International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:6, No:2, 2012

# The Effect of Ageing on Impact toughness and Microstructure of 2024 Al-Cu-Mg Alloy

Swami Naidu Gurugubelli

***Abstract*—**The present study aims at determining the effect of ageing on the impact toughness and microstructure of 2024 Al-Cu - Mg alloy. Following the 2 h solutionizing treatment at 450°C and water quench, the specimens were aged at 200°C for various periods (1 to 18 h). The precipitation stages during ageing were monitored by hardness measurements. For each specimen group, Charpy impact and hardness tests were carried out. During ageing the impact toughness of the alloy first increased, and then, following a maxima decreased due to the precipitation of intermediate phases, finally it reached its minimum at the peak hardness. Correlations between hardness and impact toughness were investigated.

***Keywords*—**Ageing, alloy, hardness, microstructure.

## I. INTRODUCTION

AGE hardened Al-alloys are widely used in engineering applications due to the considerable improvements in their yield strength and hardness by controlled thermo-mechanical treatments. Micromechanisms governing fracture characteristics of such alloys depend on coherency and distribution of precipitates, grain size and shape, grain boundary precipitates, presence of other second phase particles which result from impurities. The unstable fast fracture, even if it is ductile, becomes frequent because the strengthening lowers the level of toughness, and this becomes a problem with large scale structures. Since the fracture of many engineering components is promoted under dynamic conditions, there is a need to understand the fracture behaviour of materials under dynamic loads. Moreover, fracture characteristics under the impact load seem to become important, because the application to transportation vehicles will increase [1]. Therefore, during fracture mechanics tests, it may be advantageous to include Charpy impact tests so that empirical correlations between the various fracture parameters can be developed.Various studies have been published on evolution of microstructure, tensile properties and fracture toughness of precipitation hardened Al-alloys [2-11]. Some researchers have also interested in the nondestructive characterization of aged Al-alloys. Hagemaier and Kleint [12] investigated the conductivity-hardness-ageing treatment relationship of Al alloys in various tempers. Gefen et al. [13,14] studied the variance in ultrasonic attenuation during ageing of 2024 alloy. Hagemaier [15] established a correlation between conductivity versus strength and hardness versus strength for the 7075-T6 and 2024 -T3/T4 alloy specimens.

Rosen et al. [16] studied the precipitation- hardening in 2219 alloy by measuring sound velocity, attenuation and hardness. Measurements as a function of ageing time at various temperatures were found to exhibit prominent changes and anomalies related to the formation of precipitates. The influence of precipitation kinetics during ageing on electrical conductivity and hardness in both unstretched and plastically deformed 2024 alloy specimens was investigated by Rosen et al. [17]. Natan and Chihoski [18] developed a new method of evaluating heat treatments of Al-alloys by constructing in a hardness- conductivity field formed by a network of curved coordinate lines of quenching and ageing times. Rosen et al. [19] characterized sound velocity and attenuation, eddy current and hardness measurements on precipitation-hardened 2024 alloy subjected to a series of different pre-ageing heat treatments prior to various tempers. However, there is yet little known [1, 20] in regard to the effect of precipitation on impact toughness.

## II. EXPERIMENTAL

The rectangular bar of 2024 alloy is machined and specimens for hardness and impact test are prepared. Chemical composition of the alloy determined using optical emission spectrometer Q8 Magellan is given in table I.

TABLE I
CHEMICAL COMPOSITION OF 2024 ALLOY

| Element | Weight % |
|---|---|
| Al | 92.4 |
| *Cu* | 4.2 |
| *Mg* | 1.7 |
| *Fe* | 0.35 |
| *Cr* | 0.06 |
| Si | 0.32 |
| Mn | 0.63 |
| *Zn* | 0.22 |
| *Ti* | 0.09 |
| P | <0.03 |

The specimens are solution treated at 450°C for 2 h, then, quenched in water. They are aged at 200°C for various ageing times (1-18 h). At pre-determined intervals, the specimens are cooled rapidly to room temperature and subjected to the mechanical tests. The aged specimens are kept at -24oC.

The evolution of microstructure is monitored by hardness measurements using a Vickers micro-hardness tester. Five hardness measurements are taken on each specimen from the different regions to determine a mean value of hardness. Impact fracture energies are measured with a pendulum type of test machine at room temperature. Fracture surfaces of the Charpy specimens are examined under a scanning electron microscope.

---

Swami Naidu Gurugubelli is with the Jawaharlal Nehru Technological University Kakinada, Vizianagaram, Andhra Pradesh, India. (Phone: +91 9963001596; e-mail: gsnaidujntuk@gmail.com).

## III. Results and Discussion

In the case of Al-Cu alloys, the microstructural evolution is complex, and the precipitation sequence varies depending on the degree of super-saturation and the ageing temperature. Where as in 2024 alloy, two successive transitions exist from super-saturated solid solution, namely, GP - θ”- θ’ - θ (Al2Cu) and GPB - S”- S’- S (CuMgAl2). The complete precipitation sequence can only occur when the alloy is aged at temperatures below the GP zone solvus. The mechanism of the transformation sequence usually involves heterogeneous nucleation at the sites of earlier products, resulting in fine and uniform precipitate dispersions [9, 21].

The age hardening process is very often investigated by hardness measurements that monitor the precipitation sequence. Fig.1 shows the variation in hardness of 2024 alloy as a function of ageing time at 200°C. Following a remarkable increase from 122 to 154 VHN within the first 4 h of ageing, hardness increased slightly up to its maximum of 162 VHN at 10 h ageing.

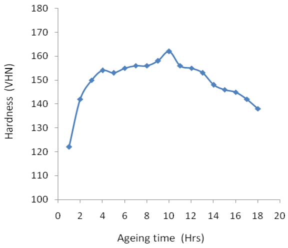

Fig. 1 Variation in hardness of 2024 alloy as a function of ageing time

The contribution to hardness depends on the coherency of the precipitate with the matrix, size and distribution of the precipitates and the proximity of the particles. In general, the increase in hardness depends on the variation in the stress fields in the vicinity of the precipitate. After quenching from solid solution the alloy contains regions of solute segregation. This clustering produces local strain which results in an increase in hardness. With additional ageing, the hardness is increased further by the ordering of larger clumps of Cu atoms on certain planes of the matrix (θ”). Next, definite precipitate platelets of θ’, which are coherent with the matrix, form. The coherent precipitate produces an increased strain field in the matrix and a further increase in hardness. After longer ageing the equilibrium phase, which is no longer coherent with matrix, is formed. Therefore, the hardness starts to decrease.

The impact toughness is strongly dependent on microstructural variables, and affected by a number of factors, such as yield strength, ductility, temperature, and fracture mechanism. As seen in Fig. 2, the room temperature impact fracture energy of 2024 alloy aged at 200oC reaches its maximum (51.5 J) within the first five hours, then, decreases down to 22 J at longer ageing times. The specimen with the highest hardness has the lowest impact toughness.

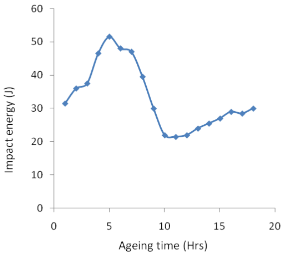

Fig. 2 Variation in impact energy of 2024 alloy as a function of ageing time

The SEM fractographs of the specimens aged for 5 h and 11 h are shown in Fig.3. There is a clear difference between the fracture surfaces. Fracture surface associated with the lowest toughness condition has an appearance consisting of dimples; small and shallow voids formed round the larger inclusions. The decrease in impact energy, in contrary to hardness, can be related to the formation of metastable precipitates. Increasing the hardness and the yield strength by precipitation makes the alloy more brittle and decreases the impact fracture energy since less plastic work can be done before the strain in the plastic zone is sufficient to fracture the test specimen. A similar result has been reported for aged 7178 alloy [22]. The results are also in agreement with previous studies on various Al alloys, reporting an increase in strength on ageing is accompanied by a corresponding decrease in the plane-strain fracture toughness [23].

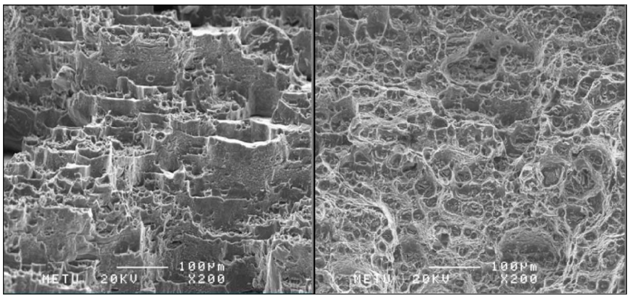

Fig. 3 Fracture surfaces of impact specimens aged at 200oC a. for 7 h b. for 13 h

## IV. Conclusions

After solutionizing at 450°C for 1 h and quenching, the variance in the impact toughness and hardness of 2024 Al-alloy as a function of ageing time is determined.

The maximum hardness is reached after 10 hr ageing. This is attributable to the increased volume fraction of precipitates, which contribute to the increased elastic modulus of the aged specimen. During ageing, when coherent zones turn to semi-coherent intermediate precipitates and the volume fraction of precipitates increases, the hardness and the elastic modulus also increases.

Impact fracture energy makes a maximum within the first five hours, then, decreases to 22 J at longer ageing times. The decrease in impact energy, in contrary to hardness, can be related to the formation of metastable precipitates. Increasing the hardness and the yield strength by precipitation makes the alloy more brittle and decreases the impact toughness since less plastic work can be done before the strain in the plastic zone is sufficient to fracture the test specimen. The specimen with the lowest impact toughness corresponds to the highest values of hardness.

## REFERENCES

[1] T.Kobayashi, Mater. Sci. Eng. A286 (2000) 333-341.
[2] N.Ryum, Acta Metall. 16 (1968) 327-332.
[3] I.Kovacs, J.Lendvai, T.Ungar, T.Turmezey, G.Groma, Acta Metall. 25 (1977) 673-680.
[4] G.G.Garrett, J.F.Knott, Metal. Trans. 9A (1978) 1187-1201.
[5] A. Melander, P.A.Persson, Acta Metall. 26 (1978) 267-278.
[6] T.S.Srivatsan, J Mater. Sci. 27 (1992) 4772-4781.
[7] A.K.Mukhopadhyay, Q.B.Yang, S.R.Singh, Acta Metall. Mater. 42 (1994) 3083-3091
[8] X.Z.Li, V.Hansen, J.Gjonnes, L.R.Wallenberg, Acta Mater. 47 (1999) 2651-2659.
[9] S.P.Ringer, K.Hono, Mater. Charact. 44 (2000) 101-131.
[10] G.Waterloo, V.Hansen, J.Gjonnes, S.R.Skjervold, Mater. Sci. Eng. A303 (2001) 226-233.
[11] D. Dumont, A. Deschamps, Y. Brechet, Mater. Sci. Eng. A356 (2003) 326-336.
[12] D.J.Hagemaier, R.Kleint, Metal Progress (1964) 115-118.
[13] Y.Gefen, M.Rosen, Mater. Sci. Eng. 8 (1971) 246-247.
[14] Y.Gefen, M.Rosen, A.Rosen, Mater. Sci. Eng. 8 (1971) 181-188.
[15] D.J.Hagemaier, Mater. Eval. 40 (1981) 962-969.
[16] M.Rosen, E.Horowitz, S.Fick, R.C.Reno, R.Mehrabian, Mater. Sci. Eng. 53 (1982) 163 -177.
[17] M.Rosen, E.Horowitz, L.Swartzendruber, S.Fick, R.Mehrabian, Mater. Sci. Eng. 53 (1982)191-198.
[18] M.Natan, R.A.Chihoski, J Mater. Sci. 18 (1983) 3288-3298.
[19] M.Rosen, L.Ives, S.Ridder, F.Biancaniello, R.Mehrabian, Mater. Sci. Eng. 74 (1985) 1-10.
[20] J.Champlin, J.Zakrajsek, T.S.Srivatsan, P.C.Lam, M.Manoharan, Mater. Design 20 (1999) 331-341.
[21] D.Sun, X.Sun, D.O. Northwood, J.H.Sokolowski, Mater. Charact. 36 (1996) 83-92.
[22] G.T.Hahn, A.R.Rosenfield, Metall. Trans. 6A (1975) 653-670.
[23] I.Kirman, Metal. Trans. 2 (1971) 1761-1770.