IMPROVEMENT ON THE STRENGTH OF 6063 ALUMINUM ALLOY BY MEANS OF SOLUTION HEAT TREAMENT

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ABSTRACT

The paper examines the solution heat treatment of an extruded 6063 aluminum alloy. The study shows that the strength and fracture resistance of this metal alloy can be influenced to an appreciable extent by the solution heat treatment used in this investigation.

The ultimate tensile strength (UTS) increases as the solution time increases from 6 to 20 hours for treatment temperature of 90°C. The maximum UTS (198.8MPa and 188.6 MPa) occur at 120°C and 150°C respectively at the solution holding time of 10hours. While, at 120°C and 10hrs, the UTS are relatively the same as the as-received specimen, though the latter exhibits a higher fracture stress. Annealing at 470°C results to lower UTS value (114.3MPa) and poor fracture resistance (522MPa).

The results of the experiment are found to be in near perfect agreement with Voce Empirical Model. These observations have shown that solution treatment at 150°C for 10 hrs can produce significant plastic flow before fracture of 6063 aluminum alloys. Irrespective of the treatment process adopted, the stress- strain behavior is essentially the same for strains within the range $0 \leq \varepsilon \leq 0.005$.

INTRODUCTION

The mechanical and physical properties of aluminum alloys are affected by working temperature. The 7xxx series of age-hardenable alloys that are based on the Al –Zn – Mg – Cu system are known to develop the highest room-temperature tensile properties of any aluminum alloys that are produced through conventionally cast ingots. Solid solution strengthening or second phase hardening process has been used to improve the strength of these alloys series at temperatures above 100 to 200°C.

The elevated-temperature performances of aluminum alloys are improved through the use of rapid solidification technology. For most aluminum alloys at temperatures below zero, the changes in mechanical properties are insignificant. The yield and tensile strengths may increase while elongation decrease slightly and impact strength remains approximately constant. Of great interest is its low elongation compared with certain austenitic ferrous alloys. The retention of toughness is of major importance for equipment operating at low temperature. The 6xxx (6061 – T65) series alloy are noted to have good fracture toughness at room temperature and at – 196^0C, but its yield strength is lower than that of 2219 – T87 alloy. The initial strength of 6xxx series alloys is enhanced through alloying with element such as copper, magnesium, zinc, and silicon. Because, these alloying elements in various combinations show increasing solid solubility in aluminum with increasing temperature, it is possible to subject them to heat treatments, which will impart pronounced strength. Such treatments include solution heat treatment, quenching, precipitation or age hardening.

Through proper combination of solution heat treatment, quenching, cold working and artificial aging, the highest strengths can be obtained. Much work has been done over the last three decades to investigate the strengthening behavior of f.c.c metals due to relatively simple and well-defined stress conditions. In most cases the unidirectional tensile test is applied.

However, necking and facture occurs as soon as a true strain $\varepsilon=0.3$ is reached, giving no chance for any higher deformation [M. Zehetbaur, w. Pfeiler, and J Schrank].

In this study it thus becomes of importance to examine the strength behavior of aluminum alloy more closely and evaluate the effect of temperature –time on the strength behaviour. In this paper, 6063 aluminum alloy is solution heat treated at various temperature and time.

METHODOLOGY

Specimen preparation

An extruded 12.5mm diameter rod sample of Aluminum alloy 6063 with the chemical composition shown in table1 was obtained from NIGALEX, Nigeria plc.

The as-received rod was cut and machined into standard tensile test pieces as shown in figure 1in conformity with BS18 standard. The tensile bar had gauge length of 25.25mm with a diameter of 5.05mm

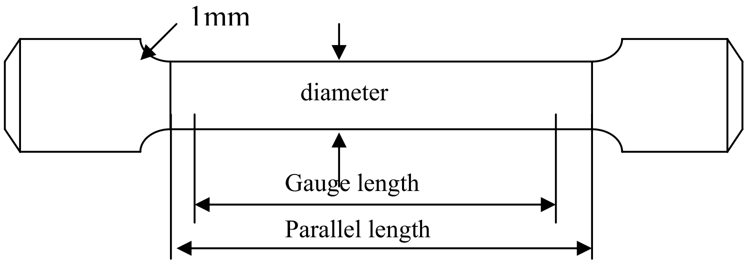

Figure 1 Tensile test specimen

Heat Treatment

The heat treatment procedure carried out on test samples is as follows:

The specimen were heated to a single-phase solid solution temperature of 520 °C and held for 1hour at this temperature. They were water quenched to room temperature.

To avoid natural aging after quenching the specimens were held at about 4°C. They were further tempered in the furnace to temperature between 90,120,150 and 200°C for 2, 6 10 and

20hrs respectively for precipitation hardening of the materials. Two sets of control samples were arranged: the first set involves annealing at 470°C for 1hour and furnace cooled, while the second set remained as - received.

Tensile Test – The tensile bars were tested in the as received and heat treated conditions using Monsanto Tensometer with a load of 10KN.

Table 1: Chemical composition of 6063 aluminum alloy

Element	% Composition	Element	% Composition	Element	% Composition
Si	0.4441	Mg	0.5711	Ca	0.0033
Fe	0.2026	Zn	0.0060	Sr	-0.0003
Cu	0.0117	Cr	0.00267	Al	98.7378
Mn	0.0131	Ti	0.0080		

Table 2. Temperature and Time of heat treatment effects on the mechanical properties of 6063 aluminum alloys

Heat treatment temperature, °C	Time (hrs)	Ultimate tensile Stress MPa	Fracture stress MPa
90°	2	134.21	64.61
	6	168.98	86.97
	10	151.58	86.97
	20	183.89	109.34
120°	2	144.13	84.49
	6	173.95	101.88
	10	198.80	121.76
	20	183.89	106.85
150°	2	149.10	84.49
	6	168.98	96.91
	10	188.86	134.19
	20	119.28	54.67
200°	2	178.92	116.79
	6	193.83	111.82
	10	164.01	104.37
	20	119.28	64.61
Solution treated at 520°C and quenched in water	1	131.71	69.58
Control, annealed at 470°C	1	114.31	52.18
As received (not heat treated)		183.89	129.22

Results and Discussion

The results of the tensile strength and fracture toughness evaluations are displayed in table 2 and figures 1-10.

A. Effects of Thermal treatment on Tensile Strength.

The results of the experiments showed that, 6063 aluminum alloy solution treated at 90^0C, 120^0C and 150^0C attain maximum tensile strength at holding time of 10hrs (figures 1-3). It is observed that at lower strain $0 \leq \varepsilon \leq 0.005$, the stress-strain variation at 90^0C is similar. There is a similar case at 120^0C, but for 6 – 10 hrs holding time this agreement extend to strain in the neighborhood of $\varepsilon \leq 0.011$ (figure 2). The stress-strain behavior for holding time of 2, 6, and 20 hrs has close agreement at strain $0 \leq \varepsilon \leq 0.010$ for solution treatment at 150^0C.

As the holding temperature increases to 200^0C, the strength of the metal alloy reduces (figure 4). There is perfect and significant agreement in the stress-strain behaviour for as-cast, solution treated at 520^0C for 1 hour and water quenched, and annealed at 470^0C specimens at strain $0 \leq \varepsilon \leq 0.01$. However, the tensile strength of as-cast sample is higher than those of others (figure 5).

The above observations have indicated that irrespective of the treatment process adopted, the stress- strain behavior is essentially the same for strains within the range $0 \leq \varepsilon \leq 0.005$.

B. Voce Empirical Relation and Experimental Results

Experimental results fitted well into the Voce empirical relation

σ (Mpa) = 421.698-233.947 exp (-8.633ε), (Ming Dao and Ming Lie, 2001).

Using the above equation, solution treated specimen at 90^0C for two hours shows extensive plastic flow than those at 6 hrs, 10 hrs and 20 hrs. This implies that ductility decreases as the holding treatment time increases. Maximum affective strain of 32×10^{-3} is attained at about 425 MPa effective stresses (Fig 6). Extensive plastic flow occurred at 10 hrs treatment time for 120^0C solution treatment temperature. Maximum effective strain of about 36 x 10^{-3} achieved for 425 MPa effective stresses (figure 7). And for 150^0C solution treatment, maximum effective strain of 39 x 10^{-3} achieved at 10 hrs for 425 MPa effective stress (figure 8). While at 200^0C, the maximum effective strain of 36.5 x 10^{-3} is attained at 20 hrs holding time (figure 9).

The as-cast specimen has a maximum effective strain of 36 x 10^{-3} at 425 MPa higher than specimen annealed at 470^0C and solution treated at 520^0C (figure 10).

The study shows that solution treatment of 6063-aluminum alloy at 150°C for 10 hrs can produce significant plastic flow before fracture. It then implies that there were more dislocations produced due to this treatment than those generated during casting. It also revealed that at higher temperature in the neighborhood of 0.4 T_m (T_m – melting temp) of aluminum, the increase or change in dislocation density is negligible and thus of little effect.

The as-received sample contains high dislocation density as a result of previous extrusion process leading to high strength. The annealed specimen strength dropped as a result of the precipitation of non-coherent particles of Mg_2Si. The extent of strength is determined by the amount of Mg_2Si in solid solution. While the presence of spherical pores in the solution treated specimens attribute to the lowering of the UTS.

A holding time may have influence on the UTS if specimens are solution treated at a lower temperature (e.g. 90°C). Rather, it should be held at lower temperature for much longer period. (20hrs). But for short holding time of 2hrs, a higher treatment temperature will be required (e.g. 200°C)

At low temperature a number of nuclei grows slowly and the Mg_2Si precipitated thus remain coherent and the strength progressively increases as the holding time increases. Conversely, at high temperature, the rate of diffusion increases with the formation of relatively few nuclei, which grows with holding time. The earlier improvement in strength is shortlived as a result of the formation of incoherent second phase particles.

It should be noted that dislocation multiplication has a hardening effect on the material since dislocations provide the mechanisms of plastic deformation of metals. Furthermore, dislocations in the crystal can form loops, pile up on the grain boundaries and precipitate particles, and arrange themselves in various forms of cells or substructures called dislocation networks. These arrangements act as obstacles to the motion of other dislocations, thus providing the important mechanism of hardening. The formation of Mg_2Si precipitates is necessary for the hardening of the aluminum alloy 6xxx series.

Conclusion

This work has shown that aged material is generally stronger than the as cast material. And appropriate solution treatment temperature and holding time has decisive effects on the strengthening, hardening and ductility of aluminum alloy 6063. The precipitation of Mg_2Si particles and the subsequent dislocation multiplication are major parameters responsible for this deduction.

The Stress-strain behavior of this alloy is essentially the same at strain within the range $0 \leq \varepsilon \leq 0.005$ and it is independent of the thermal process adopted.

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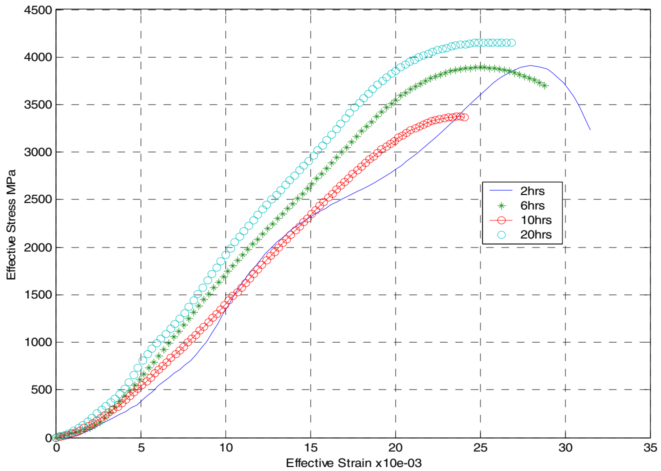

Fig 1 Graph of Effective Stress versus Effective Strain at 90 degrees celcius

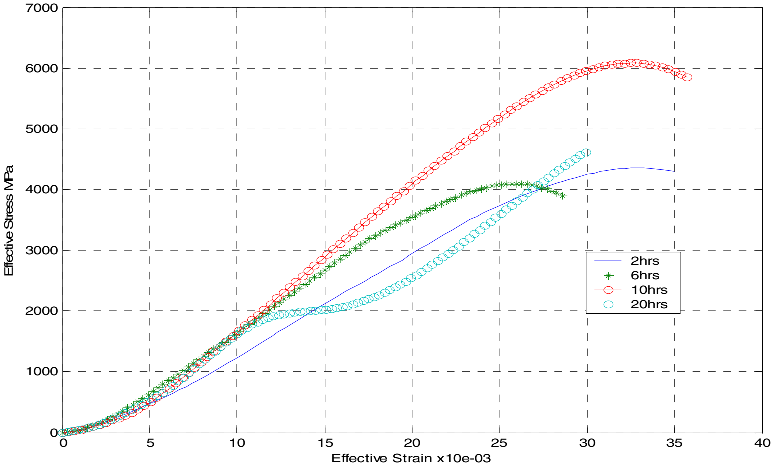

Fig 2 Graph of Effective Stress versus Effective Strain at 120 degrees celcius

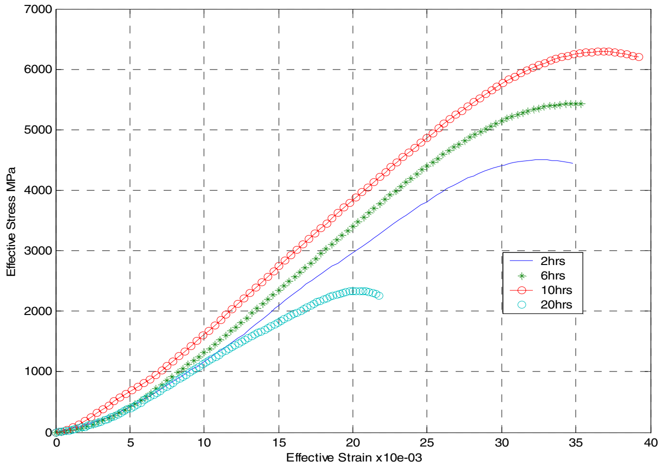

Fig 3 Graph of Effective Stress versus Effective 150 degrees celcius

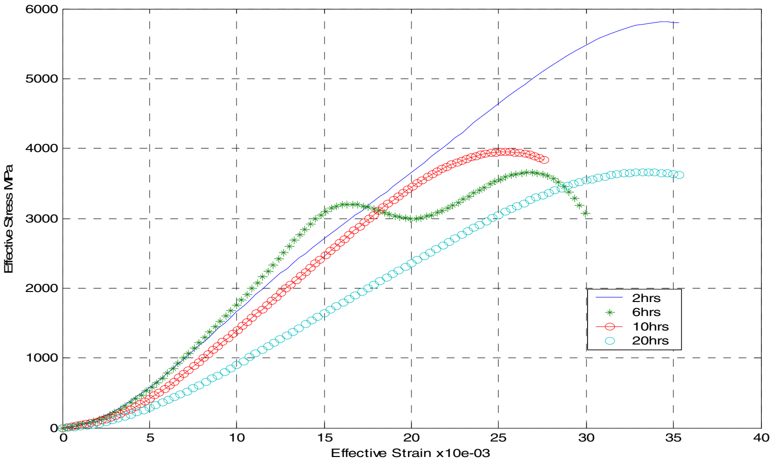

Fig 4 Graph of Effective Stress versus Effective Strain at 200 degrees celcius

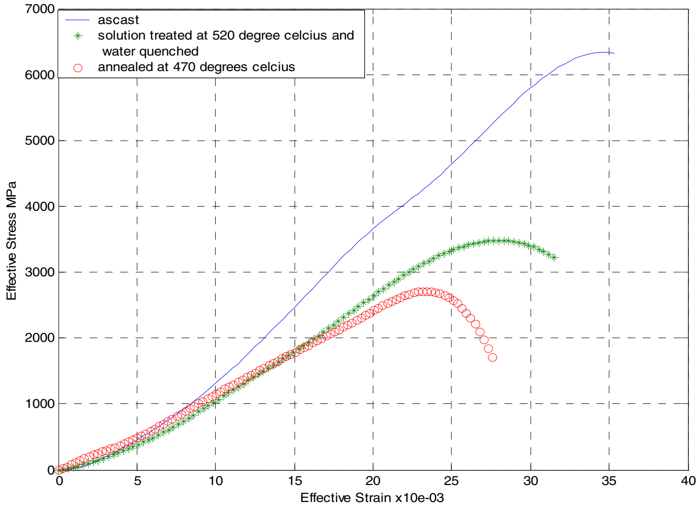

Fig 5 Graph of Effective Stress versus Effective Strain

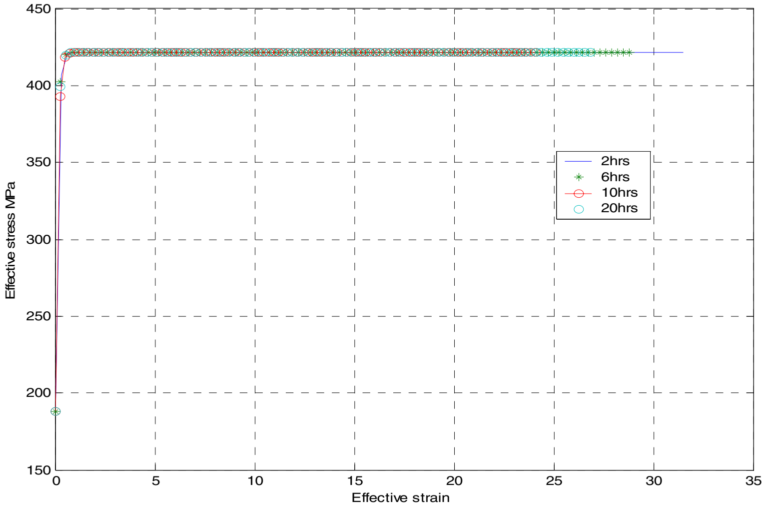

Fig 6 Graph of Effective stress versus Effective strain using Voce equation at 90 degrees celcius

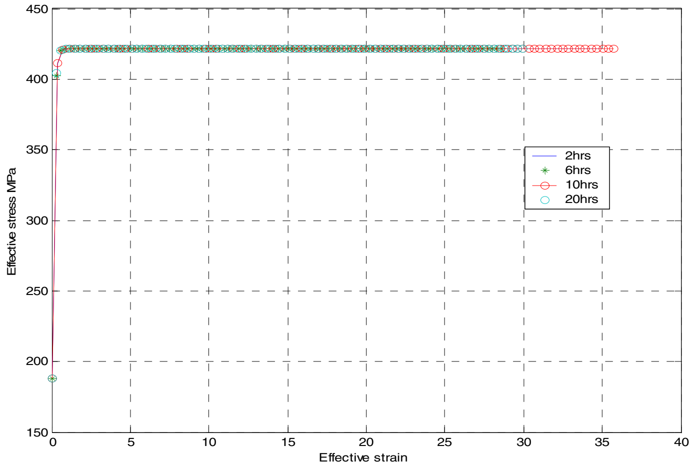

Fig 7 Graph of Effective stress versus Effective strain using Voce equation at 120 degrees celcius

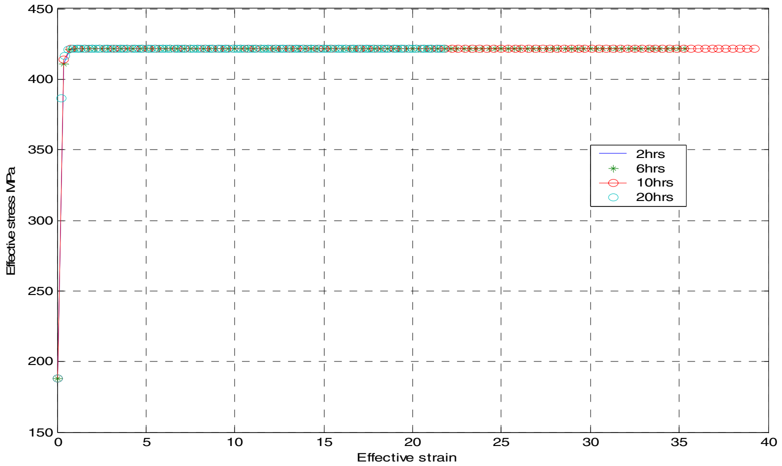

Fig 8 Graph of Effective stress versus Effective strain using Voce equation at 150 degrees celcius

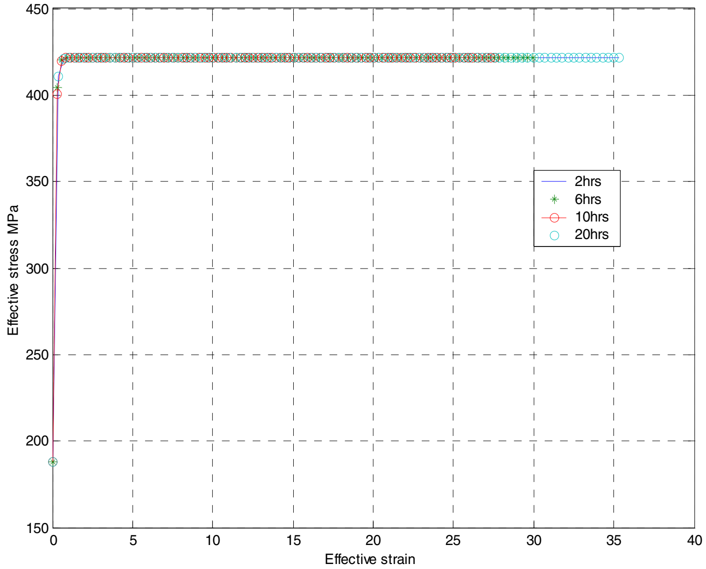

Fig 9 Graph of Effective stress versus Effective strain using Voce equation at 200 degrees celcius

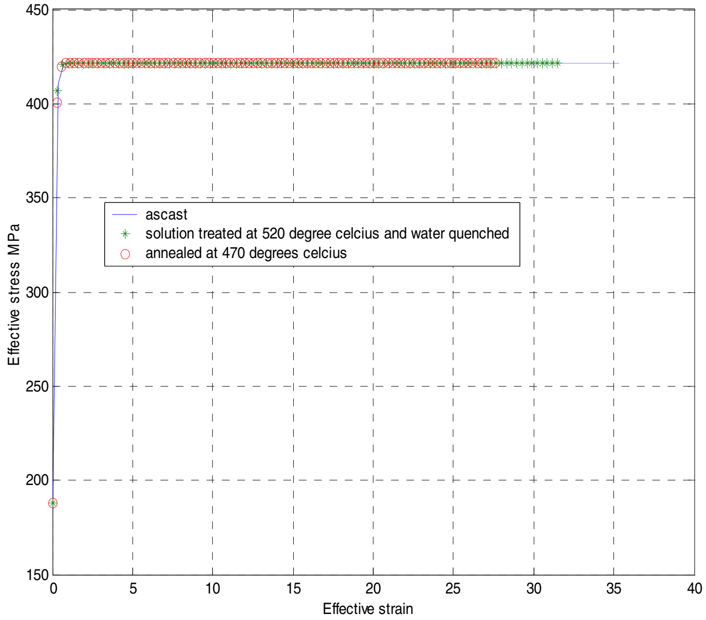

Fig 10 Graph of Effective stress versus Effective strain using Voce equation