International Journal of Advance Research in Science and Engineering
Volume No.07, Special Issue No.04, March 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

STUDY ON TENSILE STRENGTH ON ARTIFICIALLY AGED Al-Mg-Si ALLOY USING TAGUCHI'S TECHNIQUE

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ABSTRACT

Al-Mg-Si alloy has been selected by many designers and engineers for different kind of applications. Further, its strength is improved by cold working, grain size refining, precipitation hardening and dispersion hardening. The requirement of Al-Mg-Si alloy grows rapidly because it has unique combination of properties, which make it as one of the most versatile engineering materials. In the present study, experiments are conducted to investigate the effects of age hardening parameters like, Solutionizing Time, Aging Temperature and Ageing Time on tensile strength of Al-Mg-Si alloy using Taguchi's Design of Experiments. A linier regression model is used to predict the response. From the results it can be seen that, the ageing temperature and time have a imperative effect on the response whereas, solutionizing time does not have a significant effect. For a specific set of parameters the hardness is improved from 154 to 210 MPa, resulted in an increase in Ultimate Tensile Strength by about 40%.

Keywords— Al-Mg-Si alloy, Design of Experiments, Ultimate Tensile Strength (UTS), Artificial aging.

I.INTRODUCTION

The process is called Age Hardening which involves three distinct steps: Solution Treatment to minimize segregation in the alloy, Quenching to create a supersaturated solid solution and Aging to facilitate the formation of coherent precipitates which strengthen the alloy by interfering with dislocation movement. The strength of Al-Mg-Si alloys may be improved by the formation of very small uniformly dispersed particles of a second phase within the original phase matrix; this must be accomplished by appropriate heat treatment techniques [1-10]. The presence of major solutes such as Mg and Si in the 6XXX series alloy shows exceptional increase in strength during precipitation hardening [11-14]. Researches on precipitation sequence reveals that, the variation of the hardness versus aging temperature and time can be associated to the transformation of phase taking place during aging treatment. The increase in mechanical properties during aging is due to the vacancy

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assisted diffusion mechanism in under aged and peak aged conditions [15-18]. The formation of GP zones depends upon the aging temperature, which distorts the lattice planes [19]. This distortion of the lattice planes hindering the dislocation movement as long as the coherency exists in the lattice [20-22].

II. EXPERIMENTAL PROCEDURE

A. *Specimen Preparation*

Commercially available Al-Mg-Si alloys are melted in a furnace at 800° C. After complete melting, an appropriate amount of degasser hexachloroethane tablets are added followed by a small amount of alkaline powder (to remove impurities forming slag). Mixing was done manually to allow the gases to escape.

Figure 1: Mold prepared for pouring molten metal after casting

The permanent mold made of cast iron is preheated in a separate furnace at 600°C for 2 hr. The melt is poured into the preheated permanent mold and allowed to solidify. Table 1 shows the nominal composition weight percentage of Al-Mg-Si matrix material.

Table I

Composition (Wt.%) OF Al-Mg-Si alloy

Material	Si	Cu	Fe	Mg	Cr	Al
Wt % (Cast)	0.60	0.20	0.65	0.99	0.25	Balance
Wt% (Standard)	0.40 – 0.80	0.15 – 0.40	0.70 max	0.80 – 1.20	0.04 – 0.35	Balance

A. *Artificial aging treatment*

The tensile samples are prepared as per ASTM-E10 standards shown in figure 2. The specimen prepared for the above test is subjected to age hardening heat treatment. Specimens are soaked at 550°C for 3 hr, then immediately quenched in water at room temperature. The solutionized specimens are artificially aged in the furnace at 100°C, 150°C and 200°C for 5, 8 and 11hr, obtained during hardness test to get peak hardness. Figure

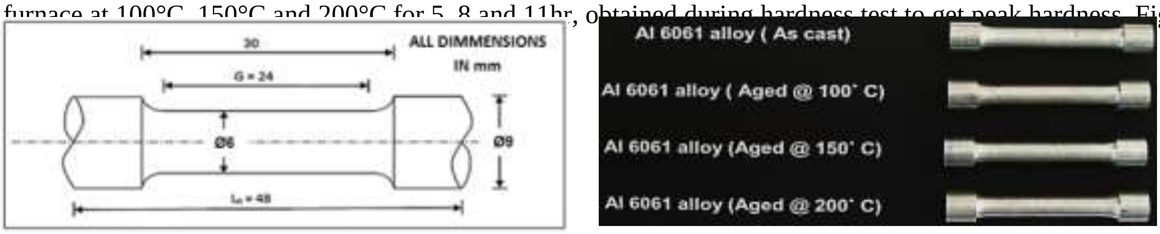


Figure 2: Sample prepared for Ultimate tensile strength test (ASTM-E10M)

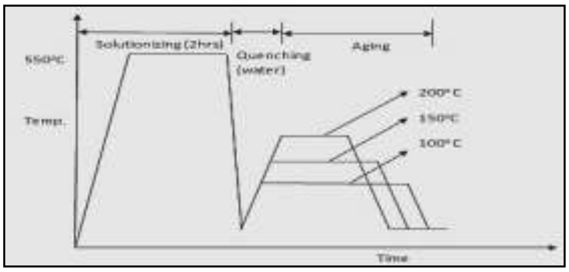


Figure 3: Age hardening treatment cycle for Al 6061 alloy

III. EXPERIMENTAL DESIGN AND ANALYSIS

A. Experimental Design

Classical experimental design methods are complex and difficult to use. Additionally large number of experiments needs to be carried out when number of parameters is large as stated by Luo et al., [25].

In this study, the Taguchi method is used to determine optimal parameters for maximum tensile strength. In the Taguchi method, process parameters, which influence the product, are categorized into two main groups: control factors and noise factors [23-24].The control factors are used to select the best conditions for stability in design, whereas the noise factors represent all factors that cause variation. Taguchi proposed to acquire the characteristic data by using orthogonal arrays, and to analyze the performance measure from the data to decide the optimal process parameters. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only. L_9 orthogonal array is used with 3 factors and 3 levels. The analysis is made using MINITAB 16 software. The sequence of operations involved in the age hardening of non-ferrous aluminium alloys consist of solutionizing, quenching and artificial aging. In the above mentioned sequence, the major process parameters considered for the analysis are Solutionizing time (A), Aging temperature (B) and Aging time (C) at three levels are chosen [26]. The factors and levels of experimentation is given in Table 2. The experimental design and the average tensile strength values are depicted in Table 3.

Table 2

Factors and levels of experimentation

Symbol	Parameters	Level 1	Level 2	Level 3
A	Solutionizing Time (h)	1	2	3
B	Ageing Temperature	100	150	200
C	Ageing Time (h)	5	8	11

Table 3

Experimental design and average measured ultimate tensile strength values

Exp. No.	Factor A	B	C	Ultimate Tensile
1	1	100	5	170
2	1	150	8	185
3	1	200	11	154
4	2	100	8	199
5	2	150	11	192
6	2	200	5	154
7	3	100	11	210
8	3	150	5	185
9	3	200	8	165

9 3 200 8 165

IV. RESULTS AND DISCUSSION

In this study, the experiments are carried out for identifying the effects of process parameters such as Solutionizing time (A), Aging temperature (B) and Aging time (C) to maximize the UTS. The main effect plots for UTS (larger is the better) is shown in figure 4. From the plot it is evident that the aging time and aging temperature are the significant parameters that has highest influence on the UTS. Lower aging temperature and higher aging duration results in higher UTS value, but higher aging temperature shows lower UTS. The rise in temperature causes the aging rate to increase due to the enhanced rate of diffusion of solid atom through the matrix. Solutionizing time found to be least contributing process parameter to influence the UTS. This is because in unreinforced alloy, the influence of solutionizing time is confined only to ensure complete solubility of β-phase in α-phase [27]. It is also evident from the main effects plot that solutionizing time of 2 hr, aging temperature of 100° C and aging time of 10 hr are the optimum parameter combination to obtain maximum UTS during age hardening of Al 6061 alloy as shown in figure 5. The measured UTS from experiment and the predicted values from regression equation are given in Table 4.

It can be seen from the ANOVA Table (Table 5) that the aging temperature has the highest contribution (55.74%), followed by aging time (23.94%). Since the P value of solutionizing time is grater then 0.05, which indicates that solutionizing time doesn't have significant effect on the UTS.

We consider a measure of the model's overall performance referred to as the coefficient of determination and denoted by R^2. In the model, R^2 is obtained equal to 95.40% for UTS values. This indicates that the age hardening process parameters explain 95.40% of variance in UTS. The normal probability plot of the residuals is shown in figure 6. The predicted values are found to be statistically similar to the actual measured values, based on the probability plot. A check on the plot in figure 6 shown that the residuals generally fall on a straight line implying that the errors are distributed normally. Table 4 clearly shows that, the predicted value obtained from regression equation is quite close to the experimental observation. The fit obtained from experimental UTS values and predicted values are found to be good. The % error between the experimental results and the predicted values for UTS lie within 0.06 to 4.44. In the prediction of UTS values the average absolute error for hardness is found to be as about 2.41%. Analysis of variance (ANOVA) essentially consists of partitioning the total variation in an experiment into components ascribable to the controlled factors and error. The ANOVA for UTS values is carried out for a significance level of $\alpha = 0.05$, i.e., for a confidence level of 95%. The sources with P values less than 0.05 are considered to have statistically significant effect on the response.

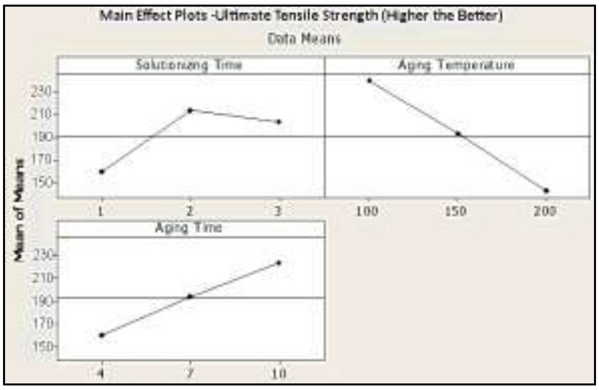


Figure 4: Main effect plot of UTS for the age hardening of Al 6061 alloy

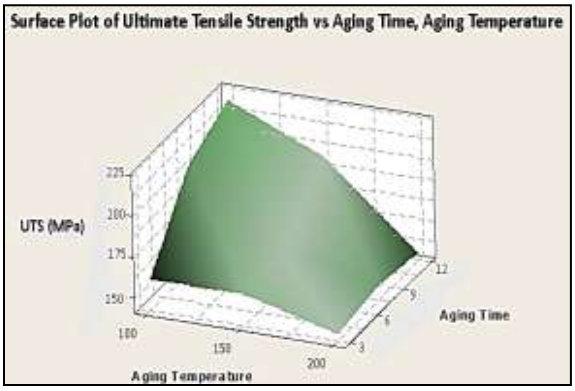


Figure 5: Surface lot of UTS vs aging time and aging Temperature

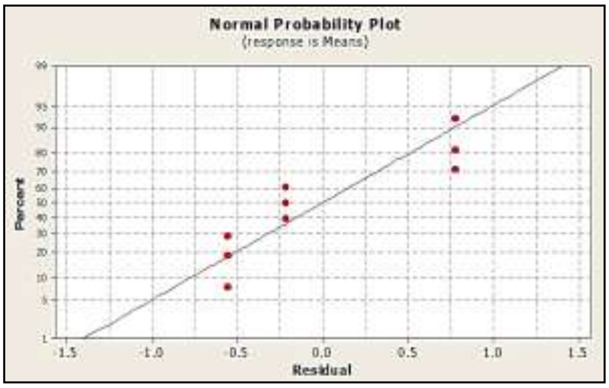
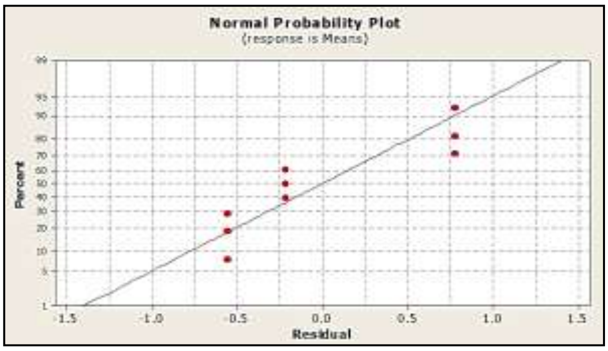


Figure 6: Normal probability plot for UTS measurement.



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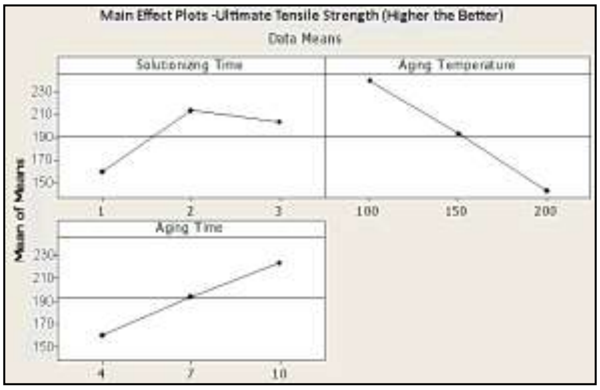
IJARSE
ISSN: 2319-8354



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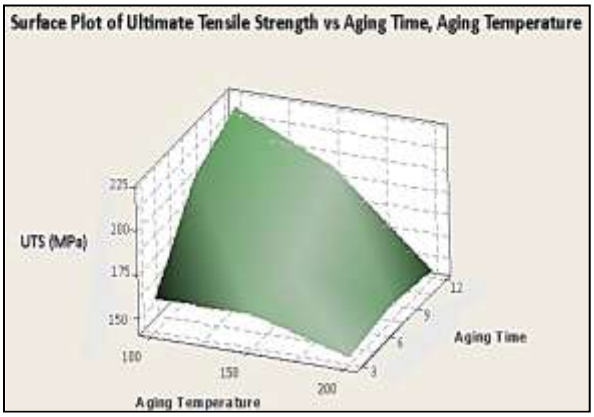

Figure 5: Surface lot of UTS vs aging time and aging Temperature

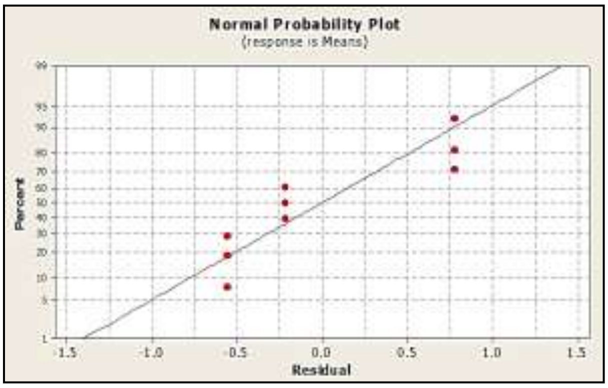

Figure 6: Normal probability plot for UTS measurement.

Table 4

Regression data showing measured, predicted and residual values for the UTS.

Exp. No.	Measure dUTS (MPa)	Predicted UTS (MPa)	Differenc e	% Error
1	170	172.71	2.71	4.44
2	185	185.04	0.04	0.06
3	154	155.37	1.37	2.32
4	199	200.04	1.94	2.73
5	192	193.61	1.61	2.33
6	154	156.82	2.82	4.78
7	210	210.41	0.41	0.55
8	185	186.2	1.2	1.94
9	165	166.53	1.53	2.55
			Average error = 2.41	

The regression equation for UTS is,BHN= 167.0 + 2.17 * Solutionizing Time (A)- 0.0967 * Aging Temperature (B) + 1.06 * Aging Time (C)

Table 5

Analysis of variance for UTS values

P value <0.05 has significant effect on UTS

V.CONCLUSION

Based on the experimental results, the following conclusions can be drawn,

- The experimental results show that the aging temperature has the highest influence on the UTS followed by the aging time.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contribution	Rank	R^2
Solutionizing Time (A)	2	48.22	48.22	24.11	16.69	0.057	19.17	3	95.40%
Aging Temperature (B)	2	140.222	140.222	70.111	48.54	0.020	55.74	1	
Aging Time (C)	2	60.222	60.222	30.111	20.85	0.046	23.94	2	
Residual Error	2	2.889	2.889	1.444					
Total	8	251.556							

- The investigation reveals that maximum UTS is obtained at aging temperature of 100□C, aging time of 10 hr and solutionizing time of 2 hr.
- It is also observed that UTS decreases with increase in aging temperature due to enhanced rate of diffusion.

- From the experiments it is also inferred that solutionizing time has very less influence on the UTS.
- The analysis of the study demonstrate that there is a good agreement between the experimental and the predicted values of the UTS.

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