Study of Microstructure And Hardness Along With Compression Test of Heat Treated Aluminium 2014 Alloy

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Abstract- *Microstructures, hardness and true stress strain through compression test have been studied for for Aluminum 2014 alloy. Heat treated surfaces were characterized with scanning electron microscopy (SEM) and optical microscopy to determine the mechanisms and phases. It was determined that the heat treated alloy with aging of 3 hours and 6 hours shows an excellent balance of high hardness and lower strain rates compared to non heat treated Al alloy. This was attributed to their more ductile body centered cubic (BCC) solid solution phase along with the formation of Mg_2Si phases. The XRD analysis of non heat treated 2014 alloy shows the distribution of Mg_2Si in Alloy as a measure element for strengthen the alloy. This study provides guidelines for fabricating novel, high compressive strength, and high hardness Al 2014 alloy for potential use where low weight high strength required.*

I. INTRODUCTION

Predominant metal as Aluminum in aluminum alloys is very important for several research fields [2]. The typical alloying elements are copper, magnesium, manganese, silicon, zinc. 2014 aluminum alloy is an aluminum alloy often used in the aerospace industry [2]. It is easily machined in certain tempers, and among the strongest available aluminum alloys, as well as having high hardness. However, it is difficult to weld, as it is subject to cracking.

Mechanical properties of ductile materials are normally determined by tensile test. However, when the plastic deformation is the aim of the study, the compression test is the most suitable as it allows large deformations without the fracture of the specimen. For this test, the cylindrical specimen is the most adopted. However, in this case, the damage must be evaluated. Numerical analysis (i.e., finite element analysis—FEA) may be used to predict the damage for materials with elastic-plastic behavior. But, first, it is needed to perform classical model (analytical) and material (experimental) analysis. Many studies were carried out concerning aluminum under axial compression; among them, Hopperstad et al. [1], Andrews et al. [2], and Gioux et al. [3] studied the compression of aluminum foams. Ferguson et al. [4] proposed an analytical model for predicting the mechanical properties of bimodal nano aluminum alloys, concerning the grain size. Pled et al. [4,5,7] have done a numerical study of the crushing of circular aluminum tubes, with and without aluminum foam fillers. Han and Kim [6] proposed a new criterion for ductile fracture in sheet metal forming process. Luo et al. [12] performed isothermal compression tests of 7A09 aluminum alloy concerning solid cylindrical specimens. Rees [8] studied aluminum alloy sheets by plane strain compression. Wu et al. [9] determined the flow behavior and constitutive equations of 7050 aluminum alloy in isothermal compression. Kyaˇckaj et al. [10, 14] studied the workability of AlMgSi aluminum alloy prepared by powder metallurgy, by means of analytical (damage) and numerical methods. Some researches concerning damage of other metals have also been done, and some are listed here: Stefanik et al. [11] have determined the values of the normalized Cockcroft-Latham (nCL) for multi slight rolling based on tensile test of BSt500S steel. Xia et al. [6,16] studied the effects of temperature and strain rate on the damage value of AZ80 magnesium alloy. Alexandrov and Jeng [13] proposed a general method for the modified Cockcroft-Latham criterion at elevated temperatures. Quan et al. [14] evaluated the ductile fracture criteria for 42CrMo steel by compressions at different temperatures and strain rates. Landre et al. [15] contributedto the discussion of decoupled ductile fracture criteria and their use with finite element analysis, testing samples of AISI 1040

Aluminium alloys find a wide variety of uses because of its characteristics such as the low density, high corrosion resistance, easy workability, electrical and heat conductivity. In addition, the excellent mechanical and tribological properties of aluminium have led to extensive use of these alloys in engineering such as plain bearings, internal combustion engine pistons and cylinder liners, aircraft constructions, etc. [4].

The alloy composition of 2014 is

- Aluminium Remainder
- Chromium 0.1% max
- Copper 3.9% - 5%
- Iron 0.7% max
- Magnesium 0.2% - 0.8%
- Manganese 0.4 - 1.2%
- Remainder Each 0.05% max
- Remainder Total 0.15% max
- Silicon 0.5% - 1.2%
- Titanium 0.15% max
- Titanium + Zinc 0.2% max
- Zinc 0.25% max

The increased use of cast aluminium alloys in automotive applications such as engine blocks and cylinder heads creates a need for a deeper understanding of fatigue performance. Improvement in the mechanical properties of aluminium alloys can be significantly made by the precipitation of the finely dispersed second phase in the matrices. This is accomplished by the solution treatment of the material at high temperature followed by quenching. The second phase then precipitated at elevated temperatures like 150^{o}C, 160^{o}C, 180^{o}C and 200^{o}C. For aluminium alloys this procedure is usually referred to as age hardening and is also known as precipitation hardening [3,17]

Influence of the alloying elements on the properties of aluminium alloys

Silicon adding to the Al alloy corrosion resistance is only slightly affected. With increase content of Si decrease of the fluidity.

Copper improves high temperature strength, but decrease the corrosion resistance of alloy.

Magnesium material which is lighter then aluminium and shows the same strength properties. It is the main alloying element in some Al alloys, but in the majority of them is rather considered as impurity. The role of magnesium in Al-Si alloys is to precipitates β phase (Mg_2Si).

Al-Mg alloys are characterized with high strength and good ductility. Proper amount of magnesium in alloy will also gives very high response to heat treatment.

Advantages of Wrought Aluminum Alloys:

Corrosion Resistance, Thermal conductivity, Strength/Weight Ratio, Fracture Toughness and Energy Absorption Capacity, Cryogenic Toughness, Fatigue Strength, Workability, Ease of Joining, Recyclability.

Advantages of Cast Aluminum Alloys:

Ease of casting, high strength, quality of finish.

Properties of aluminium:

- Density
- Electrical conductivity and resistivity
- Non magnetic properties
- Thermal conductivity
- Reflectance and emissivity
- Corrosion resistance
- Thermal expansion
- Melting temperature
- Specifics and latent heats

Chemical composition of 2014 alloy:

Wt% (4.44% Cu, 0.85% Si, 0.77% Mn, 0.45% Mg and balance alloy)

II. EXPERIMENTAL DETAILS

Methodology

The prediction of hardness and compressive strength by means of changing aging time and temperature of Al-2014 alloys are studied in this article. All these are studied which the help of literature review and by hit and trial method. After that we will conclude all the results and discussions.

Sample preparation

Heat treated aluminium 2014 alloy was used for the experiment. The samples were prepared from Al-2014 alloys for age hardening at the different temperatures and time. Cylindrical shape of 8 mm diameter and length 25 mm each were machined from heat treated Al-2014 alloy for wear test and a block of 25*25*25 mm was prepared for compression test. The test sample was prepared by lathe operation, i.e. by turning operation. The microstructures of these samples were observed under optical microscope and SEM (Scanning Electron Microscopy) after etching with Kroll’s etchant/ or Killer’s etchant.

Heat treatment

The samples were heated to a single phase solid solution temperature 400^{o}C for 2 hours. It is quenched in water at room temperature. They were further heat treated at different aging temperatures and different aging time like 150^{o}C, 180^{o}C and 200^{o}C for 3 hours and 6 hours for precipitation of intermetallic in the matrix. All the heat treatment was done in furnace. After the precipitation, the physical properties of aluminium alloys are extensively changed. The table 1 are listed the process of heat treatment.

Heat treatment temperature(^{o}C)	Time(in hours)
Solutionizing treatment 400^{o}C and quenching at room temperature	2
150	3 6
180	3 6
200	3 6

Hardness test

Hardness values of these samples were determined by using Brinell hardness test with an applied load of 100 kg

Compression test

The compression test was carried out in the universal testing machine which is ideal for high capacity tension, compression and shear testing.

Characterization techniques

- XRD analysis of Non heat treated sample of Al 2014
- Optical analysis
- SEM analysis

III. RESULTS AND DISCUSSIONS

Microstructures of non heat treated and heat treated samples by Optical

Microscopy and SEM microscopy with XRD of Heat treated alloy

Optical microphotograph of non heat treated and heat treated aluminium 2014 alloy are shown in Figures 1 and it is again confirmed by SEM investigation as shown in Figure1. It can be observed from the optical microphotograph of non heat treated alloy that the eutectic mixture of α-aluminium and silicon is present along the grain boundaries of primary α-aluminium grains in non heat treated alloy. The microstructure images illustrated in Fig.1 show the dark globular grey-coloured phase and rod-shaped phases formed at the grain boundaries. OM analysis results taken from the dark non-shaped grey-coloured phases proved that this phase was rich in Al, Cu, Mg, and Si. According to SEM analyze the non-shaped dark gray-colored phase is Mg2Si and elongated phase is CuAl2. The effect of aging is affected by various factors viz. solid solution strengthening, substrate's recovery and recrystallization and new phase precipitation. The first two factors lower the strength of the alloy with the increase in aging time, but phase precipitation strengthens the alloy. The intermetallic phases of CuAl2 and MgSi2 were formed by the alloying elements during solidification confirmed by XRD analysis, as shown in Figure 2. More specifically, the 2014-A material was characterized by elongated grains with a transversal size of about 50 µm and by large intermetallic particles aligned in the flow direction: globular Al2Cu (θ) particles and blocky shaped clustered particles containing Fe, Mn, Si and Cu. When Al2Cu precipitates are coarse and placed along grain boundaries of the alloys, the effect of copper on the hardness and strength of the alloy is very limited because of the solubility at the longer aging time. Also the fragility of hard Al–Cu precipitates in grain boundaries affects the toughness of the alloy negatively.

The alloy was solution treated at 450^{o}C and the quenched in water. After the solution treatment, the alloy was aged at the different temperature for different time. Figure 3 shows the optical microstructures of the specimens solution treated for different durations. The results were confirmed through SEM analysis as shown in Figure 4. It is obvious that increasing solution heat treatment duration causes the dissolution of more copper atoms in α (Al) grains. In the microstructure of the specimen treated for 4 h some undissolved Al2Cu phases in the grain boundaries can be seen. The amount of undissolved Al2Cu phase is decreased in the specimens solution treated for 6 and 8 h. There are some undissolved Al2Cu at the grain boundaries. But prolonging aging treatment durations may cause grain growth. The increase in the size of α (Al) grains causes a decrease in the mechanical properties of the alloy. Instead of being dissolved in aluminum grains, their resulting microstructure becomes spherical during heat treatment at the different aging temperature and time the chemical compositions of the undissolved intermetallic phases were determined by SEM analysis and are given in the relevant section of this study as shown in Figure 4.

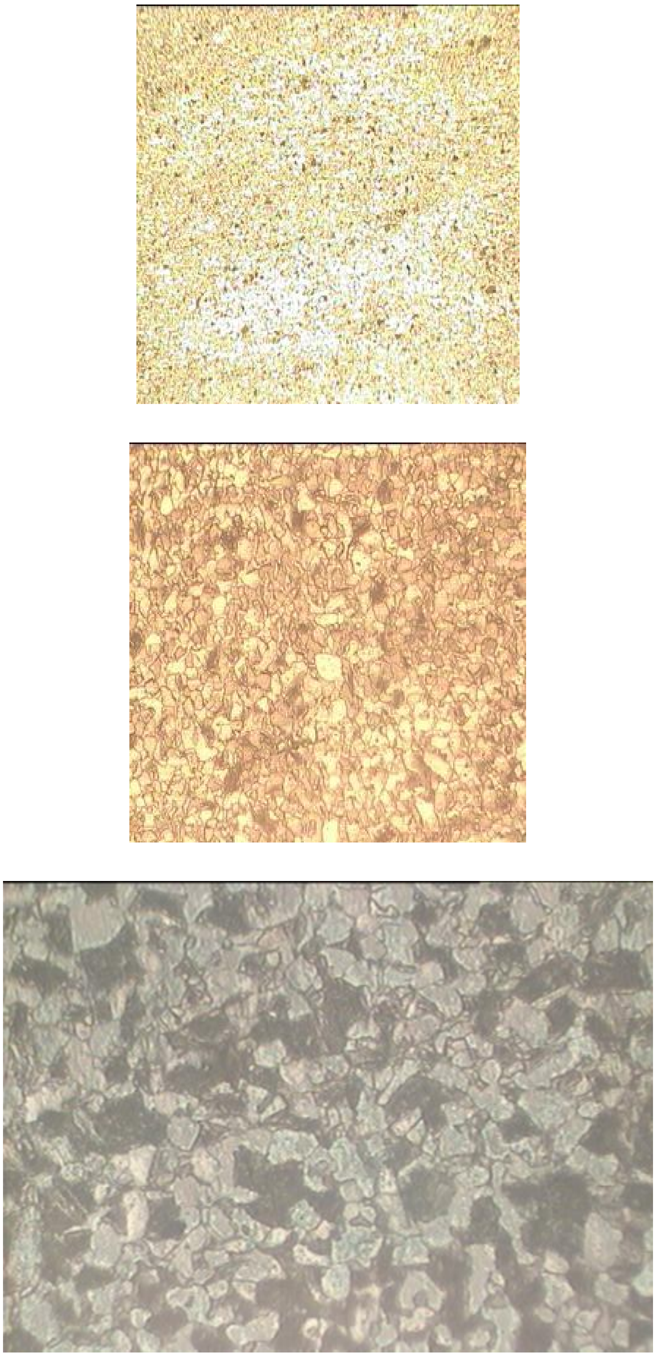


Fig 1: Optical microstructure of the non heat treated and heat treated Al-2014 alloy at 20µm
Magnification

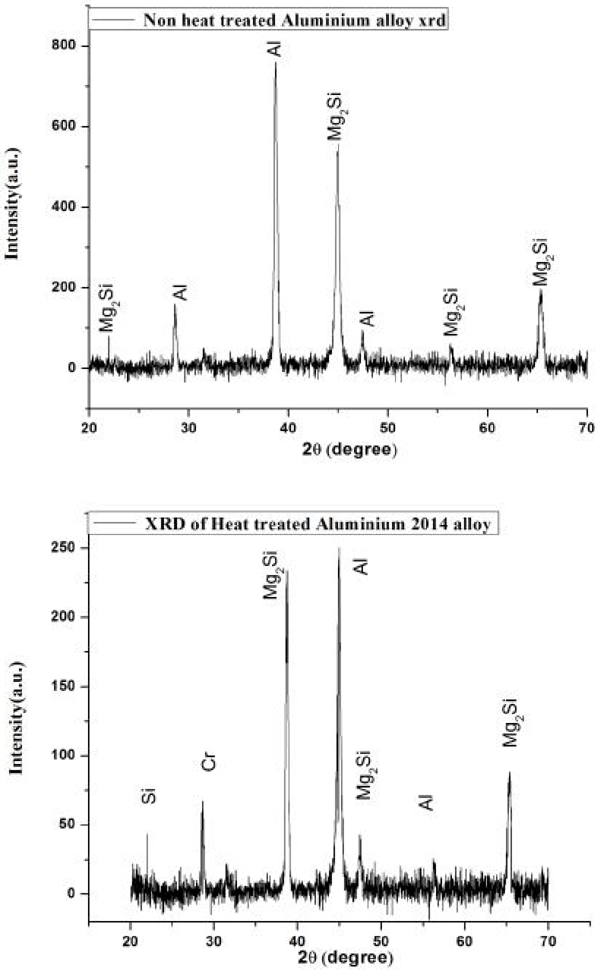
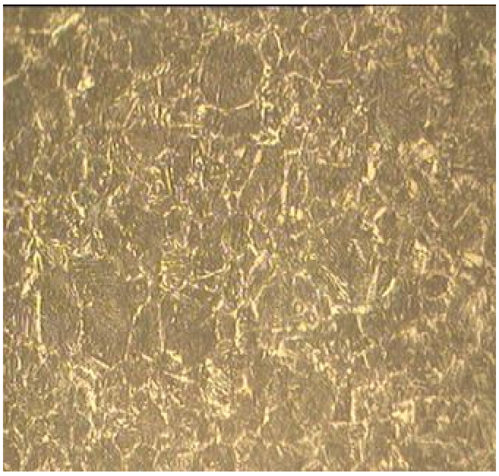


Fig 2 XRD-plot of Al-2014



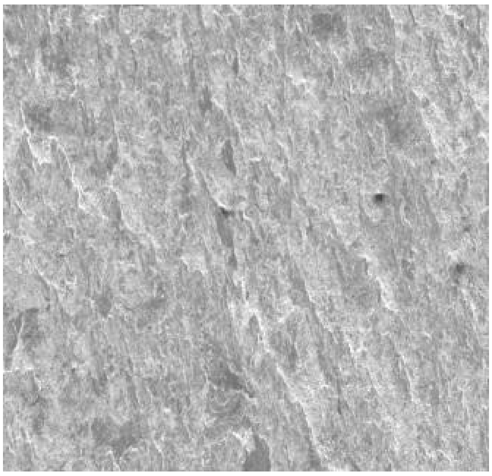


Figure 3 (i): At aging temperature 150^{o}C and aging time 6 hours (a) Optical micrograph (b) SEM micrograph

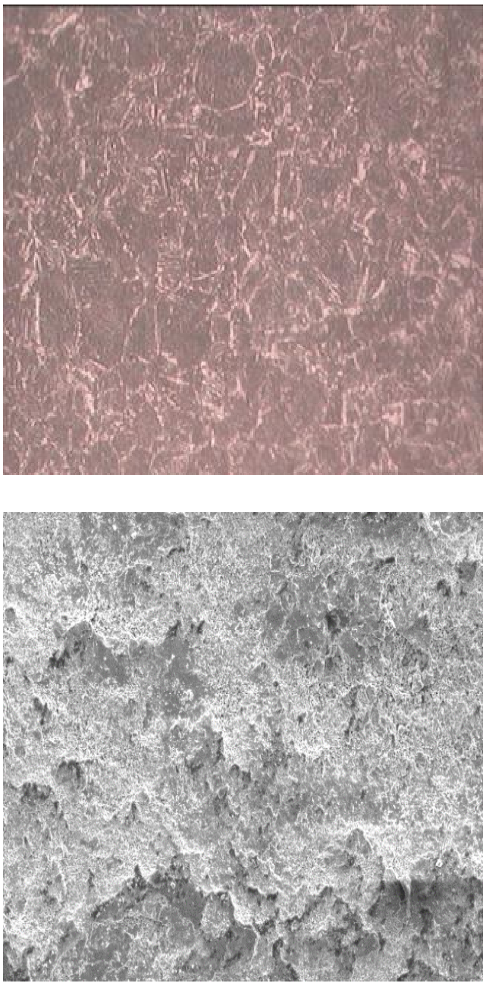


Figure 3 (ii): At aging temperature 180^{o}C and aging time 6 hours (a) Optical micrograph (b) SEM micrograph

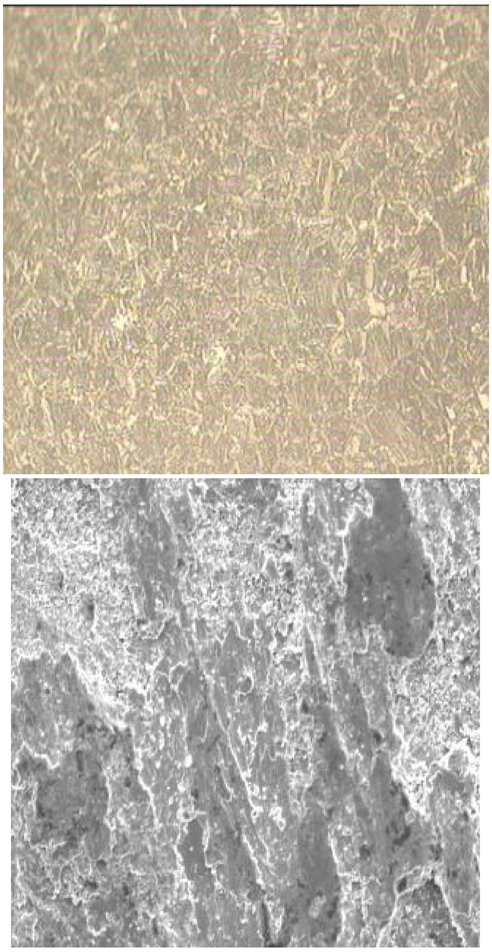
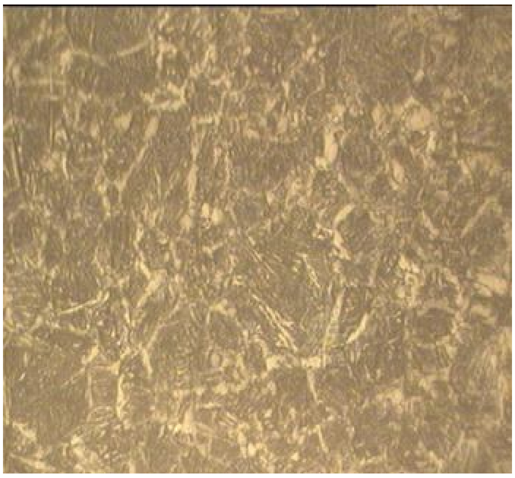


Figure 3 (iii): At aging temperature 200^{o}C and aging time 6 hours (a) Optical micrograph (b) SEM micrograph



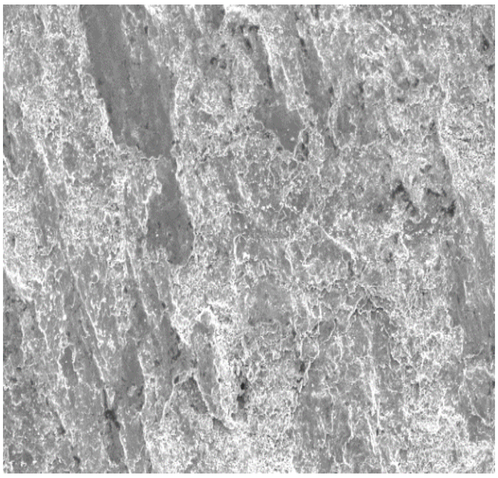


Figure 3 (iv) : At aging temperature 180°C and aging time 3 hours (a) Optical micrograph (b) SEM micrograph

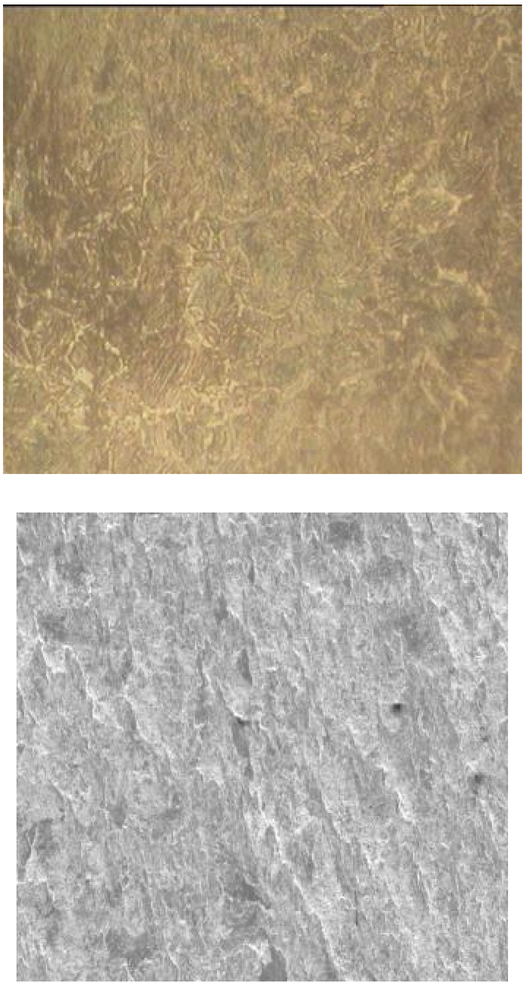


Figure 3 (v) : At aging temperature 200°C and aging time 3 hours (a) Optical micrograph (b) SEM micrograph

IV. HARDNESS RESULT

The hardness of the specimens was determined after different aging treatments either at different time or temperature. The hardness values of the specimens after aging treatments are listed in table 2. The hardness value of the as-cast sample was measured as BHN 85. The increase in hardness was due to the formation of precipitates which interacted with the dislocation movements. The decrease in hardness might have been due to over-aging of the specimen. Hardness is found to increase with increase the formation of intermetallic at the grain boundaries. As aging temperature increase the silicon content in the material increases and as a result hardness increase. The hardness of alloy increased because of artificially age hardening. The hardness of aluminium alloy was significantly improved by the precipitation of finely dispersed second phase (CuAl2) in the matrix produced solution treatment followed an aging.

Table 2: Hardness of heat treated Al-2014

Sample	Hardness(BHN)
150°C 6 hours	97
180°C 6 hours	99
200°C 6 hours	94
150°C 3 hours	98
200°C 3 hours	99

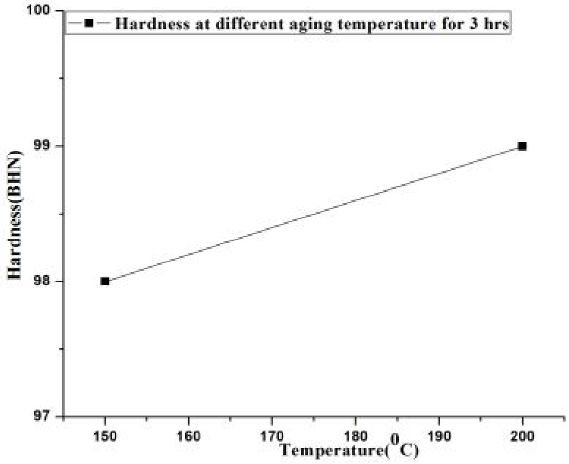


Figure 4 : Hardness for 150 and 200°C aging temperature At aging time 3 hours

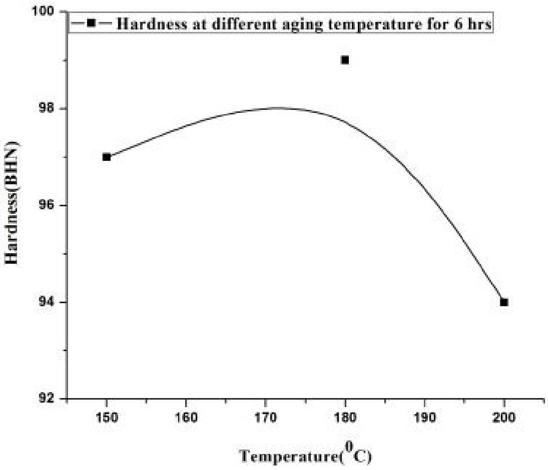


Figure 5 : Hardness for different aging temperature At aging time 6 hours

4.4 True stress and True strain curve from compression test

True stress and true strain curves obtained during compression of aluminium alloys at a strain rate of 0.01/s. From the figure, it is clear that the peak stress and flow stress increase with increasing aging time. If the true stress based on the actual cross-sectional area of the specimen is used, it is found that stress-strain curve increases continuously until plastic deformation occurs. If the strain measurement is also based on instantaneous measurement, the curve is called true stress-strain curve. Many attempts have been made to fit mathematical equations to this curve. The most common is a power expression of in the form

$$\sigma = A\,\varepsilon^n$$

Where, σ= true stress, A is strength coefficient, n is the strain hardening exponent. BLUEHILL software incorporated with the UTM machine automatically generates the flow curve for each specimen instantaneously after the experiment using the true stress and true strain data saved in computer's database. It uses the engineering equation to generate the flow curves.

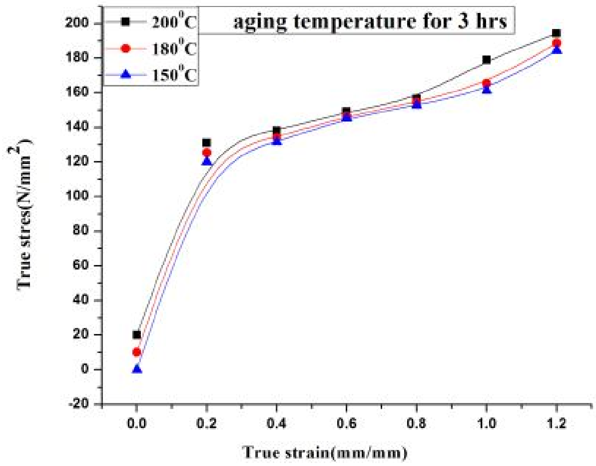


Figure 6 : True stress vs true strain for 150, 180 and 200^0C aging temperature At aging time 3 hours

From the figure 6 it is clear that as stress ranging from 100 to 149.43 N/mm^2 , the slope of the curve is less . that means in the range of 0.4 to 0.9 mm/mm , the deformation is slowly moving forward , but as it reaches the value 149.43 N/mm^2 , sudden it shows the little jump in slope of the curve. That means at the final stage the stress becomes maximum but strain does not get higher side. Similarly, in fig 7 curve is continuous from 148 N/mm^2 to onward. Slope of the curve is continuous in nature means As stress increasing strain also increases.

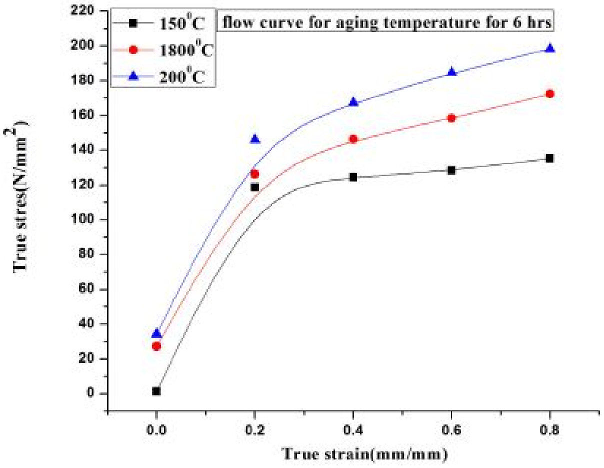


Figure 7 : True stress vs true strain for 150, 180 and 200^0C aging temperature At aging time 6 hours

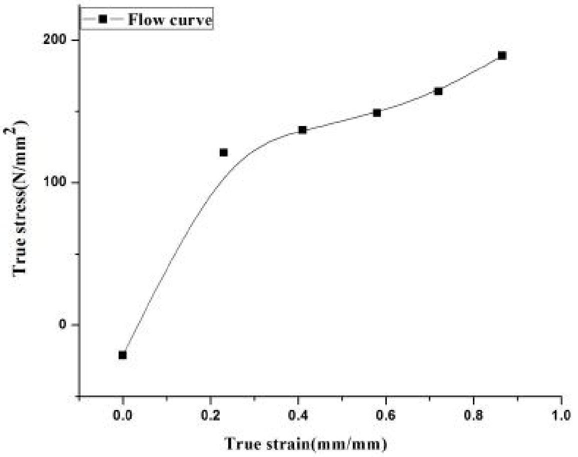


Fig 8 : flow stress-strain curve for compression test before heat treatment of Al 2014

Flow stress strain curve for compression test before aging shows that on applying compressive load, first material tends to develop internal stress ie material develop resisting force in terms of internal stress. After some time it tends to be deformed plastically but at first it deforms elastically then after due to continuous load application it goes to severe plastic deformation.

In both results (ie in 3 and 6 hours of aging) initially deformation is same as non heat treated sample, but after some time it shows the drastic deformation with internal stress generation.

As comparison result between 3 hours and 6 hours of aging shows slight difference in stress strain rate ie as compare to 3 hours of aging ,6 hours of aging shows more strength.

V. CONCLUSION

The present investigation was mainly devoted to examining the effect of the microstructural features resulting from solution heat treatment and age hardening on aluminium 2014 alloy.

The results reveal the following:

- Increase in aging temperature refines and distributes the eutectic silicon particles in aluminium alloy and breaks down in dendritic structure.
- Increase in aging temperature from 150^oC to 200^oC revealed continuous reduction in wear rate.
- The hardness of aluminium alloy was significantly improved by the precipitation of finely dispersed second phase (CuAl2) in the matrix produced solution treatment followed an agin
- True stress and flow stress increases with increasing true strain.
- True stress decreases with increasing in aging temperature.
- True stress decreases with decreasing true strain.
- Strain hardening component depends on the stress and strain

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