IMPROVEMENT OF THE MECHANICAL PROPERTIES OF ALUMINUM 6063 T5 EXTRUDATES BY VARYING THE AGING CONDITION COST-EFFECTIVELY

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ABSTRACT

Aluminum 6063 T5 is artificially age hardened alloy contains magnesium (0.45-0.9%) and silicon (0.2-0.6%) as the main alloying elements. Age hardening process is used to harden this alloy by forming second phase particles of Mg_2Si. In this work, mainly focusing the enhancement of properties like hardness and strength of Aluminum 6063 T5 extrudates, and increase the production rate while keeping the cost effectiveness. Two step age hardening treatment is going to be developed as a substitution for existing single step age hardening treatment applied in local industry to reduce the total time period and temperatures while improving the mechanical properties.

***Key words*:** Al 6063 T5, Age hardening, Hardness, Energy consumption

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 an alternative for other metals (ferrous and non-ferrous), ceramics and woods. Even though the usage of aluminum 6063 T5 extruded products is rapidly expanding all over the Sri Lanka, the properties like hardness and strength are not up to the required level and cost is relatively high **[2].** The local demand for aluminum extruded products such as structural applications: window and door frames, partitioning, L bars, U bars, and ladders cannot be accomplished by the existing capacity of Sri Lankan industries. Parameters of age hardening process those 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 applied in local industry takes 270 min where 90 min are spent to bring the samples to a temperature of 205^{o}C and this temperature is maintained for another 150 min and finally about another 30 min is spent to bring back the products to the room temperature. In two step aging process, initially the temperature is increased to a certain T_1 value, maintained at this temperature for a certain time period and the temperature is elevated to T_2 and maintained for another time period, after which they were 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 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^{o}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.

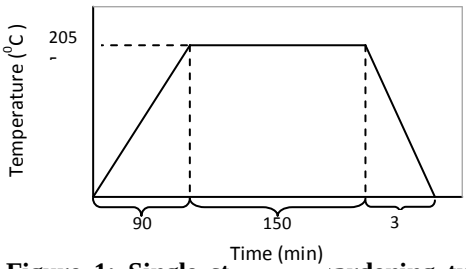

Figure 1: Single step age hardening treatment applied in industry

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 literatures [3,4]. In first stage, samples were subjected to age hardening treatment varying the T_1 and t_1.

The rates of heating in first and second stages were kept at 3^{o}C/min and 2^{o}C/min respectively, and furnace cooling was applied as in the heating profile used in industry. T_1 was adjusted between 150 and 200 ^{o}C while t_1 was set at the range of 30-90 min. Hardness and tensile strength were measured for all heat treated samples. The T_1 and t_1

values correspond to the sample with maximum hardness and tensile strength were selected as the best combination in the first stage. In second stage this combination was kept constant while T_2 and t_2 were adjusted in the ranges of 200-240 ^oC and 30-90 min respectively. Again Hardness and tensile strength were measured for all heat treated samples. The time periods of $t_1$and t_2, and temperatures of T_1 and T_2 corresponds to the maximum hardness and tensile strength were taken to calculate the energy consumption.

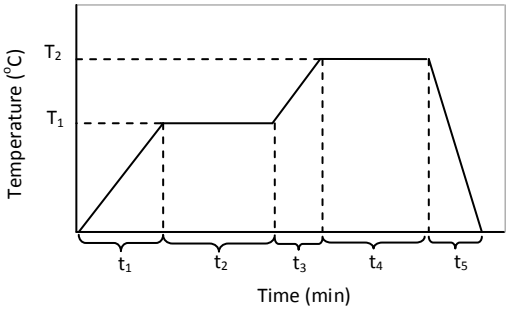

Figure 2: Proposed two step age hardening treatment

3. RESULTS

Average Hardness and Tensile strength of extrudates produced using Single step age hardening treatment applied in industry were measured as 47.05 HV and 228.41Nmm^{-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 developed two step age hardening treatment (Fig.3) having T_1=175^{0}C, T_2=225^{0}C, t_1=60 min and t_2=40 min were measured as 51.10 HV and 240.86 Nmm^{-2} respectively, and time period for this treatment was evaluated as 220 min.

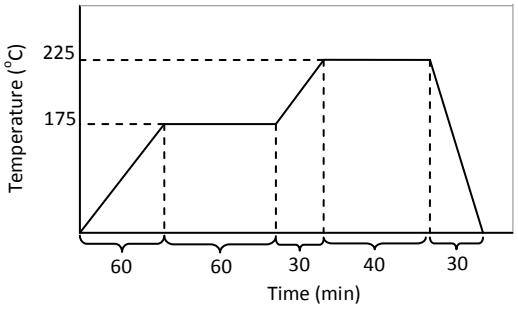

Figure 3: Developed two step age hardening treatment with optimized parameters

According to the Literatures [4, 5], second step aging time is more effective in improving the mechanical properties relative to the first step aging time. Therefore, the influence of second step aging time on mechanical properties was studied and results are shown in Fig.4 and Fig.5.

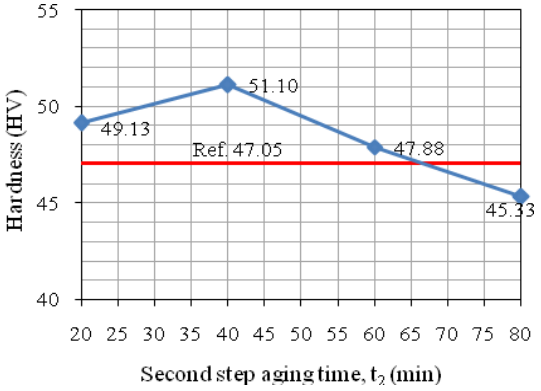

Figure 4: Hardness Vs Second step aging time, t_2

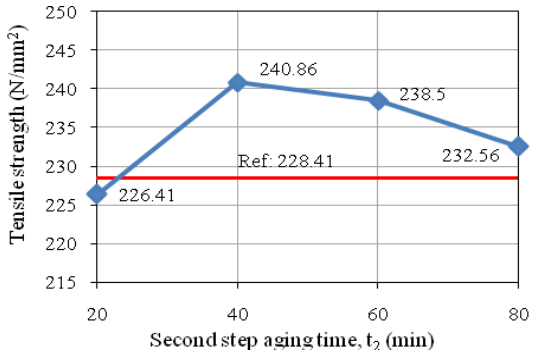

Figure 5: Tensile strength Vs Second step aging time, t_2

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

$$E = mc\theta \quad (1)$$

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 23.08% considering the time-temperature curves in Fig.3.

4. DISCUSSION

As this is an industry based project always facts related to the industry and limitations of the parameters of existing furnaces must be considered. Therefore, maximum temperature of the furnace, 250^{o}C was taken into consideration in deciding the age hardening temperatures. According to equation 1, heat energy consumption is increase with the increased temperature. Therefore though a decrease in the age hardening time was achieved when tested at higher temperatures, the results were unpractical in terms

of industry. According to the literatures [6,7], two step age hardening process had been applied for improving the mechanical properties of age hardenable alloys. However they were not effective in terms of industry because either they are time consuming or not continuous as shown in Fig.6 [7].

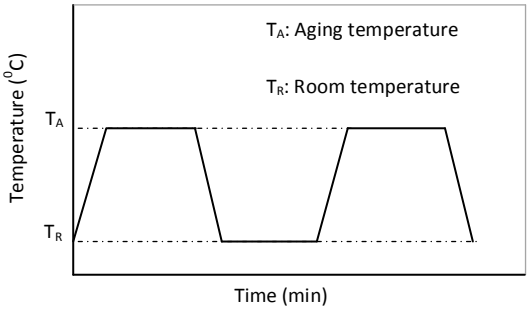

Figure 6: time consuming discontinuous age hardening profile

The total time period for single step age hardening profile used in local industry was evaluated as 270 min. However, two step age hardening profile developed in this work takes time period of 220min. Therefore, time saving of 50 min or 18.52% could be achieved relative to the heat treatment profile used in industry. Energy saving was calculated as 23.08% and that is a huge advantage to the industry.

According to the Fig.5, maximum hardness obtained was 51.10 HV and that was achieved with the aging time of 40 min. Comparative to the reference sample having a hardness of 47.05 HV this is a remarkable improvement. The decrease in hardness while increasing the aging time from 40 min (Fig.5) could be caused by over aging of precipitates that leads to a reduction in stability of the primary, metastable and coherent precipitates, leading to their dissolution and replacement with semi-coherent phase [8]. This could be the reason for reduction of maximum tensile strength of 240.86 Nmm^{-2} (Fig.6).

When the age hardening is done at temperature T_1 with corresponding precipitate's critical radius of r_{c1} (below the critical radius, most of clusters will be unstable and dissolved), clusters having the radius of r_1 ($r_1 > r_{c1}$) will survive and continue to grow [4]. However, if the temperature is increased to some higher value T_2, as the second step of the aging treatment, the critical radius is changed as r_{c2} ($r_{c2} > r_1 > r_{c1}$). Then most of clusters having radius r_1 are dissolved and others are reached to the radius of r_{c2} and further grown. As a result, the mean size of the particles increases while the overall number of clusters decreases that lead to make the inter-particle space larger. This condition causes passing the dislocation through particles, leaving a loop of dislocation around the particle, in other words, dislocation bypassing of large particles by Rowans bowing.[4,9] Therefore two step aging process leads to improve the hardness and strength.

5. CONCLUSIONS

The developed two step age hardening process is effective in terms of achieving higher hardness of 51.10 HV and tensile strength of 240.86 Nmm^{-2} in Al 6063 T5 alloy extrudates. The reduced total time period of 220 min and reduced first step aging temperature of 175^{o}C in developed two step age hardening process lead to decrease the energy consumption by 23.08% relative to the age hardening process used in local industry. Therefore, local industry can utilize developed two step age hardening process to improve the mechanical properties of Al 6063 T5 alloy extrudates cost effectively while increasing the production rate.

6. REFERENCES

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