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Time and Strain Response of Repeated Ageing Treatments on Recycled Al-Si-Cu Alloy

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Abstract: - The objective of this study was to investigate the time response of 3-stage artificial ageing treatments on strength properties of recycled Al-Si-Cu alloy with a view to obtaining useful empirical relationships for predicting required treatment cycles. True compressive stress, micro hardness and strain (%) were evaluated in response to ageing time and repeated ageing. The results of compression and hardness tests showed that alloy hardness and compressive stress increased with ageing time, and that these properties also increased with repeated ageing. The results also showed that alloy strain (%) reduced with ageing time and repeated ageing, indicating increasing strength or strain hardening of the alloy with repeated ageing. Using these results, empirical models of the form $\phi_n = \phi_0 e^{\alpha t}$, and $\phi_n = \phi_0 e^{\alpha N}$ are established for predicting the required ageing time and/or number of ageing treatments to raise the strength (or hardness) of an alloy to desired levels to meet service requirements. The strain response of the alloy is modelled as $\varepsilon_n = \varepsilon_0 e^{-\alpha t}$.

Keywords: *- time response, recycled Al-Si-Cu, repeated ageing, strength, hardness, straining*

I. INTRODUCTION

Aluminium alloys have become preferred materials for automotive components because of their light weight and good mechanical properties, offering also better strength to weight ratio materials for these industries [1,2,3]. Aluminium usage provides up to 55% weight savings when compared to steel- which translate into improved fuel economy and reduced greenhouse gas and pollution emission- while offering the same or better stiffness and crashworthiness. Energy savings from light weighting and the resulting increase in-use fuel efficiency far outweigh the energy cost of prime aluminium. However, if the aluminium used is recycled metal, even the energy to produce the metal can be reduced significantly. Re-melting of recycled metal saves almost 95% of the energy required to produce prime aluminium from ore, and thus triggers associated reductions in population and greenhouse emissions from mining, ore refining and melting [4,5]. Although most metals alloy with aluminium, few have sufficient solubility in it. Common addition elements are Mg, Cu, Ti, Na and Sr. Al-Si-Cu alloys within 7-10% silicon and 2-4% copper are mainly used for automotive and airplane parts because of their superior mechanical properties, weldability, castability, and machinability, and also combine high strength, high elongation and very good corrosion resistance.

Metals are generally strengthened by introducing lattice defects which provide obstacles to dislocation motion. The strength and hardness of certain aluminium alloys (and some other metal alloys) may be enhanced by the formation of extreme small and uniformly dispersed second phase particles within the original phase matrix in precipitation or age hardening process. The precipitate particles act as obstacles to dislocation movement and thereby strengthen the heat-treated alloy [1,2,4]. Several aluminium alloys have shown a marked response to age hardening [3,5].

The objective of this study was to investigate the time response of repeated ageing treatments of recycled Al-Si-Cu alloy, with a view of determining its suitability for production of high integrity parts.

II. MATERIALS AND METHODS

Assorted aluminium scraps were collected and cleaned of dirt mainly accumulated dust and trapped oil particles. They were then melted in steel crucibles at 720 ^{o}C and cast into round bars of size Ø30mm using galvanized steel moulds. Test specimens of size Ø20mm×25.4mm were machined from the cast. The chemical

(ED-XRFS) composition of the alloy (presented in Table 1) shows that the recycled alloy is an Al-Si-Cu alloy with properties suitable for a wide range of applications; the seemingly high percentage of Fe is partly due to the reaction with the galvanized steel moulds used for casting considering the high melt temperature.

Table 1: Chemical (ED-XRFS) composition (wt. %) of the recycled aluminium alloy

Al	Si	Ca	Sc	Mn	Fe	Ni	Cu	Others
75.2	16.9	0.22	0.15	0.347	1.29	0.160	3.730	0.957

2.1 Solution Treatment

Test specimens were heated to the designated solution treatment temperature, followed by quenching in water at room temperature and finally reheated to the ageing temperature as shown in Fig. 1 [1,3]. Specimens were removed from the furnace at intervals of 15 mins up to a maximum ageing time of 1½ hours. The same procedure was used for 2nd and 3rd stage treatments.

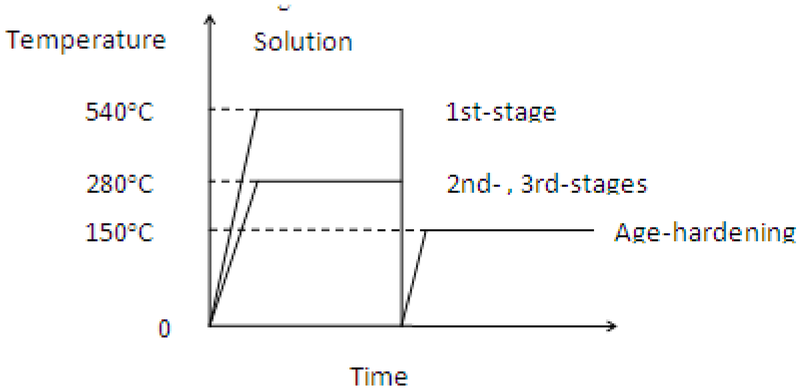

Figure 1: The solution treatment process

2.2 Compression and Hardness Tests

Compression tests were carried out using ELE Compact-1500 compression testing machine. Subsequently, characteristics of strength (hardness, UCS, % strain) were determined. The Vicker's micro-hardness test was carried out on the aged specimens using the Matsuzawa Micro Hardness Tester- Model MHT-1 at a load of 300g with time indentations of 5 seconds.

III. RESULTS AND DISCUSSION

The experimental results are summarized in Figure 2- 7.

3.1. Compressive Hardness and Strength

The results of compression and hardness tests (Figures 2,3) showed that alloy hardness and compressive stress increased with ageing time following exponential trends. The time response of these strength properties was modelled by the generalized equation (1):

$$\phi_n = \phi_0 e^{\alpha t} \qquad (r^2 \geq 0.9803) \qquad (1)$$

where, ϕ_0 - alloy strength property (UCS or HV) preceding ageing treatment; ϕ_n- alloy strength property after ageing; α - the hardening characteristic of the alloy; t - ageing time. The power hardening characteristic of alloy strength n was found to be between 0.002 and 0.0037 for both UCS and HV.

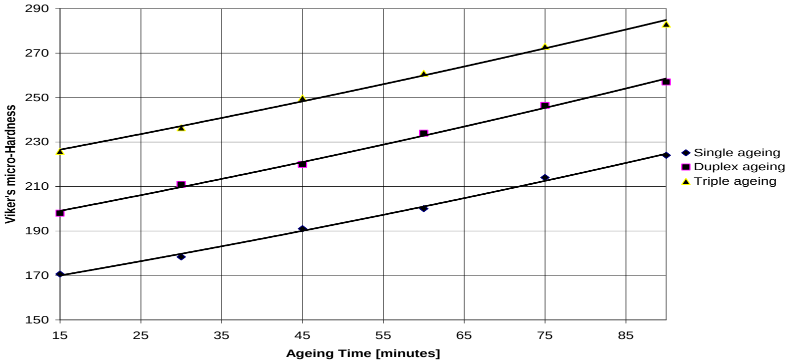

Figure 2: Time response graph of alloy hardness

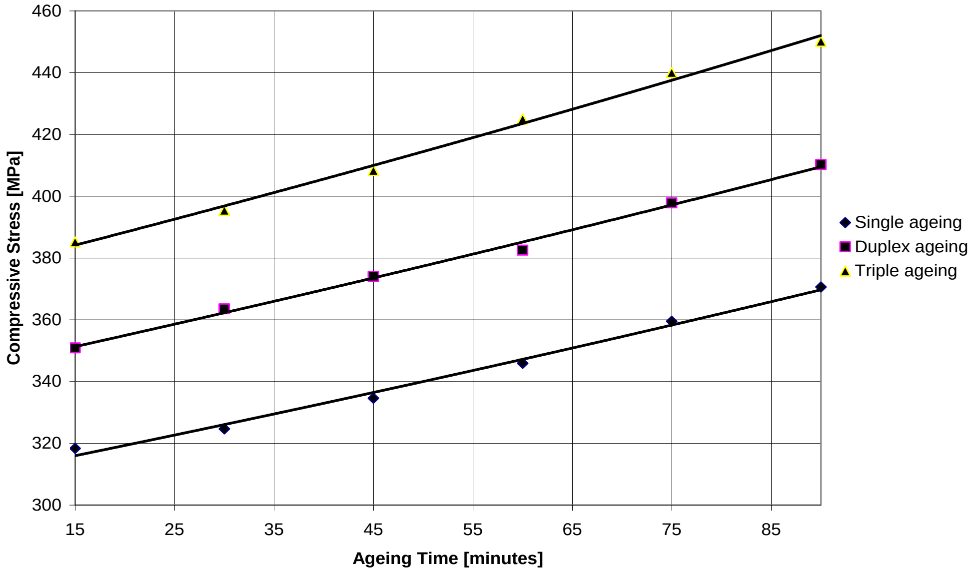

Figure 3: Time response graph of alloy strength

3.2. Time response The trends of Figures 4-5 also show that these properties also increased with repeated ageing. From these plots the relationship between strength properties and number of ageing treatments was modelled by equation (2):

$\phi_n = \phi_0 e^{\alpha N}$ $(r^2 \geq 0.9890)$ (2)

where α is the hardening characteristic of the alloy, and N – the number of ageing treatments required. The hardening characteristic of the alloy α was found to be between 0.0648 and 0.1329.

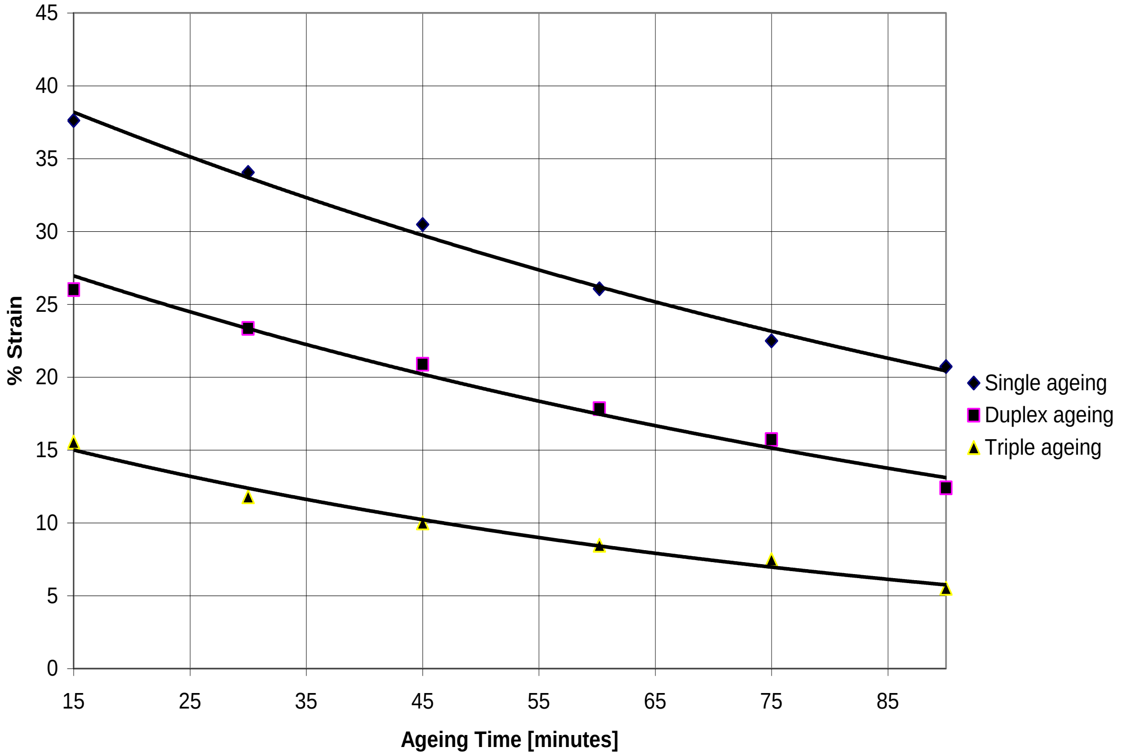

Figure 4: Time response graph of alloy strain

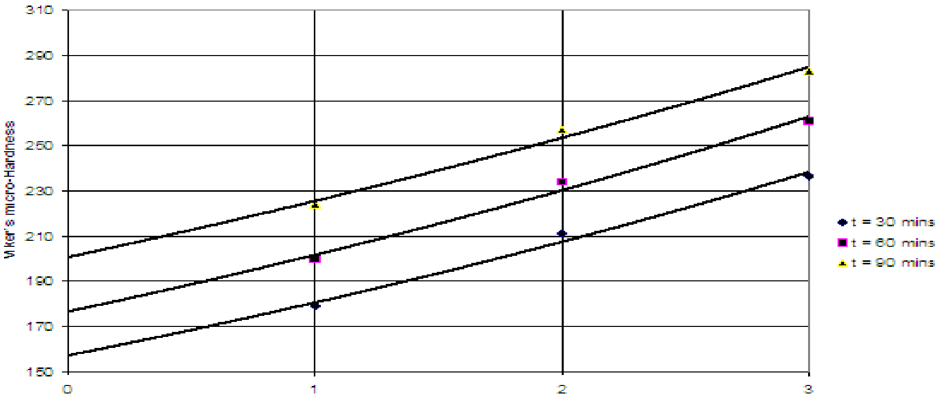

Figure 5: Response graph of alloy hardness with repeated ageing

3.3. Strain response

The results (Figure 6) indicated that the percentage (%) reduction of specimens reduced with increased ageing time. These are indications of increasing strength or strain hardening of the alloy with repeated ageing [3,6]. The time response of % reduction was modelled by equation (3):

$$\varepsilon_n = \varepsilon_0 e^{-\alpha t} \ (r^2 = 0.9803) \quad (3)$$

where the hardening characteristic of the alloy was found to be between 0.0083 and 0.0128. The results (Figure 7) also indicated that % reduction also reduced with repeated ageing. From these plots the relationship between strength properties and number of ageing treatments was modelled by equation (4):

$$\varepsilon_n = \varepsilon_0 e^{-\alpha N} \ (r^2 \geq 0.9728) \quad (4)$$

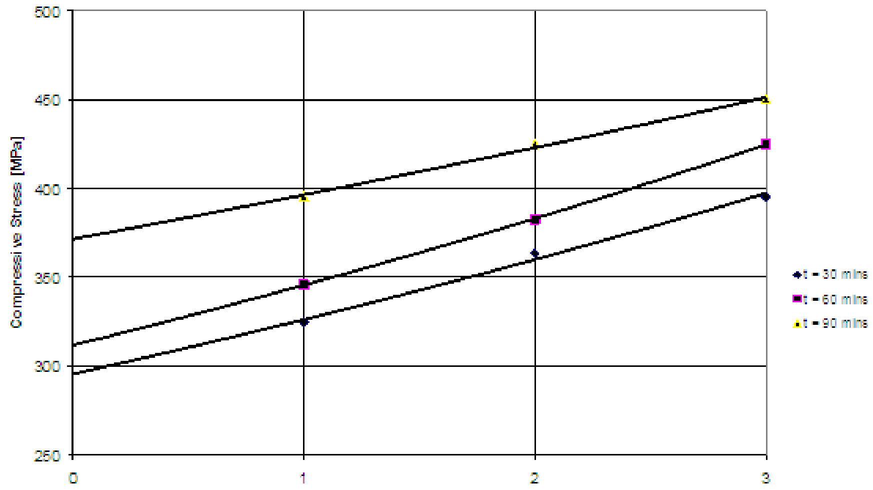

Figure 6: Response graph of alloy strength with repeated ageing

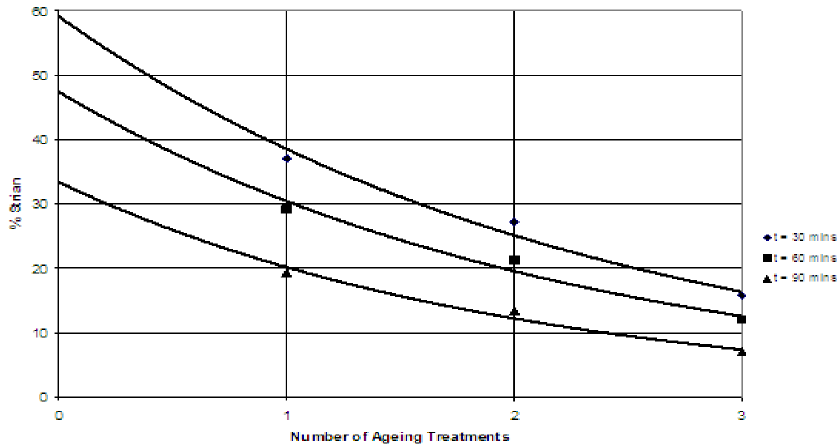

Figure 7: Response graph of strain with repeated ageing treatments

Equations (1) – (3) are similar to empirical models reported in related investigations [5,6] to obtain characteristic curves of the yield stress and tensile strength to predict target strength. Equation (4), previously modelled as a linear relationship in [1], presents a better model for predicting the strain response of the alloy in repeated ageing.

IV. CONCLUSION

The time required to raise the strength properties to desire levels can be predicted using equations (1) and (3), and the required number of ageing treatments or stages by equations (2) and (4). Strength properties of the recycled aluminium alloy increased with ageing time and repeated (multi-stage) ageing treatments, while the strain induced in the material reduced. The results show that further alloying is possible and the recycled alloy can be further improved, thereby increasing its potential use for production of high integrity parts.

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