MECHANICAL PROPERTIES ENHANCEMENT OF AL-SI (ADC12) ALLOY BY HEAT TREATMENT

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Abstract—The present work deals with the effect of heat treatment on the mechanical properties Al-Si (ADC12) alloy. The mechanical properties such as tensile strength, compressive strength, hardness and impact strength of the composites in as cast and heat treated condition were studied in order to achieve the maximum properties. Microstructural examination of the alloy in as cast and heat treated condition was carried out to observe the effect of aging. X-ray diffraction of the alloy in as cast and heat treated condition was done to know the phases present in the material. The fracture surface study was done to ascertain the type of fracture taking place in the alloy. It is observed that there is a substantial improvement in the mechanical properties of the alloy due to heat treatment as compared to the as cast alloy. The microstructural study of the cast alloy shows aluminum dendrites with dendritic arm spacing in the range of 25 microns. The eutectic silicon solidifies in the inter-dendritic region and around the dendrites. On heat treatment the plate shaped eutectic silicon is fragmentated into spherical shape. X-ray diffraction analysis shows major peaks of aluminum and minor peaks of intermetallic phases such as CuAl2, Al-CuMg and Mg2Si in as cast as well as in heat treated condition. Tensile fracture surface study shows the fracture is taking place by inter- granular manner (crack propagation along the grain boundary) and morphology of dendrites in the fracture surface.

Keywords—Al-Si alloy; heat treatment; tensile strength; compressive strength; hardness; impact strength; tensile fracture.

I. INTRODUCTION

Considerable efforts are being made to explore the possibilities of improving the mechanical strength of Al so as to meet the requirements for various applications. In order to improve the mechanical strength and modulus of aluminium, it is alloyed with various alloying elements such as Cu, Fe, Zn, Mg, Si, Mn etc [4]. Amongst the various aluminium alloys, Al-Si alloys are used extensively because of their properties like low coefficient of thermal expansion, good bearing properties, good corrosion resistance and adequate strength and are therefore used frequently in aerospace and automobile structural components. It is convenient to divide aluminium alloys into two major categories: cast and wrought alloys. These categories are based on the primary mechanism of property development as heat-treatable and non-heat treatable alloys. Many alloys respond to thermal treatment based on phase solubility. These treatments include solution heat treatment, quenching and precipitation or age hardening. Other materials can be work hardened through mechanical reduction, usually in combination with various annealing procedures for property development. These alloys are referred to as non-heat treatable or work hardening alloys.

II. EXPERIMENTAL WORK

2.1 Material

Al-Si (ADC12) alloy is selected for study in this work. The chemical compositions of aluminium alloy were analyzed using glow discharge spectrometer.

<table>
<thead>
<tr>
<th>Property</th>
<th>ADC12 alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Heat, J/g°C</td>
<td>96.2</td>
</tr>
<tr>
<td>Elastic Modulus, GPa</td>
<td>68.90</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion, K-1</td>
<td>31.1 x 10^-5</td>
</tr>
<tr>
<td>Poisson Ratio</td>
<td>0.33</td>
</tr>
</tbody>
</table>

2.2 Specimen Preparation

The specimens for various mechanical tests were prepared in accordance with the BIS codes mentioned in the table 3.

<table>
<thead>
<tr>
<th>Test</th>
<th>Code</th>
<th>Dimension</th>
<th>No. of specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile</td>
<td>IS 1608</td>
<td>10 mmØ</td>
<td>3</td>
</tr>
<tr>
<td>Compressive</td>
<td>IS 1757</td>
<td>L/D 1.5-2.0</td>
<td>3</td>
</tr>
<tr>
<td>Impact</td>
<td>IS 1503</td>
<td>55x10x10 V Notch 2mm depth</td>
<td>3</td>
</tr>
<tr>
<td>Hardness</td>
<td>IS 1586</td>
<td>15 mmØ, L=15 mm</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 1 Chemical Composition of ADC 12 alloy

<table>
<thead>
<tr>
<th>Property</th>
<th>ADC12 alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, g/cm³</td>
<td>2.76</td>
</tr>
<tr>
<td>Thermal Conductivity, W/mK</td>
<td>10-40 at 1100°C</td>
</tr>
</tbody>
</table>

Table 2 Properties of ADC12 alloy

Table 3
2.3 Heat Treatment
The specimens of alloy were heat treated in a programmable furnace to compare the properties in as cast and aged condition. There were three stages involved in the heat treatment.

i) Solutionising: The specimens were heated to a temperature of 490 ± 5 °C for 8 hours until the alloy solute elements are completely dissolved in the Al solid solution.

ii) Quenching: The solution treated specimens were rapidly cooled into oil (at room temperature) to prevent the precipitation of the solute elements and to obtain a super saturated solid solution and

iii) Artificial aging: To improve the strength and hardness of the material the specimens were reheated to 135°C /150°C /175°C /200°C /230°C for 6 hours each and then allowed to cool in the still air.

2.4 Mechanical Testing
The specimens were tested at room temperature for various tests. Mechanical properties such as UTS and Compressive strength were evaluated on computerized Universal testing machine (INSTRON M/c, Model 5586) 400KN Capacity at a strain rate of 0.5 mm/min. Hardness and Impact strength were evaluated on Analog Rockwell hardness tester (FIE make, model VM 50) and Charpy Impact Tester (FIE make, model FIT 30) at MANIT, Bhopal.

2.5 Microstructural Examination
Samples for microstructural characterization were polished according to standard metallographic procedures. Various steps involved during the process were polishing the specimens with different grade of emery papers and then finally with fine polishing alumina using polishing cloths. The samples were etched with Keller’s reagent and observed in a SEM.

2.6 X-ray diffraction Study
X-Ray diffraction analysis of ADC 12 alloy in as cast and heat treated conditions were carried out using Rikagu (Model Miniflex-2) X-ray diffractometer to find out the phases present in the sample. The solid sample was packed on a sample holder of size 15 mm x 20 mm rectangular cavity having depth of 2 mm. The samples were scanned at a scanning speed of 5 degree (2θ) per minute in the diffraction angle (2θ) range of 0 to 90°. The measurement was done at an applied voltage of 30 kV and current of 15 mA. The X-ray diffractogram obtained from the test shows the relationship between diffraction angle (2θ) and relative intensity. The ‘d’ (interplanar spacing) corresponding to each peaks were obtained from the measured files are used for identification of different phases in the material. The phases present in the samples were identified by comparing experimental d-values from standard reference card of JCPDS (Joint Committee of Powder Diffraction Standard) file.

2.7 Fracture Surface Study
For fracture surface study the fractured tensile specimens were cut, cleaned with acetone and fixed on a copper holder using double sided copper tape and coated with platinum, before keeping under observation through a SEM.

III. RESULTS AND DISCUSSION

3.1 MECHANICAL PROPERTIES

3.1.1 Tensile Strength

![Fig (3.1) shows the variation of tensile strength at different aging temperature.](image)

Fig (3.1) shows the variation of tensile strength at different aging temperature.

3.1.2 Compressive Strength
Fig (3.2) shows the variation of Compressive strength at different aging temperature.

Fig (3.2) shows the variation of Compressive strength of the alloy and the composites. It is noted from the figure that Compressive strength value was 484.39 MPa for alloy which decreases to 373.39 MPa for 10% SiC composite and on further increases in SiC reinforcement to 15% the Compressive strength value decreases to 353.04 MPa. So it is observed here that there is decrease in compressive strength with increase in SiC percentage. It is understood that dispersion of SiC particles in aluminium alloy matrix tends to reduce the compressive properties as during compression the soft aluminium matrix will compress and the SiC particles which are very hard are not deformed at the same rate as the matrix does. This non uniform deformation of matrix and hard particles results into development of cracks at the interface hence lowering the compressive strength of aluminium alloy particle composites.

Fig (3.3) shows the variation of hardness at different aging temperature.

3.1.3 Hardness

Fig (3.3) shows the variation of hardness for ADC12 alloy in as cast and heat treated conditions. It is noted from the figure that hardness increases with aging temperature reaches a high value then decreases. The value of hardness being 49 HRB in as cast condition which increases to 53 HRB at 175 C aging temperature. The highest value of tensile strength recorded was 55 HRB at 200 C. On further increase in aging temperature the value of hardness decreases to 45 HRB at 230 C aging temperature. There is a sharp fall in the hardness value when the aging temperature is 230. It is observed that hardness increases with aging temperature up to 175–200 C and then it decreases to a lower value, here the peak age is obtained at 200 C.

Fig (3.4) shows the variation of Impact Strength at different aging temperature.

3.1.4 Impact Strength

Fig (3.4) also shows the variation of impact strength of the alloy and the composites. It is observed from the figure that the impact strength for alloy was 0.73 Kgm which decreases to 0.57 Kgm and 0.50 Kgm respectively for 10% and 15% SiC composite. The impact strength value indicates that impact strength decreases with increase of SiC concentration in the composites. It is quite understandable that dispersing hard ceramic particles in soft matrix reduces the energy absorption capability of the material. More is the dispersion of SiC particles lesser is the impact strength. When there is sudden impact the interface between the particles and the matrix breaks and decohesion produces new surfaces and the energy is released. On the other hand in the case of aluminium alloy the matrix material absorb the impact energy without fracturing.

3.5 Microstructural Study

3.5.1 Microstructure of ADC12 Alloy

Microstructure of Aluminum silicon alloy (ADC12 alloy) solidified in a cast iron mold shows aluminum dendrites with dendritic arm spacing in the range of 25 microns. The eutectic silicon solidifies in the interdendritic region and around the dendrites (fig 1). The higher magnification micrograph (fig 2) depicts plate shaped eutectic silicon and the other intermetallic phases. The plate shaped eutectic silicon is usually 20-25 micron in length and 2-5 micron in width. In some instances the eutectic silicon are needle shaped.
Mechanical Properties Enhancement of Al-Si (ADC12) Alloy by Heat Treatment

3.6 X-ray diffraction Study

X-ray diffraction study was conducted on the experimental d-values, 20 values and corresponding intensity of major peaks and minor peaks of intermetallic phases present in alloy are compared with standard values obtained from JCPDS cards. It is observed that there are major peaks of aluminium and minor peaks of intermetallic phases such as Al$_2$CuMg, CuAl$_2$, Mg$_2$Si and Si in ADC12 alloy in as cast condition. X-ray diffractogram of ADC12 alloy in heat treated condition is shown in Fig. It also indicates the presence of major peaks of aluminium and minor peaks of intermetallic phases such as Al$_2$CuMg, CuAl$_2$, and Mg$_2$Si.

3.7 Fracture Surface Study

The fracture surface study was done to ascertain the type of fracture taking place in the alloy and composite. In case of aluminium silicon alloys, aluminium is a ductile material which fracture in ductile manner having considerable amount of plastic deformation on the other side silicon is a metalloid which fracture by brittle manner. In Al-Si alloy, silicon is preferentially segregated around the aluminium dendrites and provide easy path for crack nucleation and propagation. In Al-Si alloy the fracture is taking place by inter-granular manner (crack propagation along the grain boundary). When we observe the fractograph of Al-Si alloy it shows the morphology of dendrites in the fracture surface.

CONCLUSIONS

The experimental study reveals following conclusions:

1. Tensile strength of alloy and composite almost remains constant.
2. Compressive strength of composites decreases with increase in SiC concentration.
3. Hardness of the composites increases with increase in SiC concentration.
4. Impact strength of composites decreases with increase in SiC concentration.
5. The microstructure of alloy shows aluminium dendrites and plate shaped eutectic silicon. Microstructure of composites shows uniform distribution of SiC particles in the base matrix with good interface bonding.
6. Fractograph shows that in case of alloy fracture is taking place by inter- granular manner and in case of composites it is by particle decohesion and fracture, both simultaneously.

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REFERENCES


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