

Effect of Artificial Aging Temperature on Mechanical Properties of 6061 Aluminum Alloy

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ABSTRACT

Aluminum alloys have been attracted by several engineering sectors due to their excellent strength-weight ratio and corrosion resistant properties. These are categorized into 1, 2, 3, 4, 5, 6, 7 and 8xxx on the basis of alloying elements. Among these 6xxx series contains aluminum–magnesium–silicon as alloying elements and are widely used in extruded products and automotive body panels. The major advantages of these alloys are good corrosion resistance, medium strength, low cost, age hardening response no yield point phenomenon and Ludering. 6xxx series alloys generally have lower formability than other aluminum alloys which restrict their utilization for wide applications. Keeping in view of the shortcomings in the set of mechanical properties of 6xxx series the efforts were made to improve the tensile strength and toughness properties through age hardening. In present study heat treatment cycles were studied for 6061 aluminum alloy. Three different age hardening temperatures 160, 200 and 240°C were selected. The obtained results showed that 17.26, 7.69, and 10.51% improvement in tensile strength, toughness and hardness respectively was achieved with solution treatment at 380°C followed by an aging 240°C. Microstructural study revealed that substantial improvements in the mechanical properties of 6061 aluminum alloy under heat treatment were achieved due to precipitation of Mg₂Si secondary phase.

Key Words: Aluminum Alloy 6061, Solution Treatment, Age Hardening, Microstructure, Mechanical Properties.

1. INTRODUCTION

Aluminum is very light and soft metal in periodic table. Due to light weight it is highly attracted by modern manufacturing technologies. Its mechanical properties can be enhanced through alloying. Aluminum alloys have been greatly appreciated and consumed by several engineering sectors including; aircrafts, automotive, buildings and marine etc due to their excellency in strength-weight ratio and corrosion resistant

properties [1-2]. Table 1 shows the capability of aluminum to be alloyed with different metals and nonmetals. Depending on the type of alloying elements, aluminum can be utilized by various sectors. It is reported that worldwide 90% pipes and tubes are manufactured from 6xxx aluminum alloy. This type of aluminum alloy contains Si and Mg as a major alloying element. 6xxx aluminum alloys are heat treatable.

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Literature pertaining to 6061 aluminum alloy, hereinafter referred to as 6061-AA, reveals that heat treatments efforts are ongoing to improve the tensile strength in order to make it more efficient and reliable [3-4]. Many others have noted the challenges to improve the strength without compromising on its toughness value through age hardening treatment.

Age hardening of aluminum alloys include two major steps; solution treatment and artificial aging. Solution treatment involves heating of materials above its critical temperatures, soaking for a particular time and rapid quenching. Quenching is carried out to trap the dissolved constituents in solid solution [4-5]. Whereas, artificial aging means re-heating of the solution treated samples in the range of 175-420°C for various time periods in order to precipitate the secondary phase [6]. Previous research revealed that the selection of appropriate temperature and time in artificial aging is the critical step. Substantial improvement in the mechanical properties of the 6xxx series aluminum alloy has been observed by most of the researchers after aging in the range of 180-260°C. The sole reason behind the dramatic change in the properties

is the formation of secondary stable phases. From previous work, it is noted that the formation of Mg₂Si (stable β phase) involves transformation of many metastable phases both coherent and semi-coherent when 6xxx aluminum alloys are artificially age-hardened in the range of 180 and 260°C [7-10].

Although much efforts have been paid to improve tensile and hardness properties through age hardening, however little work is reported to evaluate the effect of secondary micro phases on the toughness and bending property. Due to diverse applicability it is important to design such heat treatment cycle through which it could be possible to improve mechanical properties. Efforts were made to optimize the aging temperature to obtain set of better strength and higher toughness values of 6061-AA.

2. MATERIALS AND METHOD

Aluminum alloy (6061) was purchased from the local market (Karachi). Chemical composition of the aluminum alloy was determined by using optical emission spark spectrometer (Model: Bruker Q2-ION). The obtained average composition of 6061-AA is given in Table 2, which indicates that Mg and Si are the major alloying elements. Before heat treatment, standard specimens of tensile, toughness and bend tests were prepared by performing machining operation as per sample specifications as shown in Fig. 1. Afterward, the samples were heat treated (solution treatment and age hardening) in a muffle furnace, as per designed heat treatment cycles of Fig. 2. Later on tests were performed in order to evaluate mechanical properties.

TABLE 1. ALUMINUM ALLOY SERIES AND THEIR ALLOYING ELEMENTS

Alloy Series	Principal Alloying Element
1xxx	Pure Aluminum
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium and Silicon
7xxx	Zinc
8xxx	Other Element

TABLE 2. CHEMICAL COMPOSITION OF 6061-AA

Elements	Si	Cr	Cu	Fe	Mg	Mn	Ti	Zn	Al
Percentage	0.54	0.38	0.005	0.64	1	0.39	0.005	0.03	Rest

For microstructural investigation, samples were ground and polished using emery paper of 800,1000,1200 grid sizes and finally etched in solution containing

25ml of methanol, 25ml of nitric acid, 25ml of hydrochloric acid and one drop of hydrofluoric acid [11-14].

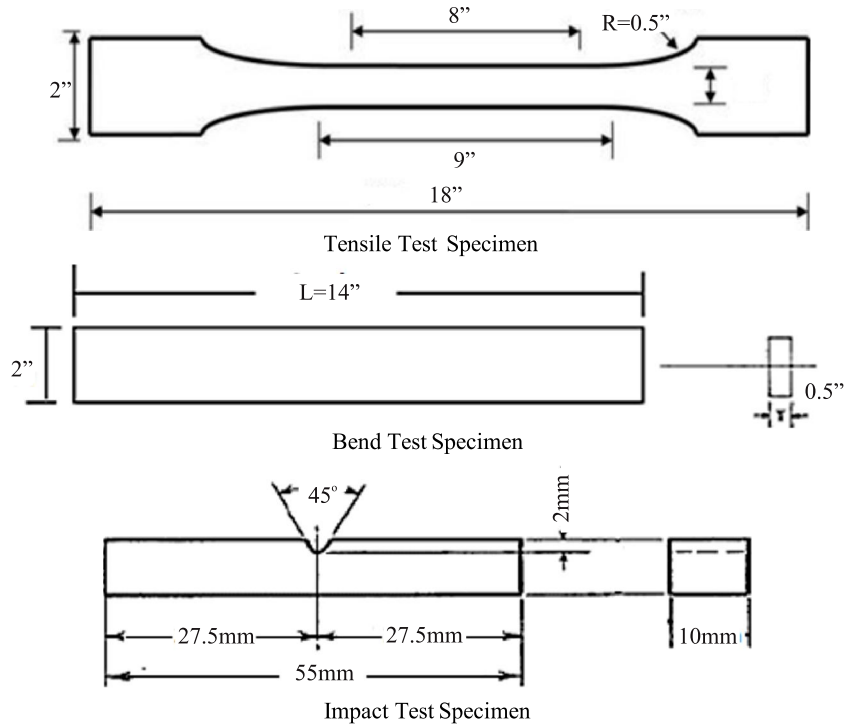


FIG. 1. SAMPLE SPECIFICATIONS FOR TENSILE, IMPACT AND BEND TEST [15]

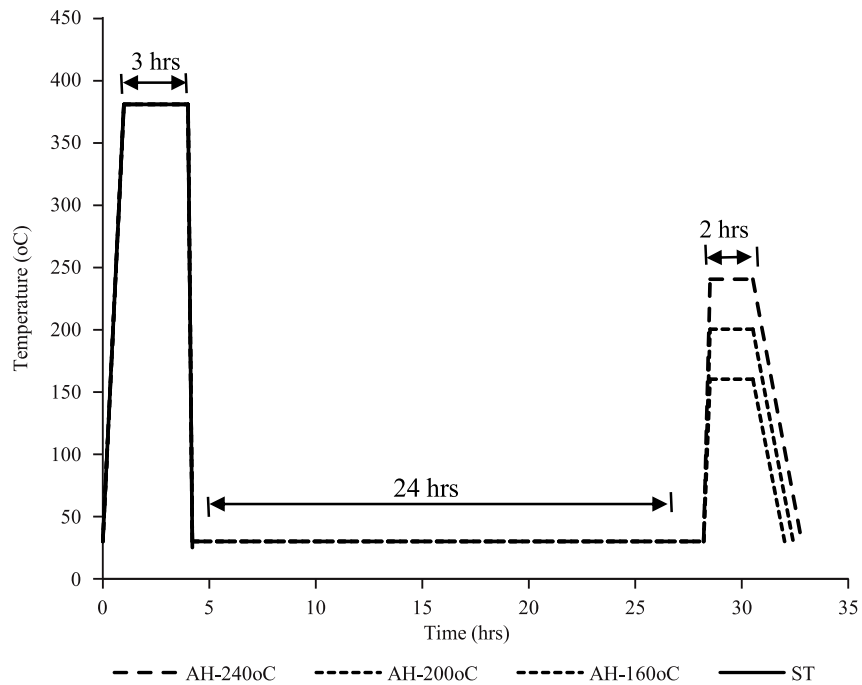


FIG. 2. HEAT TREATMENT CYCLES

3. RESULTS AND DISCUSSION

Tensile test results of 6061-AA are shown in Fig. 3 which indicate significant alteration in the UTS (Ultimate Tensile Strength) and PE (Percent Elongation) achieved at different conditions. It can be seen in Fig. 3 that when 6061-AA with 157 M. Pascal UTS was age hardened at 160, 200 and 240°C, its UTS was increased to 172, 177, and 184 M Pascal respectively. In contrast, the percent elongation of 6061-AA samples was decreased from 38-33%. In addition, hardness and toughness results shown in Fig. 4, also indicate that with increasing the age hardening temperature the appreciable improvement in these properties were resulted. The obtained results showed that solution treatment followed by aging at higher temperature resulted high set of mechanical properties as demanded by end users of this alloy. The improvements in the tensile, hardness, and toughness

can be explained by taking into account the microstructure changes encountered during the age hardening process. It was also noted from free bend test that there was no significant effect on bending property. Minor surface roughness was observed on sample hardened at 240°C but according to the standard it was tolerable. The obtained tensile strength is compared with published results. It is noticed that the obtained maximum tensile strength was typically greater than published research [15-16]. It was also validated that age hardened 6061 aluminum alloy was more strengthened as compared to heat treated Al-Ti alloys.

Detailed microstructural examination reported elsewhere, revealed that by solution treatment at 380°C all the alloying elements were dissolved in aluminum matrix [17-18]. When the solution treated samples were aged at different temperatures the precipitation process of

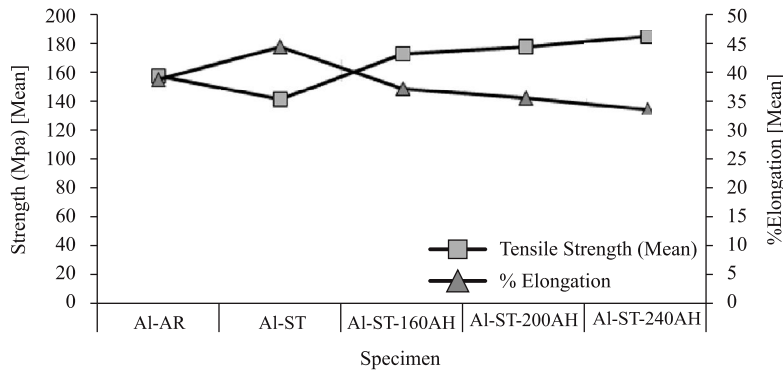


FIG. 3. RESULTS OF TENSILE STRENGTH (MPA) AND PERCENTAGE ELONGATION

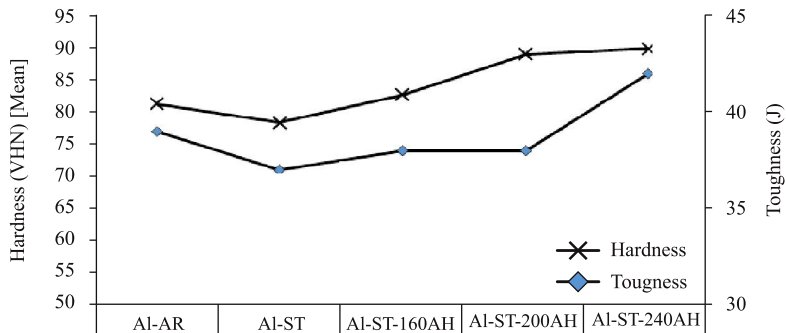


FIG. 4. RESULTS OF TOUGHNESS AND HARDNESS

secondary carbides was started according to the sequence of SSP→GPZ→β''→β'→β. Where, SSP means supersaturated phase, GPZ (Guinier Preston Zone), and β'', β' and β indicate the birth, childhood and mature position of secondary Mg₂Si, respectively. In our study it was noted that the initiation and growth of Mg₂Si are the function of the aging temperature. We noted that at 160°C aging temperature the SSP entered into GPZ which can be seen in Fig. 5(b). When the aging temperature was increased to 200 and 240°C the precipitates of secondary phase Mg₂Si were developed that can be seen in Fig. 5(c-d).

It is interesting to note that by the solution treatment the UTS, toughness and hardness of the samples was decreased as compared to received samples. The sole

reason of this decrease in the properties noted from microstructural investigation was the dissolution of the alloying element in the matrix of aluminum. When the samples were age hardened at lower and higher temperatures the precipitation of secondary carbide Mg₂Si was commenced due to which the improvement in the UTS, toughness and hardness was observed. More interestingly from the increasing trend of the UTS, toughness and hardness can be seen from Figs. 3-4. Results of the sequence of precipitation can be confirmed and validated. The present experimental study recommended that high temperature solution treatment for various soaking time should be carried out to evaluate the effect of solutionizing temperature on mechanical properties of 6061-AA.

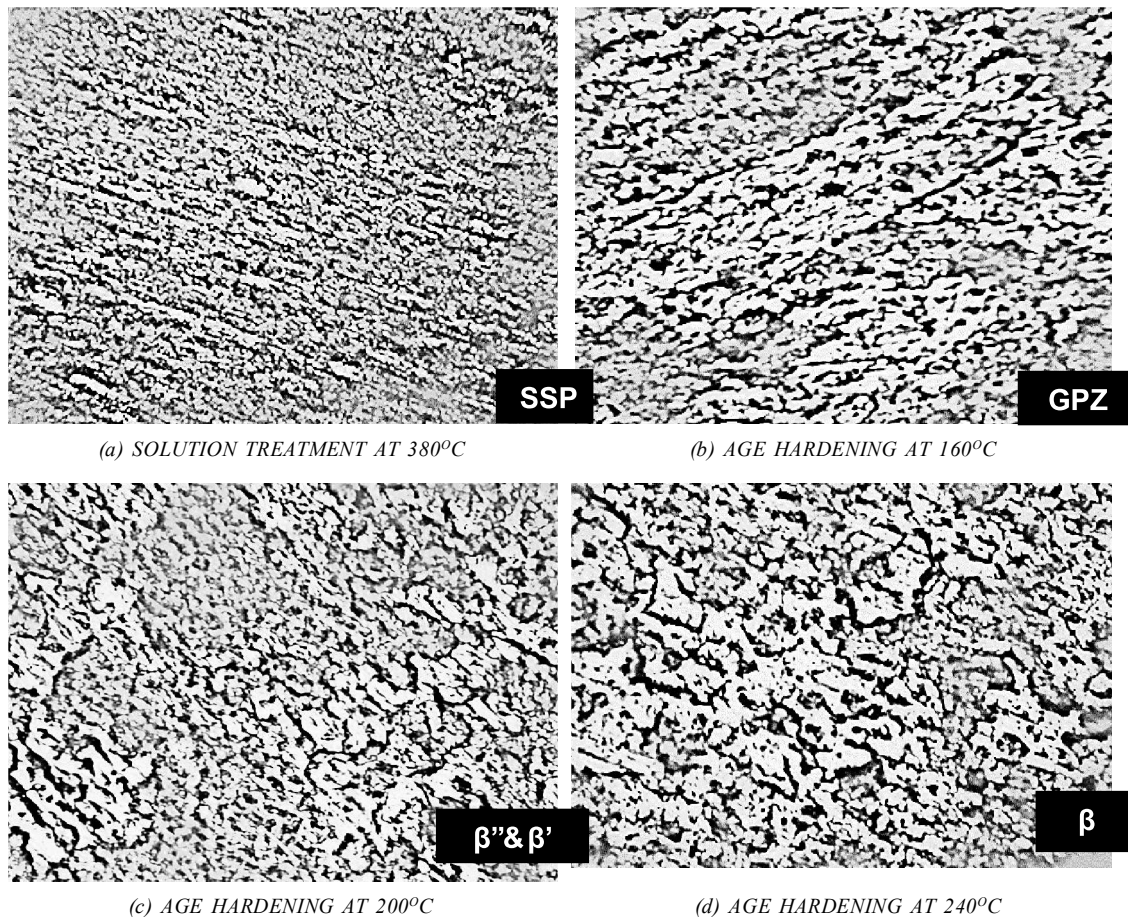


FIG. 5. MICROSTRUCTURE OF ALUMINUM ALLOY AFTER

4. CONCLUSION

It is concluded that the aging of solution treated samples has a positive effect on mechanical properties. Aging at the higher temperature increases the nucleation rate of Mg₂Si precipitates. It can also be concluded that maximum hardness, strength and percentage elongation and toughness is attained at 240°C due to intermediate grain size and evenly distribution of Mg₂Si precipitates.

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