DOR:

Research Paper

Investigating the Effect of T6 Heat Treatment on Mechanical Properties of 7075 Al Alloy

Mohsen Emami[1*], Vahid Hasan Nasab[1]
[1]Department of Mechanical Engineering, Behbahan Khatam Alanbia University of Technology, Behbahan, Iran
[*]Email of the Corresponding Author: Dr.emami@bkatu.ac.ir
Received: March 29, 2024; Accepted: June 23, 2024

Abstract
Age hardening is one of the most important methods used to improve the mechanical properties of non-ferrous alloys such as nickel, titanium, magnesium, and aluminum alloys. However, finding the optimal age hardening parameters to achieve higher mechanical properties—such as hardness, yield stress, tensile strength, and fatigue life—is essential. In this study, the effect of T6 heat treatment parameters, including solution and aging conditions, on the mechanical properties of commercial alloy 7075 was investigated. The Taguchi method was employed to design the experiments and analyze the results. Solution temperature, solution time, aging temperature, and aging time were the T6 heat treatment factors considered in this design. Temperatures of 430, 470, and 510 °C and times of 15, 35, and 55 minutes were set as the solution treatment levels. Additionally, temperatures of 140, 170, and 200 °C and times of 2, 7, and 12 hours were determined as the aging treatment levels. Upon optimization, the material achieved a Vickers hardness of 137.28 HV, yield strength of 266.91 MPa, tensile strength of 377.64 MPa, elongation to break of 15.19%, and fatigue life of 1,193,304 cycles. According to the research findings, achieving optimal mechanical properties such as hardness, tensile strength, and fatigue strength requires specific and distinct heat treatment conditions.

Keywords
T6 Heat Treatment, Age Hardening, Aluminum Alloy 7075, Taguchi, Mechanical Properties, Optimization

1. Introduction

Heat treatment in its broadest sense, refers to any of the heating and cooling operations performed to change the mechanical properties, metallurgical structure, or residual stress state of a metal product. Age hardening (precipitation hardening) is one of the methods of strengthening metal material by creating hard and completely dispersed particles in it. One of the fundamental characteristics of a precipitation-hardening alloy system is the temperature-dependent equilibrium solid solubility, in which the dissolution of the soluble phase increases as temperature increases. Although most binary aluminum alloys meet this condition, many show minimal precipitation hardening, and these alloys are not usually considered heat-treatable. For example, alloys of the aluminum-silicon and aluminum-manganese binary systems exhibit only minor changes in mechanical properties after precipitation heat treatment. The main aluminum alloy systems with precipitation hardening include:

- Aluminum-copper systems with strengthening from $CuAl_2$
- Aluminum-copper-magnesium system (magnesium intensifies precipitation)
- Aluminum-magnesium-silicon systems with strengthening from Mg_2Si
- Aluminum-zinc-magnesium systems with strengthening from $MgZn_2$
- Aluminum-zinc-magnesium-copper system

The formation of finely dispersed precipitates during the aging heat treatment is a requirement for precipitation strengthening of supersaturated solid solutions. In general, there are three steps in the age hardening heat treatment:

- Solution heat treatment: dissolution of soluble phases
- Quenching: rapid cooling to ambient temperature to develop a supersaturated solid solution
- Age hardening: precipitation of solute atoms

The purpose of solution heat treatment is to achieve complete dissolution of alloy elements. After the alloy has been heated to a certain temperature in the single-phase region for a certain period, it is rapidly cooled in water. The quenched alloy is a supersaturated solid solution and is therefore in an unstable state, where excess solute atoms tend to leave the solution. In the third stage of aging heat treatment, the supersaturated solid solution of the main alloying elements in aluminum is decomposed to form fine and dispersed precipitates in the metal matrix. In other words, the aging step is to allow the strengthening phase to form precipitates from the supersaturated solid solution. Precipitation strengthening of supersaturated solid solutions can be achieved at room temperature (natural aging) or elevated temperature (artificial aging). Artificial aging must not only take place below the equilibrium solvus temperature but also below a metastable miscibility gap called the solvus line of the Guinier-Preston (GP) region. T6 and T4 respectively refer to natural and artificial aging heat treatment of aluminum alloy [1]. The sequence of phases formed in the precipitation hardening heat treatment for 7000 series aluminum alloys can be summarized as follows [2,3].

1. α-Supersaturated solid solution
2. Unstable GP zones
3. Unstable phase η'
4. stable phase η($MgZn_2$)

The GP zones range in size from tens of angstroms in diameter. They are regions of the matrix lattice that are distorted, rather than individual particles of a new phase that have a different lattice. As a result, they are completely coherent with the matrix, causing local but often significant strains. These mechanical strains, combined with the presence of a locally solute-rich, sometimes ordered lattice, can account for large changes in the mechanical properties of the alloy before any long-range microstructural changes occur [1]. 7075 is an aluminum alloy with zinc (Zn) as the primary alloying element. The composition of this alloy includes zinc, magnesium, copper, silicon, iron, manganese, titanium, chromium, and other metals. Aluminum alloy 7075 has excellent mechanical properties, good formability, strength, toughness, and fatigue resistance. Compared to other aluminum alloys, it is more susceptible to embrittlement due to microsegregation. However, it has much better corrosion resistance than the 2000 series alloys. 7075 is one of the most common aluminum alloys used for high-stress structural applications. The mechanical property of the high strength-to-weight ratio is achieved by the precipitation hardening mechanism. The microstructure of 7075 aluminum alloy is very sensitive to heat treatment. Previous research has shown that precipitation hardening changes the size, composition, and distribution of intermetallic deposits in this alloy [4,5]. To obtain 7075 Al alloy with high strength, heat treatment is a key process to improve the mechanical properties after the forming process. The T6 precipitation heat treatment is one of the most common methods of increasing the mechanical properties of this alloy [6, 7]. Chen et al. [8] investigated the effects of T6 heat treatment process parameters (solution time and temperature, aging time and temperature) on microstructure and mechanical properties of large-weight aluminum alloy flywheel housing parts formed by local-loading squeeze casting. Their mechanical property test results indicated that the improvement of strength was limited with the increase of solution temperature and solution time, but the elongation improved significantly. It is worth noting that solution and aging conditions significantly affect the heat treatment results. Sowrabh et al. [9] conducted a study on the impact of multi-step aging treatment on Aluminum alloy 7075. Their findings demonstrated that the modified aging treatment notably enhanced the hardness and ultimate tensile strength of the alloy. In previous studies, the solution temperature of 465-490°C, the aging temperature of 115-190°C, and the aging time of 5-48 hrs have been suggested for the T6 heat treatment of 7075 aluminum alloy [1]. Aging heat treatments are usually low-temperature, and long-term processes. The furnace holding time in solution and aging operations has a considerable impact on the final product in precipitation heat treatment. Therefore, the choice of time-temperature cycles for precipitation heat treatment should be carefully considered. The results of previous studies have shown that temperature and time of solution and artificial aging in T6 heat treatment are important parameters that determine the mechanical properties of 7075 aluminum alloy. In addition, the longer the aging process in the furnace, the higher the production costs. This is especially problematic for small heat treatment workshops with limited equipment and furnaces. For this reason, reaching the optimal conditions and reducing the furnace holding time in the age hardening process can considerably reduce costs and increase the productivity of these workshops. Unfortunately, the cycle required to maximize one property, such as hardness, is usually different from that required to maximize others, such as yield strength, tensile strength, and fatigue strength. Optimizing the age hardening parameters to achieve the highest mechanical properties using statistical methods is an effective way to improve productivity. This study evaluates the impact of the solution and artificial aging parameters of the T6 heat treatment process on the mechanical properties of aluminum 7075. The Taguchi DOE method is used to determine the optimal condition for each mechanical property.

2. Experimental Design

Design of experiments (DOE) is an efficient technique for systematic planning and statistical evaluation of experiments. Taguchi's method is considered one of the common methods of experimental design and optimization and has been widely used in the design of various process tests [10, 11]. As stated in the introduction section, the Taguchi method has been employed in this research to design the experiments and analyze the results. Specifically, the study utilizes Taguchi to investigate the impact of the main factors of the T6 age hardening process, including solution temperature, solution time, aging temperature, and aging time, on the mechanical properties of 7075 aluminum samples. In this experimental design, three levels were considered for each of the four parameters mentioned in the T6 heat treatment operation. Table 1 shows the parameters (factors) and their values (levels) for the experiment. The solution temperature values (430, 470, and 510 °C) were chosen using the results of previous research to cover a wide range of previously reported temperatures.

Table 1. Parameters and their values for designing the experiments

Process parameters	Unit	Level 1	Level 2	Level 3
Solution temperature	(°C)	430	470	510
Solution time	(min)	15	35	55
Aging temperature	(°C)	140	170	200
Aging time	(hr)	2	7	12

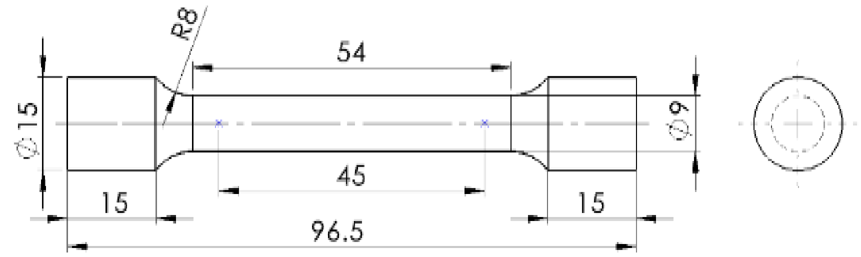
The time range of the solution operation was ascertained based on the dimensions of the test samples. Due to the small dimensions of the test samples, solution times of 15, 35, and 55 minutes were determined. It should be noted that if the thickness of the sample increases, the solution time should be increased. In this research, the temperature and time of aging heat treatment including temperatures of 140, 170, and 200 °C and times of 2, 7, and 12 hr were chosen in such a way that despite achieving relatively high hardness, optimal aging times can be obtained compared to other resources. One reason for using the Taguchi method in this research is the employment of orthogonal arrays. That is, in this method, each parameter has equal weights, which allows for optimal design with minimal execution and cost. An L9 orthogonal array was used, requiring 9 tests. While full factorial design would require 81 experiments, and response surface design would require 60. Despite this, by Taguchi's L9 array for four parameters and three levels each, only main effects and no interactions are visible. Table 2 shows the tested parameters (factors) and their values (levels) for each experiment.

Table 2. Experiments designed based on orthogonal L9 array

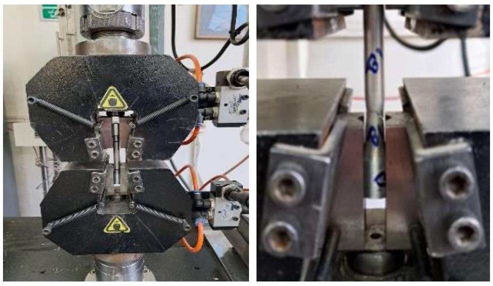
Test No.	Solution Temp. (°C)	Solution Time (min)	Aging Temp. (°C)	Aging Time (hr)	Number of Specimens
1	430	15	140	2	3
2	430	35	170	7	3
3	430	55	200	12	3
4	470	15	170	12	3
5	470	35	200	2	3
6	470	55	140	7	3
7	510	15	200	7	3
8	510	35	140	12	3
9	510	55	170	2	3

3. Materials and Methods

A bar made of aluminum alloy 7075 with a diameter of 14 mm and a length of 6 m was used to prepare the test samples. 27 samples were fabricated from the 7075 aluminum alloy bar for hardness, tensile and fatigue tests. Cylindrical pieces with a diameter of 13 mm and a length of 10 mm were machined for the hardness tests. The cross-sectional faces of the samples were polished by a polisher made by Pouyesh Sanat Yekta Co. using 180 to 2000 grit sandpaper to prepare for hardness testing. A laboratory box furnace model F11L-1250 manufactured by Azar Furnace Co. was used to heat the samples. The T6 heat treatment operation was carried out as per the solution and aging temperatures and times shown in Table 2. Each specimen was solution heat treated followed by water quenching to room temperature. Immediately after quenching, each sample was aged under the conditions specified in Table 2 followed by air cooling. Then each batch of heat-treated samples was subjected to mechanical tests including hardness, tensile, and fatigue tests. The Micro Vickers hardness tester model MV400 made by Pouyesh Sanat Yekta Co. was used to measure the hardness of the samples. The tensile test specimens were designed and fabricated per the standard test method of tension testing of Aluminium alloy products of ASTM B557M-15. In Figure 1(a), the two-dimensional model of the tensile test samples is shown. The STM-150 universal testing machine manufactured by Santam Co. was used to conduct the tensile tests. In Figure 1(b), a sample is prepared for testing in the tensile machine, and in Figure 1(c), the sample after failure is shown.



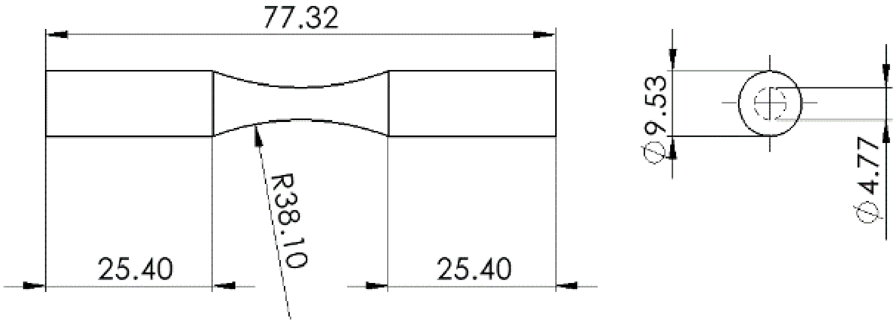
(a)



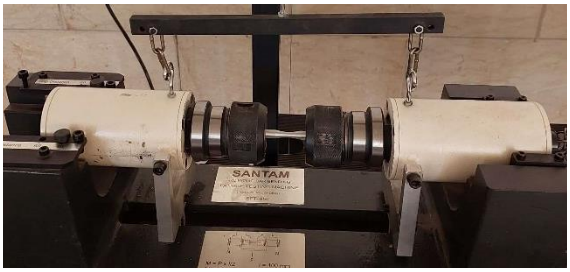
(b) (c)

Figure 1. (a) Schematic of the tensile test specimen, (b) A sample prepared for testing in the tensile machine (c) A sample after fracture

Cylindrical specimens with reduced gage section (i.e. hourglass specimen) for rotating bending fatigue test, were designed according to ISO 1143:2021 [12]. The fatigue specimen geometries and dimensions are shown in Figure 2(a). The rotating bending fatigue tests were performed with a Santam SFT-850 fatigue test machine with a frequency of 30 Hz. In Figure 2(b), a sample is prepared for testing in the fatigue machine, and in Figure 2(c), the sample after failure is shown.



(a)



(b)

(c)

Figure 2. (a) Schematic of a fatigue test specimen, (b) A sample prepared for testing in the fatigue machine, (c) A sample after fracture

4. Analysis of Results

4.1 Mechanical Properties Measurements

After T6 heat treatment, the mechanical properties of the samples including hardness, yield strain, yield stress, tensile strength, elongation to break, and fatigue life were measured and the average values were recorded as shown in Table 3. In addition, the tensile and fatigue samples after failure are shown in Figures. 3 and 4 respectively.

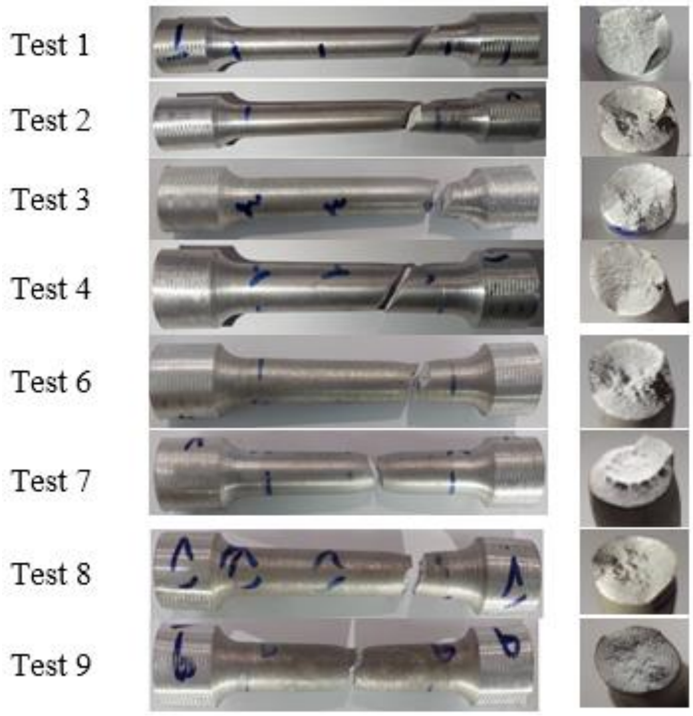


Figure 3. The tensile test samples after failure

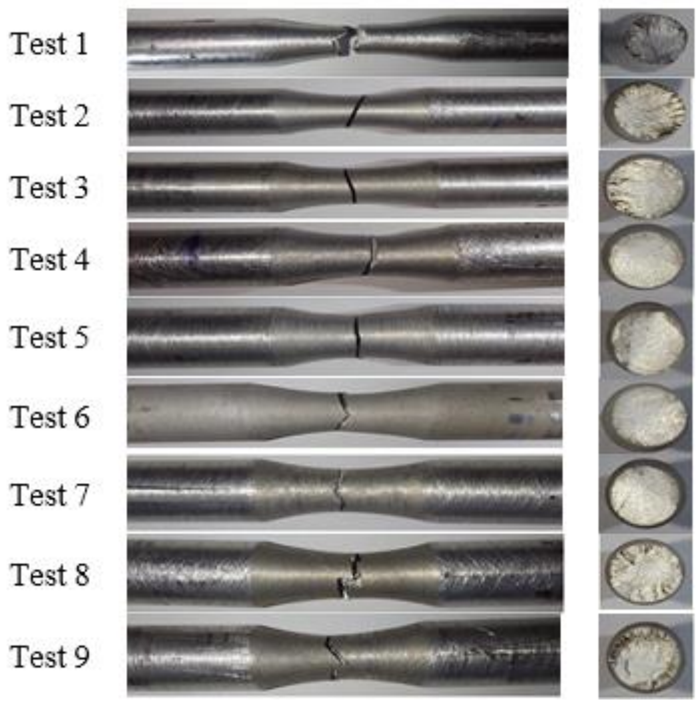


Figure 4. The fatigue test samples after failure

Table 3. The average value of mechanical properties of samples after T6 heat treatment

Test No.	Solution Temp. (°C)	Solution Time, (min)	Aging Temp. (°C)	Aging Time, (hr)	Hardness (HV)	Yield Strain	Yield Stress, (Mpa)	Tensile Strength, (Mpa)	Elongation to Break %	Fatigue life, Cycle
1	430	15	140	2	107.203	0.133	175	303.76	29.16	86500
2	430	35	170	7	102.027	0.167	160	284.10	31.24	59639
3	430	55	200	12	74.867	0.111	130	221	27.78	721429
4	470	15	170	12	112.654	0.144	216	295.55	22.35	476300
5	470	35	200	2	92.720	0.133	186	299.48	32.22	786976
6	470	55	140	7	119.786	0.155	170.691	310.64	32.49	1010663
7	510	15	200	7	89.903	0.111	200	279.88	26.24	304422
8	510	35	140	12	137.282	0.144	245	350.66	27.63	214871
9	510	55	170	2	114.469	0.122	255	344.47	29.16	33777

4.2 Statistical Analysis

In this study, the statistical analysis of the experimental results was performed using the signal-to-noise ratio (S/N) analysis. Signal-to-noise (S/N) is the ratio of the desired signal to unwanted random noise and represents the performance characteristics of the observed data as an objective function. These S/N ratios are derived from the quadratic loss function and expressed on a decibel (dB) scale. In addition, the signal-to-noise ratio (S/N) can be used to measure the percentage contribution of process parameters through analysis of variance [13]. In the optimization process, the signal-to-noise ratio (S/N) as an objective function can be divided into three types (quality characteristics): 1- the smaller the better, 2- the larger the better, and 3- the nominal the better [14]. The objective of the present experiment is to maximize the response, and hence "the larger the better", is used as the desired characteristic. The signal-to-noise ratio (S/N) for the quality characteristic "the larger the better" is as follows:

$$\frac{S}{N} = -10\, log[\frac{1}{n}(\sum_{i=1}^{n}\frac{1}{yi^2})] \tag{1}$$

where n is the number of observations and is the i-th value observed in an$y$ i experiment. Regardless of the type of quality characteristic, parameters that have the highest signal-to-noise ratio (S/N) always result in optimal quality with minimum variance [14]. As a result, the optimal level of the process parameters is the level that has the highest signal-to-noise ratio (S/N).

4.3 Hardness

The calculated signal-to-noise (S/N) ratios for the hardness of the 7075 aluminum samples at each level of process parameters are presented in Table 4.

Table 4. Response table for signal-to-noise (S/N) ratio for hardness

Level	Solution Temp.	Solution Time	Aging Temp.	Aging Time
1	39.42	40.24	41.64	40.37
2	40.65	40.76	40.79	40.27
3	41.00	40.08	38.63	40.42
Delta	1.58	0.68	3.01	0.15
Rank	2	3	1	4

It's important to note that the process parameter with a higher rank and larger delta has a greater impact on the hardness result, as shown in the table. Based on the ranking result, aging temperature, solution temperature, solution time, and aging time have the greatest contribution to the sample's hardness. Figure 5 displays the main effects plot for the signal-to-noise (S/N) ratio concerning the average hardness of the 7075 aluminum samples.

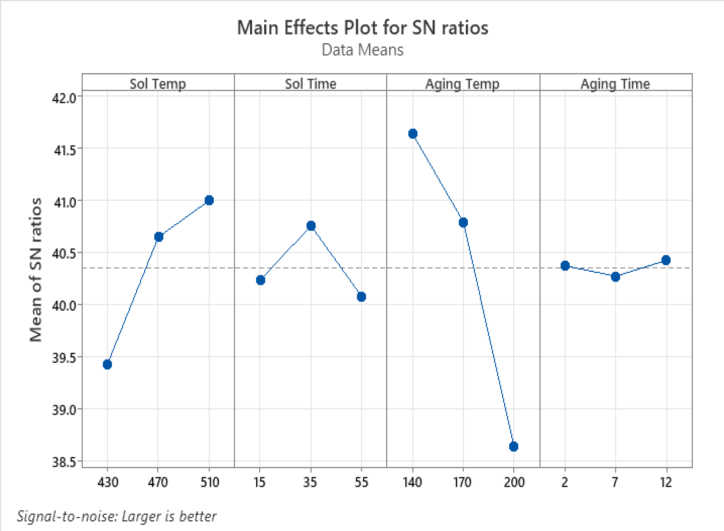


Figure 5. Main effects plot of S/N ratios for hardness

Based on the signal-to-noise (S/N) ratio analysis, the optimal parameters to achieve the highest hardness for aluminum 7075 in T6 precipitation hardening heat treatment are as follows: solution temperature of 510°C, solution time of 35 minutes, aging temperature of 140°C, and aging time of 12 hours. Moreover, Figure 5 shows that increasing aging time above 140°C decreases material hardness. This may be attributed to the effect of overheating on the solute-rich microstructural domains or GP zones. The GP zones get dissolved at temperatures over 150°C, and the resulting precipitate is coarse and widely distributed, leading to lower hardness [1].

4.4 Yield Stress

The calculated signal-to-noise (S/N) ratios for the yield stress of the 7075 aluminum samples at each level of process parameters are depicted in Table 5. From the table, it is evident that the solution temperature has the highest impact on the yield stress, followed by aging temperature, aging time, and solution time, respectively.

Table 5. Response table for signal-to-noise (S/N) ratio for yield stress

Level	Solution Temp.	Solution Time	Aging Temp.	Aging Time
1	43.74	45.86	45.76	46.13
2	45.57	45.75	46.30	44.92
3	47.31	45.02	44.56	45.58
Delta	3.57	0.84	1.74	1.21
Rank	1	4	2	3

In Figure 6 the main effects plot for the signal-to-noise (S/N) ratio of the average yield stress of the 7075 aluminum samples is shown. The results of signal-to-noise (S/N) ratio analysis show that the maximum yield stress for aluminum 7075 in T6 precipitation hardening heat treatment occurs at a solution temperature of 510°C, a solution time of 15 minutes, an aging temperature of 170°C and an aging time of 2 hours.

Figure 6. Main effects plot of S/N ratios for yield stress

4.5 Tensile Strength

The response table for the signal-to-noise (S/N) ratio for tensile strength is shown in Table 6.

Table 6. Response table for signal-to-noise (S/N) ratio for tensile strength

Level	Solution Temp.	Solution Time	Aging Temp.	Aging Time
1	48.54	49.33	50.13	49.97
2	49.60	49.83	49.74	49.28
3	50.19	49.16	48.45	49.07
Delta	1.66	0.67	1.68	0.91
Rank	2	4	1	3

From this table, the aging temperature, solution temperature, aging time, and solution time respectively are the parameters with the highest impact on the tensile strength of 7075 aluminum samples. Also, the main effects plot of S/N ratios for tensile strength are shown in Figure 7.

Figure 7. Main effects plot of S/N ratios for tensile strength

The results of signal-to-noise (S/N) ratio analysis show that the solution temperature of 510°C, solution time of 35 minutes, the aging temperature of 140°C and an aging time of 2 hours is associated with the highest tensile strength for the T6 age hardened 7075 aluminum samples.

4.6 Elongation to Break

Table 7 shows the response table for the signal-to-noise (S/N) ratio for elongation to break. The parameters with the highest impact on the elongation to break of 7075 aluminum samples, respectively, are solution time, aging time, aging temperature, and solution temperature.

Table 7. Response table for signal-to-noise (S/N) ratio for elongation to break

Level	Solution Temp.	Solution Time	Aging Temp.	Aging Time
1	22.42	21.28	22.52	22.65
2	22.19	22.69	21.79	22.57
3	21.90	22.53	22.20	21.29
Delta	0.52	1.41	0.73	1.35
Rank	4	1	3	2

Figure 8 displays the main effects plot of S/N ratios for elongation to break. The results of the signal-to-noise (S/N) ratio analysis demonstrate that the highest elongation to break for the T6 age hardened 7075 aluminum samples is associated with a solution temperature of 430°C, a solution time of 35 minutes, an aging temperature of 140°C, and an aging time of 2 hours.

Figure 8. Main effects plot of S/N ratios for elongation to break

From Taguchi's S/N ratios shown in Figures 5, 6, and 7 it appears that raising the solution temperature to 510 °C leads to an increase in both yield strength and tensile strength, but a decrease in elongation. Indeed, increasing the material's tensile strength reduces its elongation to break, due to increased brittleness. These findings may be attributed to the greater solution of the constituent phases and the higher precipitation obtainable at higher solution temperatures. As can be seen from the S/N ratio graphs presented in Figure. 8, it is clear that the solution treatment of the material at a low temperature of 430°C has increased its elongation to break. This is because the constituent phases have not dissolved significantly at this point, and the material has found a lower precipitation. As can be seen in Figures. 5, 6, and 7 increasing the aging temperature of the material from 170°C to 200°C results in lower yield and tensile strengths, but higher elongation. At higher aging temperatures, more GP zones dissolve resulting in the formation of a coarse and widely distributed precipitate, leading to lower strength. It can be observed from Figures. 5, 6, and 7 that the samples exposed to a temperature of 200°C are over-aged. This implies that the strength of these samples has been significantly reduced, while there may be some improvement in other characteristics such as an increase in elongation to break and fatigue life.

4.7 Fatigue Life

Table 8 displays the S/N ratios for the fatigue life of the 7075 aluminum samples at each level of process parameters. From this table, it is clear that the aging temperature, solution temperature, aging time, and solution time are the most significant factors affecting the fatigue life.

Table 8. Response table for signal-to-noise (S/N) ratio for fatigue life

Level	Solution Temp.	Solution Time	Aging Temp.	Aging Time
1	22.42	21.28	22.52	22.65
2	22.19	22.69	21.79	22.57
3	21.90	22.53	22.20	21.29
Delta	0.52	1.41	0.73	1.35
Rank	4	1	3	2

In Figure 9, we can observe the main effects plot for the signal-to-noise (S/N) ratio concerning the average fatigue life of the 7075 aluminum samples.

Figure 9. Main effects plot of S/N ratios for fatigue life

The results of signal-to-noise (S/N) ratio analysis show that the highest fatigue life for aluminum 7075 in T6 precipitation hardening heat treatment is achieved at a solution temperature of 470°C, a solution time of 55 minutes, an aging temperature of 200°C, and an aging time of 12 hours. Also, as can be seen in Figure 9, increasing the solution temperature of the material from 470°C to 510°C decreases the fatigue life. This probably occurs due to the increase in the brittleness of the material at the solution temperature of 510°C. Previous research has shown that the eutectics (mainly composed of $MgZn_2$, Al_2CuMg, and Mg_2Si) formed during overheating are quite brittle and can preferentially act as crack propagation paths [15]. Figure 9 also shows that when the aging time increases from 2 hours to 12 hours, the fatigue life of the material increases.

4.8 Regression Equations

The following regression equations have been generated by Minitab 21.3 to predict the hardness, yield stress, tensile strength, elongation to break, and fatigue life of the age-hardened material. These predictions are based on the age hardening parameters which include solution temperature, solution time, aging temperature, and aging time. By using these regression formulas, it becomes possible to predict the mechanical properties of the age-hardened material within the range of levels defined in the experimental design of this study.

Hardness = -677.2 + 2.646 Sol Temp + 1.312 Sol Time + 1.707 Aging Temp - 1.124 Aging Time - 0.002559 (Sol Temp)^2 - 0.01882 (Sol Time)^2 - 0.006766 (Aging Temp)^2 + 0.1051 (Aging Time)^2

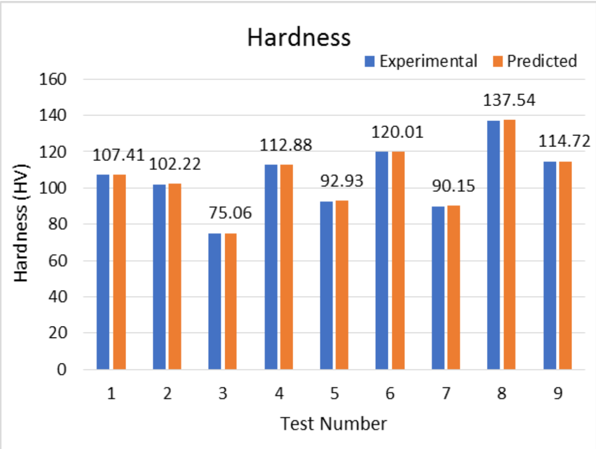
Yield Stress = -527.9 - 0.9418 Sol Temp + 0.7356 Sol Time + 9.364 Aging Temp - 14.42 Aging Time + 0.002044 (Sol Temp)^2 - 0.01471 (Sol Time)^2 - 0.02876 (Aging Temp)^2 + 0.9708 (Aging Time)^2

Tensile Strength = -945.6 + 3.383 Sol Temp + 3.275 Sol Time + 4.300 Aging Temp - 8.813 Aging Time - 0.002862 (Sol Temp)^2 - 0.04716 (Sol Time)^2 - 0.01534 (Aging Temp)^2 + 0.4378 (Aging Time)^2

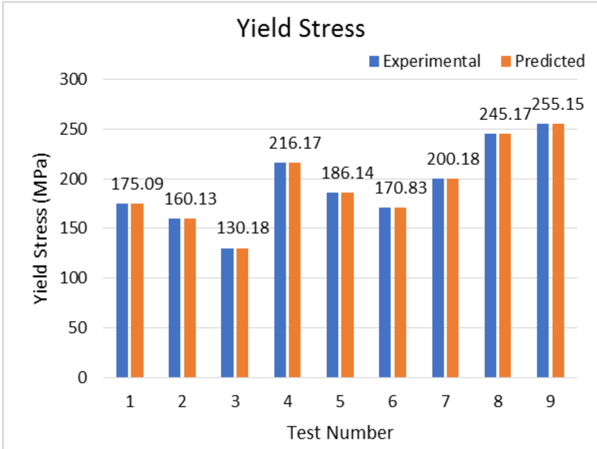
Elongation to Break = 8.378 + 0.1185 Sol Temp + 0.2406 Sol Time - 0.2914 Aging Temp + 0.2982 Aging Time - 0.000136 (Sol Temp)^2 - 0.002812 (Sol Time)^2 + 0.000835 (Aging Temp)^2 - 0.03499 (Aging Time)^2

Fatigue Life = - 40576520 + 152164 Sol Temp - 760.2 Sol Time - 60371 Aging Temp + 40302 Aging Time - 0.2310 (Sol Temp)^3+ 2.024 (Sol Time)^3 + 0.7209 (Aging Temp)^3 - 136.4 (Aging Time)^3.

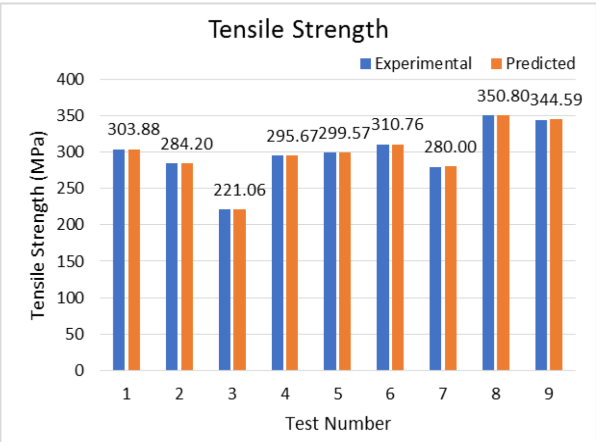
Figure 10 compares the predicted and experimental values for (a) hardness, (b) yield stress, (c) tensile strength, (d) elongation to break, and (e) fatigue life. The date label for the predicted values is shown above the bar charts. It is noteworthy that the experimental values are displayed in Table 3. The relative error between the predicted and experimental values in graphs (a) to (e) of Figure 6 are 0.22%, 0.08%, 0.04%, 0.65%, and 2.69%, respectively. The graphs in Figure 10 demonstrate that the regression formulas effectively predict the mechanical properties of aged samples.



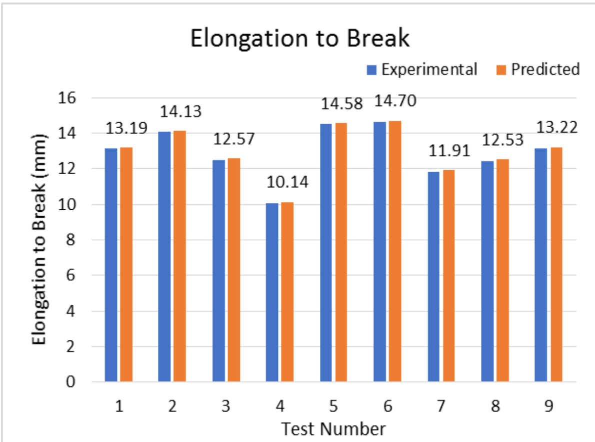
(a)



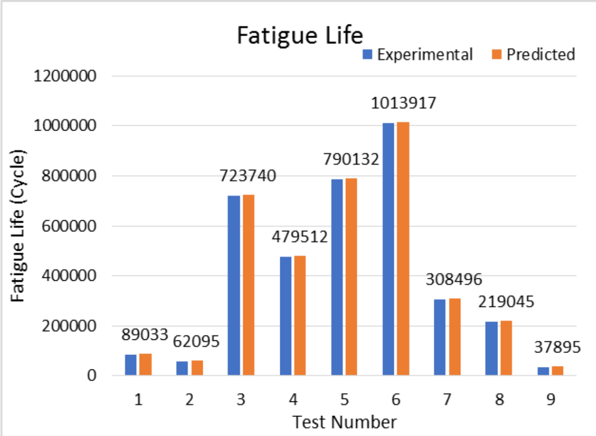
(b)



(c)



(d)



(e)

Figure 10. Comparison of predicted and experimental values for (a) hardness, (b) yield stress, (c) tensile strength, (d) elongation to break, (e) fatigue life

5. Conclusions

In this research, Taguchi's DOE method was used to obtain optimal parameters of T6 heat treatment to achieve higher mechanical properties of 7075 aluminum alloy. In this method, an orthogonal L9 array was used to design the experiments, and the results were analyzed using Minitab 21.3 software. Based on the analysis, it appears that optimizing the parameters of solution temperature, solution time, aging temperature, and aging time can have a significant impact on improving the mechanical properties of aluminum 7075 in T6 precipitation hardening heat treatment. It is recommended to use the optimal parameters to achieve maximum value in each mechanical property such as hardness, yield stress, tensile strength, elongation to break, and fatigue life. Using the optimal values, Vickers hardness of 137.28 HV, yield strength of 266.91 MPa, tensile strength of 377.64 MPa, elongation to break of 15.19%, and fatigue life of 1193304 cycles were obtained. Also, the obtained regression formulas can be used to accurately calculate the mechanical properties of the aged samples.

6. References

[1] Handbook A. 1991. Heat Treating of Aluminum Alloys. ASM Handbook.

[2] Hadjadj, L., Amira, R., Hamana, D. and Mosbah, A. 2008. Characterization of precipitation and phase transformations in Al–Zn–Mg alloy by the differential dilatometry. Journal of Alloys and Compounds. 462(1-2): 279-283. doi:10.1016/j.jallcom.2007.08.016.

[3] Sha, G. and Cerezo, A. 2004. Early-stage precipitation in Al–Zn–Mg–Cu alloy (7050). Acta Materialia. 52(15): 4503-4516. doi:10.1016/j.actamat.2004.06.025.

[4] Andreatta, F., Terryn, H. and De Wit, J. 2003. Effect of solution heat treatment on galvanic coupling between intermetallics and matrix in AA7075-T6. Corrosion Science. 45(8): 1733-1746. doi:10.1016/S0010-938X(03)00004-0.

[5] Luiggi, N.J. and Valera, M.d.V. 2017. Kinetic study of an AA7075 alloy under RRA heat treatment. Journal of Thermal Analysis and Calorimetry. 130: 1885-1902. doi:10.1007/s10973-017-6683-8.

[6] Tiringer, U., Kovač, J., and Milošev, I. 2017. Effects of mechanical and chemical pre-treatments on the morphology and composition of surfaces of aluminium alloys 7075-T6 and 2024-T3. Corrosion Science. 119: 46-59. doi:10.1016/j.corsci.2017.02.018.

[7] Song, M. and Chen, K. 2008. Effects of the enhanced heat treatment on the mechanical properties and stress corrosion behavior of an Al–Zn–Mg alloy. Journal of Materials Science. 43: 5265-5273. doi:10.1007/s10853-008-2773-0.

[8] Chen, Q., Zhao, W., Jiang, J., Huang, M., Li, M., Wang, Y., Ding, C., and Zou, D. 2023. Effect of T6 heat treatment on microstructure and mechanical properties of large-weight aluminum alloy flywheel housing parts formed by local-loading squeeze casting. Journal of Materials Research and Technology. 24: 1612-25. doi:10.1016/j.jmrt.2023.03.084.

[9] Sowrabh, B.S., Gurumurthy, B.M., Shivaprakash, Y.M., and Sharma, S.S. 2023. Characterization studies on 7075 aluminium alloy under as-cast and in multiple step T6 conditions. Journal of The Institution of Engineers (India): Series C. 104(1): 69-92. doi:10.1007/s40032-022-00909-6.

[10]. Cetin, M.H., Ozcelik, B., Kuram, E. and Demirbas, E. 2011. Evaluation of vegetable based cutting fluids with extreme pressure and cutting parameters in turning of AISI 304L by Taguchi method. Journal of Cleaner Production. 19(17-18): 2049-2056. doi:10.1016/j.jclepro.2011.07.013.

[11] Baghel, M., Krishna, C., Namdev, A Kumar, A. and Yadav, Y. K. 2023. Optimization of heat treatment parameters using Taguchi method to improve compressive strength of MWCNTs/Al6082 composites. Materials Today: Proceedings. 82: 263-269. doi:10.1016/j.matpr.2023.01.221.

[12] ISO 1143:2010. 2021. Metallic materials-Rotating bar bending fatigue testing. SECfS.

[13] Sailaja, M., Rao, C. M., Bhuvaneswari, K., Lavanya, M.S., Shanmuka Priya, N. and Chandini, P. 2021. Application of Taguchi method and ANOVA for the optimization of AA6061-T6 responses. Journal of Mechanical and Mechanics Engineering. 7(2): 53-61.

[14] Freddi, A. and Salmon, M.2019. Design Principles and Methodologies. Springer. doi:10.1007/978-3-319-95342-7.

[15] Xu, D., Rometsch, P. and Birbilis, N. 2012. Improved solution treatment for an as-rolled Al–Zn–Mg–Cu alloy. Part I. Characterisation of constituent particles and overheating. Materials Science and Engineering: A. 534: 234-243. doi:10.1016/j.msea.2011.11.065.