Enhancement of Hardness of Aluminum 6063-T6 alloy by Applying Two Step Age Hardening Process

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Abstract— *Aluminum 6063 T6 is an alloy that is mainly used for structural applications such as window and door frames, partitioning, L bars, U bars, and ladders. It contains magnesium (0.45-0.9%) and silicon (0.2-0.6%) as the main alloying elements. T6 denotes the heat treatment process of solution treatment is followed by artificially age hardening. Age hardening process is used to improve the hardness and strength of this alloy by forming second phase particles of* Mg_2Si *which act as a barrier for dislocation movement.*

This work is mainly focused on the enhancement of hardness of Aluminum 6063 T6 extrudates, and increasing the production rate while keeping the cost effectiveness. Two step age hardening treatment is developed as a substitution for the existing single step age hardening treatment applied in local industry, to reduce the total time period and temperatures while improving the hardness. In this work, average hardness value of Aluminum 6063 T6 extrudates produced in local industries is taken as the reference and that is improved up to the required level by varying the time periods and temperatures of two step age hardening process.

The developed two step age hardening process is effective in terms of achieving hardness of 68.4 HV that is a significant improvement relative to the reference hardness value of 63.5 HV. The reduced total time period of 210 min and reduced second step aging temperature of 175 °C in developed two step age hardening process lead to decrease the energy consumption by 30.72% and time period by 28.57% relative to the age hardening process used in local industry.

Keywords— Al 6063 T6, age hardening, hardness

I. INTRODUCTION

Aluminum alloys are highly preferred as a structural material, especially for building construction purposes and for automotive and aircraft bodies (Matucha, 1996). Presently aluminum and its alloys are used as alternatives for other metals (ferrous and non-ferrous), ceramics and wood because of their properties like light weight, durability , surface finish and extrudability.

The usage of aluminum 6063 extruded items is rapidly expanding in Sri Lanka, Even though the properties like strength and hardness are not up to the required level and further cost is relatively high. The demand in locally for aluminum extruded products for structural applications such as partitioning, window and door frames, U bars, L bars, and ladders cannot be satisfied by the existing manufacturing capacity of local industries. Major parameters of age hardening treatment which are time and temperatures need to be changed to decrease the production time and energy consumption while enhancing the mechanical properties. The single step age hardening process presently used in local industry takes 270 min out of which 90 min are spent to bring the samples to a temperature of 205 °C, this temperature is maintained for another 150 min and finally about another 30 min is spent to bring the products back to the room temperature as shown in Fig 1 (De Silva & Perera, 2012). In the proposed two step aging process under this work, initially the temperature is increased to a certain T_1 value, kept at this temperature for a certain time period t_1 and then temperature is reduced to T_2 and kept for another time period t_2, after which the samples are allowed to cool up to the room temperature. In this work, aging process parameters of T_1, T_2, t_1 and t_2 are adjusted to improve the hardness and strength while minimizing the energy consumption and total time period.

II. METHODOLOGY

Aluminum 6063 alloy samples obtained from Alumex (pvt) Ltd were solution treated by keeping at 540 ^{0}C for 3 hours in a Muffle furnace to dissolve Mg_2Si precipitates prior to the age hardening process. Subsequently, samples were allowed to cool in normal air to form a super saturated solid solution as carried out in the industry. The single step age hardening treatment used in the above mentioned company (Fig 1) and mechanical properties of their extrudates: hardness and tensile strength of 63.5 HV and 205.5 Nmm^{-2} respectively, were taken as references.

As an initial step, process parameters of T_1, T_2, t_1 and t_2 in the proposed two steps age hardening treatment (Fig 2) were decided, based on the literatures (De Silva & Perera, 2012)

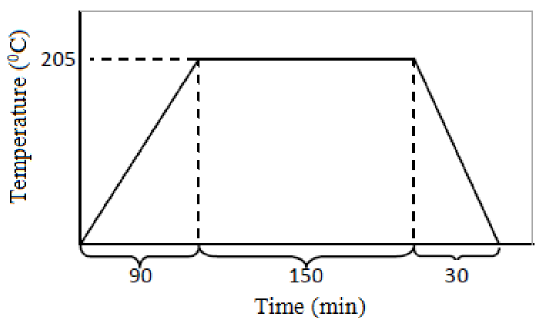

Figure 1. Single step age hardening process in industry

Firstly, T_2, t_1 and t_2 parameters were taken as 175 ^{0}C, 40 min. and 60 min. respectively as constants and heat treatments were carried out by changing T_1 as 190 ^{0}C, 200 ^{0}C, 205 ^{0}C, 210 ^{0}C and 215 ^{0}C for three samples per cycle. Then hardness of samples was measured and the required T_1 was selected by optimizing hardness.

In second stage, T_1, t_1 and t_2 parameters were kept as constants and heat treatments were then carried out by changing T_2 as 150 ^{0}C, 165 ^{0}C, 175 ^{0}C, 185 ^{0}C and 195 ^{0}C for three samples per cycle. Then hardness was measured and required T_2 was selected by optimizing hardness. In the third stage, T_1, T_2 and t_2 parameters were kept as constants and heat treatments were carried out by changing time t_1 as 30 min, 40 min, 50 min and 60 min for three samples per cycle. The hardness of samples was then measured and required t_1 was selected by optimizing hardness measurements.

Finally, T_1, T_2 and t_1 parameters were kept as constants and heat treatments were carried out by changing t_2 as 40 min, 50 min, 60 min, 70 min and 80 min for three samples per cycle. The hardness was then measured and required t_2 was selected by optimizing hardness measurements.

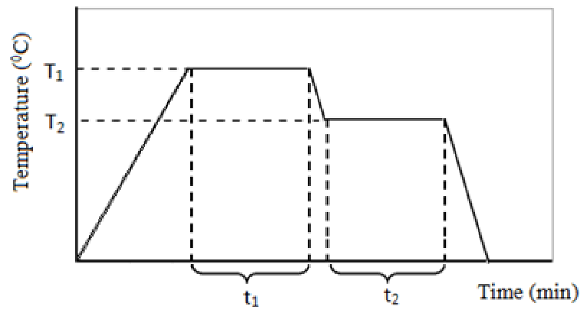

Figure 2. Proposed two-step age hardening process

Strength and hardness measurements were again taken for the samples age hardened by using the developed two steps aging process. Energy consumptions were calculated based on the ratio of the area covered by the heat treatment curves.

III. RESULTS

Extrudates produced using the single step age hardening treatment in Fig 1 showed average hardness and tensile strength of 63.5 HV and 205.5 Nmm^{-2} respectively. Total time period for that treatment was evaluated as 270 min.

The developed two steps age hardening treatment (Fig 3) comprises T_1=205 ^{0}C, T_2=175 ^{0}C, t_1=40 min and t_2=50 min, and the total time period for this treatment was evaluated as 210 min. Average hardness and tensile strength of samples subjected to this treatment were measured as 68.4 HV and 222.4 Nmm^{-2} respectively.

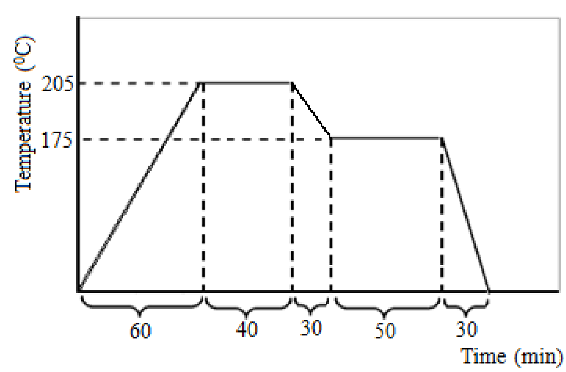

Figure 3. Developed two steps age hardening process with optimized process parameters

Results of the four stages are shown in Fig 4,5, 6 and 7 below.

Stage 1- T_1 as a variable and T_2, t_1, t_2 as constants

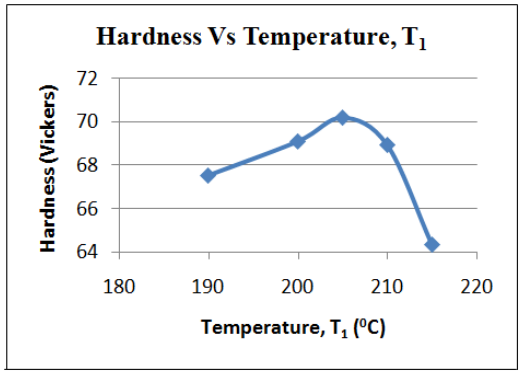

Figure 4. Hardness verses Temperature, T_1

Stage 2- T_2 as a variable and T_1, t_1, t_2 as constants

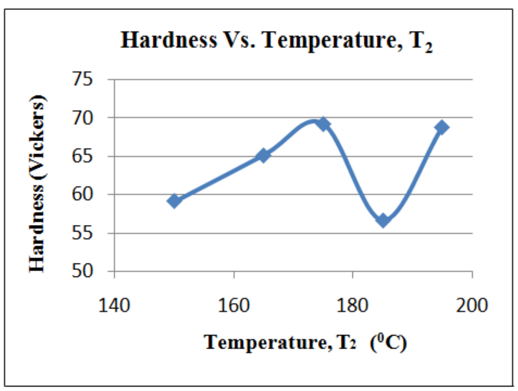

Figure 5: Hardness verses Temperature, T_2

Stage 3- t_1 as a variable and T_1, T_2, t_2 as constants

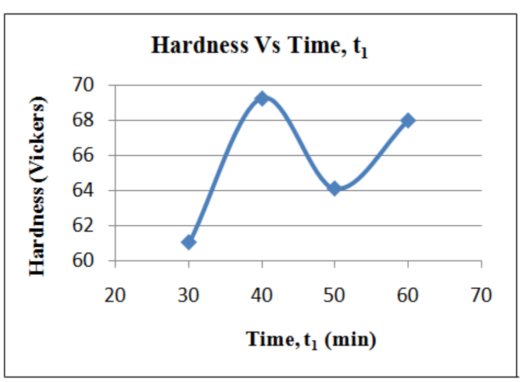

Figure 6: Hardness verses Time, t_1

Stage 4- t_2 as variable and T_1, T_2, t_1 as constants

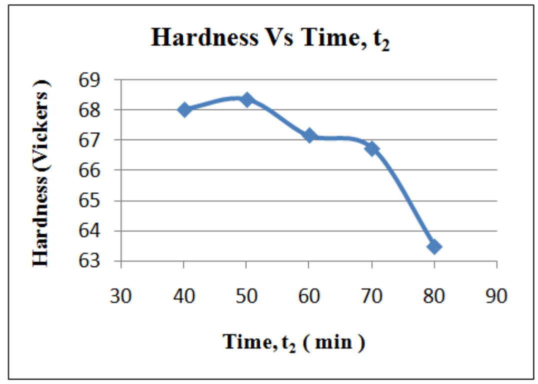

Figure 7: Hardness verses Time, t_2

The heat absorbed by the object with mass "m"can be found using the equation;

E = mcθ... 1

Where;

E = heat energy absorption
c = specific heat capacity
θ = temperature difference
m = mass

m and C are constants for a given object. Therefore, considering the area under the temperature-time curve heat energy consumption can be evaluated theoretically. Based on the time-temperature curves in Fig 1 and Fig 3, percentage energy saving was calculated as 30.72%.

IV. DISCUSSION

Experimental results show both hardness and strength of samples treated by the developed aging profile have been increased significantly and both energy and total time period have been saved compared with the local industry's age hardening profile. Literature shows (Raghavan, 2007; Subbarao et al., 1972) that two steps age hardening treatment had been applied for improving the mechanical properties of age hardenable alloys. However this was not effective in terms of industrial applications because either it is time consuming or not continuous as shown in Fig 8 (Askelend and Phule, 2007).

In the age hardening treatment, hardness and strength are increased due to formation of precipitates that restrict the dislocation movements. According to the critical radius phenomena, in precipitate growing, above the critical radius precipitates are stable and below the critical radius most of the precipitates will be unstable and dissolved. Therefore precipitates of nearly the same size are formed when it is subjected to a one step aging profile (Raghavan, 2007). At a higher aging temperature of precipitates of larger sizes are formed due to the large critical radius corresponding to that temperature.

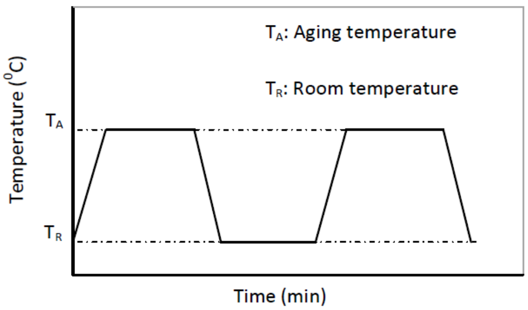

Figure 8. Time consuming discontinuous age hardening treatment (Raghavan, 2007)

With the soaking time, precipitates are grown, however over-aging causes reduction of hardness and strength. When age hardening is done at temperature T_1 with corresponding precipitate's critical radius of r_{c1}, clusters having the radius of r_1 ($r_1>r_{c1}$) will survive and continue to grow (Subbarao et al., 1972, Yao et al., 2001). However at the same temperature, below the critical radius r_{c1}, most of clusters ($r_2<r_{c1}$) will be unstable and dissolved. If the temperature is reduced up to T_2, as the second step of the aging treatment, the critical radius is changed as r_{c2} ($r_{c2}<r_{c1}$). Then some clusters having a size close to radius r_2 ($r_2>r_{c2}$) which have remained in stage one will survive and continue to grow. At temperature T_2 new clusters are formed and clusters having the size of r_3 ($r_3>r_{c2}$) continue to grow while most of clusters with the size $<r_{c2}$ are dissolved.

According to the above explanation, in the developed age hardening process, the mean size of the particles (precipitates) is increased and the particle size distribution is reduced while the overall number of particles is decreased. Further, in this particle distribution inter-particle space becomes larger. This condition causes passing the part of dislocation between two particles, leaving a loop of dislocation around the particles, in other words, dislocation by passing of large particles by "Rowans bowing" (Royset and Tundalan, 2004). Therefore the developed two step aging process leads to improve the hardness and strength.

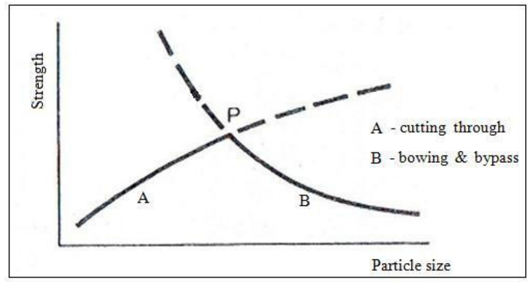

Figure 9. Relationship between particle size and strength for one- step age hardening of Al 6063 (Jacobs, 1999)

In the single step aging process, the mean size of the particles (precipitates) is reduced. Therefore, dislocations can pass through the particles that is known as "cutting through mechanism" (Rafiq Hussein et al., 2000; Zuo and Jing, 2009) In this case both cutting through and Rowans bowing mechanisms are functional while cutting through mechanism becomes predominant. However, in the single step aging process, the effect of cutting through mechanism on increasing the hardness and strength is low as the mean size of the particles is low (Fig 9). Therefore in the single step aging process, relatively low hardness and strength can be obtained.

III. CONCLUSION

The developed two steps age hardening treatment is effective in achieving a higher hardness of 68.4 HV and tensile strength of 222.4 Nmm^{-2} in Al 6063 T6 alloy relative to the hardness and tensile strength of 63.5 HV and 205.5 Nmm^{-2} respectively given in single step treatment. In the developed treatment reduced total time period of 210 min. and reduced second step aging temperature of 175 ^{o}C lead to a reduction in the energy consumption by 30.72% and in the time period by 28.57% relative to the single step age hardening process applied in local industry. Therefore, the local industry can utilize the developed two step age hardening treatment to improve the mechanical properties of Al 6063 alloy extruded articles while enhancing the production rate cost effectively.

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