Research Inventy: International Journal of Engineering And Science
Vol.12, Issue 5 (May 2022), PP 40-43
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Determination of Optimized Ageing Mode for Al-Mg-Si Alloy

Hoang Anh Quang, Ha Bach Tu
Mechanical Engineering Faculty, Thai Nguyen University of Technology, Thai Nguyen, Vietnam

Abstract: *Ageing temperature and ageing time directly affect the hardness of aluminum alloy. The studies in this paper were carried out on Al-Mg-Si aluminum alloy samples, after hardened the samples were aged at 120÷180°C for about 2h÷6h. The experimental planning method was used to give an experimental model* $Y = -73{,}7 + 1{,}42Z_1 + 11{,}58Z_2 - 0{,}027Z_1Z_2 - 0{,}0042Z_1^2 - 0{,}9Z_2^2$ *(Z_1- temperature, °C; Z_2 – time, h; Y-hardness, HV) to find the aging mode for the highest hardness (60.6HV): 156°C-4.1h.*

Keywords: *Aluminum alloy, determination, Al-Mg-Si alloy.*

Date of Submission: 04-05-2022 Date of Acceptance: 18-05-2022

I. INTRODUCTION

Aluminum and aluminum alloys have a lot of advantages, so they are widely used, but the biggest disadvantage of aluminum and aluminum alloy is their low hardness and strength. In order to improve the durability, it is necessary to age the alloy. The durability can increase several dozen times after aging [1,2,3].

The study of aluminum alloy ageing process has been interested very early, especially with alloy systems such as dura. New alloy systems such as Al-Mg-Si have many advantages (cheaper, lighter, higher corrosion resistance in comparison with dura) that need to be exploited but have not been fully studied to improve hardness and durability.

Researching aluminum alloy aging requires a combination of several methods: using electron microscopy [3,4,5] to directly observe the phases, investigating the influence of technological parameters on mechanical properties, process modeling [6,7].

In terms of limited equipment, the topic focuses on building a mathematical model describing the relationship between technological parameters (temperature, time) with hardness. On that basis, the optimal ageing mode is proposed.

II. EXPERIMENTS

2.1 Samples preparation

Samples after casting, the organization received is often unbalanced (segregation, eutectic reaction,...), uniform annealing is conducted to overcome this situation.

Annealed samples are analyzed for composition. Analysis results: Mg: 0.56%; Si:0.84%; Fe:0.73%; the rest is Al.

The samples are taken from aluminum profiles with rectangular cross-section, the sample size is 25x12x5

2.2 *Experimental equipments*

Experimental studies were conducted at the laboratories of Hanoi University of Science and Technology, with the following main equipment:

- Resistance furnace, capacity 2.5KW-220V-1000°C;
- Resistance furnace, capacity 5KW-220V-1000°C;
- Drying cabinet, capacity 3.2KW-220V-250°C;
- Vicker ТПП-2 hardness tester;
- Chemical composition analysis equipment;
- Differential thermal analyzer.

2.3 Selection of ageing mode

From the analyzed chemical composition Mg: 0.56; Si: 0.835; Fe :0.73, the mass ratio of Mg/Si is: 0.67 (<1.73 corresponding to the Mg_2Si phase). In the organization of the alloy after annealing, in addition to the Mg_2Si phase, there is also a Si phase. The composition of the Mg_2Si phase in the alloy is: 0.88(%). Based on the Al-Mg-Si pseudo-system phase diagram through the Al-Mg_2Si cross-section [2], the hardening temperature is determined as: 535°C.

The sample is heated to 535°C, kept at heat for about 45÷60 minutes (dissolving completely into solid solution), then quenched in cold water (creating a solid solution that is supersaturated with alloying elements).

Based on the results of differential thermal analysis (Figure 1), the temperature range is selected from (100÷180)°C, corresponding to the thermal peaks at 100°C and 175°C. In this paper, the temperature range for testing is selected as (120÷180)°C .

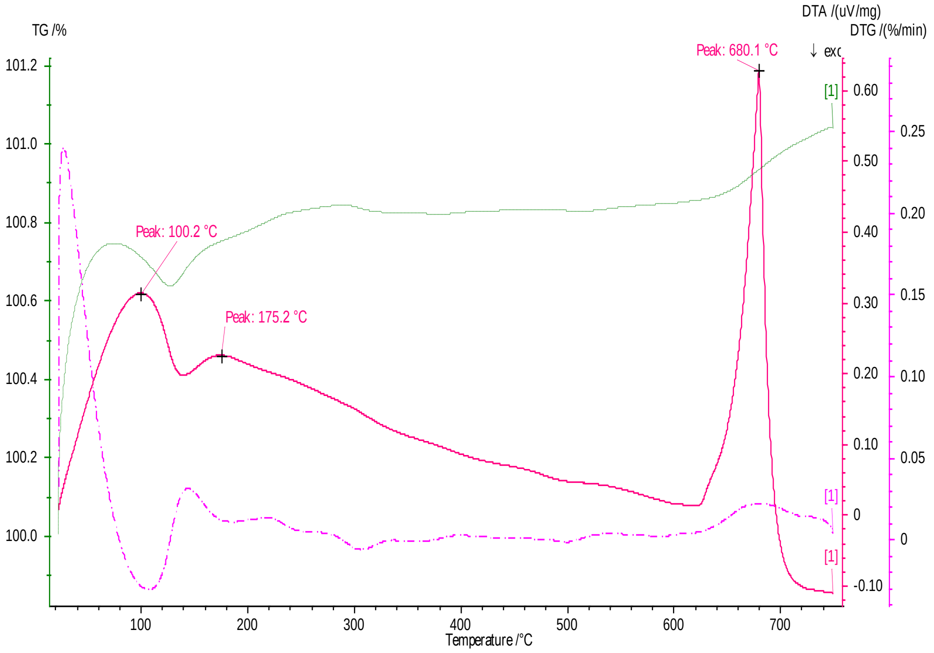


Figure 1. *Diagram of differential thermal analysis of Al-Mg-Si samples after quenching*

III. RESULTS AND DISCUSSION

3.1. Selection of influencing parameters

Through the literature review and the results obtained from the exploratory experiments, the main influencing parameters were selected as follows:

- Aging temperature, °C: Z_1
- Aging time, h: Z_2,

The range of influencing parameters is selected as listed in Table 1. The parameters are selected based on working requirements, in this paper the hardness (Y, HV) is selected for survey.

Table 1. *Survey values for influencing parameters*

	Ageing temperature Z_1, °C	Ageing time Z_2, h
Original value, Z^0_j	150	4
Divide interval, ΔZ_j	30	2
Upper bound	180	6
Lower bound	120	2

3.2. Set up the experiment matrix

To construct the experiment matrix, firstly the variables Z_j are converted to dimensionless variables x_j by:

$$x_j = \frac{Z_j - Z_j^0}{\Delta Z_j} \tag{1}$$

The general equation has the form:

$$y = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2 + b_{11}x_1^2 + b_{22}x_2^2 \tag{2}$$

Total number of experiments:

$$N = 2^k \; 2k + n_0 \tag{3}$$

k = 2 is the number of influencing parameters,
n_0 = 1 is the number of experiments in the center where the code values of the parameters are zero.
Therefore, the total number of experiments is: $2^3 + 4 = 9$

Table 2. *The values of Z_j and x_j*

N^0	x_0	x_1	x_2	Z_1	Z_2
1	+1	-1	-1	120	2
2	+1	+1	-1	180	2
3	+1	-1	+1	120	6
4	+1	+1	+1	180	6
5	+1	-1	0	120	4
6	+1	+1	0	180	4
7	+1	0	-1	150	2
8	+1	0	+1	150	6
9	+1	0	0	150	4

In order for the experimental matrix to be orthogonal, the square must be transformed to the form:

$$x'_j = x_j^2 - \frac{\sum_{i=1}^{N} x_{ij}^2}{N} = x_j^2 - \overline{x_j^2} \tag{4}$$

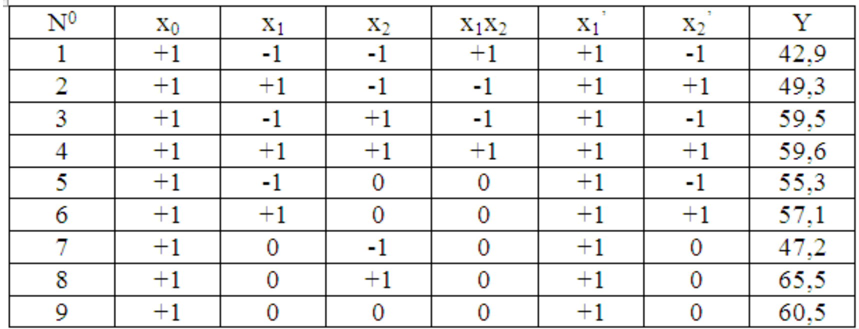
Orthogonal quadratic matrix with k = 2 given in table 3.

Table 3. *Experimental Matrix*

STT	x_0	x_1	x_2	x_1x_2	x_1’	x_2’
1	+1	-1	-1	+1	+1/3	+1/3
2	+1	+1	-1	-1	+1/3	+1/3
3	+1	-1	+1	-1	+1/3	+1/3
4	+1	+1	+1	+1	+1/3	+1/3
5	+1	-1	0	0	+1/3	-2/3
6	+1	+1	0	0	+1/3	-2/3
7	+1	0	-1	0	-2/3	+1/3
8	+1	0	+1	0	-2/3	+1/3
9	+1	0	0	0	-2/3	-2/3

On the basis of the experimental plan mentioned in Table 3, the experiments are conducted. The results are presented in Table 4.

Table 4. *Full experimental results*



N^0	x_0	x_1	x_2	x_1x_2	x_1'	x_2'	Y
1	+1	-1	-1	+1	+1	-1	42,9
2	+1	+1	-1	-1	+1	+1	49,3
3	+1	-1	+1	-1	+1	-1	59,5
4	+1	+1	+1	+1	+1	+1	59,6
5	+1	-1	0	0	+1	-1	55,3
6	+1	+1	0	0	+1	+1	57,1
7	+1	0	-1	0	+1	0	47,2
8	+1	0	+1	0	+1	0	65,5
9	+1	0	0	0	+1	0	60,5

From the table of experimental results, the experimental coefficients are calculated, the obtained mathematical model has the form:

$$Y = 60{,}2 + 1{,}4x_1 + 7{,}5x_2 - 1{,}6x_1x_2 - 3{,}8x_1^2 - 3{,}6x_2^2 \tag{5}$$

Switch to variable Z_j:

$$Y = -73,7+1,42Z_1+11,58Z_2–0,027Z_1Z_2 – 0,0042Z_1^2 – 0,9Z_2^2 \qquad (6)$$

The fit of the model is checked by Fisher's standard:

$$F = \frac{S^2_{du}}{S^2_{11}} \qquad (7)$$

$F = 2,05 < F_{0,01;6;5} = 28,2$. The selected model is suitable.

3.3. Technology optimization

$$\begin{cases} \dfrac{\partial Y}{\partial Z_1} = 1,42 - 0,027Z_2 - 0,0084Z_1 \\ \dfrac{\partial Y}{\partial Z_2} = 11,58 - 0,027Z_1 - 1,8Z_2 \end{cases}$$

Solve the system of equations: $\begin{cases} \dfrac{\partial Y}{\partial Z_1} = 1,42 - 0,027Z_2 - 0,0084Z_1 = 0 \\ \dfrac{\partial Y}{\partial Z_2} = 11,58 - 0,027Z_1 - 1,8Z_2 = 0 \end{cases}$

Resulting to: $\mathbf{Z_1 = 155,8; Z_2 = 4,1}$

Thus, it is needed to age the alloy at 155.8°C for 4.1h to get the maximum hardness, then the maximum hardness is: $\mathbf{Y_{max} = 60.7}$

The relationship between the alloy hardness and the technological parameters is built according to the equation:

Y = -73,7 + 1,42Z1 + 11,58Z2 – 0,027Z1Z2 – 0,0042Z12 – 0,9Z22

IV. CONCLUSION

The higher the ageing temperature, the faster the ageing process occurs. At 120°C, 150°C, 180°C, the hardness reaches the maximum (55.5HV; 60.6HV; 58.3HV) when ageing for a period of 3.6h; 4.2h and 4.6h. To achieve maximum hardness, it is necessary to age at 155.8°C for 4.1h.

Conflict of interest

There is no conflict to disclose.

ACKNOWLEDGEMENT

This work was supported by Thai Nguyen University of Technology, Vietnam.

REFERENCES

[1]. Nguyễn Khắc Xương, *Vật liệu kim loại màu*, Nhà xuất bản Khoa học và kỹ thuật, 2003. (Vietnamese)

[2]. Phạm Thị Minh Phương-Tạ Văn Thất, *Công nghệ nhiệt luyên*, Nhà xuất bản giáo dục, 2000. (Vietnamese)

[3]. Đoàn Châu Long, *Hóa già hợp kim nhôm*, Hội thảo khoa học, Bộ môn Vật liệu học và Nhiệt luyện, 2003. (Vietnamese)

[4]. Semiatin, S.L., Montheillet, F., Shen, G. *et al.* Self-consistent modeling of the flow behavior of wrought alpha/beta titanium alloys under isothermal and nonisothermal hot-working conditions. *Metall Mater Trans A* **33,** 2719–2727 (2002). https://doi.org/10.1007/s11661-002-0394-9

[5]. Raghavan, V., & Cohen, M. (1975). Solid-state phase transformations. In *Changes of State* (pp. 67-127). Springer, Boston, MA.

[6]. Lê Công Dưỡng,*Vật liệu học*, Nhà xuất bản giáo dục, 2000. (Vietnamese)

[7]. Nguyễn Minh Tuyển, *Quy hoạch thực nghiệm*, Nhà xuất bản khoa học và kỹ thuật. (Vietnamese)

Hoang Anh Quang. "Determination of Optimized Ageing Mode for Al-Mg-Si Alloy." *International Journal of Engineering and Science*, vol. 12, no. 5, 2022, pp. 40-43.