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Effects of deformation ratio on the mechanical properties and microstructures changes in an Al-Mg-Si alloy

Hichem FARH[1], Rebai GUEMINI[1], Fares SERRADJ[2], Karim DJEMMAL[1]
[1]*Department of Physics, Oum el Bouaghi University-ALGERIA*
e-mail: farhichem@gmail.com
[2]*Laboratory of Material Thermodynamic Properties and Surface Treatments, Department of Physics, Mentouri University of Constantine-ALGERIA*

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Abstract

An investigation has been done to study the effect of deformation ratio and two-step ageing treatment on the microstructure and the mechanical properties in an Al-Mg-Si aluminum alloy. Transmission electron microscopy is used in order to follow the distribution and the morphology of the hardening precipitates. The hardness of the alloy increases with the increasing deformation ratio. The maximum of hardness increases and is shifted to low time with an increase of the deformation ratio. The density of precipitates is more increased and the precipitates become more inhomogeneously distributed when the deformation combines with two-step ageing treatments.

Key Words: Al-mg-si alloys, deformation ratio, artificial ageing, precipitation.

1. Introduction

Al-Mg-Si age-hardening alloys, with medium to high strength, excellent formability and good recycling ability, possess great application potential in the automobile industry and have been subjected to extensive research [1–3]. The required material properties are achieved by thermally treating the material [4]. This thermal treatment consists of three main processes:

1. SHT (Solution Heat Treatment): this is where the material is held at an elevated temperature for a sufficient time, so that all the constituents are taken into solid solution, giving one single phase.

2. Quenching: this is when the material is rapidly cooled from the SHT temperature to room temperature, so as to “freeze” this super-saturated state within the material at room temperature, giving a microstructure condition known as “Super Saturated Solid Solution” (SSSS).

3. Ageing: age-hardening is the final stage in the development of the properties of heat treatable alloys.

It is the controlled decomposition of the SSSS to form finely dispersed precipitates [5, 6]. Some alloys undergo ageing at room temperature (natural ageing), but most require heating for a time interval at one or more elevated temperatures (artificial ageing) [7].

The schedule of thermomechanical treatment in this case involves two-step ageing and so the natural pre-ageing duration becomes one of the manufacturing process variables. Microstructural changes in Al-Mg-Si alloys during Quenching-Natural Ageing-Deformation-Artificial Ageing (Q-NA-DAA) scheme are more complicated and less investigated than the conventional T8 Quenching-Deformation-Artificial Ageing (Q-D-AA) scheme. Most investigations show that cold deformation after quenching suppresses GP-zones formation and accelerates the nucleation and growth of intermediate phases [8–11].

Precipitation processes in the Al-Mg-Si system have been extensively researched in the recent past and emphasis has been placed on the Mg:Si ratio and the effects that it has on the process and properties[12–14]. The general precipitation process is commonly accepted to follow the following sequence [13–16]: Super saturated solid solution $\rightarrow$ atomic clusters $\rightarrow$ GP zones $\rightarrow \beta'' \rightarrow \beta\prime \rightarrow \beta$ (Mg_2Si).

The mechanical properties in the cast aluminum alloys after ageing treatment are significantly influenced by various process parameters, such as natural ageing, pre-aging, heating rate to the final ageing temperature, and the conditions of artificial ageing. Apart from a few publications, [17–19] most of the previous research on cast Al-Mg-Si alloys has focused primarily on two parameters: artificial ageing temperature and time. Consequently, there are no established guidelines for optimizing the ageing parameters to obtain peak tensile properties. Extensive investigation of these parameters in wrought Al-Mg-Si alloys has led to the development of innovative heat-treatment procedures [20]. This study was performed to understand the effects of single and two-step artificial age hardening, and the amount of deformation on the mechanical properties of an Al-Mg-Si alloy.

2. Experimental procedure

The Al-Mg-Si alloy was provided by the Banbury Laboratories of Alcan International Ltd. It was prepared by direct chill casting process in a 178 mm diameter mould. The chemical composition of the investigated alloy is given in Table.

Table. Chemical composition of the investigated alloy. All values in wt%.

Cu	Mg	Si	Mn	Cr	Fe	Zr	Al
0.42	1.01	0.62	0.006	0.002	0.21	0.13	bal

The thermomechanical treatment procedures for all specimens were divided into two types.

1. The specimens were annealed for 2 hours at 550 $^\circ$C using a heating rate of 50 $^\circ$C min^{-1}. They were then cold deformed (by 0%, 5%, 10%, 25% and 50% of thickness) followed by artificial ageing at 180 $^\circ$C for different times (single artificial age hardening).

2. The specimens were annealed for 2 hours at 550 $^\circ$C using a heating rate of 50 $^\circ$C min^{-1}, water quenched at room temperature, cold deformed (by 0%, 5%, 10% and 25% of thickness) then pre-aged at 150 $^\circ$C for 10 hours followed by artificial ageing at 180 $^\circ$C for different times (two-step artificial age hardening).

3. Results and discussion

Figure 1 presents the variation of microhardness as function of the ageing time at 180°C. It can be seen the effect of the deformation ratio during single artificial ageing of the studied alloy immediately after solutionizing and quenching at room temperature. The curves showed that the HV increases with an increase of the deformation ratio. The age hardening curves of the alloy, when subjected to all testing conditions, have the same shape, that is the hardness increases gradually and approaches a maximum value ($HV_{\max}$) and then decreases gradually. In fact, the change of $HV_{\max}$ with deformation ratio has resulted into the following groups: G1 (0%–10%) and G2 (25%–50%). The $HV_{\max}$ in the second group (G_2) is higher than it is in the first group (G_1). The earlier maximum of HV present at about 65 minutes of ageing is observed in the second group (25%–50%). We notice also that the maximums of hardness are shifted to low ageing time when the alloy is more deformed. The $HV_{\max}$ of the alloy increases by about 15% when deformation ratio is 25%, compared to no deformed alloy. In fact, the deformations accelerate the precipitation of the hardening phase β''.

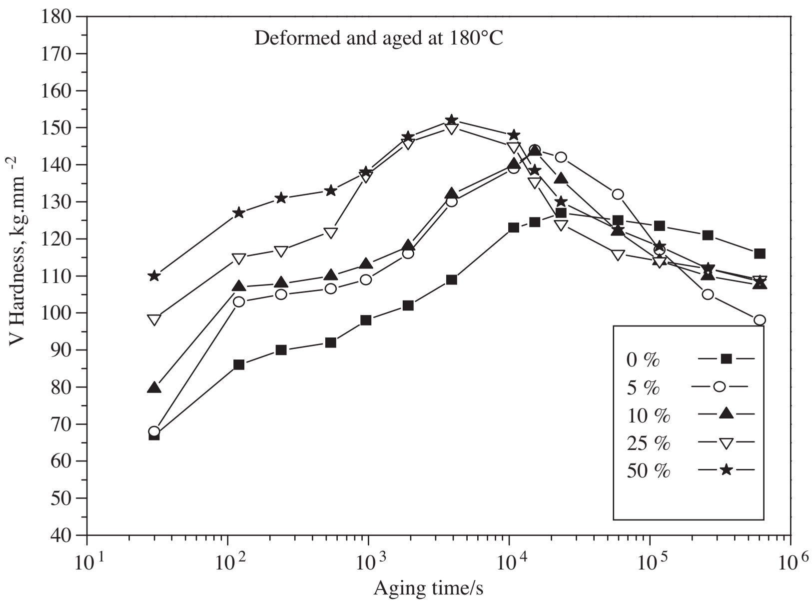

Figure 1. Effect of the deformation ratio in the thermomechanical treatment on the age hardening of the alloy at 180 °C.

Figure 2 shows a typical distribution of the precipitates observed in the alloy solution treated for 2 hours at 550 °C, cold rolled at room temperature up to 10% and 50% then aged at 180°C for 5 hours. We can observe that the coarsening and the density of the precipitates are more significant when the alloy is more deformed.

Figure 3 shows the effect of the deformation ratio. The alloy is solution treated for 2 hours at 550 °C, water quenched at room temperature, and then pre-ageing at 150 °C for 10 hours followed by artificial ageing at 180 °C for different times. We notice similar shape of the curves as observed in Figure 1. However, it can be seen that the $HV_{\max}$ of two-step artificial aged alloy is higher than that of single artificial aged alloy for the different cold rolling deformation ratio. Furthermore, we observe similar changes of $HV_{\max}$ with increasing deformation ratio that observed in single aged alloy. The effect of the deformation in the single ageing alloy is more significant than that in the two-step ageing alloy.

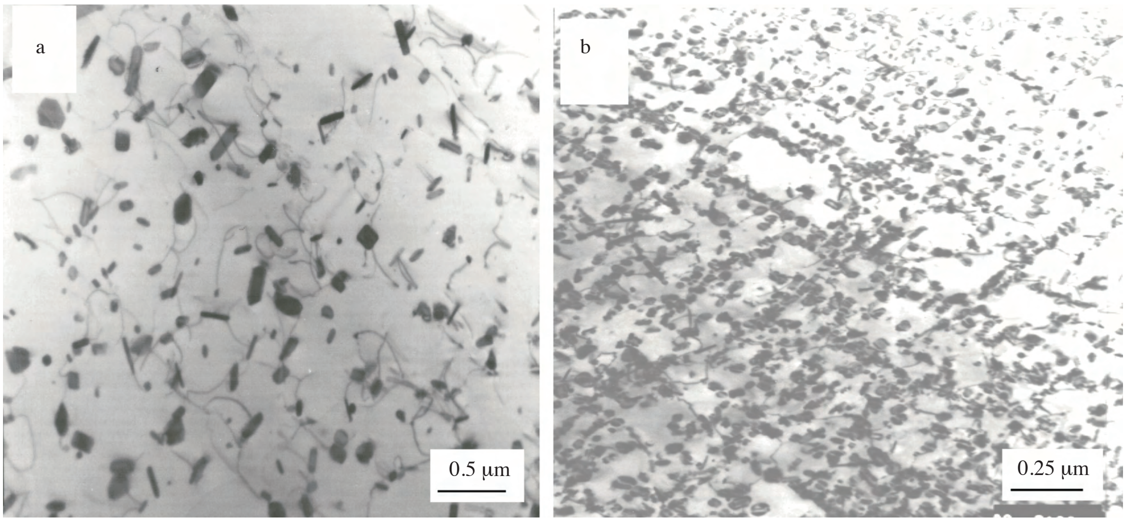

Figure 2. Effect of deformation on the distribution of the precipitates observed in the alloy solution treated for 2 hours at 550 °C, under (a) 10% deformation then aged at 180 °C for 5 hours; (b) 50% deformation then aged at 180 °C for 5 hours.

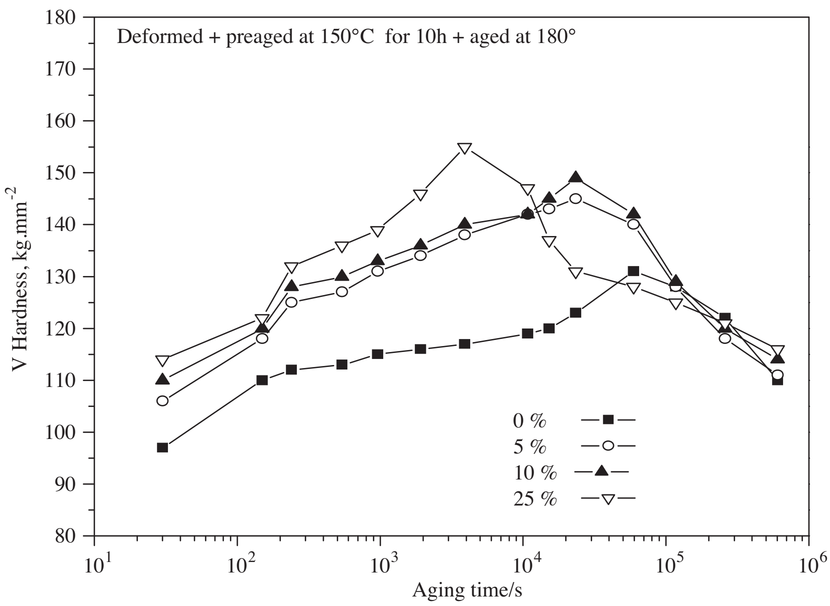

Figure 3. Effect of the deformation ratio in the thermomechanical treatment on the age hardening of the alloy aged at 150 °C for 10 hours, then aged at 180 °C.

Figure 4 shows the transmission electron microscopy micrographs of the alloy at different ageing condition. The bright-field image reveals needle-shaped precipitates with the long axis along <100> of the matrix direction in the alloy aged at 180°C for 5 hours (Figure 4(a)). According to Dutta and Allen [15], these precipitates are designated as β''. A noticeable modification in the precipitate structure is found after deformation as shown in Figure 4(b) and Figure 4(c). The needle-shape precipitates become larger in size and less homogeneous. This is also accompanied by a change in the dislocation configuration. When deformation combines with two-step ageing, the precipitates become larger and more inhomogeneously distributed, Figure 4(c).

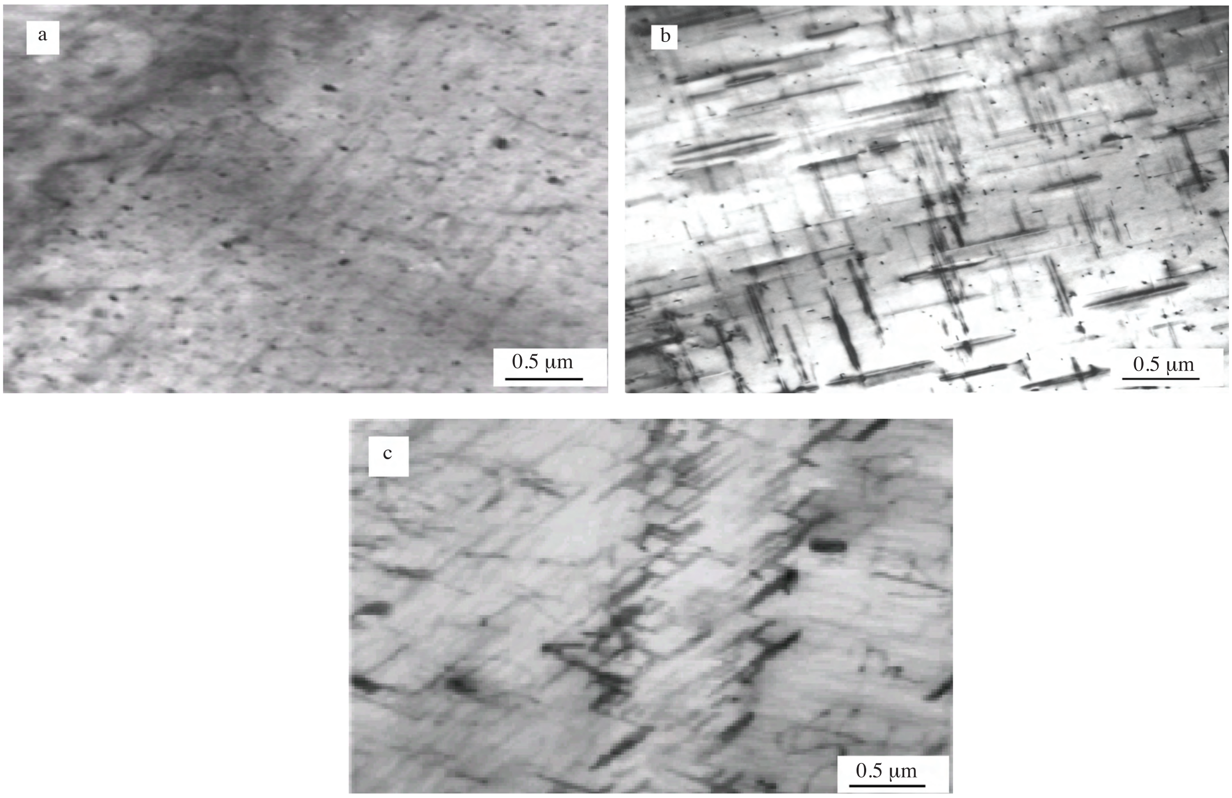

Figure 4. Transmission electron microscopy micrographs of the alloy under different conditions: (a) aged at 180 °C for 5 hours, (b) 30% deformation and aging at 180 °C for 5 hours; (c) 30% deformation and aging at 150 °C for 10 hours then aged at 180 °C for 5 hours.

4. Conclusion

The effects of the deformation and ageing treatments on the microstructure and the mechanical properties of AlMgSi alloy have been investigated by transmission electron microscopy and hardness measurements. The main experimental results can be summarized as follows

The combination of the thermomechanical treatment and the two-step artificial ageing causes an increase in hardness and strength due to the acceleration of the precipitation of the hardening phases. The peak-aged hardness has increased by about 15% when the alloy is deformed 25% reduction in thickness.

The thermomechanical treatments accelerate the coarsening of the precipitate.

The maximum of hardness in the case of the two-step artificial aged alloy is higher than that of single artificial aged alloy for the different cold rolling deformation ratio.

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