Study of the Effects of Two Step Age Hardening Process on Mechanical Properties of Aluminum 6063-T5 Alloy

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Abstract

Aluminum 6063 T5 is an alloy and containing magnesium (0.45-0.9%) and silicon (0.2-0.6%) as the main alloying elements. T5 denotes the heat treatment process: cooling from hot working and artificially aged. Aging process is used to harden this alloy by forming second phase particles of Mg_2Si. This work is mainly focused on the enhancement of hardness of Aluminum 6063 T5 extrudates, and increasing the production rate cost effectively. Two step age hardening treatment is developed as a substitute for the existing single step age hardening treatment used in local industry, to reduce the total time period and temperatures while improving the hardness. In this research work, average hardness value of extrudates produced in local industries is taken as the reference point and that is improved up to the required level by varying the time periods and temperatures of two step age hardening treatment.

1. Introduction

Aluminum is one of the most abundant elements in the earth crust (about 8% by weight of the earth's solid surface) [1]. Considering properties like durability, light weight, extrudability and surface finish, at present aluminum and its alloys are used as alternatives for other metals (ferrous and non-ferrous), ceramics and wood. Even though the usage of aluminum 6063 T5 extruded products is rapidly expanding all over Sri Lanka, the properties like hardness and strength are not up to the required level and the cost is relatively high. The local demand for aluminum extruded products for structural applications such as window and door frames, partitioning, L bars, U bars, and ladders cannot be satisfied by the existing capacity of Sri Lankan industries. Parameters of age hardening process which are time and temperatures need to be changed in order to reduce the energy consumption and production time while improving 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 (Fig.1). In the two step aging process, initially the temperature is increased to a certain T_1 value, maintained at this temperature for a certain time period t_1 and then temperature is lowered to T_2 and maintained for another time period t_2, after which the samples are allowed to cool back to the room temperature. In this work, process parameters of T_1, T_2, t_1 and t_2 are changed to improve the mechanical properties while considering the minimization of the total time period and energy consumption.

2. Methodology

The 6063-T5 alloy samples supplied by local Al Alloy extruded product manufacturing company were solution treated by keeping at 540^{0}C for 3 hours in a Muffle furnace prior to the age hardening treatment to dissolve Mg_2Si precipitates. Subsequently, these samples were air quenched to create a super saturated solid solution as performed in the industry. The age hardening treatment used in the above mentioned company (Fig.1) and mechanical properties of their extrudates, hardness and tensile strength were taken as references.

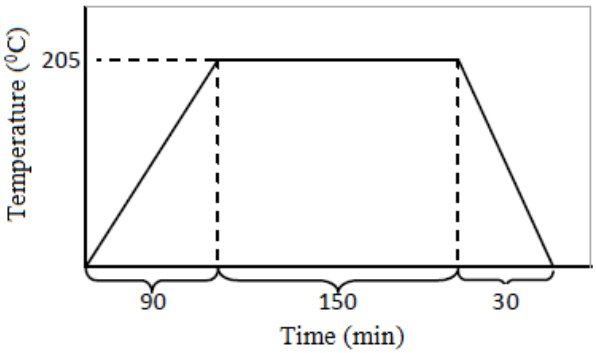

Figure 1: Single step age hardening treatment applied in industry.

In the proposed two step age hardening treatment (Fig.2), as an initial step, process parameters of T_1, T_2, t_1 and t_2 were decided according to the literature [2]. In the first stage, T_2, t_1 and t_2 parameters were taken as 175 ^{0}C, 40 min. and 60 min. respectively as constants and then 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 T_1 was taken by optimizing hardness.

In the 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 of samples was measured and T_2 was taken by optimizing hardness. In the third stage, T_1, T_2 and t_2 parameters were kept as constants and heat treatments were then 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 t_1 was taken by optimizing hardness.

In the final stage, T_1, T_2 and t_1 parameters were kept as constants and heat treatments were then carried out by

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changing t_2 as 40 min, 50 min, 60 min, 70 min and 80 min for three samples per cycle. The hardness of samples was then measured and t_2 was taken by optimizing hardness.

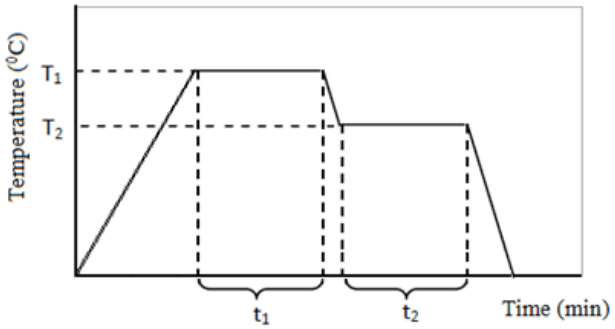

Figure 2: Proposed two step age hardening treatment

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

3. Results

Average hardness and tensile strength of extrudates produced using single step age hardening treatment applied in industry were measured as 63.5 HV and 205.5 Nmm^{-2} respectively. Total time period for that treatment was evaluated as 270 min. These mechanical properties and time period are taken as reference values. Average hardness and tensile strength of samples subjected to the developed two step age hardening treatment (Fig.3) taking T_1=205^{0}C, T_2=175^{0}C, t_1=40 min and t_2=50 min were measured as 68.4HV and 222.4 Nmm^{-2}respectively, and time period for this treatment was evaluated as 210 min.

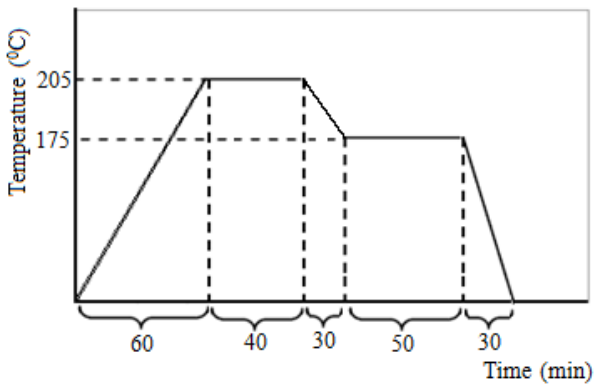

Figure 3: Developed two step age hardening treatment with optimized parameters

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

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

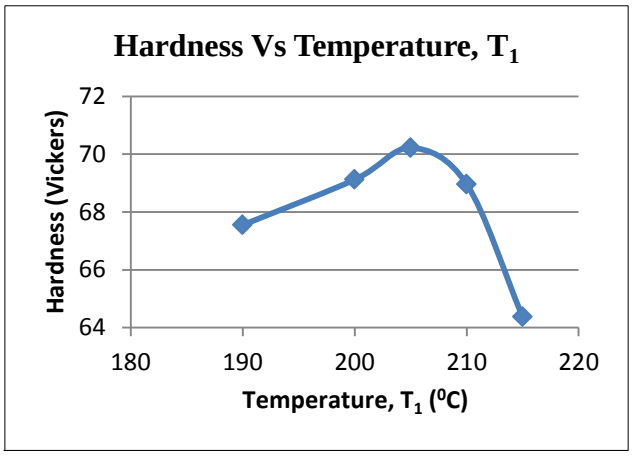

Figure 4: Hardness verses Temperature, T_1

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

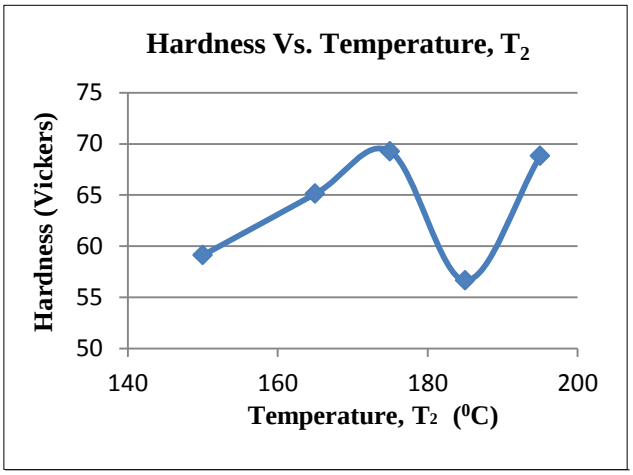

Figure 5: Hardness verses Temperature, T_2

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

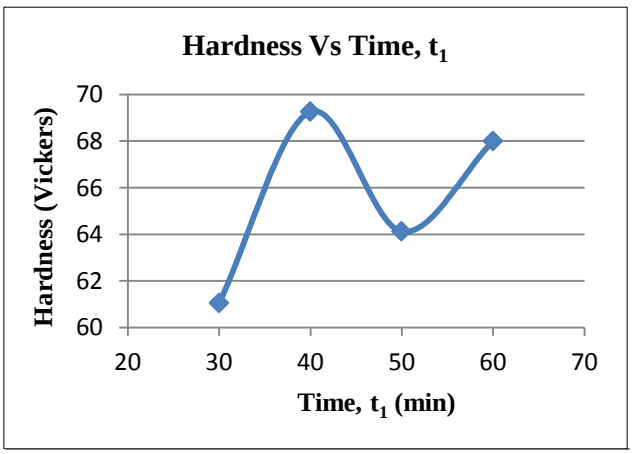

Figure 6: Hardness verses Time, t_1

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

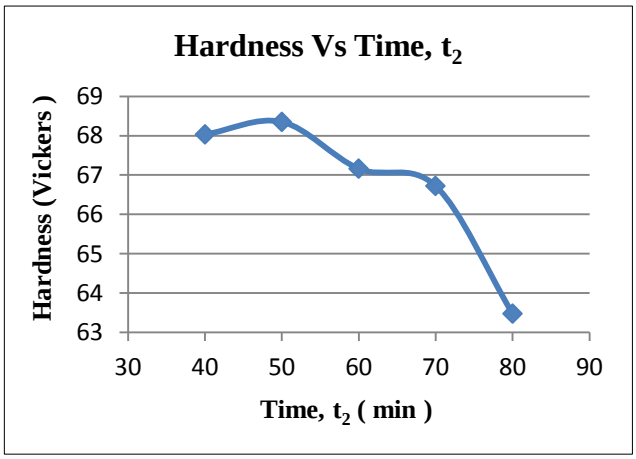

Figure 7: Hardness verses Time, t_2

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

$$\mathbf{E = mc\theta} \quad \text{.....} \quad 1$$

Where;

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

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

4. Discussion

According to the results, both hardness and strength of samples treated by the developed aging profile have been increased and both energy and time have also been saved compared with the local industry's aging profile. Literature shows [4,5] that two step age hardening process had been applied for improving the mechanical properties of age hardenable alloys. However this was not effective in terms of industry because either it is time consuming or not continuous as shown in Fig.8 [3].

In the age hardening process, 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 [4]. At a higher aging temperature of precipitates of larger sizes are formed due to the large critical radius corresponding to that temperature.

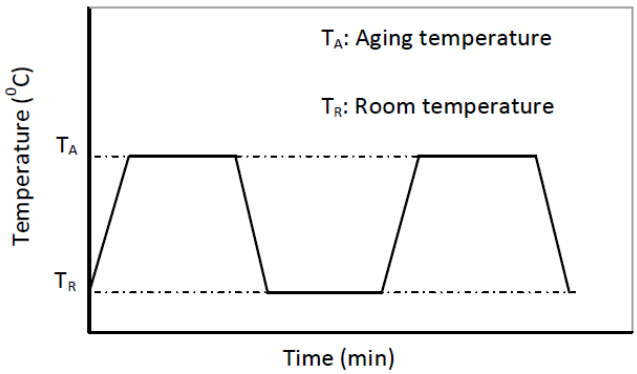

Figure 8: Time consuming discontinuous age hardening profile [4].

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 [5,6]. 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 [8]. Therefore the developed two step aging process leads to improve the hardness and strength.

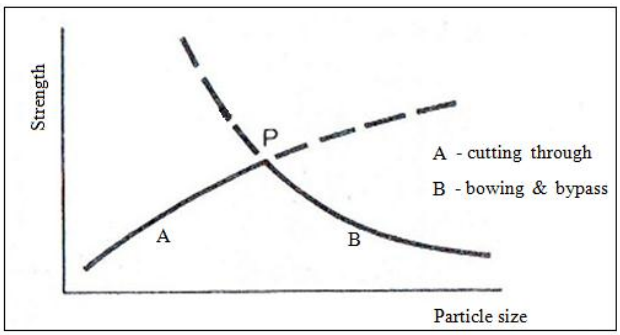

Figure 9: Relationship between strength and particle size for a one step age hardening alloy [7]

In the single step aging process, the mean size of the particles (precipitates) is reduced. Therefore, dislocations

can pass through the particles (cutting through mechanism). 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.

5. Conclusions

The developed two step age hardening process is effective in terms of achieving a higher hardness of 68.4 HV and tensile strength of 222.4 Nmm^{-2}in Al 6063 T5 in alloy extrudates. The reduced total time period of 210 min and reduced second step aging temperature of 175°C in the developed two step age hardening process lead to a decrease in the energy consumption by 30.72% and in the time period by 28.57% relative to the age hardening process used in the local industry. Therefore, the local industry can utilize the developed two step age hardening process to improve the mechanical properties of Al 6063 T5 alloy extrudates while increasing the production rate cost effectively.

References

[1] K.H. Matucha, *Structure and properties of nonferrous alloys*, Cambridge, New York, pp. 213-276, 1996.

[2]G.I.P. De Silva, W.C Perera., "*Improvement of the Mechanical Properties of Aluminum 6063 T5 Extrudates by Varying the Aging Condition Cost-Effectively"* South Asian Institute of Technology and Medicine (SAITM) research symposium on advancement of science, Sri Lanka, 2012.

[3] D.R. Askelend and P.P. Phule, *Essentials of Materials Science and Engineering*, Baba BarkhaNath Printers, Delhi pp. 420-448, 2007.

[4]V. Raghavan, *Al–Mg–Si Phase Diagram Evaluations, Journal of Phase Equilibria and Diffusion*, Vol. 28: No. 2, 2007.

[5] E.C. Subbarao, L.K. Singhal, D. Chakravorthy, M.F. Merriam and V. Raghavan, *Experiments in Materials Science*, TMH Edition, McGraw-Hill Inc., New York, pp. 84-89, 1972.

[6]J.Y. Yao, D.A. Graham, B. Rinderer and M.J. Couper, *A TEM study of precipitation in Al–Mg–Si alloys*, Micron 32, pp.865–870, 2001.

[7]M.H. Jacobs, *TALAT Lecture 1204 - Precipitation Hardening*, Interdisciplinary Research Centre in Materials, the University of Birmingham, UK, 1999.

[8] J. Royset , U. TundalandReiso, *Comparison of Properties of Extruded 6xxx Alloys in T5 Temper versus T6 Temper.* Hydro Aluminium R&D Sunndal, PO Box 219, N-6601 Sunndalsora, Norway, 2004.