Investigation of Mechanical Properties and Grain Structure of 5xxx Aluminium Alloys under Precisely Controlled Annealed Conditions

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Abstract- An attempt has been made to investigate the influence of micro structure on mechanical properties such as tensile strength, elongation, hardness, and elongation of the 5xxx alloys under different annealed conditions. Pure Aluminium material does not possess sufficient strength hence the application are limited to a few. The alloying element Magnesium added to pure Aluminium enhances the mechanical properties through solid solution and leads to improve strain hardening ability. The large strength to weight ratio of 5xxx alloys find applications in aircraft industries. The experiments were carried out for a composition of Al 5xxx alloy having 92.47 % of Al and 6.46% of Mg in the form of rod produced by extrusion process. The correlation of mechanical properties with grain structure is established in the study.

Index Terms- 5xxx series alloy, Al-Mg alloy, heat treatment, mechanical properties, grain structure.

I. INTRODUCTION

Aluminium is remarkable for it's low density and ability to resist corrosion. Due to inadequate strength, pure aluminium is not usually used for structural applications. Hence for structural applications instead of pure Aluminium, it is found to be necessary to add other alloying elements to aluminium. Such alloys exhibit excellent combination of strength, fatigue resistance, formability and high corrosion resistance which is highly essential for aerospace industry. The most important Aluminium alloy of 5xxx series is obtained by adding Magnesium as the alloying element to form solid solution have been reported [1] as high corrosion resistant material, which finds application in offshore structures.

Heat treatment of Al-Mg alloys modifies the micro structure of alloys and the resulting phase transformation influences the mechanical properties such as strength, ductility, toughness, hardness and wear resistance thus making them even more suitable for the manufacture of aircraft components. The addition of alloying elements to aluminium is the principal method used to produce a selection of different materials that can be used in a wide assortment of structural applications.

The influence of various kinds of annealing conditions on grain size and corresponding mechanical properties of Aluminium alloys has been reported [2]. A predominant shift from strain induced grain boundary to nucleation followed by growth grain boundary can be obtained under controlled annealing conditions [3].

The phenomenon of solidification of alloys to fine grain boundaries in the annealing process was observed by others [4,5]. It is established that mechanical properties of Aluminium alloys can be improved by heat treatment processes [6].

The present research tests this hypothesis by investigating the variation of grain structure and mechanical properties when 5xxx Aluminium alloy subjected to different annealed conditions, under precisely setting the temperature gradient under controlled environment.

II. METHODS AND MATERIALS

The characterization of the specimen was carried out in spectrometer (German made, foundary master) connected with Wasag Lab Software is shown in figure 1. It was identified the major constituents of 5xxx alloy as 92.47% Al and 6.46% Mg by weight. Using 20HP constant torque centre lathe (VDF - Heidenreich & Harbeck) all the specimens were machined under identical conditions (feed : 0.30 mm/ rev, depth of cut : 0.25 and rpm : 220) to ASTM B557 standard shape and size (12.5 mm diameter, 100 mm long) is shown in figure 2

Figure 1: Spectrometer

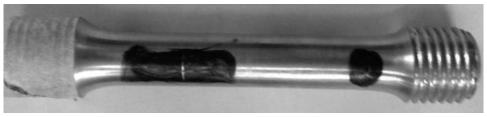

Figure 2: Specimen machined as per standarad

The heat treatment of the alloy was done in a Muffle Furnace with advanced electronic temperature controller attached with digital timer has shown in the figure 3. The initial temperature of the furnace was set at 330^0C and 150 minutes soaking time was set as per the standards available for 5xxx alloys.

Figure 3: Muffle Furnace

The computer based active closed loop temperature control system of the furnace maintains the temperature uniformity of the chamber and assures isolation of the material from the surroundings. All the four samples were treated identically in the muffle furnace and following four types of annealing process were conducted in the study.

Annealing was carried out in four conditions, namely (1) air cooling, (2) furnace cooling, (3) Cold compressing and (4) re-annealing followed by air cooling. The details of the annealing conditions are as follows,

- One of the specimen was allowed to air cool (AC) in the room temperature (33^0C).
- Another three specimens were kept it in muffle furnace for furnace cooling (FC).
- One among the above three was subjected to furnace cooling and it was cold compressed at 5 % by upsetting in the axial direction (FCC).
- The second furnace cooled specimen was re-annealed at the same conditions and allowed to cool in the room temperature (FCRAA).

An extensive study on four significant mechanical properties - Hardness, Tensile stress, Proof stress and percentage of elongation of 5xxx alloy were conducted to all the four different annealing conditions.

The mechanical properties namely proof stress, tensile strength and elongation of the specimen after annealing was investigated in the Universal Testing Machine (UTM) having capacity 400 kN is shown in figure 4. The dial gauge readings obtained from the extensometer mounted on the specimen was used to find the actual elongation and the corresponding strain induced in the specimen under different loading conditions in the experiment.

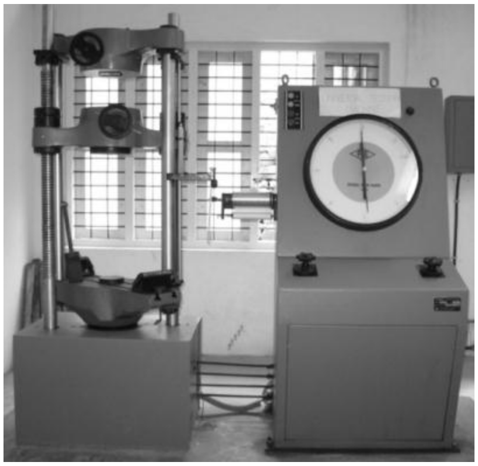

Figure 4: Universal Testing Machine (UTM)

Yeild point of the Aluminium alloys was found to be difficult to capture in the tensile test, hence corresponding proof stress was evaluated at 0.2% of the gauge length from the line of propportinality. The stress- strain graphs for the different annealed conditions were plotted, figure 5.

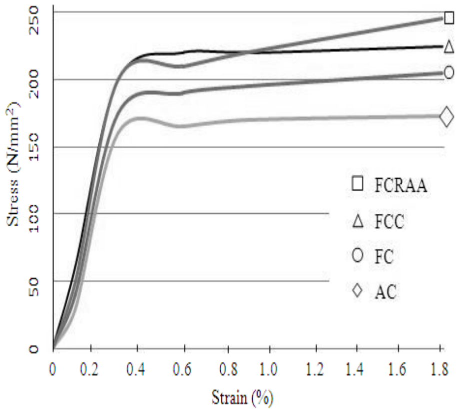

Figure 5: Stress – Strain graph at different annealed conditions

The hardness of all the four specimens was tested in the Brinell hardness tester. A steel ball indenter of diameter 10mm under 1000 kg force applied for 10 seconds. The diameter of the indentation ‘d’ was measured with the help of a 10X optical microscope. The corresponding Brinell hardness number was calculated using the following expression.

$$HBS = \frac{2P}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$

Since Aluminium alloys are soft, the cutting has done at a distance of 3 mm from the plane to be polished and intervening distorted material was removed by wet grinding followed by fine polishing with the aid of 24 micron abrasive powder. Using optical microscope (200X), the grain structure of the 5xxx alloy at different annealed conditions were explored in the present work.

III. RESULTS AND DISCUSSIONS

The influence of different annealing processes on various mechanical properties was quantified in terms of tensile strength, elongation, proof stress and hardness of the 5xxx specimen. Their performance variations against the non-heat treated 5xxx alloy are shown in Fig. 6(a), 6(b), 6(c) and 6(d) respectively. The results obtained from 200X optical microscope exhibit the grain sizes for both furnaces cooled and air cooled annealed conditions found to be challenging and their grey scale grain images are shown in figure 7(a) and 7(b) respectively.

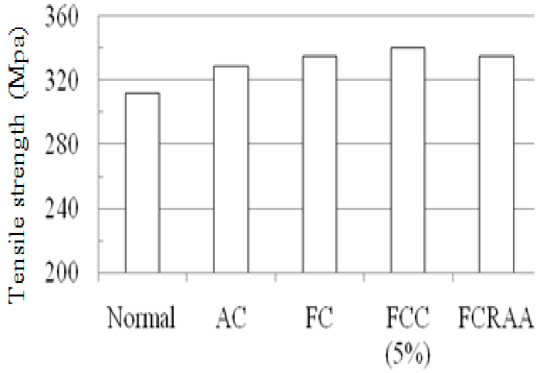

Figure 6(i)

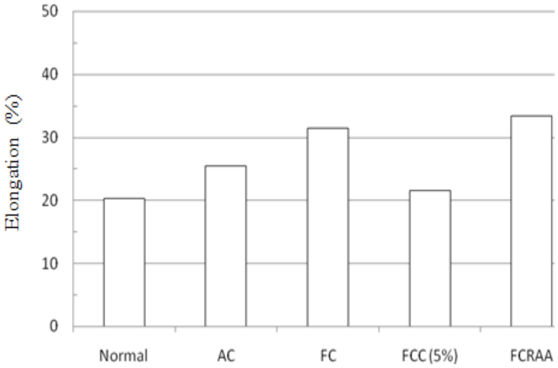

Figure 6(ii)

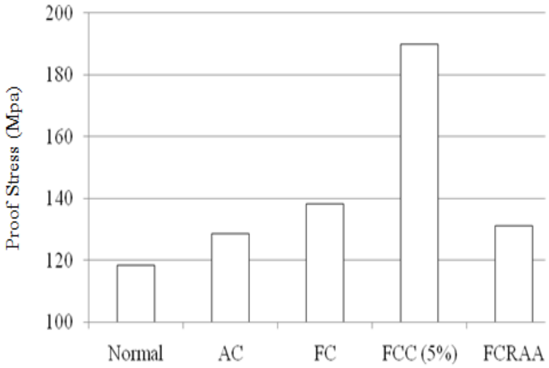

Figure 6(iii)

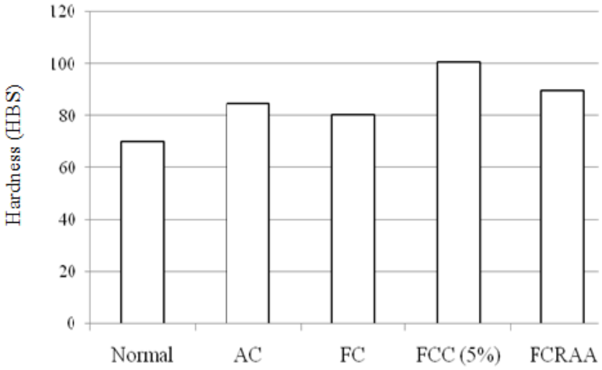

Figure 6(iv)

Figure 6: the variation of mechanical properties at different conditions

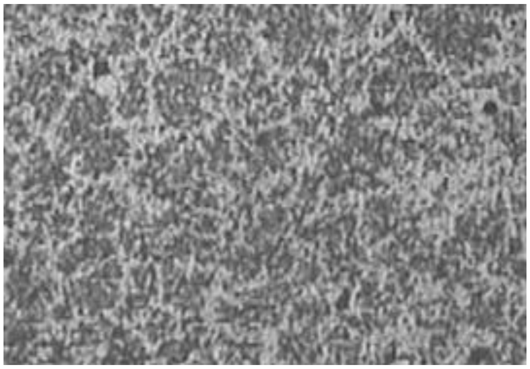

Figure 7 (i)

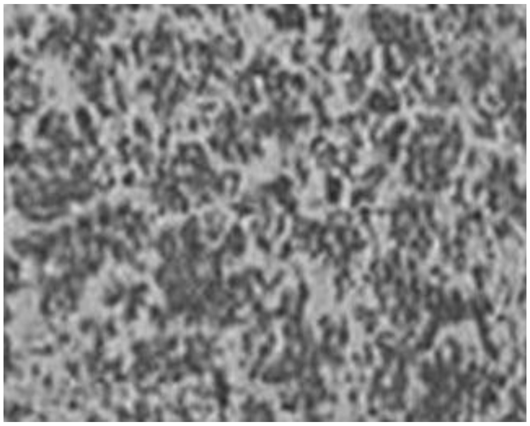

Figure 7(ii)

Figure 7(i) & 7(ii): the grain structure of air cooled and furnace cooled specimens at
200X magnification

IV. CONCLUSIONS

- The anealing carried out under furnace cool condition improve the hardness singinfiacntly.

- Furnace cooled annealing process provide 66% improvement of tensile strength in comparison with initial condition.
- Proof stress which is a direct measure of yield point shows found to be higher in furnace cooled annealing process.
- In furnace cooled anealing proceses size of the grains found to be decreased from coarse to fine range due to the the formation of Mg_2Al_3 particles at the boundaries. This refinement of the grain size results in higher elongation property for the 5xxx alloys.

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NOMENCLATURE

AC	-	Air cool
FC	-	Furnace cool
FCC	-	Furnace cooled cold compressed
FCRAA	-	Furnace cooled re-annealed and air cooled
ASTM	-	American Society for Testing and Materials
Rpm	-	Rotations per minute

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