the novelty and utility of the new metal. The wide popularity of Al alloys in the automobile industry stems from their high strength to weight ratio, excellent casting characteristics, and good mechanical properties including wear resistance, low Co-efficient of thermal expansion, high thermal conductivity and high corrosion resistance. Al-Si-Cu alloys are mainly used in cast form in critical components like pistons, valve lifters, cylinder liners, engine blocks, etc. These applications demand the study of techniques to improve the wear properties of these alloys. In the recent years the usage of cast Al–Si-Cu alloy components in automotive and marine industries has increased significantly. Such alloys are invariably treated for modification prior to casting to achieve improved properties and performance.

Modification is the process by which the coarse and acicular Si is transformed to fine fibrous form. The process also involves the decrease of the surface tension of the aluminium that leads to silicon particles more rounded and smaller. It also improves fatigue, fracture toughness, impact properties. Hence modification results in improved tensile strength and ductility, with higher improvement in the latter compared to the former. Grain refinement has also drawn the attention of many researchers during last few years. It has been reported that grain refinement leads to fine equiaxed grain structure, which in turn results in improved mechanical and wear properties. Modifier and grain refiners are to be added to the molten Al –Si-Cu alloys to get combined grain refinement and modification effects. The objective of the study is to develop an AC2A alloy with Mg modification through Gravity die casting technique. Study its effect on the microstructure and mechanical properties before and after the heat treatment. Thus improve the mechanical properties of AC2A alloy and enhance its application to a wide extend.

EXPERIMENTAL DETAILS

Casting Preparation and Sequence of Operation

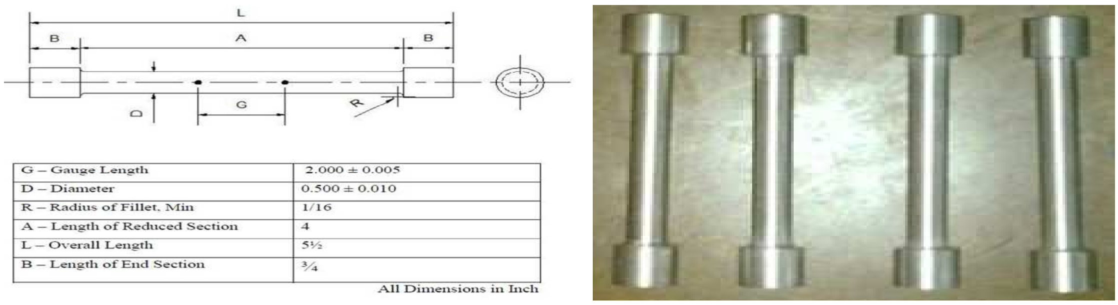
The aluminium ingots were cleaned using acetone to make it free from moisture. Cast iron moulds are used for casting. Graphite coatings are provided inside the moulds for easy separation of the castings from the mould after solidification. The moulds are then preheated to a temperature of 250°C. Electric Induction Furnace is used for the melting of metal. The furnace is having a capacity of 3 tonnes. Size of the mould is 20cm x 15cm x 5cm. 10 kg of aluminium alloy is weighed using a weight balance. The furnace is heated to 700^{o}C to become red hot and the alloy is charged in the crucible. Coverall flux of 100 gm is also added into the crucible while charging the alloy. The purpose of adding the flux is to prevent the melt surface from oxidation and contamination. Hexachloroethane tablets were added to degas the melt after ingots gets completely melted. 500 gm of Al-10% Mg master alloy was added into the crucible and complete melting is ensured. To remove further the dissolved hydrogen and nitrogen gas is bubbled through the molten metal. Here nitrogen gas is bubbled for about 45 minutes. Mechanical stirring is done at a temperature of 580^{0}C for 20 min at 425 rpm in order to mix the elements well and mainly to acquire the required mechanical property. The molten metal is poured into the preheated moulds without any turbulence at 720^{o}C. Then the moulds are allowed to solidify.

Specimen Preparation

For identifying the properties of AC2A aluminium alloy, mechanical tests were conducted. For the purpose of making specimens, the material casting is machined and specimens were cut down from the bottom halves. All tests were conducted as per ASTM standards.

Tensile Test as per ASTM B557 – 06

A gauge length of 2.000+/-0.005” was marked on the tensile specimen. The tensile properties were measured by using a Universal testing machine Instron model 1195, at room temperature. The test was carried out by gripping the ends of the specimen on the Instron machine and applying increasing pull on the specimen till it fractures.



G – Gauge Length	2.000 ± 0.005
D – Diameter	0.500 ± 0.010
R – Radius of Fillet, Min	1/16
A – Length of Reduced Section	4
L – Overall Length	5½
B – Length of End Section	¾

All Dimensions in Inch

Figure 1: Tensile Test Specimen as per ASTM Standard

Impact Test as per ASTM E23

Impact tests are widely employed in which notched specimens are broken by a swinging pendulum. The most common tests of this type are the Charpy V-notch tests which are described in ASTM E23.

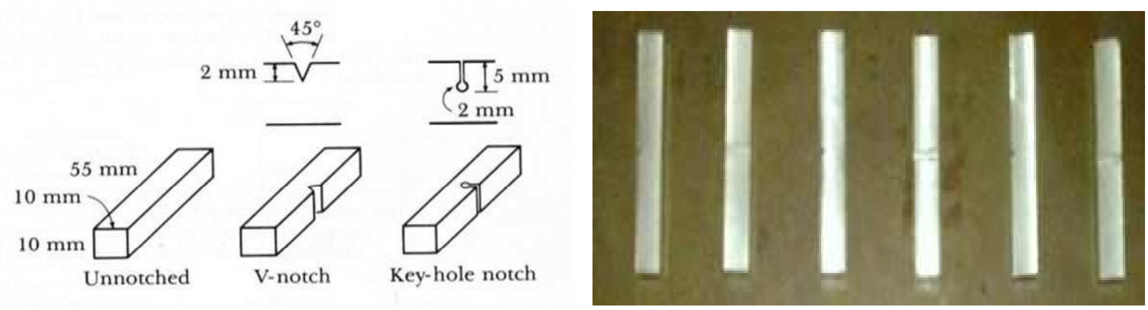


Figure 2: Impact Testing Specimen as per ASTM Standard

Hardness Test as per ASTM E18

ASTM E18 relates with Rockwell hardness testing. Here B scale is used and value is HRB. The load used is 100kgf. ASTM E140 - 07 - Standard Hardness Conversion Table also can be used to convert the HRB scale to the required other scales, say VHN, BHN, HRC etc.

Figure 3: Hardness Testing Specimen as per ASTM Standard

Metallographic Samples

Two small cylindrical specimens, of dimension 1.5 cm x 1.5 cm, were cut from the bottom of the pencil castings. Four grades of emery papers were used: 100, 220, 400 and 600grit. After grinding, polishing was carried out on the specimen. 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.

Figure 4: Metallographic Specimen

Chemical Analysis

Spectromax, a bench top unit is used as chemical analyzing equipment. All of the important elements in the metal industry can be determined with this analyzer, including traces of carbon, phosphorous, sulfur and nitrogen.

Heat Treatment (T6 Condition)

To improve the mechanical properties of modified AC2A alloy heat treatment process is done on mechanical test samples. Heat treatment process comprises mainly of Solution Treatment & Quenching followed by Artificial Ageing / Precipitation Heat Treatment. The machined samples were placed inside the resistance furnace. The temperature of the furnace was maintained at 500^0C. This process is continued for a period of 10 hrs. After 10 hrs the samples were taken out and were quenched in water. After Solution treatment the samples were subjected to natural ageing for 12 hrs. The artificial ageing was carried out in an air oven at 150^0C. The ageing period was kept to 6 hrs.

RESULTS & DISCUSSIONS

Chemical Analysis

The results show the percentage of elements in the AC2A alloy and modified alloy. The modified alloy shows a percentage of 0.93 % of Mg with the addition of 1% by weight of Al-5% Mg Master Alloy. The percentage of Si in the modified alloy is 5.70 by Wt% as the range is 4 – 6 % in the AC2A alloy. The percentage of Cu in the modified alloy is 4.10 by Wt% as the range is 3 – 4.5 % in the AC2A alloy.

Table 1: Chemical Analysis of AC2A and Modified AC2A Alloy

Elements	AC2A alloy Wt in %	Modified AC2A alloy Wt in %
Cu	3.0 – 4.5	4.10
Mg	0.1 max	0.93
Si	4.0 – 6	5.70
Fe	0.9 max	0.80
Mn	0.55 max	0.55
Ni	0.3 max	0.28
Zn	0.55 max	0.55
Pb	0.2 max	0.15
Sn	0.05 max	0.03
Ti	0.25 max	0.20
Cr	0.15 max	0.10
Al	Balance	Balance

Tensile Test Results

Modified AC2A alloy

The table shown below gives the yield strength, ultimate tensile strength and % elongation of six tensile test specimens. From the table, their standard deviation and mean values were found out.

Table 2: Tensile Test Result of Modified AC2A Alloy

Sl No	Tensile Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	% Elongation
1	117	202	3.2
2	113	206	2.8

Table 2: Contd.,

3	114	206	3.0
4	117	206	3.3
5	111	201	3.0
6	117	203	2.9
Standard Deviation	**2.34**	**2.08**	**0.17**
Mean	**115**	**204**	**3.0**

The Tensile yield strength of unmodified AC2A alloy is 110 MPa. As from the table we can see that six numbers of specimen was tensile tested and it was found that the tensile yield strength of modified AC2A alloy has been increased to 115 MPa. It is also evident from the table that ultimate tensile strength of modified alloy is increased from 195 MPa to 204 MPa. % Elongation, which was 2.0 %, has been increased to 3.0 %. Tensile strength yield strength of the alloys in castings increases with increase of % Mg but with decrease in ductility of cast alloys.

Modified AC2A Alloy after T6 Condition

The table shown below gives the yield strength, ultimate tensile strength and % elongation of six tensile test specimens. From the table, their standard deviation and mean values were found out. The Tensile yield strength of modified AC2A alloy is 115 MPa.

As from the table below we can see that six numbers of specimen was tensile tested and it was found that the tensile yield strength of modified AC2A alloy after T6 condition has been increased to 192 MPa. It is also evident from the table that ultimate tensile strength of modified alloy after T6 condition is increased from 204 MPa to 283 MPa. % Elongation, which was 3.0% before heat treatment, has been increased to 3.9 %.

Heat treated samples with composition of Mg from 0.1-1.5% have shown an improvement on mechanical properties as compared to as-cast alloys.

Table 3: Tensile Test Result of Modified AC2A Alloy after Heat Treatment

Sl No	Tensile Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation
1	195	281	3.8
2	189	286	3.7
3	191	280	4.1
4	189	286	3.8
5	186	285	3.9
6	198	281	4.0
Standard Deviation	**3.65**	**2.56**	**0.20**
Mean	**192**	**283**	**3.9**

Comparison of Tensile Test Results

The tensile yield strength of un-modified AC2A alloy is 110 MPa which has been increased to 115 MPa in modified AC2A alloy and the value again increased to 192 MPa by heat treatment. The Ultimate tensile strength of un-modified AC2A alloy is 195 MPa which has been increased to 204 MPa in modified AC2A alloy and the value again increased to 283 MPa by heat treatment. The % elongation of unmodified AC2A alloy is 2.0 % which has been increased to 3.0 % in modified AC2A alloy and the value again increased to 3.9 % by heat treatment.

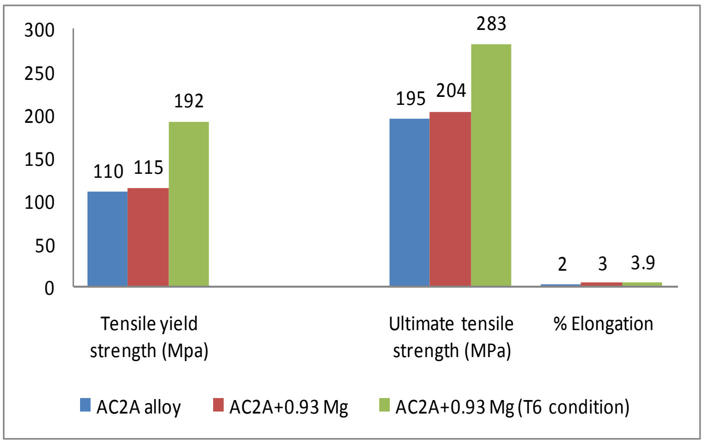


Figure 5: Comparison of Tensile Tests Result

Hardness Test Results

The table shown below gives the BHN value of six hardness test specimens. From the table, their standard deviation and mean values were found out.

Table 4: Hardness Test Results

Sl No	HRB Value (Modified)	HRB Value (T6 condition)
1	88	112
2	89	109
3	90	113
4	89	112
5	85	109
6	88	109
Standard Deviation	**1.58**	**1.73**
Mean	**88**	**111**

Comparison of Hardness Test Results

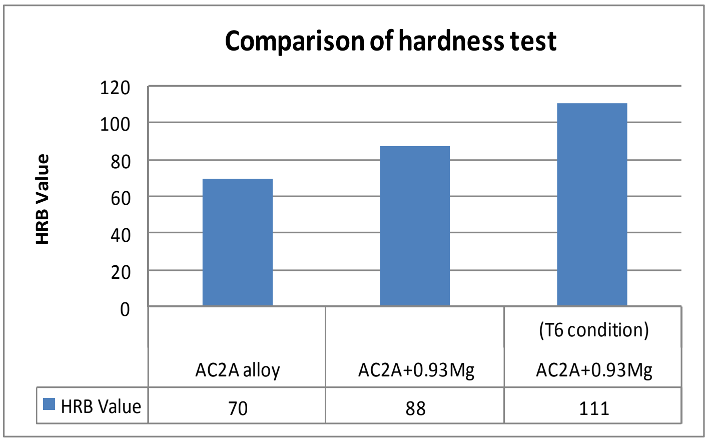


Figure 6: Comparison of Hardness Test Results

The HRB Value of un-modified AC2A alloy is 70 which have been increased to 88 in modified AC2A alloy and the value again increased to 111 by heat treatment. Addition of Mg to Al-Si-Cu alloys accelerates and intensifies the age hardening process and produces a remarkable increase in hardness. The composition of quenched and aged aluminium matrix changes with ageing time due to the precipitation of Al_2Cu and Mg_2Si phases. The hardness is due to the cooperative precipitation of Al_2Cu and Mg_2Si phases.

Impact Test Results

The table shown below gives the impact value of six impact test specimens. From the table, their standard deviation and mean values were found out.

Table 5: Impact Test Results

Sl No	Impact Value (J) (Modified)	Impact Value (J) (T6 Condition)
1	6.9	9.2
2	7.1	10.0
3	7.3	8.9
4	8.2	9.2
5	7.9	9.4
6	7.8	8.9
Standard Deviation	**0.47**	**0.37**
Mean	**7.5**	**9.3**

Comparison of Impact Test Results

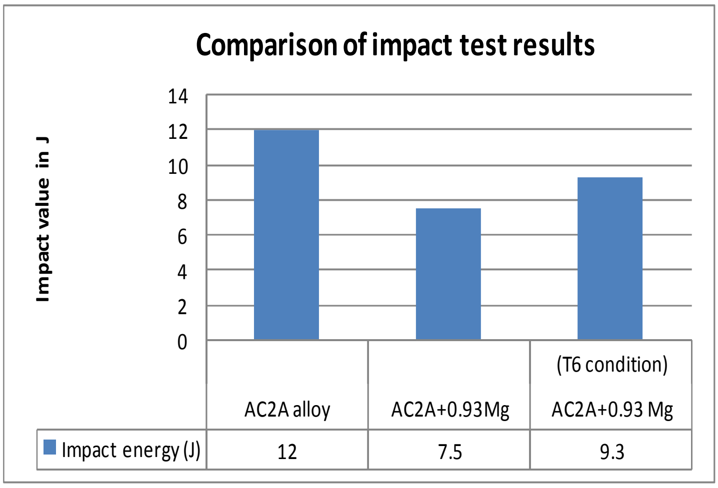


Figure 7: Comparison of Hardness Test Results

The Impact Value of un-modified AC2A alloy is 12 J which have been reduced to 7.5 in modified AC2A alloy and the value again increased to 9.3 by heat treatment. The Mg modified alloy shows a reduction in impact value due to high Cu content and leads to the precipitation of $CuAl_2$ phases. Microporosity usually resulting from the dissolved H_2 and N_2 gas is also a reason to reduce the impact strength of the alloy.

The dislocation slip band in the matrix is a kind of microcrack initiator. The matrix has areas where there is no reinforcement such as silicon particles or intermetallic precipitates. These local non-reinforced areas are relatively soft and dislocation slip can be easily produced under external stress.

Microstructure Analysis

Microstructure of Modified AC2A Alloy

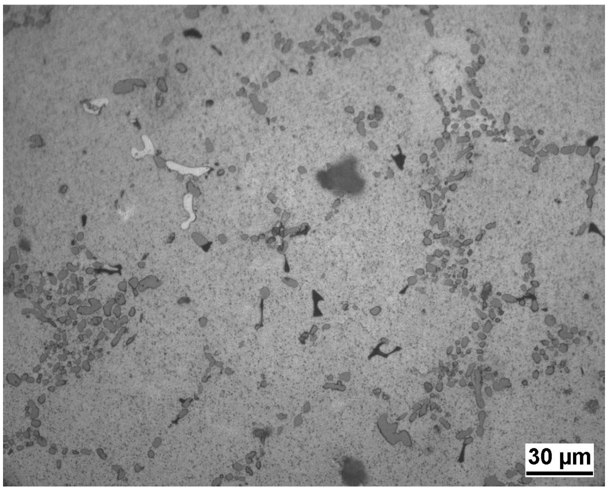


Figure 8: Microstructure of Modified AC2A Alloy

The microstructure consists of mainly precipitates like Al_2Cu, Mg_2Si, Al_2CuMg, and $Al_4CuMg_5Si_4$. Mg refines the eutectic Si morphology from needle to fibrous one. The modified eutectic Si in fibrous form will not act as stress concentrator and hence the mechanical properties of the alloy will be improved, the dark black dot shows the porosity in the casting. Modification results in segregation of Al_2Cu, Mg_2Si which makes it difficult for them to dissolve during solutionising heat treatment. The Mg addition leads to the transformation of a large portion of the Plate shaped β Al5FeSi intermetallic into α– Fe script phase. Due to the compact form of α–Fe intermetallics, they are less harmful to mechanical properties.

Microstructure of Modified AC2A Alloy after Heat Treatment

The alloy samples for the evaluation of tensile properties, hardness properties, impact properties and metallographic studies were subjected to the following T6 heat treatment. It follows Solutionising at 500^0C for 10 hrs, Hot water quenching, Natural aging for 12 hrs, Artificial aging at 180^0C for 6 hrs.

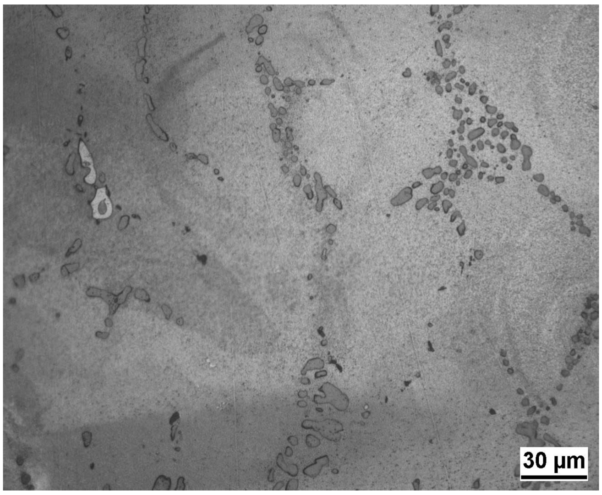


Figure 9: Microstructure of AC2A Alloy after T6 Condition

Solution heat treatment changes the morphology of eutectic silicon from fibrous to rounded one, resulting in a significant decrease of Si particles. After T6 condition, fine precipitation of Al_2Cu, Mg_2Si which are fine and coherent with matrix are distributed uniformly in the matrix. The composition of quenched and aged samples changes with ageing time due to the precipitation of Al_2Cu, Mg_2Si phases.

CONCLUSIONS

Enhancement of AC2A with Mg modification is performed and for evaluating mechanical & microstructural properties, tensile tests, hardness tests, impact tests, and microstructural analysis were conducted. The modified alloy shows a percentage of 0.93 % of Mg with the addition of 1% by weight of Al-5% Mg Master Alloy. The modification leads to an increase in tensile yield strength, ultimate tensile strength and % elongation and after heat treatment the value again increases. Modification results in segregation of Al_2Cu, Mg_2Si which makes it difficult for them to dissolve during solutionising heat treatment. The Mg addition leads to the transformation of a large portion of the Plate shaped Al_5FeSi intermetallic into α–Fe script phase. Solution heat treatment changes the morphology of eutectic silicon from fibrous to rounded one, resulting in a significant decrease of Si particles. After T6 condition, fine precipitation of Al_2Cu, Mg_2Si which are fine and coherent with matrix are distributed uniformly in the matrix. The composition of quenched and aged samples changes with ageing time due to the precipitation of Al_2Cu, Mg_2Si phases. The BHN Value also increases in the modified alloy and also after T6 condition. The hardness is due to the cooperative precipitation of Al_2Cu and Mg_2Si phases. The modified alloy shows a slight decrease in the impact value due to high Cu content and leads to the precipitation of $CuAl_2$ phases. Microporosity usually resulting from the dissolved H_2 and N_2 gas is also a reason to reduce the impact strength of the alloy.

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