The Effect of T6 Heat Treatment on 7075 Aluminum on its Hardness and Tensile Strength

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Abstract. This study aimed to determine the effect of T6 heat treatment on 7075 aluminum on its hardness and tensile strength. The T6 heat treatment process was heating the test specimens in an oven at various temperatures of the solution heat treatment (SHT) of 350°C, 400°C, 450°C, and 500°C for 2 hours. This process was then followed by quenching for 45 minutes and an artificial aging process at temperature of 120°C for 48 hours. The tests carried out included: Vickers hardness test, tensile test using ASTM B557-84 standard, microstructure test, and XRD test. The test results showed that the hardness and tensile strength before T6 heat treatment were 59.1 VHN and 235.7 MPa, respectively. After the T6 heat treatment was carried out, the hardness results were 105.8, 87.3, 108.9, and 171 VHN and tensile strength of 318.3, 415, 571.7, and 618.3 MPa, respectively. These results indicated that highest hardness was found in the SHT temperature of 500°C, while the increase in tensile strength was found in the temperature of SHT 500°C. It can be obtained because the formation of precipitate after the artificial aging process was due the formation of Al₂CuMg and MgZn₂.

1. Introduction
Aluminum is the second most abundant metal in the world. It is used to manufacture automotive industry parts and other parts such as air frames, engines, and satellite components. Aluminum is used in the manufacture of these products because it has lightweight, which is three times lighter than steel (7.83 g/cm³), a density of only 2.7 g/cm³, and corrosion resistance such as the environment, atmosphere, water, petrochemicals [1]. Aluminum is widely used in the automotive industry due to its mild nature. The current trend of energy source is the use of electrical energy, e.g. battery found in the cars. The advantages of using an electric car are: 1). environmentally friendly, 2). reducing the use of fuel oil sources, and 3). not noisy. However, the use of electric cars may also bear some disadvantages including: 1). low speed cars, and 2). limited duration of car driving due to limited battery power. The limited power is due to the influence of the load received by the automotive industry products, namely: oil-fueled cars and electric-powered cars. Therefore, aluminum material is used to reduce the loads of the car [2]. In this case, 7075 aluminum (Al-Mg-Zn-Cu) is used since it has the highest strength compared to other series [3]. Here, heat treatment process is used to improve the mechanical properties of 7075aluminum. Since this aluminum is heat-treatable, it is necessary to improve mechanical properties of hardness and tensile strength.
The 7075 aluminum heat treatment process consists of 3 stages, namely: solution heat treatment, quenching, and age hardening. One of the heat treatments on 7075 aluminum is the T6 temper designation code. The T6 treatment process was carried out at a solution heat treatment temperature of 465°C-490°C and an aging temperature of 120°C [4]. Li, J.F. et al. [5] treated T6 with a temperature range of solution heat treatment 450-480°C and an aging temperature of 120-185°C. Meanwhile, Y. Mahathaninwong, N. et al. [6] conducted a similar research on 7075 aluminum castings material produced by rheocasting techniques. The increase in mechanical properties of 7075 aluminum is due to the formation of MgZn2 and Al2CuMg [5,6,7]. In this study, the authors focused on the optimum solution heat treatment temperature to increase hardness and tensile strength in 7075 aluminum using the T6 temper treatment.

2. Methodology

The material used in this research was 7075 aluminum with standard size for tensile test and reference to ASTM B557-84 [8] as can be seen in Figure 1. The size of the material was 25x25x15 mm for hardness testing and microstructure testing as can be seen in Figure 2. The material was sanded using sandpaper with grades of 600, 800, 1000, 1200, 1500, and 2000 and polished using autosol.

![Figure 1. Size of ASTM B557-84](image1)

![Figure 2. Microstructure test material size and hardness](image2)

Hardness test was carried out using a Vickers micro machine type HWMMT-X7 made by HIGHWOOD. Meanwhile, microstructure test was conducted using an optical microscope with a magnification of 10X. After that, XRD test was carried out using the Rigaku Benchtop machine, while the tensile test was conducted using the SANS UTM machine.

The T6 temper treatment process consisted of 3 stages: a). heating temperature solution heat treatment (SHT) with variations of temperature 350°C, 400°C, 450°C, and 500°C for 2 hours with Smit Smoergen heating oven, b). quenching process (in 1:1 nitrate-nitrite solution) for 45 minutes [4,9,10], and c). the aging process using a Borel heating furnace with a temperature of 120°C for 48 hours. This stage was then followed by the polishing using autosol. Hardness test conducted using micro Vickers type HWMMT-X7 was given a load of 100gf. The dwell time 10s was carried out on
the cross section surface while test distances from the top edge of the surface were 0.25 mm, 0.75 mm, 1.25 mm, and 1.75 mm. Micro structure testing was carried out using an optical microscope with a magnification of 10X where the etching fluids were 30 mL HCl, 2.5 mL HF, 40 mL HNO₃, 12 g CrO₃ and 42.5 mL water. In XRD test, the Rigaku Benchtop Cu-Kα1 radiation machine was used with a specimen size of 13x13x1 mm or square-shaped which has been previously treated. Meanwhile, tensile test was carried out using a SANS UTM machine with a rate of 2 mm/minute where the specimen shape was done using the ASTM B557-84 standard. The process can be seen in Figure 3.

![Figure 3. T6 Temper Process](image)

3. Results and discussion

3.1. Chemical composition of material

The spectrometer was tested on a 7075 aluminum specimen without treatment. The test aimed to determine the suitability of 7075 aluminum material specifications with ASTM standards. The test results can be seen in Table 1.

Table 1 shows the presence of Zn main alloying elements in 7075 aluminum was at 5.8113% where the results corresponded to the Zn aluminum7075 element content in ASM Handbook Vol.2. [1] which ranged from 5.1% - 6.1%.

| Element | (%) |
|---------|-----|
| Si      | 0.01 |
| Fe      | 0.1089 |
| Cu      | 1.133 |
| Mn      | 0.0162 |
| Mg      | 1.8635 |
| Zn      | 5.8113 |
| Ti      | 0.0916 |
| Cr      | 0.0916 |
| Pb      | 0.0015 |
| Sn      | 0.004 |
| Al      | 90.75 |
3.2. Hardness of material

The hardness rate of 7075-T6 Aluminum with SHT temperatures of 350°C to 500°C is shown in Figure 4. It can be seen that the optimum hardness rate was at SHT temperature of 500°C with a value of 171 VHN and a distance of 0.25 mm from the edge. When viewed from the edge test distance of 0.25 mm to 0.75 mm, the hardness rate increased from 171 VHN to 178.6 VHN. This was similar when the edge distance was 1.25 mm, where there was an increase to 181.8 VHN. Meanwhile, at an edge distance of 1.75 mm, there was a decrease to 175.2. However, when viewed from a distance of 0.25 mm to 1.75 mm, there was an increase from 171 VHN to 175.2. Therefore, it can be concluded that the hardness of the T6 material with SHT 500°C has increased hardness evenly on the surface to the core.

![Figure 4. VHN graph of 7075-T6 aluminum, SHT 500°C](image)

The following graph shows the optimum hardness rate of T6 and raw material of 7075 aluminum compared to the hardness rate of raw material with a test distance of 0.25 mm from the edge.

![Figure 5. VHN graph of RM and T6 (0.25 mm, SHT 500°C)](image)
### 3.3. Tensile strength

The results of tensile test in the T6 treatment can be seen in Table 2. T6 treatment increased tensile strength indicated in the increase in the SHT temperature from 350°C - 500°C as can be seen in Figure 6. The optimum tensile strength was obtained at a temperature of 500°C SHT with the tensile strength at T6 treatment was 618.3 MPa. These results show an increase compared to Aluminum 7075 raw material where the tensile strength was 235.7 MPa as described in Figure 7. This is in line with the study of Fei, F. W., et al. [11] stating that the SHT optimum temperature was above 470°C. In addition, the aging temperature of 120°C for 48 hours affected the optimum tensile strength. This is in line with the research of Mahathaninwong, N., et al. [6] who revealed that the aging temperature used was 120°C for 2-3 days.

| Specimen code | Temperature (°C) | Tensile strength (Mpa) | Mean     | Standard deviation |
|---------------|------------------|------------------------|----------|--------------------|
| RM            | -                | 235                    | 235.7    | 4.04               |
| 1.1           | 350              | 325                    | 318.3    | 5.78               |
| 1.2           | 350              | 315                    | 315      |                    |
| 1.3           | 350              | 315                    | 315      |                    |
| 2.1           | 400              | 410                    | 415      | 18.03              |
| 2.2           | 400              | 415                    | 415      |                    |
| 2.3           | 400              | 415                    | 415      |                    |
| 3.1           | 450              | 570                    | 571.7    | 3.24               |
| 3.2           | 450              | 570                    | 571.7    | 3.24               |
| 3.3           | 450              | 570                    | 571.7    | 3.24               |
| 4.1           | 500              | 620                    | 618.3    | 2.89               |
| 4.2           | 500              | 615                    | 618.3    | 2.89               |
| 4.3           | 500              | 620                    | 618.3    | 2.89               |

**Figure 6.** Graph of tensile strength of T6 with SHT Temperature variations and T6
The results of XRD T6 SHT 500°C can be seen in Figure 8. It can be seen that there was a component of Al$_2$CuMg precipitate matrix with peaks at 2 theta (41.22 and 68.83) and MgZn$_2$ with peaks at 2 theta (21.16, and 42.69). The peak of aluminum was between the 2 theta angle (35-40, 45-50, 60-70, 75-80, and 80-85). Meanwhile the Al$_2$CuMg peak was between the 2 theta angle (40-45, and 65-70) and the MgZn$_2$ peak was between the 2 theta angle (20-25, and 40-45). These results are in line with the research of Yazdian et al. [12]. The formation and distribution of $\eta'$ precipitate evenly from $\eta$(MgZn$_2$) in T6 treatment was in line with Li, J. F, et al. [5] and the study of Wei, G., et al [13]. The increase in tensile strength was due content of Al$_2$CuMg and MgZn$_2$ precipitate matrix components which is in line with the research of Padap, A. K., et al [7].

![Graph of tensile strength of RM & T6 SHT 500°C](image)

**Figure 7.** Graph of tensile strength of RM & T6 SHT 500°C

The difference of the microstructure of the 7075 aluminum raw material is shown in Figure 9. Whereas 7075 Aluminum material with the microstructure that received T6 treatment at SHT temperature of 350°C and T6 temperature of SHT 500°C is shown in Figure 10 and Figure 11. It can be seen that grain boundaries were formed in the treatment material, whereas in raw materials, grain boundaries were only partially formed.
Figure 8. XRD comparison of RM & T6 SHT 500°C

Figure 9. Microstructure photo of 7075 aluminum RM
Figure 10. Microstructure photo of 7075 aluminum on T6 at 350°C

Figure 11. Microstructure photo of 7075 aluminum on T6 at 500°C

The tensile test fracture on aluminum treatment T6, SHT temperature of 350°C and 500°C can be seen in Figures 12 and 13. It can be seen that the aluminum fracture of T6 temperature of SHT 350°C showed ductile fracture criteria at its tensile strength of 318.3 Mpa. Whereas in T6 aluminum fracture at SHT 500°C also showed ductile fracture criteria due to the presence of fibrous forms in the fracture (in the fracture face direction).

Figure 12. Macro-photo of 7075 Aluminum on T6 at 350°C, (a) upside fracture and (b) face-side fracture
**Figure 13.** Macro-photo of 7075 Aluminum on T6 at 500°C, (a) upside fracture and (b) face-side fracture

4. Conclusion

T6 treatment on 7075 aluminum can increase hardness and tensile strength. In this case, the highest hardness of Aluminum on T6 at SHC of 500°C was 171 VHN, while the highest tensile strength of Aluminum on T6 at SHT of 500°C was 618.3 MPa. It can be concluded that SHT temperature and aging caused formation of the matrix component of Al\textsubscript{2}CuMg with peaks at 2 theta (41.22 and 68.83) and MgZn\textsubscript{2} with peaks at 2 theta (21.16, and 42.69) on XRD test.

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