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The Effect of the Aging Time on Microstructure and Mechanical Properties of the AA7075 Alloy after T6 Heat Treatment

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In this study, the effect of the aging time on microstructure and mechanical properties of the AA7075 alloy after T6 heat treatment is investigated. The AA7075 alloys are quenched after solid solution treatment at 485°C for 2 hours and artificially aged at 120°C using five different aging times. Hardness measurements, microstructure examinations (SEM + EDS, XRD), and tensile tests are performed for the aged alloys. Fractured surfaces are also examined using SEM images after the tensile testing. The results of the studies conducted show that the hardness value of the alloys can be increased by increasing aging time, and the maximum hardness value of 192 HV is obtained for the alloy aged for 25 hours. Tensile tests also show that the tensile strength of the alloy can be increased by increasing aging time, and the maximum tensile strength value of 580 MPa is obtained for the alloy aged for 25 hours. Fractured surface examinations revealed that the ductile fracture mechanism is mostly dominant, while the planar fracture mechanism is observed as well.

Key words: AA7075 alloy, aging time, microstructure, mechanical properties, tensile strength.

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У роботі досліджено вплив тривалості старіння на мікроструктуру та механічні властивості сплаву AA7075 після термообробки T6. Сплави AA7075 загартовувалися після оброблення твердого розчину при 485°C протягом 2 годин і штучно піддавались старінню при температурі 120°C протягом п'яти різних за тривалістю процесів старіння. Міряння твердості, мікроструктурні дослідження (СЕМ + ЕДС, рентгенівська дифракція) та випробування на розтягання проводилися для підданих старінню сплавах. Злами поверхонь також досліджували з використанням зображень СЕМ після випробування на розтягання. Результати проведених досліджень свідчать, що твердість сплавів може бути підвищена завдяки збільшенню часу старіння, а для сплаву, що витримувався протягом 25 годин, отримано максимальне значення твердості у 192 HV. Випробування на розтягання також показали, що міцність на розрив сплаву може бути підвищена завдяки збільшенню тривалості старіння, а максимальне значення міцності на розрив у 580 МПа отримано для сплаву, що піддавався старінню протягом 25 годин. Дослідження зламів поверхні виявило, що механізм пластичного руйнування був переважно домінуючим, при цьому спостерігався також площинний механізм руйнування.

Ключові слова: сплав AA7075, час старіння, мікроструктура, механічні властивості, міцність на розрив.

В работе исследовано влияние времени старения на микроструктуру и механические свойства сплава AA7075 после термической обработки T6. Сплавы AA7075 закалялись после обработки твёрдого раствора при 485°C в течение 2 часов и искусственно поддавались старению при температуре 120°C в течение пяти различных по продолжительности процессов старения. Измерения твёрдости, микроструктурные исследования (СЭМ + ЭДС, рентгеновская дифракция) и испытания на растяжение проводились для состаренных сплавов. Изломы поверхностей также исследовали с использованием СЭМ-изображений после испытания на растяжение. Результаты проведённых исследований показывают, что твёрдость сплавов может быть повышена путём увеличения времени старения, а максимальное значение твёрдости в 192 HV получено для сплава, выдержанного в течение 25 часов. Испытания на растяжение также показали, что прочность сплава на разрыв может быть увеличена путём увеличения времени старения, и максимальное значение прочности на разрыв в 580 МПа получено для сплава, выдержанного в течение 25 часов. Исследование изломов поверхности показало, что механизм пластического разрушения был в основном доминирующим, при этом также наблюдался механизм плоскостного разрушения.

Ключевые слова: сплав AA7075, время старения, микроструктура, механические свойства, прочность на разрыв.

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1. INTRODUCTION

Aluminium and its alloys are commonly used in various industries such as aerospace, defence, automotive and aviation industries due to their high strength, good corrosion resistance, low density and lightweight [1, 2]. Moreover, the use of these alloys is of great importance especially in industries where weight matters [3]. The most significant advantage of the 7xxx series alloys, which are widely used in applications requiring high strength, is the ability to improve their mechanical properties using aging treatments [4, 5]. For the 7xxx series alloys, the highest strength is obtained using the T6 heat treatment [6]. Second phase precipitation systems in the 7xxx series alloys were analysed in many studies and emphasized that precipitation, supersaturated solid solution, GP zones, metastable η'-phase, and stable η-phase occurred in the structure [7, 8]. The first step of the T6 heat treatment for the 7xxx series alloys is the solution treatment. The purpose of this step is to solubilise structures formed during the hardening of the alloy. In the second step, the alloy is rapidly cooled, and the supersaturated solid solution is obtained. In the last step, the aging treatment is applied at certain temperatures and times to ensure precipitate formation. Thus, the strength is improved thanks to second phase precipitates formed in the structure as a result of aging. The distribution and size of precipitates formed in the structure as a result of aging depend on the heat treatment parameters. For this reason, it is important to determine the most appropriate parameters for the heat treatment. These parameters have an important role in achieving desired mechanical properties. The aging temperature used during the aging process after the solution treatment has a particular importance in formation of second phase precipitates. The aging temperature is a parameter which directly affects the size of precipitates formed in the structure of the alloy. The aging treatment improves the mechanical properties of the alloy. The metastable η'-phase in the structure turns into stable η-phase, which results in improved mechanical properties [9].

Therefore, this study aims to investigate the effect of the aging time on microstructure, hardness, and tensile strength of the AA7075 alloy aged using five different aging times following solid solution treatment at 485°C for 2 hours.

2. MATERIALS AND METHOD

Table 1 shows the chemical composition of the alloy used in the experimental studies. The AA7075 alloys were quenched after solid solution treatment at 485°C for 2 hours. The quenched samples were artificially aged at 120°C using five different aging times (15 hours, 20 hours, 25 hours, 30 hours, and 35 hours). The hardness measurement of the alloys was conducted using an Affri hardness measurement device and measurements were taken at five different regions. The alloys prepared by standard metallographic procedures were etched using 2 ml HF, 3 ml

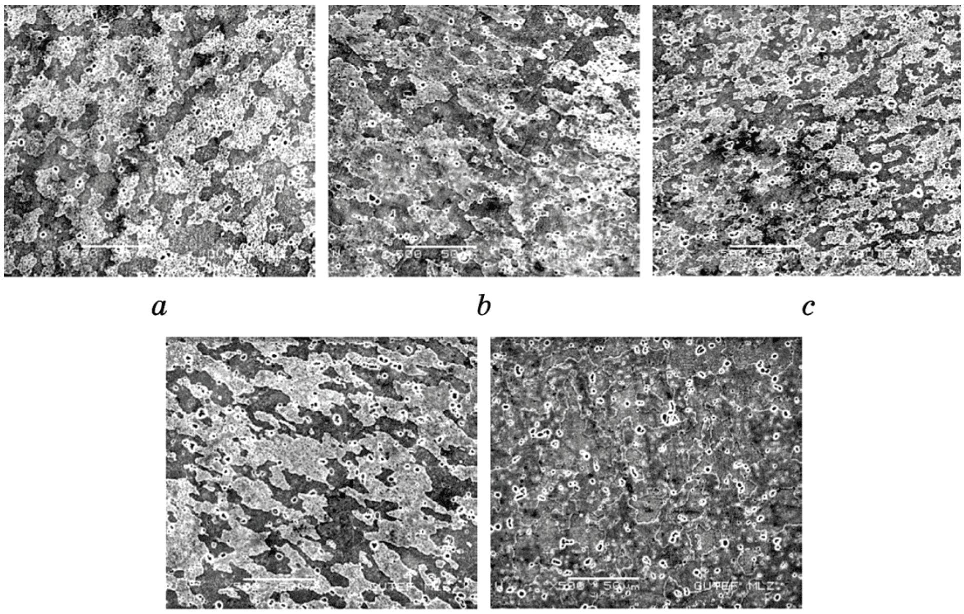
TABLE 1. The chemical composition of the AA7075 alloy used in the experimental studies.

Element	Zn	Mg	Cu	Cr	Fe	Mn
vol.%	5.9	2.734	1.561	0.2	0.196	0.0687
Element	Ti	Si	Zr	V	B	Al
vol.%	0.0343	0.0117	0.0091	0.0091	0.0025	Residue

HCI, 20 ml HNO_3, 175 ml H_2O (Keller's) solution for 10–15 seconds. 'Jeol JSM-6060' scanning electron microscope (SEM) was used for microstructure examinations and fractured surfaces. Rigaku D-Max Rint-2200 device was used for XRD analysis to determine phases formed in microstructure. Tensile tests were carried out using Shimadzu AG-IS (50 kN) tensile machine at cross head speed of 2 mm/min.

3. RESULTS AND DISCUSSION

Figure 1 shows the SEM images of AA7075 alloys aged at 120°C using five different aging times after solid solution treatment at 485°C for 2



a *b* *c* *d* *e*

Fig. 1. SEM images of AA7075 alloys aged at 120°C using five different aging times: *a*—15 h, *b*—20 h, *c*—25 h, *d*—30 h, *e*—35 h.

hours.

As shown in SEM images of AA7075 alloys aged using five different aging times, secondary phase ($MgZn_2$) precipitates formed in the structure as expected. Moreover, these precipitates formed in the structure were not very clear in the SEM images due to their nanosizes. Liu *et al.* [10] noted in their study that precipitates formed in the structure when T6 heat treatment was applied to the 7050 Al alloy were indistinguishable spherical particles, and the precipitates usually had a size of 3–7 nm. Figure 2 shows the XRD analysis results of aged alloys for 25 hours at 120°C.

As shown in Fig. 2, secondary phase precipitates formed in the structure of the AA7075 alloy aged at 120°C for 25 hours. The precipitation series of the Al–Zn–Mg–Cu alloys occur as supersaturated solid melt, GP (Guinier–Preston) zones, metastable η′–phase, and stable η–phase ($MgZn_2$) [7, 11]. In the 7xxx series alloys, the strength improvement usually depends on the type, intensity and size of precipitates formed in the structure as a result of the aging treatment [12]. Also, metastable ($MgZn_2$) and stable ($MgZn_2$) precipitates are usually spherical particles which cannot be distinguished from each other [10]. Figure 3 shows hardness and tensile strength changes of the alloys aged at 120°C using five different aging times.

As shown in Fig. 3, the hardness value of the alloys can be increased be increasing aging time. The highest hardness value (192 HV) was obtained for the alloy aged for 25 hours. The hardness values of the alloys aged for 30 hours and 35 hours (190 HV and 183 HV, respectively) decreased due to the increasing aging time. This increase in the hardness with increasing aging time can be explained by the Orowan mechanism. Precipitates formed in the structure of the alloy during the first stage occur as a result of the inhibition of dislocation movements by the GP zones consistent with the aluminium matrix and metastable $MgZn_2$

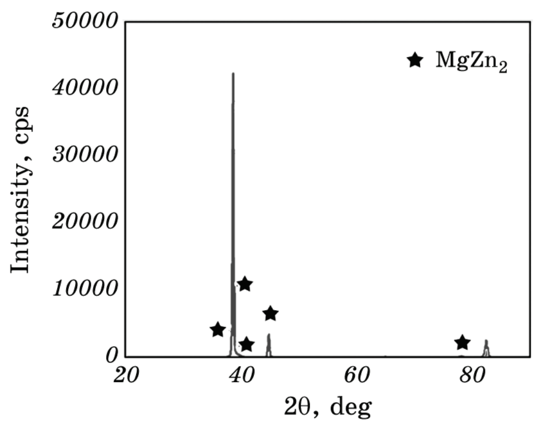


Fig. 2. XRD results of alloy aged at 120°C for 25 hours.

phases. Note that similar results have been obtained in other studies as well [11, 13].

The decrease in the hardness value as a result of the increase in the aging time, on the other hand, occurs due to averaging of the alloy. Precipitates formed in the structure of the alloy grow depending on the aging time. For this reason, the hardness of the alloy decreases. As shown in Fig. 3 the maximum tensile strength was obtained for the alloy aged for 25 hours. These results indicate that the hardness results were supported by the tensile strength results. Because the increase in the tensile strength of the 7xxx series alloys is achieved by stable $MgZn_2$ precipitates formed in the structure [11, 14].

Again as shown in Fig. 3, a decrease occurred in the tensile strength of the alloy with aging time above 25 hours. This is associated with the overaging of precipitates formed in the structure during the aging process. Mukhopadhyay *et al.* [15] reported that coarse η-phase ($MgZn_2$) formed in the structure due to averaging which led to a decrease in the tensile strength and the hardness of the alloy. The increase in sizes of $MgZn_2$ precipitates due to aging time inhibits the dislocation movement, which results in a decrease in the tensile strength of the alloy as well. Similar results were also obtained in other studies [16, 17]. Figure 4 shows the fractured surface of the AA7075 alloys aged using different aging times after the tensile testing.

As shown in Fig. 4, ductile and planar fracture occurred in the alloy. Depending on the aging time, planar fracture mostly occurred in the alloys aged for 25 hours and 30 hours, whereas the planar fracture mechanism was dominant in the fractured surface image of the alloy aged for 35 hours. This is believed to be a result of the microstructure changes in the alloy due to the aging time. According to Chun *et al.* [18], fracture behaviour varies depending on the amount of undis-

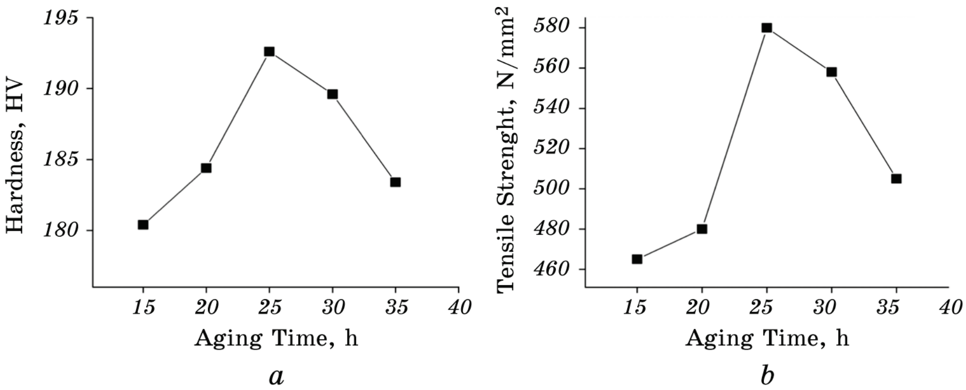


Fig. 3. Hardness (*a*) and Tensile strength (*b*) changes of the alloys aged at 120°C using five different aging times.

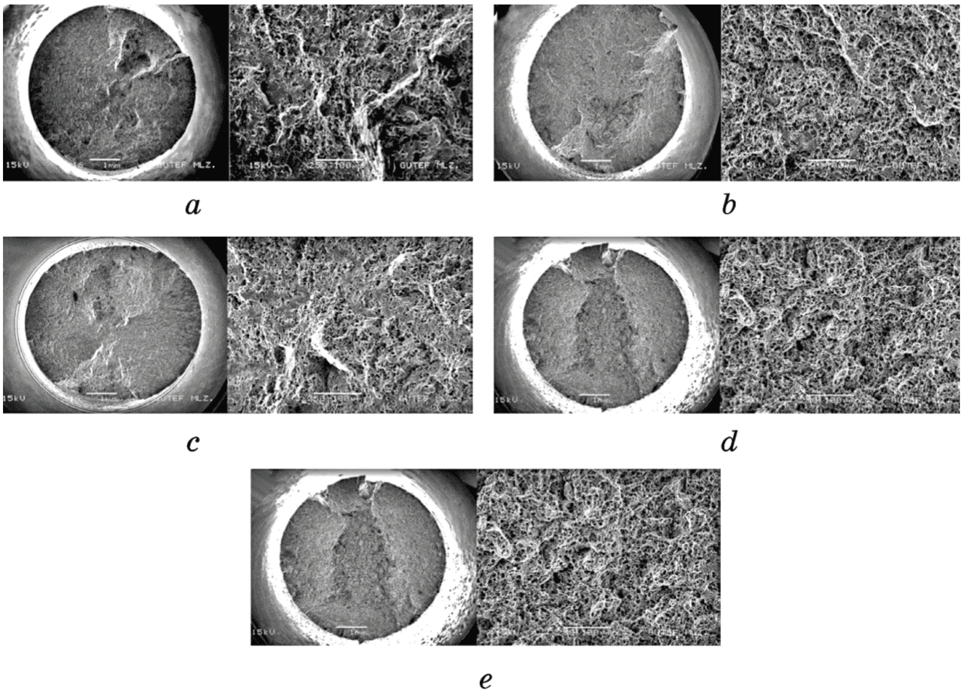


Fig. 4. Fractured surfaces of the alloys aged at 120°C using different aging times.

solved and precipitated phases in the structure of the alloy.

4. CONCLUSION

In this study, the following results were obtained.

Precipitates were observed to form in the structure of the AA7075 alloys depending on the aging time. The XRD analysis showed that $MgZn_2$ precipitates formed in the structure of the alloy.

The hardness of the alloy was observed to increase depending on the aging time. The highest hardness value (192 HV) was obtained for the alloy aged for 25 hours. There was a decrease in the hardness values of the alloys aged for 30 hours and 35 hours.

The increased aging time in the T6 heat treatment can lead to an increase in the tensile strength of the alloy. The maximum tensile strength (580 MPa) was obtained for the alloy aged for 25 hours. There was a decrease in the tensile strength values after 25 hours aging times.

The fractured surface examinations of the alloys following the tensile testing showed that the dominant fracture mechanism was the ductile fracture mechanism. In addition, the planar fracture mechanism was observed.

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