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Studying the quenching temperature on precipitation kinetics in Al-Mg-Si alloy

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ABSTRACT

In this paper, we have studied the ageing effect before and after quenching at two temperature of 400 and 500 °C of Al 6000 alloy. The Al 6000 alloy was aged at 300 °C for 48 hours. The structural properties were investigated using X-ray diffraction; the microstructural evolution was investigated using optical, scanning and transmission electron microscopies and microhardness measurement for the mechanical properties. After various states of ageing, the Al-Mg-Si alloy shows significant changes in the microstructure and mechanical behavior. After ageing, the microstructure of the matrix consisted of a two solid solution of α–Al and β– Mg_2Si phases precipitation. After two-step ageing at 300 °C and quenching, corresponding to the minimum value of microhardness, the alloy reveals small β continuous precipitates. After ageing at 300 °C of original sample, the volume fraction of this precipitate becomes higher. We found be that the best results have been obtained with the quenching at 500 °C.

KEYWORDS

Al-Mg-Si alloy;
Quenching;
Ageing;
Microstructure;
Precipitation.

INTRODUCTION

Al alloys is one of the most widely used non-ferrous structural materials in industry, and many sub-systems of multi-component Al alloys have been studied, including the establishment of their thermodynamic database[1,2]. Al-Mg-Si alloys are widely used in aerospace and civil industries because of their low densities and a favorable combination of strength and resistance to corrosion[3]. Al-Mg-Si alloys used for electrical application, mainly as conductors are required to possess a proper combination of properties, such as high strength, high electrical conductivity and optimum elongation[4].

The 6000 series Al-Mg-Si alloys have a widespread application, especially in the building, aircraft and automotive industry due to their excellent properties. The 6000 alloys contain magnesium and silicon as major addition elements. They have good extrudability and hardening characteristics as well as excellent corrosion, surface, and welding properties. In this aluminium alloys besides the intentional additions, transition metals such as Fe, Mg and Cu are always present. Even not large amount of these impurities causes the formation of a new phase component. The exact composition of the alloy and the casting condition will directly influence the selection and volume fraction of intermetallic phases[5–8].

The precipitation sequence in Al-Mg-Si1–4 alloys is atomic clusters →GP. Zones → metastable β3 precipitates → metastable β2 precipitates → stable β phase[1,2,9,10]. This precipitation sequence was observed for most investigated Al-Mg-Si alloys within a relatively wide temperature range. Previous investigation indicated that equilibrium Si phase is formed at the end of the precipitation sequence if the atomic ratio of Mg to Si is less than 2, and this phase can nucleate along the stable β particles[11,12]. However, Except for the equilibrium phase β, with composition Mg2Si, and Si, all phases are metastable. Historically, all the precipitates were assumed to have the Mg2Si composition.

In this paper, we have studied the effect of ageing at 300 °C for 48 hours of Al 6000 alloy before and after quenching at two temperatures of 400 and 500 °C for 2 hours in water, the effect was studied on microstructure, mechanical behavior and structural properties of Al 6000 alloy.

MATERIAL AND EXPERIMENTAL

The alloy containing of Al 6000 used in this study was in the form of extruded angular bar, the chemical composition is listed in TABLE 1. The samples were cross-sectioned from the supplied bar having dimensions of 1×1×1 cm3. The solution heat treatment program used for the samples is shown in TABLE 2. Four different samples were investigated with temperature treatment. The first corresponds to original sample (sample A). In the second, the second is replaced by a two-step aging (400 °C/2 h+300 °C/48 h). The third way (C) is based as the second is replaced by a two-step aging (500 °C/2 h+300 °C/48 h). Finally, in the last process (D) an aging at 300/48 h of original sample.

TABLE 1 : The chemical composition of aluminum 6000 alloy, values are in wt. %.

Alloy (wt. %)	Al	Si	Mg	Fe	Cu
	98.5	0.59	0.564	0.184	0.015

TABLE 2 : Durations (h) and temperatures (°C) of the solution heat treatments

Sample	Solution heat treatment temperature, °C		
	400	500	300
	quenched	quenched	aging
A	–	–	–
B	2h	–	48h
C	–	2h	48h
D	–	–	48h

Crystallographic and phase structures of the thin films were determined by X-ray diffraction (XRD, Bruker AXS-8D) with CuKα radiation (λ = 0.15406 nm) in the scanning range was between 2θ = 10° and 90°. For microscopic studies, specimens were polished and etched with a concentrated solution of 10 % NaOH in the water at room temperature for (30 –120 s). The scanning electron microscopy (SEM, JSM–6700F) equipped with EDX was used to examine both morphology and elemental analysis of the samples, and the microhardness variation was measured on samples using HVM-2000 hardness, at a load of 125 g applied for 30 seconds.

RESULTS AND DISCUSSION

The XRD spectrum of an original sample of Al 6000 alloy, shown in Figure 1, presents diffraction peaks representing two solid solutions: the α (Al-rich) solid solution and apparently β (Mg_2Si -rich) solid solution, as confirmed in Figure 2b. According to previous characterizations of Al-Mg-Si[5,6,9], these peaks correspond to α–Al and β– Mg_2Si phases precipitation.

The nature of the precipitates that formed in the matrix as fine and coarsened particles was examined

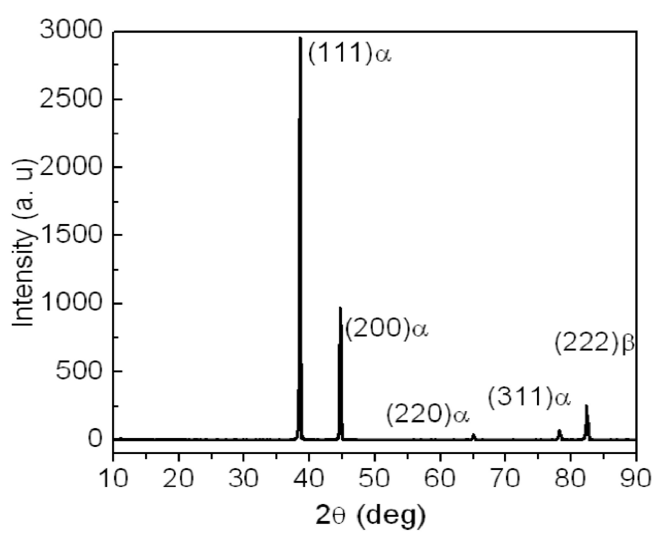


Figure 1 : The XRD analysis results of Al 6000 alloy of original sample.

by EDS analyses are shown in Figure 2. In Figure 2a, the precipitates are identified as particle 1 and particle 2 in the pre-solution treated alloy[13]. Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) analysis showed that the matrix consisted of a two solid solution of Al, Si and Mg, whereas both particles 1 and 2 consist of Al, Fe and Cu as given in Figure 2b.

peaks were observed from this Figure at 2θ = 38.5°,44.18°, 44.7°, 65.10°, 78.1° and 82.3° which can be attributed respectively to (111), (200), (220) and (311) planes of α phase, (100) and (222) plane of β phase, the Figure 3b showed that the (100) β was detected in the smaller intensity, however, Figure 3b, here the Al alloy 6000 quenched at 500 °C for 48 hours, in this case the intensity of (100) and (222) plane of β

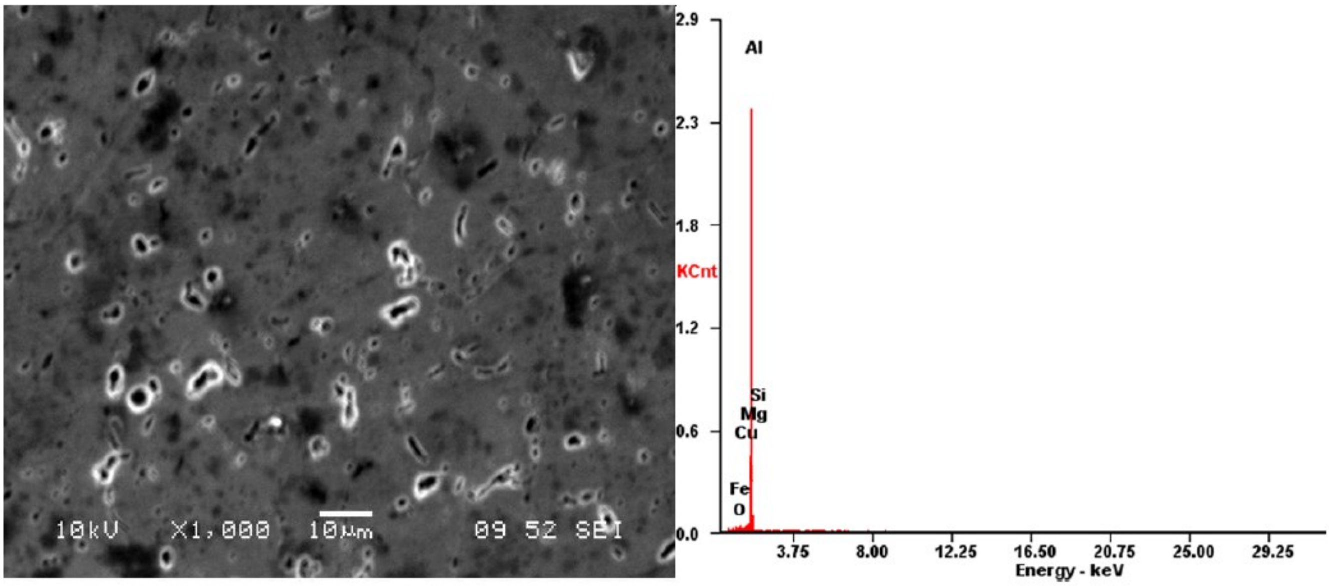


Figure 2 : Original sample: (a) SEM back-scattered electron image (BEI), (b) matrix EDS spectrum.

The Figure 3 shows the X-ray diffraction of aged at 300 °C as quenching of Al alloy 6000 at 400 and 500 °C for 48 hours. As can be seen, six diffraction phase are higher than the quenching at 400 °C.

Figure 4, present the X-ray diffraction of ageing at 300 °C for 48 hours as original sample, as can seen

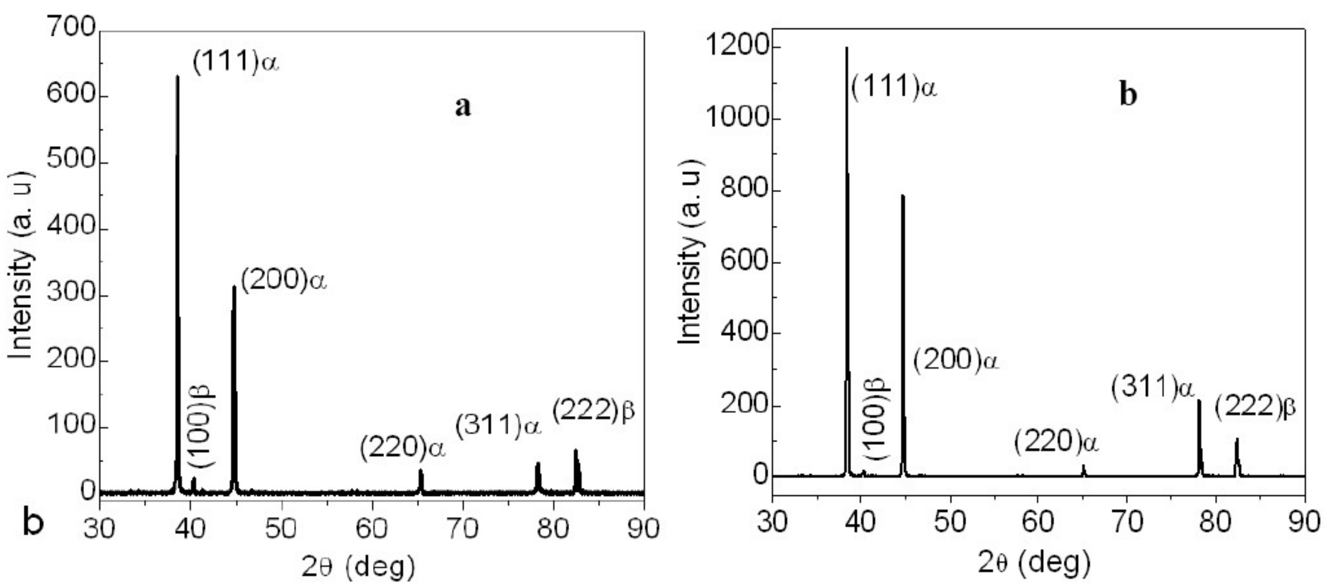


Figure 3 : The XRD analysis results of Al 6000 alloy of (a): aged at 300 °C/48 h as quenching at 400 °C, (b): aged at 300 °C/ 48 h as quenching at 500 °C.

that the variation of peaks intensity change α phase and β phase comparing with the aged as quenching. It is clear that both regions have the same crystalline structure but different lattice parameter. It is evident that β has a composition different from that of α. It is clear that its intensity becomes β phase precipitated during this treatment. However, the β phase is more important of this precipitation. Our XRD result is in good agreement with reported[14,15].

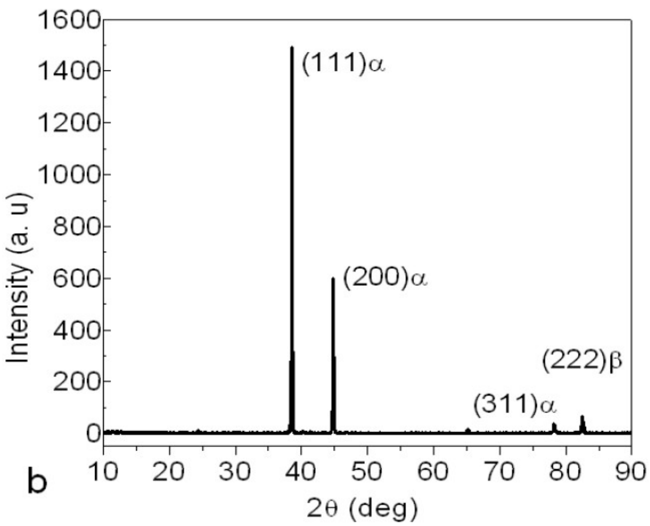
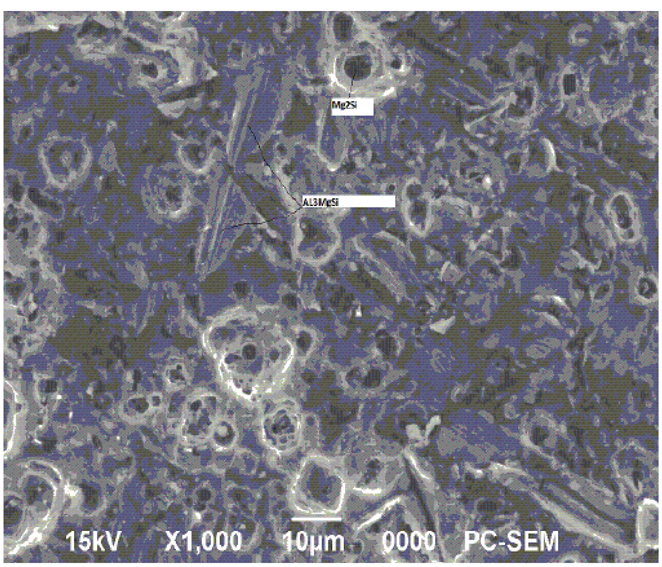


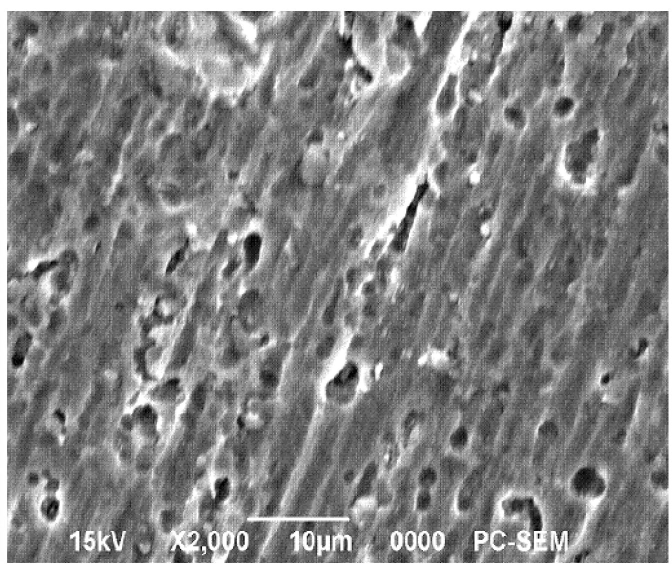
Figure 4 : The XRD analysis results of Al 6000 alloy of ageing at 300 °C/48 h as received.

The microstructures evolutions of the 6000 aluminium alloy processed of quenching at 400 °C and 500 °C after the subsequent ageing at 300 °C for 48 h are shown in Figure 5. A characteristic feature of the as quenched microstructure is the presence of higher grains that contain a high density of precipitation. It can be assumed that at lower ageing time, the microstructural evolution become more homogeneous. We have observed that precipitation is continuous at 300 °C as quenching. This reaction is more important during ageing time of 48 h as quenching at 400 °C (Figure 5a). The precipitates are fragmented with their length estimated at 1 μm. It should also be noted that the volume fraction of these precipitates is smaller than in the case of the original processed samples (Figure 2a). We have obtained similar results with Chemingui et al.[16] studied the effect of heat treatment on plasticity of Al-Zn-Mg alloy.

In the Figure 6 shows the microstructural evolution of the 6000 aluminium alloy processed of ageing at 300 °C for 48 hours as original sample. We have observed that precipitation is continuous of aging at 300 °C. However, the aging at 300 °C of original sample produces a continuous precipitation characterized by finer precipitates inside of grains. The precipitates are fragmented with their length estimated higher than of 1 μm. It should also be noted that the volume fraction of these precipitates is smaller than in the case of the ageing as quenching processed samples (Figure 5). This is due to the partial dissolution and transformation of the particles as a result of shearing. A similar observation was reported for the 6082 alloys in[17]. By contrast, the results re-



(a)



(b)

Figure 5 : Microstructures observations of Al6000 alloy with aged at 300 °C as quenching: (a) 400 °C, (b) 500 °C

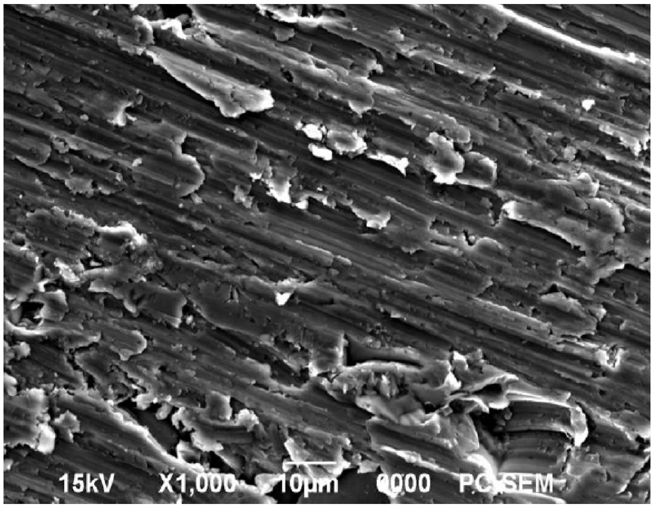


Figure 6 : Microstructures observations of Al6000 alloy with aged at 300 °C as received.

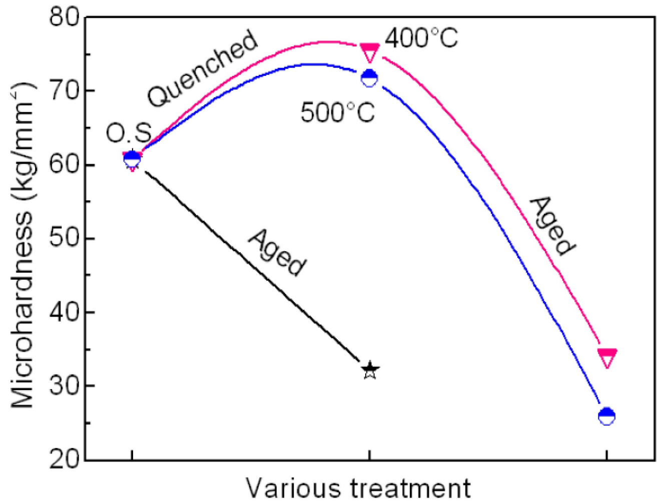


Figure 7 : Vickers microhardness variation Hv of Al 6000 alloy at different treatments.

ported in[18–20] show only partial fragmentation of the β'' precipitates.

The microhardness variation curves of Al 6000 alloy at different treatments. Original sample, quenched at a temperature of 400 and 500 °C during 2 h, ageing at 300 °C as quenching for 48 hours and ageing at 300 °C of original sample are presented in Figure 7. As can be seen, the microhardness increases after the quenching Al 6000 alloy. The alloy becomes soft with prolonging of ageing and its mechanical properties are reduced by the appearance of equilibrium precipitate β. It has been found that a continuous precipitation can cause major changes in the microstructure and properties of solid alloys.

CONCLUSIONS

The ageing effect at 300 °C pending time 48 hours before and after quenching at a temperature of 400 and 500 °C of Al 6000 alloy on the structural, microstructural and mechanical properties were investigated. The following conclusions can be drawn from the results presented

- After various states of ageing, the Al-Mg-Si alloy shows significant changes in the microstructure and mechanical behavior.
- After ageing, the microstructure of the matrix consisted of a two solid solution of α–Al and β– Mg_2Si phases precipitation.
- After two-step ageing at 300 °C of quenching, corresponding to the minimum value of microhardness, the alloy reveals small β continuous precipitates.
- After ageing at 300 °C of original sample, the volume fraction of this precipitates becomes higher. We found be that the best results have been obtained with the quenching at 500 °C.

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