[AMT06] Effect of natural aging prior to heat treatment on tensile property of Al-1.2Si-0.5Mg-0.25Fe sheet alloy

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Introduction

Good formability, good corrosion resistance and reasonably good strength of the 6XXX series aluminum alloys have made them a good candidate for automotive body applications. In Europe, the high formability of Al alloy, AA6016 has made it the main automotive skin alloy, while in North America, AA6111 is a preferred alloy because of its good final strength and good dent resistance (Burger *et al*., 1995).

A solution heat-treatment followed by natural aging that is commonly termed as T4 temper is carried out on 6XXX series aluminium alloys because they are unstable at room temperature and display a variation in mechanical properties over an indefinite period of time (ASM 1993). It is also to promote age hardening response (Burger *et al*. 1995; Hirth *et al*., 2001). Recrystallization occurs during the solution heat-treatment, thus resulting in microstructural changes that significantly influence the mechanical properties of the alloy sheets (Burger *et al*. ,1995).

Heat-treatable alloys achieve an additional strength during the paint-bake treatment of the final automotive construction. They have low T4 yield strengths and exhibit excellent formability. An increase in strength, typically around 180MPa is achieved after the paint-bake (Burger *et al*., 1995). Thus, they have a combined good formability of the T4 temper with a better service strength of the age-hardened state (Engler and Hirsch 2002). It is reported that the increase in yield strength is due to grain refinement (Burger *et al*., 1995). This is agreeable to the Hall-Petch relationship that relates the yield stress, σ_y to the grain size, d, through the expression

$$\sigma_y = \sigma_o + k_y d^{-1/2} \quad (1)$$

where σ_o is the friction stress and k_y is a positive constant of yielding associated with the stress required to extend dislocation activity into adjacent unyielded grains. It serves to demonstrate that yield stress increases as the grain size is decreased (Furukawa *et al*., 1996).

The aim of this work is to study the influence of natural aging time on the tensile strength of Al-1.2Si-0.5Mg-0.25Fe sheet alloy. This work is also to determine whether a shorter natural aging time can be tolerated.

Materials and methods

High purity materials i.e. aluminium, silicon, magnesium and iron were used to prepare aluminium alloy of composition Al-1.2Si-0.5Mg-0.25Fe by conventional casting. Melting was carried out at 850 °C under argon atmosphere using graphite crucible and cast in a steel mould to produce 5mm-thick plate. The plates were homogenized at 550 °C for 24 hours, then followed by hot rolling and cold rolling to a final thickness of 1mm. Specimens were cut according to ASTM E-8M standards (ASTM 1992) for tensile test. The specimens were solution heat-treated at 540 °C for 30 minutes and air-quenched to room temperature followed by natural aging from 2 to 28 days (T4 temper). Upon completing the required T4 temper, some of the specimens were heat-treated at 180 °C for 30 minutes to simulate the paint-bake condition in automotive industries and others were heat-treated at 180 °C for 11 hours (the peak strength condition) to achieve peak strength. Tensile specimens were then tested at room temperature on a computerized 2.5 tons capacity Instron 5567 universal testing machine. The tensile test was carried out Natural aging of 14 and 28 days followed by heat-treatment at 180 °C for 30 minutes gave ultimate tensile strength values of 172 MPa and 177 MPa respectively (FIGURE 1). It is using uniaxial tensile stress with a speed of 1 mm/min. For microstructural study, the specimens were etched in Keller's reagent and observed under Carl Zeiss Axiotech 100 HD optical microscope. Grain size numbers were determined according to ASTM standard (ASTM 1992) by means of an image analyzer system, Carl Zeiss KS300.

Results and discussion

FIGURE 1 shows the relationship between the ultimate tensile strength of the solution heat-treated sheet formed specimens of Al-1.2Si-0.5Mg-0.25Fe alloy and the natural aging time for both the automotive paint-bake (180 ^{o}C, 30 minutes heat-treatment) and the peak-strength (180 ^{o}C, 11 hours heat-treatment) conditions. The ultimate tensile strength of the Al-1.2Si-0.5Mg-0.25Fe alloy heat-treated at 180 °C for 30 minutes without natural aging was 136 MPa. This is very much lower than the typical ultimate tensile strength for the 6XXX series alloy that is about 180 MPa. This low strength is expected as there was no natural aging involved.

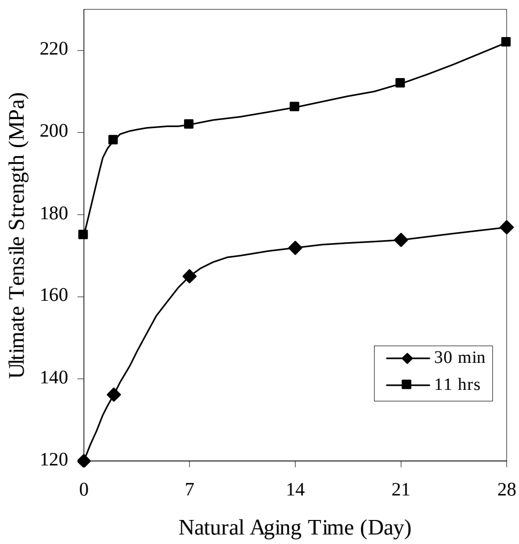


FIGURE 1 Changes in ultimate tensile strength for Al-1.2Si-0.5Mg-0.25Fe sheet alloy for various natural aging times followed by i) heat treatment at 180^{o}C for 30 minutes (automotive paint-bake condition) and ii) heat treatment at 180^{o}C for 11hours (peak strength condition)

noted that there is only a slight increase in the tensile strength for natural aging times longer than 14 days. The small increase in ultimate tensile strength for increasing natural aging time is believed to be attributed to the presence of coherent Guinner-Preston zones in the matrix, which becomes ordered as aging proceeds (Burger *et al.*, 1995). A similar pattern of the increase in ultimate tensile strength can be observed for the alloy which was heat-treated at 180°C for 11 hours to achieve peak strength. For this condition, the alloy without natural aging yielded ultimate tensile strength of 175 MPa while the ultimate tensile strength of 222 MPa was achieved for that naturally aged for 28 days (FIGURE 1). The yield strength of the specimens also followed a similar trend as the ultimate tensile strength (FIGURE 2).

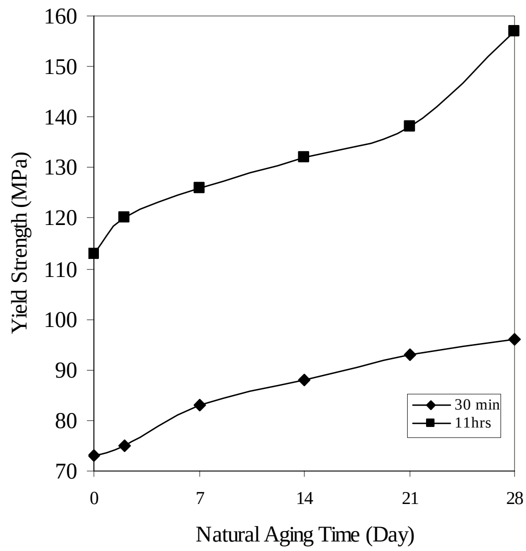
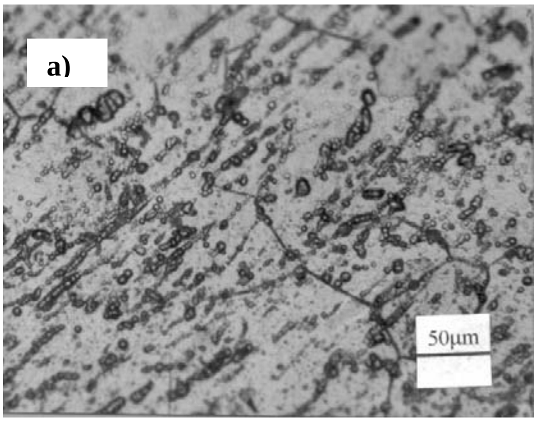
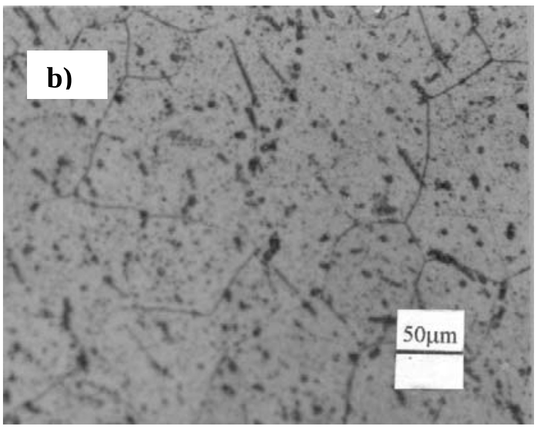


FIGURE 2 Changes in yield strength of Al-1.2Si-0.5Mg-0.25Fe sheet alloy for various natural aging times followed by i) heat treatment at 180 ^{o}C for 30 minutes (automotive paint-bake condition) and ii) heat treatment at 180^{o}C for 11hours (peak strength condition)

FIGURE 3 shows the microstructures of non-naturally aged and naturally aged alloys under the automotive paint- bake condition. It is confirmed that the naturally aged alloy has finer grains compared to non-naturally aged alloy. However, there is only a small increase in grain size of the alloys after naturally aged for 28 days compared with 14 days natural aging. This observation agrees well with the data shown in FIGURE 4 where the ASTM grain size numbers are almost unchanged after natural aging time of longer than 14 days. Larger ASTM grain size numbers indicate smaller grains and larger grain boundary area per unit volume of metal.

FIGURE 4 also shows that grain sizes decrease with natural aging time particularly for natural aging time of less than 14 days. This result supports the data in FIGURE 2 since according to Hall-Petch relationship shown by equation (1), the smaller grains yield a higher yield stress. Hence the differences in ultimate tensile strength values for different aging times are attributed to grain refinement as aging proceeds.





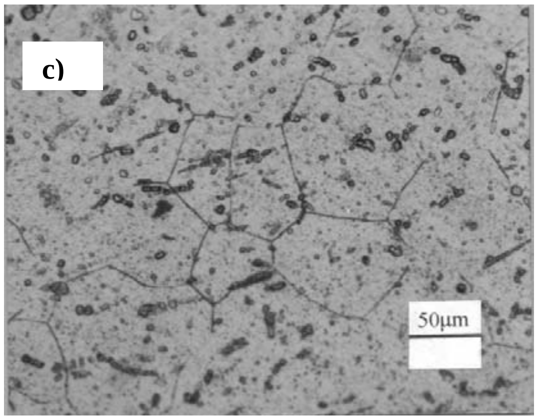


FIGURE 3 Microstructure of Al-1.2Si-0.5Mg-0.25Fe sheet alloy a) without natural aging, b) 14 days of natural aging and c) 28 days of natural aging. All alloys were heat-treated at 180°C for 30 minutes (automotive paint-bake condition).

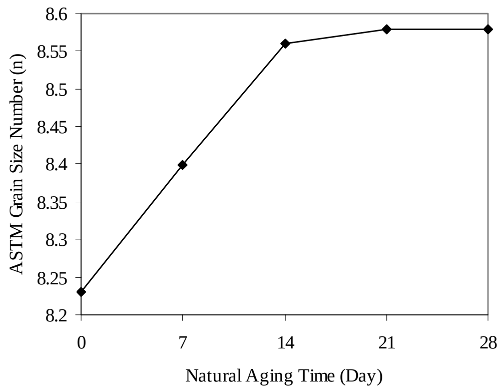


FIGURE 4 Variation of grain size number of Al-1.2Si-0.5Mg-0.25Fe sheet alloy with natural aging time. All samples were heat-treated at 180°C for 30 minutes (automotive paint-bake condition)

Conclusions

Tensile properties of Al-1.2Si-0.5Mg-0.25Fe sheet alloy increased with natural aging time for alloy heat-treated under the paint-bake and the peak strength conditions. The tensile strength of the alloy shows little increase after 14 days of natural aging, indicating that the alloy is in a substantially stable condition after 14 days of natural aging. The increase in tensile strength with increasing natural aging time is due to grain refinement as aging proceeds. As there are no significant changes in the tensile strength after natural aging of more than 14 days, this implies that a natural aging time of 14 days for Al-1.2Si-0.5Mg-0.25Fe sheet alloy is sufficient with respect to mechanical property as well as economical aspect.

Acknowledgements

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