INFLUENCE OF HEAT TREATMENT CONDITION ON MECHANICAL BEHAVIOR OF 6061 ALUMINUM ALLOY

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ABSTRACT

Aluminum alloys are lightweight, ability to resist corrosion in itself, and easy formation. 6061 Aluminum alloy widely used in industrial production of cars, boats, and is also used as raw materials in the production of other goods. This research investigated the optimal processing conditions on hardness of the impact factors hardness of the aluminum alloy 6061 from the process of artificial aging. The specimens were solution treatment temperatures 500°C and 595°C; solution aging time at 2 hours for before being water-quenching, followed by artificial aging therefore, aging times 2 hours and 8 hours ; and aging temperatures 175°C and 200 °C. The effects of heat treatment conditions on hardness were investigated using brinell hardness testing. The results found that, the aluminum alloy had the highest hardness the optimal aging condition at solution heat treatment temperature at 595 °C and with the aging temperature at 200 °C aging time for 2 hours.

1. INTRODUCTION

Nowadays there is a trend on use of aluminum alloy is likely to continue to rise in a number of industries such as parts in electrical and electronic equipment, in automotive parts manufacturing industry, aviation industry and in the Army due to its notable characteristics of light weight, ability in corrosion self-resistance including easy formability.

Alloy aluminum grade 6061 containing 0.8-1.2% of magnesium and 0.4-0.8% of silicon can be increased in both hardness and strength by methods of either cold forming or heat treatment. The precipitation process for increasing mechanical properties has made it higher in mechanical properties. General steps for age hardening aluminum alloy grade 6061 are as follows: firstly aging aluminum by solution treatment at the solution treatment temperature is carried out in order for the solid phase to dissolve and become homogeneous before secondly quenching it for magnesium and silicon to set in solid solution in quantities greater than saturation at lower temperatures before finally artificially aging it for precipitation. The formed crystals possess strong coherent precipitates that cause distortion of the vertical motion of atom thus making it hard to move when forced by an outside force. This is why aluminum alloy is higher in mechanical properties especially its hardness and strength.

The aim of this project was to carry out an additional study in part of information that has not been found from the study on how to age solids by means of precipitation process in order to optimize the aging process. The study was first carried out by looking at the influences of structures after aging the aluminum alloy grade 6061 with the precipitation process. The factorial statistical experimental plan was employed in order to study the influences of factors affecting the hardness after being artificially aged so that relationship between the hardness and the factors that significantly affect the hardness could finally be revealed.

2. RESEARCH METHODOLOGY

2.1 Experimental Design & Planning

An experimental plan was set to study related research and to consider practical recommendations of ASTM (ASTM Standards, 1998) in order to find out the right level of each factor used in the experiment. A solution constant time of the said experiment was set to 2 hours. The study of Remesh, Keshavamurthy, Channabasappa and Pramod (2009) and the experimental design 2^3 factorial entail 8 experimental conditions (treatment combinations) and each condition contains 4 replicates as to improve accuracy of the observation value and reduce experimental errors. Thirty two experiments were conducted in a random manner (randomization) in order for the effect of variable interference (noise variable) to spread by average to any bit of data and to enable each bit of data not to be dependent (independence) on each other by displaying the sequence of experiment in Table 1.

Table 1 The 2^3 Factorial Experimental Design Plan

Aging Time (H)	Aging Temp (^{0}C)	Solution Temp (^{0}C)							
		1		2		3		4	
		500	595	500	595	500	595	500	595
2	175	2	17	20	5	25	14	29	27
	200	8	24	28	7	4	16	12	13
8	175	11	18	15	19	22	10	31	3
	200	23	1	30	9	21	26	6	32

2.2 Experiment Preparation

A piece of work for use in the experiment by the ASTM (1998) standards, which is aluminum alloy grade 6061 with a diameter of 22 mm in diameter and a length of 25.40±01, was prepared.

2.3 Experiment

The experiment was conducted by aging a piece of work by means of precipitation which has 3 keys steps as follows: solution treatment, quenching and ageing. Time and temperature for each solution treatment and aging follows the sequences shown in Figure 1.

2.4 Hardness Testing

After aging a piece of work according to certain conditions, the piece or work was then measured for its hardness by using a Brinell Hardness Tester with the size of its indenter of 10 mm, its load of 500 kgf and the pressure for 30 seconds. To test for hardness, each piece was pressured and measured for four times before being measured again for the size of indentation with a Stereo Microscope. The diameter obtained from each average point was read for hardness by comparing with the table of hardness (ASTM, 1998).

2.5 Microstructure Examination

Examination on microstructure of the aluminum alloy with an electron microscope was conducted by firstly preparing the smooth and shiny surface with sandpaper, secondly polishing it with flannel and alumina powder and finally examining its microstructure by using an electron microscope.

3. RESULTS AND ANALYSIS OF DATA

3.1 Results

The hardness testing results after aging a piece of work in accordance with certain conditions and after an immediate measurement of the Brinell Hardness Tester, were shown in Table 3.

Table 3 Results

Aging Time (B)	Aging Temp (C)	Solution Temp (A)							
		Rep I		Rep II		Rep III		Rep v	
		500	595	500	595	500	595	500	595
2	175	40.15	94.05	38.60	97.80	39.49	97.65	38.98	91.45
	200	44.18	111.25	41.25	109.75	44.09	104.42	39.76	106.82
8	175	76.08	110.25	76.50	112.00	43.01	106.38	73.92	107.28
	200	52.10	115.00	57.28	118.75	72.51	110.49	54.99	113.38

Analysis of variance by using the ANOVA table at a significant level for hypothesis testing of 5% (α = 0.05) with a 2^3 factorial experimental design, the results were shown in Table 4.

Table 4 Analysis of Variance (ANOVA) for the 2^3 Factorial Experimental Design

Source	**DF**	**Sum of Squares**	**Mean Squares**	**F**	**P-Value**
A	1	23862.8	23862.8	2240.13	0.000
B	1	2116.2	2116.2	198.66	0.000
C	1	1.4	1.4	0.13	0.725
A*B	1	309.6	309.6	29.06	0.005
A*C	1	727.6	727.6	68.30	0.000
B*C	1	555.1	555.1	52.11	0.000
A*B*C	1	171.6	171.6	16.11	0.001
Error	24	225.7	10.7		
Total	31	27999.9			

From Table 4, Analysis on the influence of factors can be summarized as follows: factor A significantly affects the hardness (P-Value<0.001), factor B significantly affects the hardness (P-Value<0.001), factor C does not affect the hardness at a significant level of 0.05, a cofactor A, B significantly affects the hardness (P-Value<0.001), a cofactor A, C significantly affects the hardness (P-Value<0.001), a cofactor B, C significantly affects the hardness (P-Value<0.001) and a cofactor A, B, C also significantly affects the hardness (P-Value<0.01). This indicates that the experiment is a well-designed model that can predict and find the best answers in the form of the following equation.

$$\hat{Y} = 79.36+27.3A+8.13B-3.11AB +4.76AC-4.167BC+2.316ABC \quad (1)$$

Then test on response optimization of factors affecting the hardness after the precipitation process was carried out by requiring the hardness that is most valuable. The results of the experiment were shown in Figure 1.

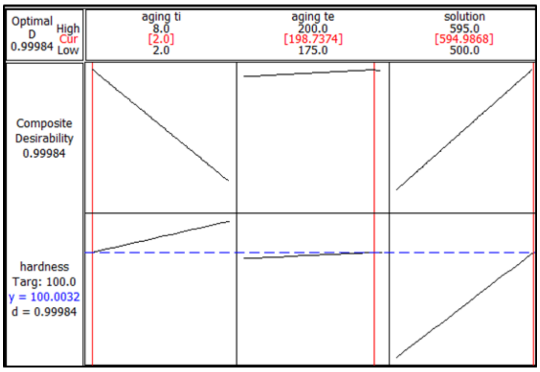


Figure 1. Analysis for the Highest Property (Maximum)

Figure 1 is an analysis for the best value (response optimization) of the factors that affect the hardness. The factor that cause hardness with high values (Maximum) is the solution temperature at 595 °C, the aging time is 2 hours and the aging temperature is 200 °C.

The results on examination of the microstructure after the ageing process carried out in accordance with the experiment. Examination on microstructure of aluminum alloy with an electron microscope was shown in Figure 2.

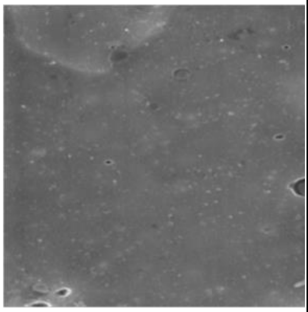
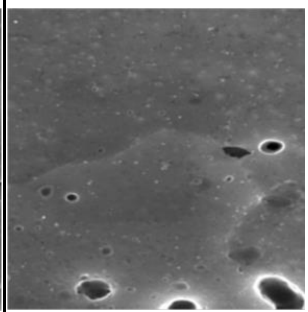
Aging Temperature at 175 ^{0}C	Aging Temperature at 200 ^{0}C
	

Figure 2 Shows the Microstructure of Aluminum after Artificial Aging

Figure 2 shows the microscopic after being aged with different temperatures of 175 ^{0}C and 200 ^{0}C for 2 hours. It was found that the size of Mg2si crystal is smaller because this type of aluminum alloy contains less volume of magnesium and silicon. The picture also shows porosity characteristics in basic structure of aluminum which normally occur in aluminum that has passed a forming process either by casting or rolling. In addition, aging at 175 ^{0}C results in a smaller size of Mg2si crystal than aging at 200 ^{0}C thus affecting the hardness of ageing at 200 ^{0}C above 175 ^{0}C.

4. SUMMARY

The results showed that all key factors significantly influenced the hardness after being aged by means of a precipitation process. Such factors as solution temperature and aging time all significantly influenced the hardness except the aging temperature that did have any significant influence. In addition, there were also influences of 2-cofactors and 3-cofactors each of which influenced the hardness significantly.

Factors affecting the hardness of aluminum alloy grade 6061 after being aged by means of a precipitation process which caused maximum hardness value were solution temperature at 595 °C, the aging time at 2 hours and the aging temperature at 200 °C respectively.

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