The Effects of Multi-Stage Ageing Treatments on Age Hardening Response of Aluminium Alloys

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Abstract

This project studies the effectiveness of various multi-stage ageing treatments, including interrupted ageing treatment, with the aim to enhance the strength by changing the precipitate distribution in some selected alloys, including AA6111, Al-4Cu-0.8Mg(wt%), and Al-4Cu-0.8Mg-0.8Si(wt%). The ageing processes are monitored by using Vickers hardness tests while characterisation of the precipitating phases is done using conventional transmission electron microscopy. To date, it has been found that multi-stage ageing treatments have little effects in AA6111, Al-4CU-0.8Mg and Al-4Cu-0.8Mg-0.8Si alloys despite of the refinement in precipitate distribution.

1. Introduction

Since the discovery made by Alfred Wilm 95 years ago, the strength of heat treatable aluminium alloys has been improved through the most common heat treatment routine (designated T6) involving solution treatment, followed by water quenching and ageing treatment at 160-200°C in order to induce precipitation hardening till the alloy reaches its peak hardness [1].

It was not until the last 20-30 years, multiple-stage ageing treatments, typically in the form of duplex ageing treatment, were developed for certain alloys to further enhance the hardening response. More recently, another form of multi-stage ageing treatments, namely interrupted ageing treatment (designated T6I6), has been reported and claimed to be very effective in further improvement in the strength achievable via a standard T6 treatment [2-3]. The T6I6 treatment is a heat treatment that involves interrupting a T6 treatment by quenching the alloy, followed by ageing at lower temperature (25-65°C) for a given period of time before the T6 treatment is resumed until peak hardness is obtained [2]. It is reported that the T6I6 treatment could display simultaneous improvements in the yield strength, tensile strength and fracture toughness of most aluminium alloys on top of the improvement in hardness values [2]. Despite the significant amount of work completed by Lumley and colleagues, the potential of multi-stage ageing treatments has not been fully exploited and explained.

Fig 1. below shows the age hardening response and precipitate microstructures of aluminium alloy 2014 with and without interrupted ageing. The insert in (a) shows hardening response during isothermal exposure at 65°C. Note that the number density of precipitates in the interrupted sample (b) is significantly higher than that in the sample without interrupted ageing.

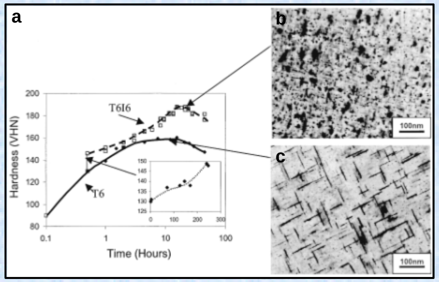

Fig. 1 Age hardening response and precipitate microstructures of AA2014 with and without interrupted ageing. (Lumley, Polmear and Morton 2004)

2. Experimental Methodology

The aluminium alloys selected for this project are AA6111(a commercial alloy produced by Alcan International Limited, with nominal composition of 0.75Cu, 0.75Mg, 0.63Si, 0.25Fe and 0.25Mn wt%) and induction cast Al-4Cu-0.8Mg (ternary) and Al-4Cu-0.8Mg-0.8Si (quaternary) alloys. For consistency, all samples were cut into 1mm thick strips. The 30 minutes solution treatments were done in salt baths of 550°C for AA6111 and 500°C for the ternary and the quaternary alloys. Samples were all quenched after solution treatments and/or pre-ageing treatments into water with the temperature maintained around 15°C. Further quenching along the heat treatment process was done using water close to room temperature. Each delay due to quenching process is kept at 1 minute for consistency.

In this project, seven hardness value data points are collected from each sample using mainly 10kg load and occasionally 5kg load during early stages of ageing.

A Philips CM20 transmission electron microscope, operated at 200kV was used to characterise the microstructure of samples subjected to different thermal treatment conditions. The foils were twin-jet electropolished in a solution of 33% nitric acid and 67% methanol (vol%) at -20°C.

3. Results and Discussions

Extensive amount of work has been completed in the collection of the age hardening curves of these alloys under different multiple ageing conditions; however only a few carefully selected curves are presented here. It is important to state that apart from the case of the ternary alloy which shows rapid first stage hardening, alloys were subjected to T6 treatments terminated at about 20-30% of the possible hardness increments; this T6I6 treatment significantly differs from the interrupted ageing treatment published by Lumley and colleagues where the T6 treatments were terminated at about 50-85%.

AA6111

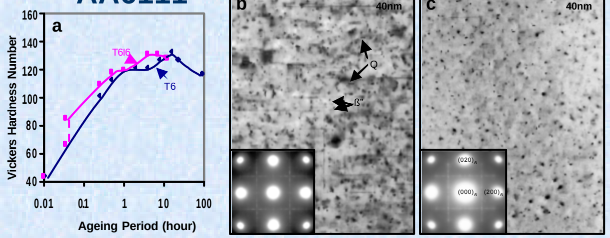

Fig. 2 Age hardening response (a) and precipitate microstructures of AA6111 with T6 treatment (b) and with T6I6 treatment (c) at peak age condition. T6: Single ageing at 180°C; T6I6: 180°C/2min+65°C/65hour+180°C.

As observed from Fig. 2(a), T6I6 treatment did not result in further improvement of the peak hardness of AA6111 despite the enhanced ageing kinetics, where the time to peak has been reduced from 16 hours to 4 hours after T6I6 treatment. When comparing Fig. 2 (b) and (c), it is observed that the precipitates resulting from T6I6 treatment showed significantly less strain contrast. However, more work has to be carried out in order to carefully characterise the changes in terms of number density and precipitate distributions.

Ternary

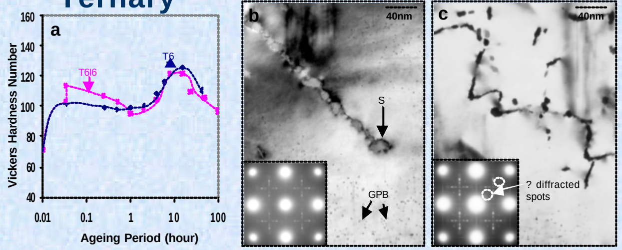

Fig. 3 Age hardening response (a) and precipitate microstructures of ternary alloy with T6 treatment (b) and with T6I6 treatment (c) at peak age condition. T6: Single ageing at 180°C; T6I6: 180°C/2min+65°C/65hour+180°C.

In the case of the ternary alloy, the sample was observed to have undergone "softening" when T6 treatment is resumed, while no improvements in peak hardness or ageing kinetics were achieved through T6I6 treatment. Smaller S phase precipitates were found to have formed along irregular helical dislocations. Larger precipitate free zones were formed surrounding the dislocations, while the number density of GPB zones has been reduced significantly after T6I6 treatment. In addition, ? phase has been introduced by T6I6 treatment as it can be characterised by the presence of diffraction spots at (1/3){022} and (2/3){022} in the corresponding selected area diffraction pattern.

Quaternary

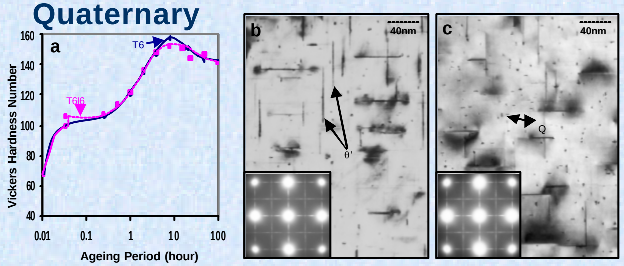

Fig. 4 Age hardening response (a) and precipitate microstructures of quaternary alloy with T6 treatment (b) and with T6I6 treatment (c) at peak age condition. T6: Single ageing at 180°C; T6I6: 180°C/2min+65°C/65hour+180°C.

No improvements were found in terms of age hardening response or faster ageing kinetics, despite the refinement in microstructure observed after T6I6 treatment. Higher number density of Q phase is observed.

4. Conclusions

- T6I6 treatment improves the age hardening kinetics of AA6111 alloy, but not in the ternary or the quaternary alloys investigated.
- Considerable refinement in the microstructure of the ternary and the quaternary alloys were observed after T6I6 treatment; while ? phase has been introduced in the ternary alloy after T6I6 treatment.
- No improvements in peak hardness were found after T6I6 treatments on all three alloys.

5. References

[1] A. Wilm, Metallugie, **vol. 8**, 1911, pp. 225-235.

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[3] R.N. Lumley, I.J. Polmear & A.J. Morton, Proc. 9th Int. Conf. on Aluminium Alloys (2004), pp. 95-95.

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