Investigation on the Aging Responses and Fracture Surface Morphology of Al- Mg –Si Alloys with Different Weight Percent of Mg and Si Compositions

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Abstract

The mechanical properties of Al-Mg-Si alloys are depending upon many factors such as alloy composition, casting method, heat treatment procedures (solution treatment temperature, aging time and temperature) and other parameters which could affects the aging response and behaviors. In this study, aging response and fracture surface morphology of two Al-Mg-Si alloys with different wt% of Mg and Si compositions of Al-Mg-Si alloys were investigated. The experimental procedures were started with a heat treatment process where firstly both alloy samples were solution treated at 540 °C for 30 minutes, followed by quenched into cold water. The solution treated alloy samples were artificially aged at an elevated temperature of 170 ^{o}C for 0.1 to 100 hours. The aging response and mechanical properties were examined by Vickers hardness and tensile test. The surface fractured morphology from the tensile specimen in peak-aged condition at 170 °C was carried out using a field emission scanning electron microscope (FESEM). It was found that the composition of Mg and Si present in the alloys affects the aging response and mechanical properties. As the composition of Mg and Si increased, the mechanical properties of the alloys also increased and gave a stronger aging response to the alloys. The FESEM analysis exhibited that the alloy P which contained higher composition of Mg and Si showed a less ductile behaviour and lower elongation properties, hence the results of the FESEM analysis are in line with the results of hardness and tensile test.

Keywords: Al-Mg-Si alloys, aging response, fracture surface

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Introduction

In recent decades, Al-Mg-Si alloys, denoted as 6000 series aluminum alloys are widely used in automotive, aircraft, structural, and various applications. This type of alloys has become the material of choice in the automotive industry especially panels body car due to its low density, good formability, and higher strength-to-weight ratio as well as corrosion resistance [1, 2]. Al-Mg-Si alloys are also known as precipitation-hardened alloys and their superior properties are mainly derived from the formation of nano sizes precipitates that formed during aging treatment [3]. Aging treatment is one of heat treatment process which has been recognized as one of the most important methods for strengthening aluminum alloys [4]. Basically, the heat treatment process in the industrial application involved three main steps: solution treatment, quenching, and aging. For 6000 series aluminum alloys, the range of temperature used for artificial aging is between 160 and190 ^{o}C [4] which correlates to paint baking treatment temperature in the automotive industry [5].

After aging treatment, a series of phases or hardened precipitates will be formed, which eventually affect the final mechanical properties of the alloy. Among the precipitates present, β'' or Mg_2Si precipitates which has the appearance of a needle is believed to be the most strengthening phase [6]. In order to obtain the optimum properties of the alloy, it is important to control the precipitation hardening effect during the aging treatment [7]. Time and temperature are known as the main parameters that are usually used in the heat treatment process [4].

The composition and the heat treatment applied to the alloys do contribute to the formation of the type of precipitates [4,8]. There are several studies on the effect of alloy compositions on the microstructure and mechanical properties of 6000 series aluminium alloys [9-12]. For example, Wang et al. [9] reported that increasing the amount of Si composition enhanced the mechanical properties of 6000 series aluminum alloys. Meanwhile, increasing the Mg in a small amount also resulted in increased mechanical properties of the alloys, which was attributed to the increase in the formation of Mg_2Si precipitates within the aluminum matrix structure after the aging treatment [10]. The addition of Cu was reported to refine and increase the distribution of needle-shaped precipitates in the alloy matrixes leading to improved mechanical properties [1,10]. Besides, Cu addition is known to enhance precipitation kinetics of the alloys during the aging treatment [1,10,12]. The presence of transition elements such as Mn and Zr containing dispersoids have raised the tensile strength and toughness of the alloys due to the production of slip homogenization with nearly uniform dislocations [13].

The objective of this study is to investigate the aging response and fracture surface of two 6000 series aluminium alloys with different wt% of Mg and Si compositions by using mechanical testing methods meanwhile FESEM analysis was used to examine the fracture surface morphology of peak-aged alloys.

Materials and Methods

In this study, two aluminium alloys from the 6000 series denoted as alloys P and Q have been used for heat treatment process. Both alloys have a different composition of Mg and Si and they were in extruded form with their thickness of 4 mm and width of 40 mm. This type of alloys is used in automotive applications. Table 1 shows the chemical compositions of the investigated alloys.

Table 1: Chemical compositions of the two Al-Mg-Si alloys (wt.%)

Alloys	Mg	Si	Mn	Cu	Ti	Fe
P	0.60	0.43	0.10	0.10	0.10	0.35
Q	0.20	0.22	0.03	0.10	0.10	0.17

The alloy samples were cut for hardness and tensile specimens before solution treated at 540 °C for 30 minutes in a furnace and quenched into cold water at 25 ^oC. Then they were artificially aged in a convection oven at a temperature of 170 ^oC between 0.1 to 100 hours. The aging temperature of 170 ^oC was selected in this study because it is commonly used in the paint baking process in the automotive industry [5]. Different time of aging was carried out in order to investigate the aging response profile of the alloys. By controlling the aging temperature and time, a variety of mechanical properties of the alloys can be obtained.

The hardness and aging response of alloy samples were monitored using Vickers hardness tester. Five hardness readings were taken for each sample to ensure accurate readings and finally, the hardness value average was calculated. Tensile test was done for the alloys that aged at 170 °C for 1, 10, and 100 hours by using an INSTRON Universal Testing Machine operating at a constant crosshead speed of 1.0 mm min^{-1}.

The fracture surface from the tensile test of peak-aged alloys P and Q were characterized using FESEM (Hitachi SU-8020). The samples were first coated with conductive materials before the microstructure was observed clearly under two magnifications of 10 and 50 µm operating at 5 to 10 kV.

Results and Discussion

Aging Response

Fig.1 shows the aging curves of alloys P and Q after aging at 170 ^oC. It can be seen that alloy P, which contained higher Mg and Si compositions i.e 0.60 and 0.43 wt. % respectively, exhibited the strongest aging response and hardness value than alloy Q (Mg: 0.20 wt% and Si: 0.22 wt%). The increase in hardness value of alloy P was believed due to the formation of hardening precipitates during aging treatment which caused strengthening effects to the alloy. It is shown clearly in Fig.1 that both alloys have similar trends where their hardness increased with increasing aging time until they reached a maximum hardness (at 10 hours) that will give a higher hardness value (70 VHN for alloy P and 48 VHN for alloy Q). After a long period of aging time, the reduction in hardness value occurred and this is known as overaging condition.

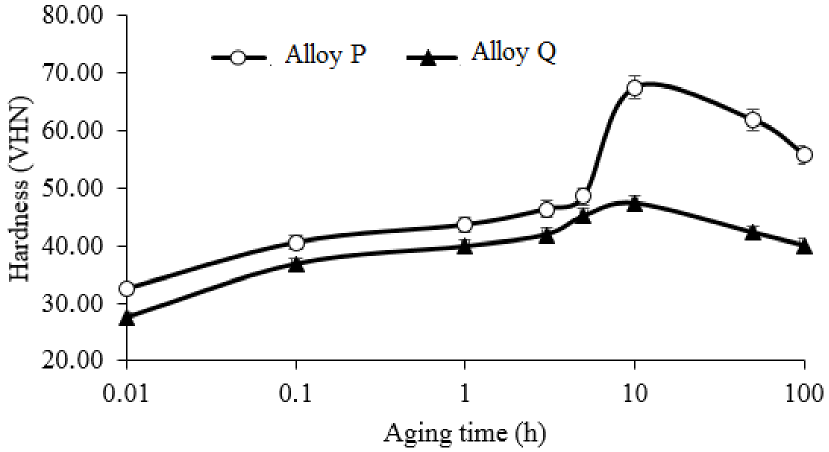


Figure 1: Aging curves of alloys P and Q after aging at 170 °C. Note that x axis is log scale

More precipitates were formed during the aging treatment as more solute atoms of Mg and Si (alloy P) present in the alloy. Based on a study by Odoh et al. [14], they reported that the higher composition of Mg and Si in 6000 series alloys will lead to the enhancement of hardness and strength of the alloys due to the increase in the number density of hardening precipitates. These precipitates can effectively impede the moving dislocation [4,15]. According to the previous researchers, the hardening precipitates are known as Mg_2Si precipitates [15]. The higher composition of Mg and Si in alloy P resulted in more availability of nucleation site for the formation of Mg_2Si precipitates leading to increased hardness and aging response as compared to alloy Q.

Tensile properties

Fig. 2 and 3 show the yield strength (YS) and elongation properties of alloys P and Q after aging at 170 °C for 1, 10, and 100 hours. From the tensile test results, it is clearly shown that alloy P exhibited the highest yield strength (YS) value than alloy Q. The presence of higher solute composition of Mg and Si in alloy P is believed to produce a large number density of precipitates resulted in an increase in the tensile properties after the aging treatment and reduction in plastic deformation and tensile elongation value (Fig. 3). The results of the tensile test are in agreement with hardness test results for the alloy that aged at 170 C for 1, 10, and 100 hours.

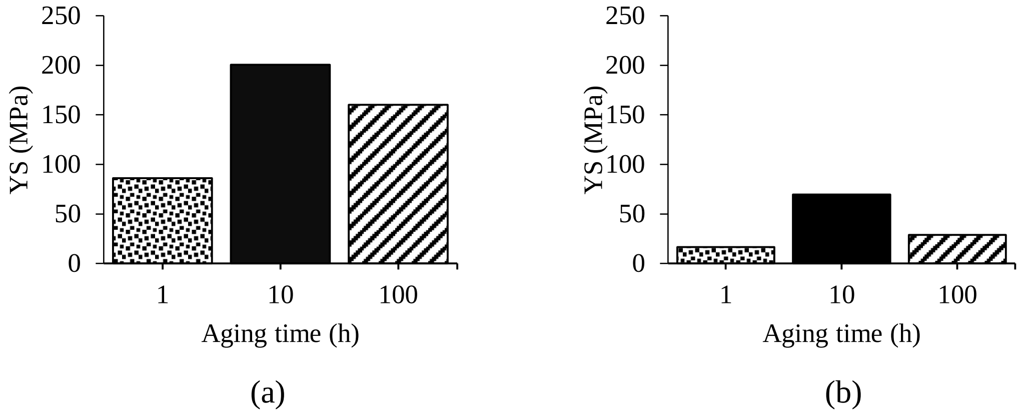


Figure 2: Yield strength (YS) of alloys (a) P and (b) Q after aging at 170 °C

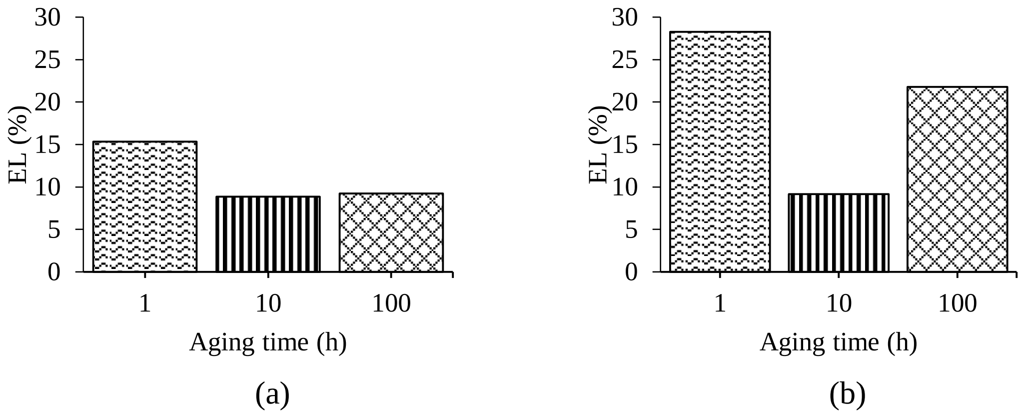
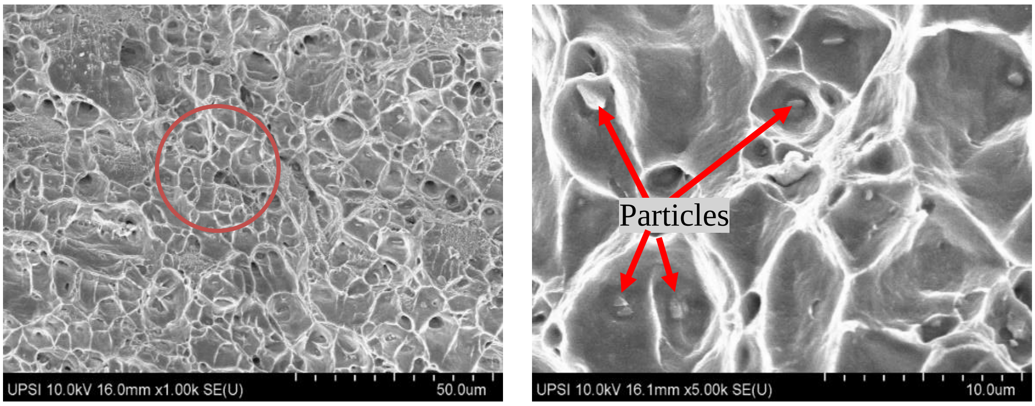


Figure 3: Elongation (EL) of alloys (a) P and (b) Q after aging at 170 °C

Fracture surface morphology

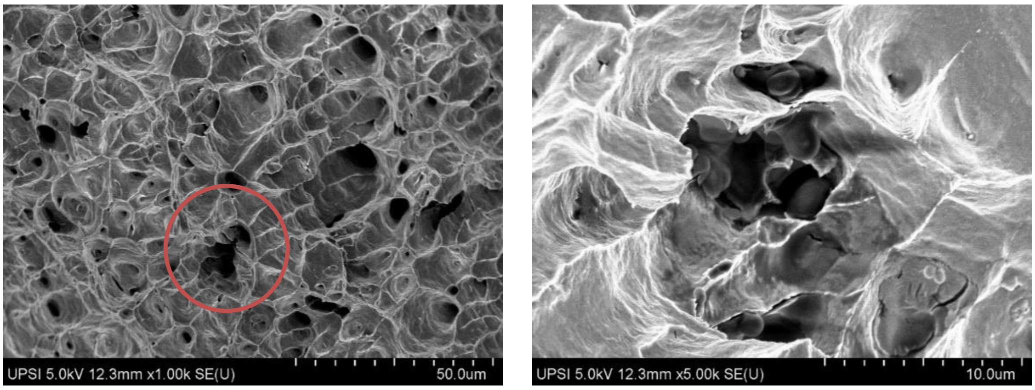
To provide insight into low elongation values corresponding to alloy P, the tensile fractured surface morphologies of two peak-aged alloys were compared as seen in Fig. 4 and 5. From the overall micrograph results, it is observed that both alloys P and Q have ductile fracture mode. The morphology of both alloys revealed a lot of equiaxed dimples covering the fracture surfaces resulting from the growth and coalescence of micro-voids [16]. Similar ductile fracture modes were found in the Al-Cu-Li and Al-Mg-Si-Cu-Mn alloys as studied by Yuan et., al. (2019) and Zhang et., al. (2014), respectively [5,17]. The depth of dimples is proportional to the plastic deformation of the alloy. The fracture surface of alloy P (Fig. 4a) revealed shallower dimples compared to alloy Q. From high micrograph magnification (Fig. 4b), more small particles were seen at the bottom of the dimple (indicated by arrow). This can be explained that during the deformation process, the small particles have been separated from the matrix and generate micro-voids in the alloy [17]. These small particles were believed to be α/β-AlFeSi and Mg_2Si which were intermetallic compounds and aging precipitates that formed during homogenization process and after aging treatment [10]. The presence of Mg_2Si precipitates in the alloy enhanced the hardness and strength, thus the mechanical properties of the alloy was improved [1, 10]

Comparing to alloy P, the fractured surface morphology of alloy Q (Fig.5) shows more ductile fracture mode due to deeper dimples covering the fracture surface. Small particles were hardly found within the dimples. Higher elongation properties were observed in alloy Q (Fig. 3b) due to fewer particles present in the alloy resulting in higher plastic deformation.



(a) (b)

Figure 4: SEM fracture surface micrographs of alloy P at (a) low and (b) high magnification



(c) (d)

Figure 5: SEM fracture surface micrographs of alloy Q at (a) low and (b) high magnification

Conclusion

The effects of Mg and Si compositions on aging response of two Al-Mg-Si alloys have been examined using mechanical testing and FESEM analysis. Based on the overall results, it can be concluded that Mg and Si composition affects the aging response and the mechanical properties of the alloys. It was found that the alloy containing a higher composition of Mg and Si possessed a stronger aging response and higher mechanical properties. From the FESEM analysis, the higher compositions of Mg and Si exhibited a less ductile behavior and this is consistent with the lower elongation properties.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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