# STUDIES ON THE EFFECT OF ARTIFICIAL AGEING HARDNESS ON TENSILE PROPERTIES AND IMPACT STRENGTH OF AL-6SI-0.5MG-2NI ALLOY

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***ABSTRACT:***The effect of different scheduled artificial ageing hardness on the tensile and impact properties of Al-6Si-0.5Mg-2Ni alloy was studied. The solution treated Al-6Si-0.5Mg-2Ni alloy was aged isochronally for 1 hour at temperatures up to 300$^{o}$C. The precipitation stages during ageing were monitored by hardness measurements. Tensile and impact properties were determined by standard tests. During artificial ageing, the yield and ultimate tensile strength were found to increase with ageing hardness; the maximum being attained at peak hardness. Ductility and impact toughness of the alloy, on the other hand decreased with ageing hardness, reaching the minimum at the highest hardness. The strength of Al-6Si-0.5Mg-2Ni alloy was best at highest hardness but exhibits poor ductility and impact strength.

***ABSTRAK:***Kajian dijalankan bagi menyelidik kesan penjadualan yang berbeza terhadap kekerasan penuaan buatan ke atas sifat tegangan dan impak aloi Al-6Si-0.5Mg-2Ni. Larutan melalui tempoh yang penuaan sama digunakan bagi merawat aloi Al-6Si-0.5Mg-2Ni selama 1 jam pada suhu sehingga 300$^{o}$C.Peringkat pemendakan sepanjang tempoh penuaan dipantau dengan ukuran kekerasan. Sifat tegangan dan impak ditentukan berdasarkan ujian piawai. Sepanjang tempoh penuaan buatan, hasil kekuatan tegangan dan kekuatan tegangan muktamad didapati bertambah dengan kekerasan penuaan; di mana ia paling maksima ketika ia berada di puncak kekerasannya. Kemuluran dan impak ketahanan aloi, sebaliknya berkurangan dengan kekerasan penuaan, di mana ia berada pada tahap minima ketika ia paling keras. Kekuatan aloi Al-6Si-0.5Mg-2Ni berada pada tahap terbaik pada kekerasan paling tinggi tetapi kemuluran dan impak kekuatannya kekal lemah.

***KEYWORDS:*** *Al-6Si-0.5Mg-2Ni alloy; ageing; hardness; tensile properties; impact strength*

## 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 [1]. Al-Si based multi-component foundry alloys provide several advantageous characteristics such as good castability, high corrosion and wear resistance, as well as high thermal conductivity and adequate strength at elevated temperatures [2]. For Al–Si–Mg alloys, age hardening is caused by the precipitation of β" and/or β' phases (precursor of $Mg_2Si$ phases) [3, 4]. 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 [2]. The use of Al-Si-Mg alloys, in particular for the automotive industry, is attractive due to its lightweight and reasonable strength after ageing treatment [6]. The accelerated need for weight reduction, however, leads to higher mechanical and thermal loading of these aluminum castings in future vehicles, requiring improved Al-Si foundry alloys concerning strength at elevated temperatures [1-3, 5].

When a heat-treatable A356 aluminum alloy undergoes precipitation hardening (age-hardening), fine precipitants will dissolve completely in a saturated matrix to achieve high strength in the material [6]. When the supersaturated solid solution undergoes aging treatment; a large amount of small and uniformly distributed precipitants will appear thus the mechanical properties of the material can be improved. Uniform and delicate $Mg_2Si$ precipitants can be obtained in the matrix of a heat-treatable Al-Si-Mg casting part with T6 treatment (involves solution treatment, quenching and artificial aging), leading to improvements in its tensile strength, elongation and toughness [3, 7].

For the development of new Al-Si-Mg-Ni foundry alloy with superior elevated-temperature strength a detailed physical understanding of the role of each particular alloying element concerning its ability to improve the high-temperature properties is required. In the past Ni was identified to significantly enhance the high-temperature performance of Al-Si foundry alloys, though just to a certain level, depending on the fraction of eutectic phase in the alloy. Ni stabilizes the contiguity of the eutectic network by increasing the volume fraction of rigid phases(Si + $Al_3Ni$) in the eutectic [8-10].

Heat treatment (HT) is a commonly used technique to enhance the mechanical properties of the respective alloys, such as strength (HT: T6) or ductility (HT: T4, T7). However, during a solution treatment the eutectic Si spheroidizes and its aspect ratio decreases, which results in a loss of the contiguity of the eutectic platelets [8, 11].

The aim of this paper is to evaluate the effects of ageing hardness on the tensile properties and Charpy impact strength of Al-6Si-0.5Mg-2Ni alloy with applications in automotive engineering.

## 2. MATERIALS AND METHODS

### 2.1 Materials

Aluminum A356 alloy, contained in a clay-graphite crucible, was melted in a gas-fired pot furnace. Nickel, in the form of chips, was initially charged into the bottom of the crucible. Magnesium (99.7% purity) in the form of ribbon and packed in an Al-foil was added to the melt. The final temperature of the melt was maintained at 900±15$^{o}$C. Before casting, the melt was degassed with solid hexachloroethane ($C_2H_6$) and homogenized by stirring at 700$^{o}$C. Casting was done in a metal mould measuring 15mm x 150mm x 300mm and preheated to 200$^{o}$C. The alloy wasanalyzed by wet chemical and spectrochemical methods simultaneously.

### 2.2 Heat Treatment

The cast samples were ground to remove the oxide layer from the surface and were homogenised for 24 hr at 500$^o$C. Samples for hardness, tension and Charpy impact tests were prepared from the homogenised plates according to an ASTM standard. Then the test samples were solution treated at 540$^o$C for 120 min and quenched in ice-salt-water solution. The solutionized samples were isochronally aged upto 400$^o$C for 1 hr to find out the proper precipitation hardening behaviour of the alloy. The tensile and Charpy impact samples were isochronally aged upto 300$^o$C for 1hr.

### 2.3 Tests

The hardness tests were carried out in a Rockwell hardness testing machine in F scale. The averages of seven consistent test results were accepted as the hardness test values for the corresponding samples. Tensile testing was carried out in an Instron testing machine at a strain rate of $10^{-3}s^{-1}$ for the alloy and the impact tests were carried out in a Charpy impact machine. The averages of three consistent test results were accepted as the tensile and impact value for the corresponding sample.

## 3. RESULTS AND DISCUSSION

### 3.1 Effect of Thermal Ageing Treatment on Hardness

The hardness values of the aged Al-6Si-0.5Mg-2Ni alloy increased with ageing temperatures up to 225$^o$C (92.6 HRF).Its hardness was observed to decrease sharply for temperatures in the range of 225-400$^o$C. This shows that the Al-Si-Mg alloy has a peak ageing temperature of 225$^o$C (Figure 1). The reasons for this may be due to the fact that a decrease in the hardness is associated with an increase in the inter-particle spacing between precipitates, which makes dislocation bowing much easier. The increase in hardness beyond an underaged condition is more pronounced with the increase of ageing temperature and the hardness decreased significantly beyond ageing of 250$^o$C.

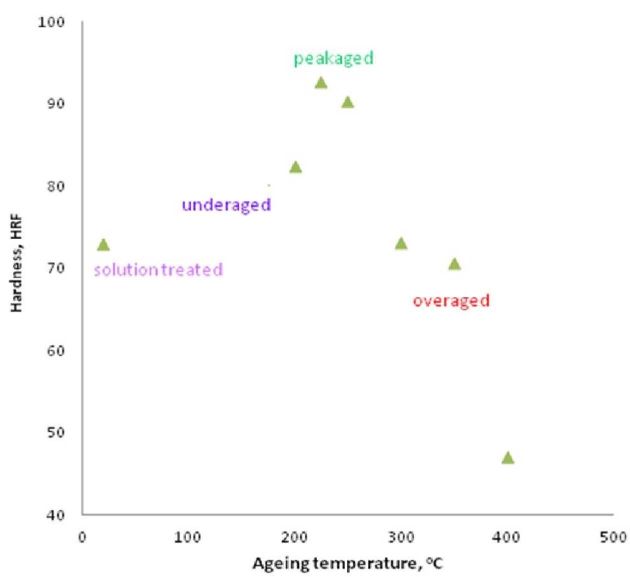


Fig. 1 Variation of hardness of Al-6Si-0.5Mg-2Ni alloy at different ageing temperatures.

### 3.2 Effect of Thermal Ageing Hardness on Ultimate Tensile Strength

Figure 2 shows the ultimate tensile strength of the Al-6Si-0.5Mg-2Ni alloy at different thermal ageing hardness. The hardness is the results of solutionizing, underageing, peakageing and overageing operations. The plot of the ultimate tensile strength against the thermal ageing hardness reveals a significant improvement of the strength at peakaged condition. Both tensile and yield strength show similar trends as can be clearly seen in Figure 2 and Figure3. The high ageing temperature (overaged) performance of Al-6Si-0.5Mg-2Ni alloy seems to be considerably reduced when exposed to over ageing thermal treatment.

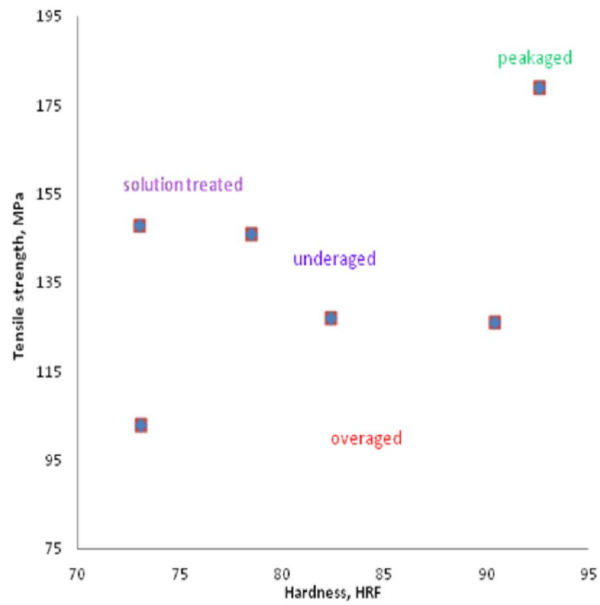


Fig. 2 Ultimate tensile strength as a function of ageing hardness of Al-6Si-0.5Mg-2Ni alloy.

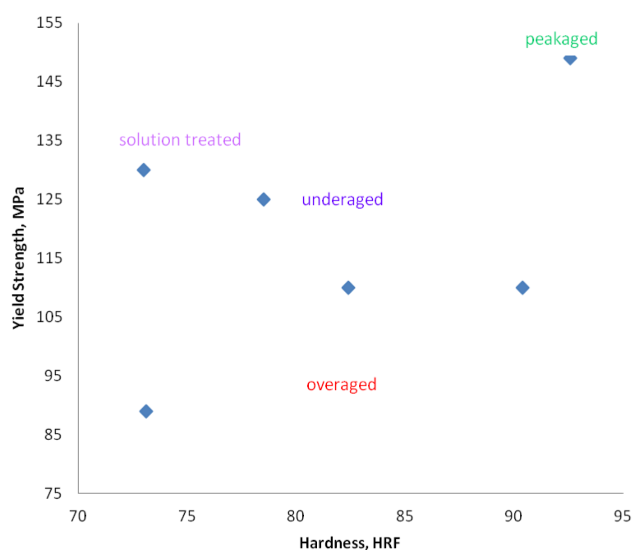


Fig. 3 Yield strength as a function of thermal ageing hardness of the Al-6Si-0.5Mg-2Ni alloy.

### 3.3 Effect of Thermal Ageing Hardness on Yield Strength

Figure 3 illustrates the influence of thermal ageing treatment on the yield strength of Al-6Si-0.5Mg-2Ni alloy depending on their ageing hardness. Obviously, in this case overageing treatment has a negative effect on yield strength. Although a linear increase of strength with increasing thermal ageing hardness is observed from underaged to peakaged condition. The yield strength of the overageing treated alloy starts at a significantly lower value and approaches the as-quenched alloy with decreasing ageing hardness(due to overage treatment).

### 3.4 Effect of Thermal Ageing Hardness on Ductility

The effect of ageing hardness on ductility of Al-6Si-0.5Mg-2Ni alloy is shown in Fig. 4.The ductility of solutionized Al-Si-Mg-Ni alloy was maximum but its hardness was found to be lower. The alloy shows maximum strength at peak hardness but maintain poor ductility. Beyond the peak ageing i.e. at overaged condition the ductility increases with hardness decreases for the alloy.

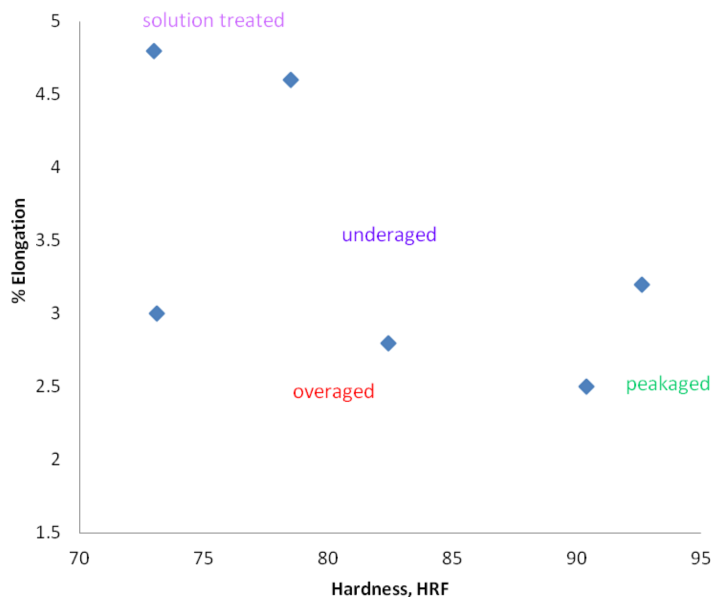


Fig. 4 Ductility as a function of thermal ageing hardness of the Al-6Si-0.5Mg-2Ni alloy.

### 3.5 Effect of Thermal Ageing Hardness on Impact Strength

Figure 5 shows the Charpy impact strength (absorbed energy) during fracture as a function of thermal treated hardness. Heat treatment, especially solution treatment and ageing (under, peak and over ageing), significantly influenced the capacity of impact strength. In the as-quenched condition, the alloy has lower hardness and lower impact strength. The capacity of impact strength was found to be lower at underaged hardness. The decrease in absorbed energy is due to brittleness caused by precipitation of intermediate phases. The maximum decrease in absorbed energy was observed in the peakaged hardness. The impact energy increases significantly from peakaged to overaged hardness due to microstructure softening at overageing

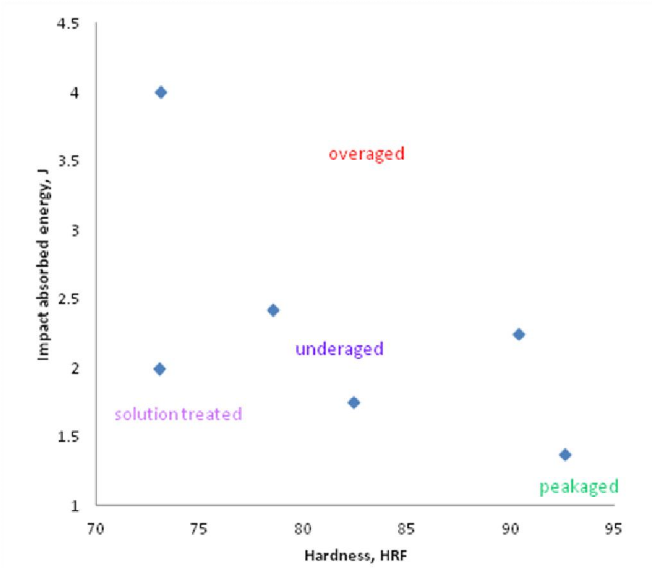


Fig. 5 Impact strength as a function of Rockwell hardness of the Al-6Si-0.5Mg-2Ni alloy in the solution treated, underaged, peakaged and over aged conditions.

## 4. CONCLUSION

The tensile and impact strength of Al-6Si-0.5Mg-2Ni heat treated alloy as a function of ageing hardness was reported. The Al-Si-Mg-Ni alloy showed improved strength at higher ageing hardness in the peakaged condition but maintain poor ductility. Maximum hardness and tensile strength was found for the cases when ageing the alloy at ~225$^{o}$C for 1 hr. Overageing reduced the hardness and tensile strength but maintained improve impact strength.

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