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The Effects Of Ageing Temperature On Tensile Properties And Fracture Behavior Of Al-6Si-0.5Mg Alloy Fabricated By Casting And Treated By T6 Heat Treatment

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Abstract: An Aluminum based in-situ alloy reinforced with Mg_2Si and Si hard particles produced by casting Al-6Si-0.5Mg alloy. The microstructure, tensile properties and fracture behavior of the alloy were investigated and the results show that the Mg_2Si and Si hard particles produced by precipitation hardening have great effects. The homogenized (24hr at 500^{o}C) and solutionized (2hr at 540^{o}C) cast alloy was subjected to ageing treatment from room temperature to 300^{o}C. The yield strength and fracture strength of the alloy increase with the increase of ageing temperature where as ductility and impact toughness decreases up to peakaged condition (1hr at 225^{o}C). The microstructure of broken tensile specimen shows both the particle fracture and interface de-bonding affect the fracture behavior of the alloy.

Keywords : Tensile properties, Fracture behavior, Precipitation hardening, Microvoid coalescence

1 INTRODUCTION

Age hardened Al-alloys are widely used in engineering applications due to the considerable improvements in their yield strength and hardness by controlled thermo mechanical treatments. Micro mechanisms governing fracture characteristics of such alloys depend on coherency and distribution of precipitates, grain size and shape, grain boundary precipitates, presence of other second phase particles which result from impurities. The unstable fast fracture, even if it is ductile, becomes frequent because the strengthening lowers the level of toughness, and this becomes a problem with large scale structures. Since the fracture of many engineering components is promoted under dynamic conditions, there is a need to understand the fracture behaviour of materials under dynamic loads. Moreover, fracture characteristics under the impact load seem to become important, because the application to transportation vehicles will increase [1]. Al-Mg-Si alloys have been widely used in transportation systems owing to their fair strength, weldability and corrosion resistance. The castings are usually heat treated to obtain the desired combination of strength and ductility. The most common is the T6 heat treatment, which consist of a solution heat treatment, water quench, natural and artificial ageing. A solutionizing treatment in the range 400-560^{o}C dissolve hardening agents in the Al matrix, homogenizes the casting, and modifies the morphology of the eutectic silicon. Castings are quenched from the solution treatment temperature to suppress the formation of intermetallic phases, retain alloying elements in solution to form a supersaturated solid solution and limit their diffusion to grain boundaries, undissolved particles or other defect locations. [2]. Al-Mg-Si alloys have been widely used in transportation systems owing to their fair strength, weldability and corrosion resistance. The precipitation sequence of solution-treated Al-Mg-Si ternary alloys during artificial aging can be reported to be: α supersaturated solid solution (SSS) → GP-I zones → metastable needle-like β″ precipitates (or called GP-II zones; formed through the transformation of GP-I as nuclei) → metastable rod-like (or lath-like) β′ precipitates → stable β phase [3]. For Al–Si–Mg alloy, a heat treatment (T6) consisting of solution treatment, quenching and ageing is often used to increase the strength by precipitating nanometer particles, which provide excellent obstacles for the dislocation movement [4-7]. For Al–Si–Mg alloys, the age hardening is caused by the precipitation of β" and/or β' phases (precursor of Mg_2Si phases) [8, 9]. Heat treatment is a commonly used technique to enhance the mechanical properties of Al-Si-Mg alloy. The objective of this research work was to study the influence of ageing temperature on the microstructure, tensile properties and fracture behavior of Al-6Si-0.5Mg alloy by age hardening.

2. EXPERIMENTAL PROCEDURE

The Al-6Si-0.5Mg alloy was prepared in a natural gas heating clay-graphite crucible furnace. In the process of preparation of the alloy, the aluminium and aluminium-silicon binary alloy melted into the clay-graphite crucible, and then magnesium ribbon (99.7% purity) was added into solution. The final temperature of the melt was always maintained at 900±15^{o}C with the help of the electronic controller. The melt was degassing with solid hexachloroethane (C_2Cl_6) and homogenized by stirring at 680^{o}C before casting. Casting was done in iron metal mould preheated to 200^{o}C. Mould sizes were 15mm x 150mm x 300mm. The alloy was analysed by wet chemical and spectrochemical methods simultaneously. The composition of the sample is shown in Table 1. The cast sample was first ground properly to remove the oxide layer from the surface. The alloy was homogenized at 500^{o}C for 24 hours. The tensile and impact specimens were prepared from the homogenized alloy according to the ASTM standard of aluminum alloy. The homogenized tensile and impact samples were solution treated at 540^{o}C for 2 hours and quenched into salt iced water solution. The solutionized samples were aged isochronally for 1 hour at different temperatures up to 300^{o}C. Tensile testing was carried out in an Instron testing machine at strain rates of 10-3/s. The averages of three consistent test results were accepted as the tensile test values for the corresponding

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sample. The Charpy test sample has 10mm x 10mm x 55 mm dimensions, a 45°V notch of 2 mm depth and a 0.25 mm root radius was hit by a pendulum at the opposite end of the notch. The pendulum was set at a certain height was released and stuck the specimen at the opposite end of the notch to produce a fractured sample. The absorbed energy required to produce two fresh fracture surfaces were recorded in the unit of Joule. Scanning Electron Micrograph of selected tensile fracture samples were observed in a Scanning Electron Microscope.

TABLE1. THE CHEMICAL COMPOSITIONS OF THE ALLOYS

Alloy	%Si	%Mg	%Fe	%Al
Al-6Si-0.5Mg	5.80	0.44	0.15	Bal

3 RESULTS AND DISCUSSION

Fig.1 illustrates the influence of ageing temperature on the yield strength (0.2% proof strength) of Al-6Si-0.5Mg alloy. The graph indicates that the yield strength increases with increase of ageing temperature up to the peakaged (1hr at 225°C) condition. With increase of ageing temperature, more intermetallic reinforcement particles are in stable form. The yield strength increases after solution treatment. The intermetallic particles could contribute as a reinforcement effect in the Al –alloy matrix. The higher yield strength is due to the effect of precipitation hardening.

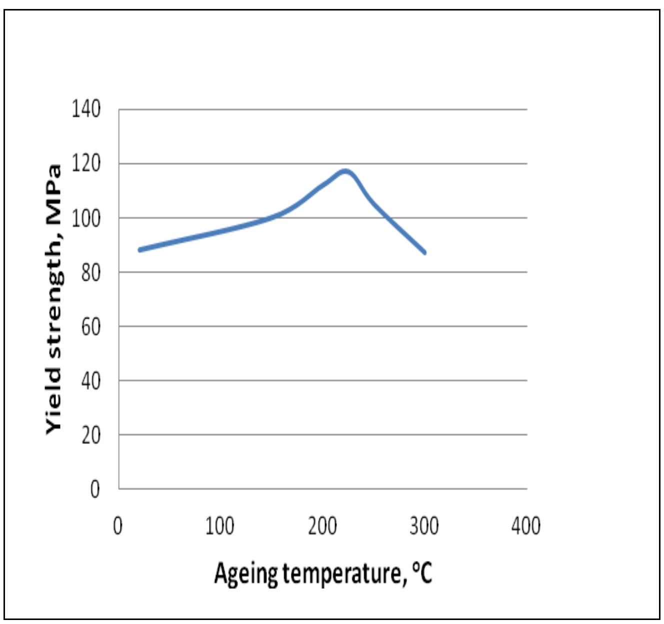

Fig.1. Variation of the yield strength with the ageing temperature of the alloy.

The ultimate tensile strength (fracture strength) (Fig.2) follows the same trend as the yield strength of Al-6Si-0.5Mg metal alloy. There is an increase of fracture strength of Al-6Si-0.5Mg metal alloy with increase of ageing temperature. At peak aged condition Al-6Si-0.5Mg metal alloy has higher fracture strength over the solution treated condition. After peakaged condition achieved, if ageing is continuing, both the yield and fracture strength decrease with ageing temperature (at overageing).

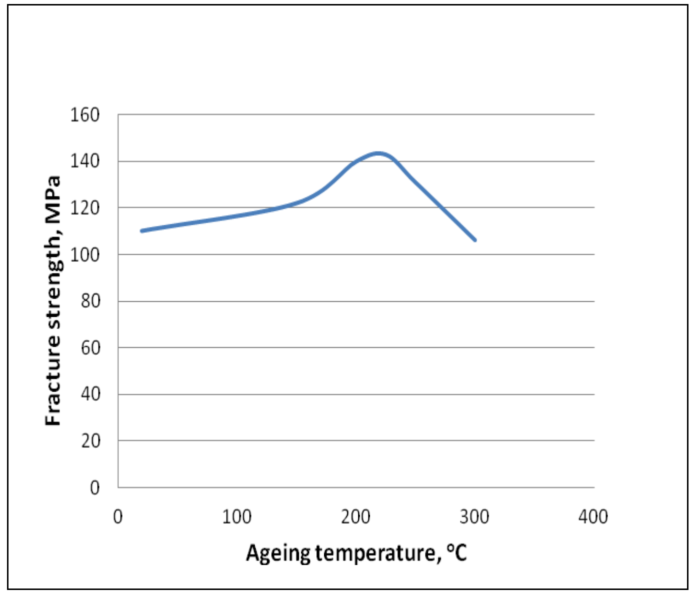

Fig.2. Variation of the fracture strength with the ageing temperature of the alloy

The influence of ageing temperature on the ductility (% elongation) is shown in fig. 3.The ductility decrease with increase of ageing temperature for the alloy. The decrease in the ductility is 30.77 % at peakaged condition of the Al-6Si-0.5Mg alloy over the solution treated condition.

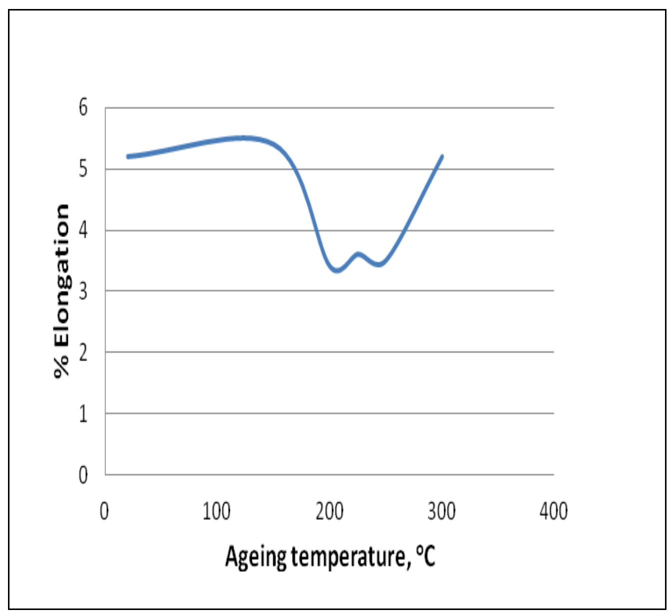

Fig.3. Variation of the ductility (% elongation) with the ageing temperature of the alloy

Fig. 4 shows the absorbed energy as a function of the artificial ageing temperature. Heat treatment especially solution treatment and ageing temperature influenced the capacity of absorbed energy. At solution treated condition, the alloy has shown higher toughness than the peakaged (1hr at 225°C) condition. The ageing temperature increases

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from room temperature to 225°C, the absorbed energy decreases for the alloy. The absorbed energy decreased a maximum due to the precipitation of intermetallic phases at peakaged condition. Further ageing from 250 to 300°C the absorbed energy increases due to overageing. The alloy with the lowest impact fracture toughness and ductility correspond to the highest value of yield and fracture strength.

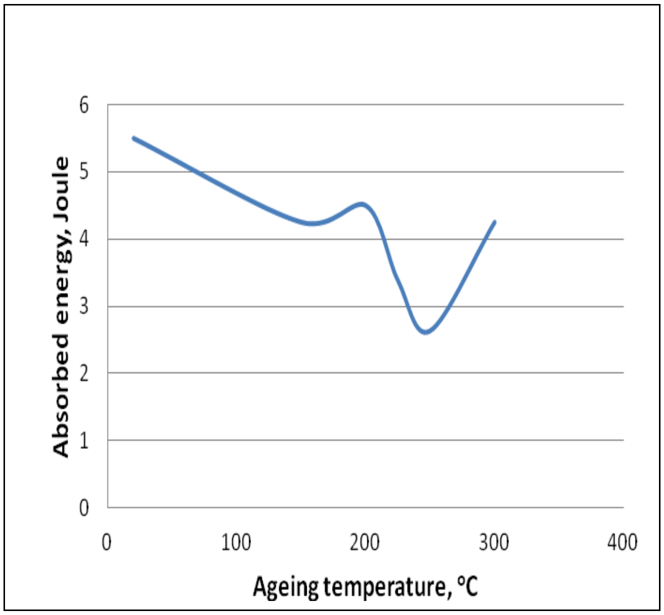

Fig. 4. Variation of the impact energy with the ageing temperature of the alloy

Fig. 5 shows the fracture surface of Al-6Si-0.5Mg alloy at solution treated condition.The fracture surface appear to be rough and normal to axis of loading.On a microscopic scale, the fracture surface appear to contain many microvoids in the matrix. The void coalescence occurrs when the voids elongates to the initial intervoid spacing.This leads to the dimpled appearance of the fracture surfaces. Brittle fracture of the alloy indicates that void growth and coalescence occurred rapidly. Fig.6 shows the ductile or mixed (ductile+ brittle) fracture for the Al-6Si-0.5Mg alloy at peakaged condition. The dimples are neither uniform nor circular in shape. The matrix-intermetallic particles decohesion is also observed for this alloy.The fracture mechanism is ductile, involving the nucleation, growth, and coalescence of voids in the matrix around the intermetallic particles. The voids grow under both the applied load and the influence of local plastic constrain until a coalescence mechanism is activated, and this followed by the total failure of the alloy.

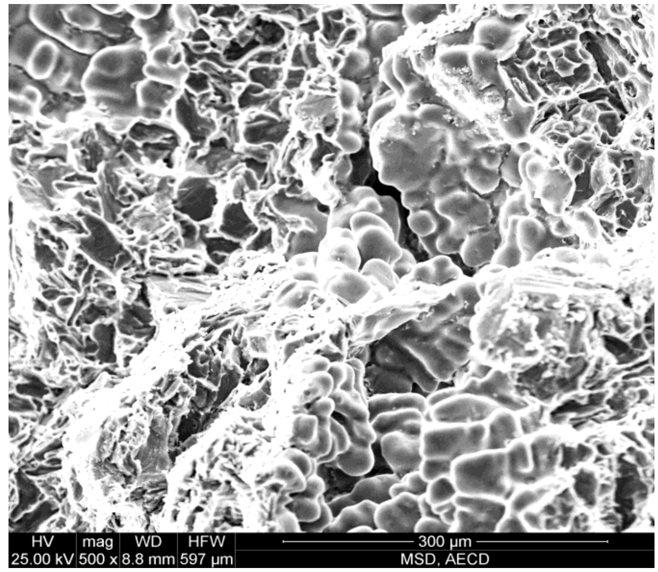

Fig.5. SEM tensile fracture surface of Al-6Si-0.5Mg alloy at solution treated condition.

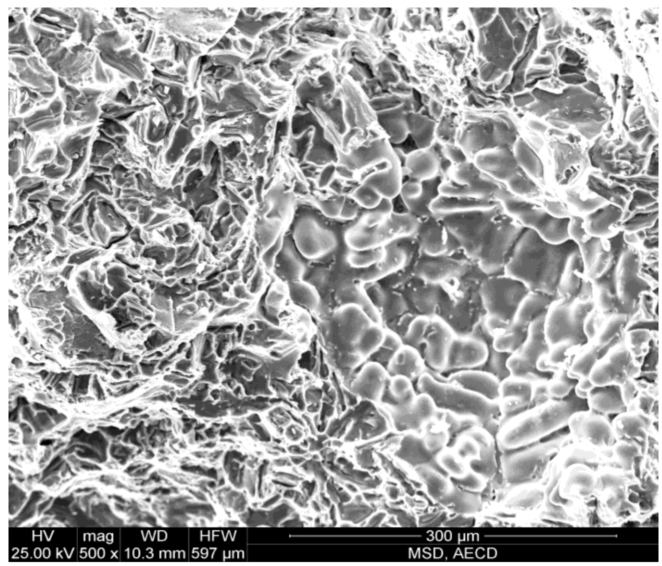

Fig. 6. SEM tensile fracture surface of Al-6Si-0.5Mg alloy at peak aged condition.

Conclusions

The tensile properties of Al-6Si-0.5Mg metal alloy at peakaged condition (1hr at 225°C) were improved due to the presence of stable intermetallic particles and fine grain structure. The yield strength and fracture strength increases with increase of ageing temperature up to peakaged condition where as ductility and impact absorbed energy of the alloy decrease.

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