Study of Fractography and Overaging in Ly_{12} Alloy

W.Q.Khan*, Q.Wang, X.Jin
College of Materials Science and Engineering,
Beijing the University of Technology, Beijing 100124, China
waheedkhan@emails.bjut.edu.cn

***Abstract*— This work is aimed to optimize the heat treatment parameters of Ly_{12} (Al-Cu-Mg) alloy for improvement in properties. Also to study the aging behavior for determination of peak strength and highlighting the limitations of over-aging (over-burning). Normal composition of the alloy is 4.0 Cu, 0.7 Mn, 0.8 Mg, 0.5 Si and balance Al. Thermal treatment process to achieve the ultimate properties is solution treatment at 500°C followed by quenching in cold water and then natural aging at room temperature for 96 hours. Main phases in this alloy are Mg_2Si & $CuAl_2$. If the heating temperature goes beyond 500°C, the over-aging of Mg_{2Si} phase occurs. Over-aging is grouped into three categories a) slightly over-ageing b) medium over-ageing and c) serious over-ageing. In the present work samples of Al alloy were heat treated at different temperatures and then the effect of over burning on microstructure and mechanical properties was studied.**

Keywords*— *Aging, GP zones, Solution treatment, Eutectic, Grain boundary

I. INTRODUCTION

These alloys are of industrial interest from the date of discovery of the phenomenon of age hardening by Alfred Wilm in 1906. These alloys have a very good strength to weight ratio and resistance to stress corrosion cracking along with low cost. So they have weight effective performance, durability, damage tolerance, reliability and manufacturability [1-4]. Al-Cu-Mg Aluminum alloys are widely used in aircraft structural members. Commonly used in the manufacture of automobile wheels, aircraft structures, screw machine products, scientific instruments and in rivets. It is an age harden able, high strength aluminum alloy [5-8]. Over ageing implies that the low melting point constituent (in general eutectics) in an alloy develops remelting on heating. It is noticed that because the actual composition of a commercial alloy has an allowable range of fluctuations, therefore, the over-ageing of the alloy of the same composition still changes because of difference in smelting technology [9-11]. As to the same plate of Al-alloy when the contents of Cu, Mg are on the upper limit actual over burn temperatures are higher and the tendency of over burning reduces a little. On the other hand if, elements like Fe and Si forms some phases of impurity, and probably make up a multiple-unit eutectic of lower melting point, thus enhance the over age tendency of alloy. A furthermore tendency of over burning in thinner sections is greater than thicker sections [12-13].

The following characteristics are found among the over aged structures:

- Balls of remelting eutectic (balls of liquid phase) have appeared in the over aged structure. When the quenching temperature goes beyond the melting point of a low melting point eutectic, liquid phase is formed, and when quenched, the liquid phase contracts to form the shape of a ball due to the surface tension.
- Parts of the grain boundary in over age structure are thickened and get rough. There exists low melting point eutectic at the grain boundary.
- An area of the triangular grain boundary has appeared in the over aged structure. This is the characteristic that appears when severe over-ageing takes place. A part of the common border of three grains melt to join together, there is also a complicated structure within an area of triangular grain boundary.

II. EXPERIMENTAL

The thickness of the as received sheet was 1.1 mm and chemical composition of the alloy under consideration is given in Table: I in weight %.

TABLE I. CHEMICAL COMPOSITION OF ALLOY

	Si	Fe	Cu	Mn	Mg	Zn	Cr	Balance
Actual	0.25	0.4	7	1.1	1.51	0.16	0.02	Al
ASTM-2024	0.5	0.5	3.8-4.9	0.3-0.9	1.2-1.8	0.25	0.1	Al

Tensile and Vickers hardness test samples were made from the annealed sheet of Al alloy. Test samples of the alloy were solution treated in batches at different temperatures for 12 minutes soaking and then quenched in water at 20°C. Selected temperatures were 175°C, 200°C, 225°C, 250°C, 275°C, 300°C and 325°C, 350°C, 375°C, 400°C, 425°C, 450°C, 475°C, 500°C, 525°C and 550°C. After quenching all the samples were naturally aged for 96 hours at room temperature.

A section of samples 10x10mm was selected and after grinding and polishing samples was etched. For etching first the Keller's reagent was used but not found effective to reveal the microstructure. Then 2~3% NaOH in distilled water was used for etching. Fractography was done on scanning electron microscope (Phillips XL-30).

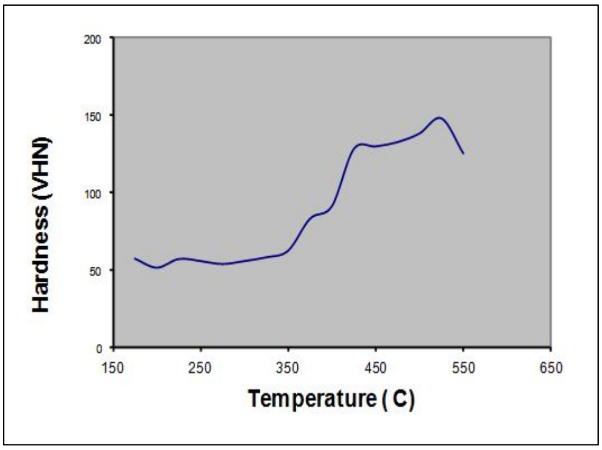
III. Results and Discussion

A. Aging Behavior

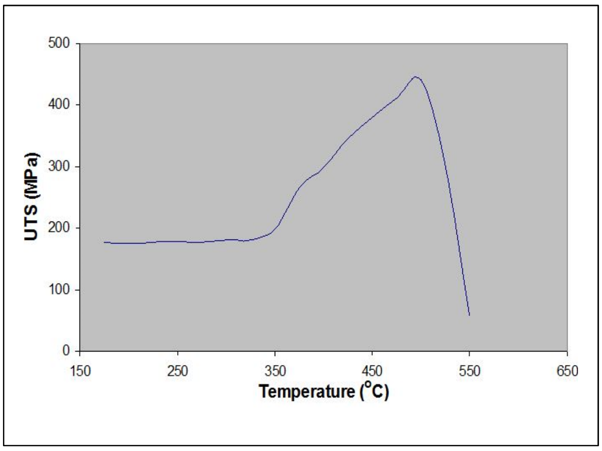
Vickers hardness testing was done on the over burnet phase and on the normal phase. The load was 1000 grams for 15 sec. The results of hardness testing, Fig. 1(a) proves that there are soft particles in the hard base matrix. This can result in easy propagation of a crack. The hardness increased with increasing solution treatment temperature and reached the peak at around 500°C. Then it decreases after 500°C, this indicates that exposing Al-Cu-Mg alloy to high temperatures can degrade its hardness.

Tensile testing was done by using 30 KN universal hydraulic testing machine. Results show that seriously over burnet structure has a detrimental effect on the tensile properties, Fig. 1(b). Among the most significant of findings was the observation that the solubility of $CuAl_2$ in aluminum increased with increasing temperature. Although the specific phases responsible for the hardening turned out to be too small. In this alloy, age-hardening is possible because of the solubility-temperature relation of the hardening constituent. The hardening constituent is $CuAl_2$. Hardening is caused by precipitation of the constituent in some form other than that of atomic dispersion, and probably in fine molecular, colloidal or crystalline form, and the hardening effect of $CuAl_2$ in alloy was deemed to be related to its particle size.

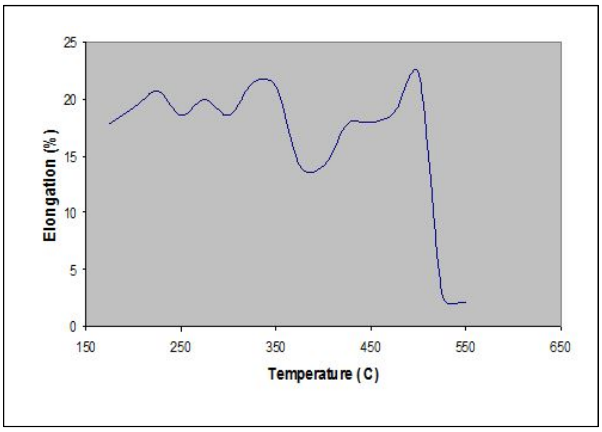
The coherent precipitates increase the strength of the alloy by distorting the lattice and creating resistance to dislocation motion. The number of precipitates increases with increasing solution treatment temperature thus increasing the strength of the alloy. However, at very high temperatures, 525 to 550°C the precipitates become large and incoherent and their strengthening effect decreases. Ageing beyond the peak ageing temperature to form incoherent precipitates is known as over aging. Elongation increases with increase in tensile strength at higher temperatures.



(a)



(b)



(c)

Fig. 1. (a) Hardness as a function of aging stages at different solution treatment temp, (b) Variation of strength with solution treatment temp at different aging stages, (c) Change in elongation with temperature

B. Microstructures

A section of samples 10x10mm was selected and after grinding and polishing, samples were etched in a NaOH solution for 10 sec and then observations were made under optical microscope.

Fig. 2. As received sample 500X

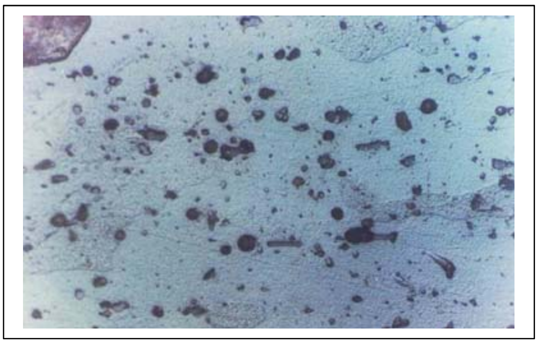


Fig. 3. Sample with peak strength 500X

Fig. 4. Cracking along the grain boundaries 200X

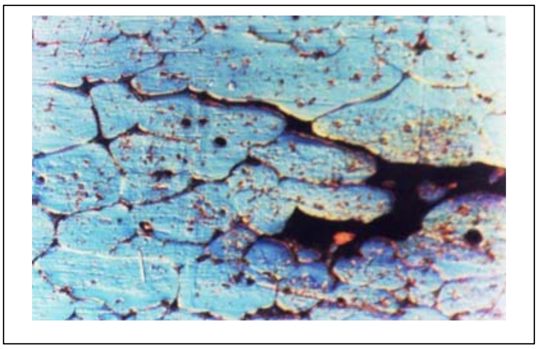


Fig. 5. Cracking along the grain boundaries 500X

Micrograph showed at Fig. 3 shows the hard and normal structure, treated at 500oC and naturally aged to maximum limits. While Figs. 4, 5 and 6 show the over aged structures with eutectic melting along the grain boundaries, which in the result weaken the structure. So if we solutionize this material above 500oC, cracking along grain boundaries occur due to severe over ageing. This effect is shown below in Fig. 4 and 5.

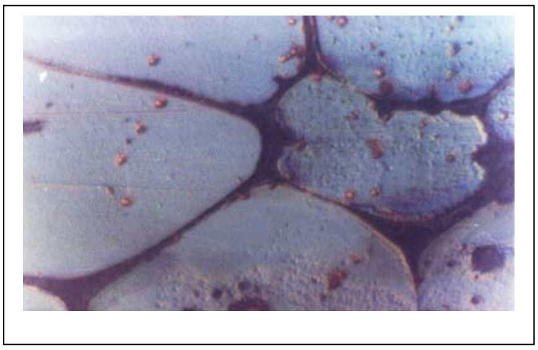


Fig. 6. Over Aged structure 1000X

C. Fractography

Fractography was done on scanning electron microscope (Phillips XL-30). SEM fractograph in Fig. 7 show faceted intergranular fracture in the sheet sample in as received condition. Fine particles along the grain boundaries and within the grains are also visible which may be identified as Mg_2Si and $CuAl_2$. SEM fractograph in Fig. 8 showing mix fracture mode indicating faceted regions and microvoids in the sample exhibited peak strength. Microcracks and microviods appeared in the sample in overaged condition, Fig. 9.

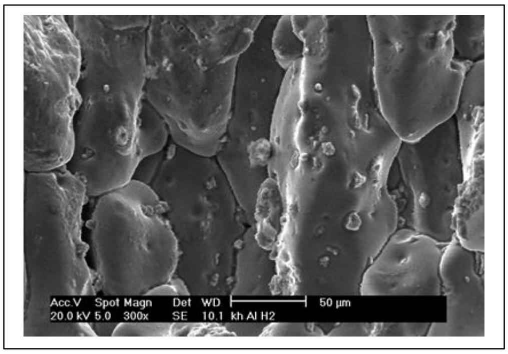


Fig. 7. SEM fractograph showing faceted intergranular fracture in the sheet sample in as received condition. Fine particles along the grain boundaries and within the grains are also visible which may be identified as Mg2Si and CuAl2. (UTS=188.67 MPa)

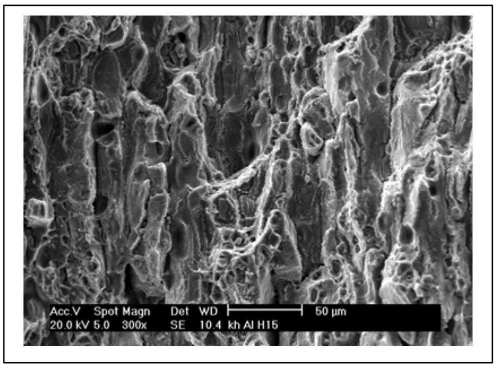


Fig. 8. SEM fractograph showing mix fracture mode indicating faceted regions and microvoids in the sample exhibited peak strength. (UTS=440.72 MPa).

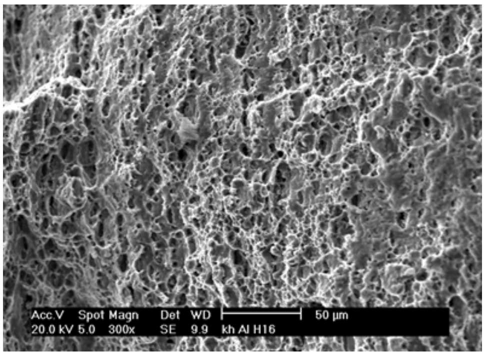


Fig. 9. SEM fractograph showing microcracks and microviods in the sample in overaged condition. (UTS= 58.65 MPa).

IV. CONCLUSION

Al-Cu-Mg alloy revealed peak strength (UTS=440.72MPa) at 500^oC. Microstructure revealed fine grain size and precipitation. Mixed fracture mode was observed in the broken tensile sample. Microstructure revealed microcracks along grain boundaries at 525 to 550^oC owing to eutectic melting at the grain boundaries which sharply decreases the strength as compared to the sample treated at 500^oC. Hence over aged structure is still regarded as an unrecovered defect in the heat treatment of Ly_{12} alloy, because soft particles are present in the hard matrix, which can easily lead to the propagation of crack under the application where cyclic stresses are present. When a product appeared has to be scraped, therefore over burning should be avoided during heat treatment as far as possible.

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