



Effect of Cyclic Heat Treatment on Microstructure and Mechanical Properties of AA 6061-T6 Aluminum Alloy

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Abstract

The effects of the repeated solution heat treatment on hardness, tensile strength and microstructure of aluminum were investigated. For this purpose, an alloy of AA6061-T6 was undergo to cyclic solution heat treatment process which is composed of repeated period (10 min) held at 520 °C for 1, 4, 8 and 12 cycles. The hardness was tested for five aging times (as quenching, one week, three weeks, one month and five months) to all cycles (1, 4, 8 and 12) firstly and it is found that the hardness of five months as aging time for all cycles has the best results (90Hv) as compared with others (as quenching, one week, three weeks, and one month), so it was adopted for all cycles to implement the tensile test and the microstructure. Hardness results were improved to Vickers hardness of (90Hv) with increasing of cycles up to 8 cycles then decreasing after that to (45Hv). Tensile results were showed an increment (34%) also for the same group of 8 cycles compared with (17%) and (9%) for 4 and 12 cycles, respectively. Microstructure is revealed that whenever cycles are increased, the precipitate phase in alloy is increased also, thus, it is improved the hardness and tensile strength.

Keywords: Cyclic Heat Treatment, Mechanical Properties, Microstructure

تأثير المعاملات الحرارية المتكررة على البنية المجهرية والخواص الميكانيكية لسبيكة الالمنيوم 6061-T6

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الخلاصة:

تم التحقق من تأثير المعاملات الحرارية المتكررة على خواص الصلادة ، الشد والبنية المجهرية للالمنيوم. لهذا الغرض تم تعريض سبيكة الالمنيوم 6061-T6 لاجراء المعاملات الحرارية المتكررة والتي تتكون من 10 دقيقة عند 520°C لمدة 4 مرات ، 8 مرات و 12 مرة. تم فحص الصلادة لحمسة ازمان (التقسية بالتصليد ، اسبوع ، ثلاث اسابيع ، وشهر واحد وخمسة اشهر) تعتيق لجميع المرات (لمرة ، 4 مرات ، 8 مرات و 12 مرة) ووجد ان خمسة اشهر كزمن تعتيق لجميع المرات اعطت افضل النتائج (90Hv) مقارنة مع الباقي (التقسية بالتصليد ، اسبوع ، ثلاث اسابيع وشهر واحد) ولهذا تم تعميمها على جميع الحالات بالنسبة لاختبار الشد والبنية المجهرية. نتائج الصلادة تحسنت الى (90Hv) مع زيادة المرات حتى 8 مرات ومن ثم تناقصت بع ذلك الى (45Hv). نتائج الشد اظهرت زيادة (34%) ايضا لنفس مجموعة 8 مرات مقارنة مع (17%) و (9%) ل 4 مرات و 12 مرة على التوالي. البنية المجهرية بينت انه كلما تزايدت ، الطور المترسب في السبيكة ازداد ايضا وهذا ما يحسن مقاومة الشد والصلادة.

1. Introduction

Aluminum alloys are utilized to collect the high strength and the light weight component, which has been compared with other alloys using in different applications. Aluminum alloys symbolized as 6xxx series that moderate the strength and heat treatable alloys. In most purpose of these alloys, both the strain

and the age hardening are extremely improves the strength. In previous study, the effect of the different aging processes has been reported using the tensile, malleability of aluminum alloys and microstructural, which are developed within this process [1]. B. Mirzakhani et. al. investigated the cold working percentage such as 20, 40 & 60% and aging process



after effecting the solution heat treatment on the AA6061 tensile strength; it is demonstrated that the tensile properties was enhanced with increasing of the cold working quantities [1]. B. Akyüz et. al. studied different aging times such as 1, 3, 6, 9, & 12 h using the solution heat treatment of AA6061; increasing the aging time was dramatically improved the hardness and the tensile strength [2]. More studies, M. N. Hawas was also investigated the aging time such as 1, 3 and 5 h affecting on the adhesive wear of AA6061-T6; it found that the hardness was improved as the aging time is increased but the wear rate was significantly affected with increasing of aging time after 30 min [3]. N. K. Zedin reported that the aging time such as 2, 4 and 6 h was affected on the hardness, the tensile properties and the microstructure of AA6061. It is showed that the hardness value and the tensile properties are improved with increasing of aging period and the microstructure could be noted that rising the aging period causes increasing in the size of grains and increasing of precipitates of second phase Al-matrix and its explained the improvement of strength and hardness [4]. S.M. Bayazid et al. reported the influence of cyclic solution treatment of the friction stir welding of AA7075 alloy; the samples were cyclically heated between two temperatures at 130 °C for up to 36 hours and then water quenched. The results showed that tensile properties and hardness were enhanced as increasing of aging time up to 24h [5]. A. Polat et al. were reported that the influence of different aging temperatures and the time on the tensile properties and the hardness of AA6061. It was found that the tensile properties and the hardness were reduced as increasing of temperature while it enhanced with the time increasing [6]. M. R. Rezaei et al. were presented that the accumulative rolling and aging time were studied showing the effecting thier on the mechanical strength and the microstructure of AA6061. It is revealed that the repeated rolling leads to increase the hardness and the tensile strength. Two aging temperatures (160 and 100°C) were done, whenever aging time increases, the hardness was improved at 100°C for all numbers of rolling but the temperature of 160°C has opposite effect on hardness [7]. R. A. Salman investigated the effect of rolling percentage such as 40% and 60% and aging time such as 0.5 and 2 h on the AA6061 tensile strength. The tensile properties and the hardness were improved with rising of aging time and rolling [8]. Many researchers have been studied the effect of cyclic heat treatment of steel on the different mechanical properties and it is demonstrated that the cyclic heat treatment enhanced the mechanical properties of steel compared with a traditional heat treatment process. Some researchers are repeated the same process and the others cyclic between two temperatures above the critical temperature of steel [9-13].

There is no investigation on the influence of cyclic solution treatment on the hardness, microstructure and tensile strength of aluminum alloys. In this research, the influence of the cyclic solution heat treatment process on the tensile properties, hardness and microstructure of AA6061-T6 was studied.

2. Material and Experimental procedure

Aluminum sheet alloy of AA6061-T6 with thickness of 3 mm was utilized in this research. The chemical composition of used material and mechanical properties as listed in tables (1 and 2). The tensile specimens were prepared according to ASTM-E8M as illustrated in Fig. 1. All specimens dimension were 10 x 10 mm, and the Vickers hardness test were done with a load of 500 g for 15 seconds. The hardness values were measured by carrying out three measurements value for each sample and mean values were taken.

Table (1): The chemical composition of AA6061-T6

Element	Standard (%) [14]	Actual (%)
Cr	0.04-0.35	0.1
Cu	0.15-0.4	0.21
Mn	<=0.15	0.085
Si	0.4-0.8	0.64
Fe	<=0.7	0.6
Al	Remain	Remain

Table (2): The mechanical properties of used material

Property	Standard [14]	Actual
Hardness (Hv)	107	102
Tensile strength (MPa)	Max. 310	275
Yield strength (MPa)	Max. 276	215
Modulus of Elasticity (GPa)	68.9	69

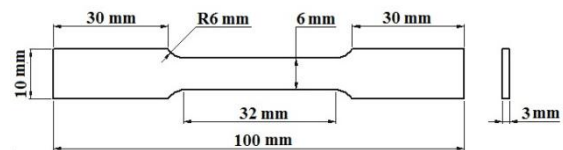


Figure (1): Tensile test specimen.

Briefly, the samples were firstly heated at (520°C) for (10 min) in a muffle furnace (solution heat treatment) and then its directly cooled using tap water. This solution heat treatment was repeated for 1, 4, 8 & 12 times as shown in Fig. 2. For more details, various aging times were used in this study such as 1 week, 3 weeks, 1 month & 5 months to investigate the optimum time and its found that the 5 months was revealed the best results; therefore, it is decided to adopt 5 months as aging time for all the specimens.

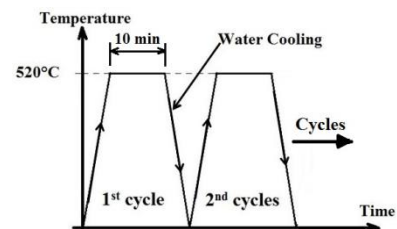


Figure (2): Schematics of the cyclic process used in this research.

The microstructural observations were done at different steps:

- a) Samples were grinding by various wet silicon carbide (320, 500, 800, 1000, and 1200 grades).



- b) The samples were then polished by diamond paste with (1.5 μm) of particle size.
- c) Clean the samples by using of distilled water and alcohol.
- d) Nital (2% HNO₃ in alcohol) then water and alcohol washing were utilized for etching.

Microstructural test is carried out via an optical microscope using a magnification of 40X.

3. Results and discussions

As mentioned above, it is used different aging times for all cycles and the obtained results are illustrated in Fig. 3.

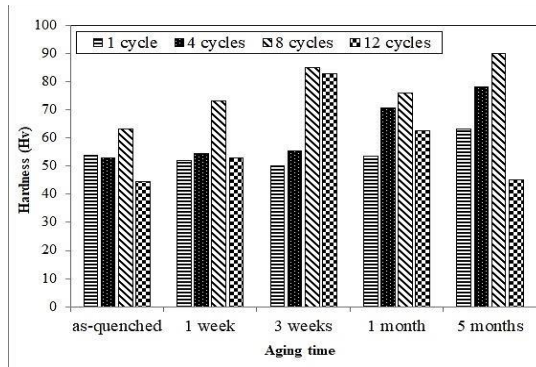


Figure (3): Hardness with aging period and cycles

From Fig.3, the hardness value of the first cycle has not affected at 1 week, 3 weeks and 1 month; however, the hardness value is moderated increased at 5 months. In cycles 4, have increased of hardness after 3 weeks and at 5 months have the greater hardness. It is noted that 12 cycles has increased in hardness up to 3 weeks and it is decreased after that. In general, the aging time of 5 months is showed that the best results. Also, the hardness is enhanced with more cycles until 8 cycles and it is decreased after that as illustrated in Fig. 4.

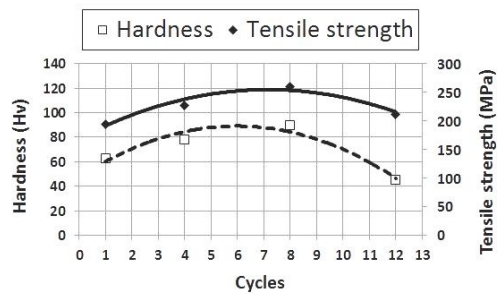


Figure (4): Hardness and tensile strength with cycles

Therefore, the hardness increases when increasing of aging period. The hardness improves with related of the aging time which perhaps clarified by the following reasons such as creation phases within the microstructure, precipitation, or modification in the grain sizes [2]. When the aging period raises, the concentration of GP zones is also raise. Hence, the degree of irregularity in the lattices was enhanced the mechanical properties of the aluminum alloys. Moreover, the increasing in aging duration minimizes the hardness of the alloy. This could be explained the coalescence of the precipitates into larger particles

which causes some little obstacles to the movement of dislocation, and also due to annealing out of the defects [4].

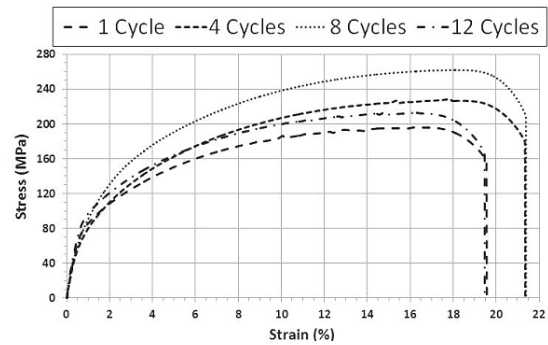


Figure (5): Tensile curves of all cycles

Fig. 5 summarizes the tensile results of all cycles. These results indicate that the highest tensile strength is at 8 cycles compared with other cycles. It can be noted that tensile strength improved with increasing of cycles up to 8 cycles and decreasing after that but it still has strength greater than 1 cycles as presented in Fig. 4. This decrease in the tensile strength of the AA6061-T6 in the over 8 cycles condition occurs maybe due to the coalescence of the precipitates into larger particles, a bigger grain size, and also the annealing of the defects [6]. It is observed that yield strength is approximately not affected for all cycles. The tensile strength values of 1, 4, 8 and 12 cycles are 196, 228, 262 and 213 MPa, respectively. The significant enhancement of tensile strength is for 8 cycles (34%) as compared with (17%) and (9%) for 4 and 12 cycles, respectively. Fig. 4 is presented that the relationship between hardness and tensile strength which have the same behavior, the cycles whenever increasing up to 8 cycles, the hardness and tensile strength are increased also, but further cycles after 8 cycles lead to decreasing of hardness and strength. Optical microscope indicates the precipitates in alloy that cause to increasing in hardness and strength, especially, at 8 cycles as illustrated in fig. 7 (c).

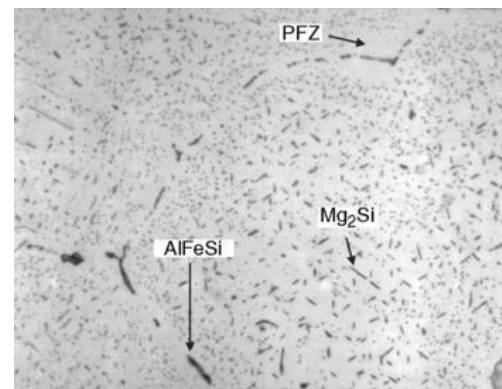


Figure (6): Micrograph of 6061 aluminum alloy, showing the precipitate-free zone (PFZ) (lack of Mg₂Si precipitates) at grain boundary [15].

The microstructure of AA6061-T6 is illustrated in fig. 7 (a, b, c and d). The stable β phase Mg₂Si and CuAl₂ was normal for 6061 Al-alloy. Specifically, the



sequence formation of separation clusters of Mg and Si atoms formation of co-clusters that include both Si and Mg. The needle-shaped β phase (Mg_2Si) was realized to be the dominant intermediate phase in the Al–Mg–Si and Al–Mg–Si–Cu alloys at early stages of aging [4]. The distribution of the stable β phase Mg_2Si and $CuAl_2$ was examined by microscopic investigation on polished samples. The predominant equilibrium second phases in 6061 alloy are $AlFeSi$, $CuAl_2$ and Mg_2Si as illustrated in fig. 6. When the copper is added to Al–Mg–Si alloys, smoothest the precipitate structure which motivates the formation of the meta-stable ($AlMgSiCu$), and enhances the hardness and strength [4]. Fig. 7 can be noted that, increasing the cycles was caused increasing in the precipitate phase as denoted. This precipitate leads to enhance the hardness and strength of 8 cycles as compared with other cycles.

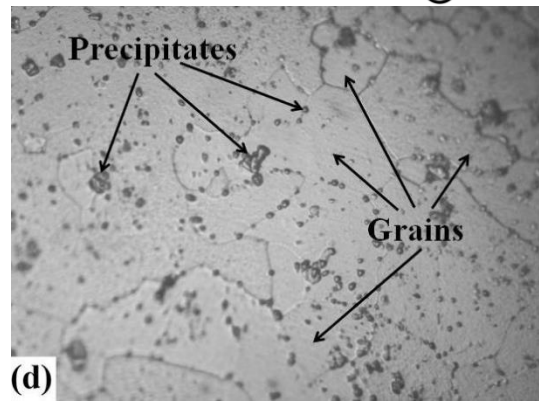
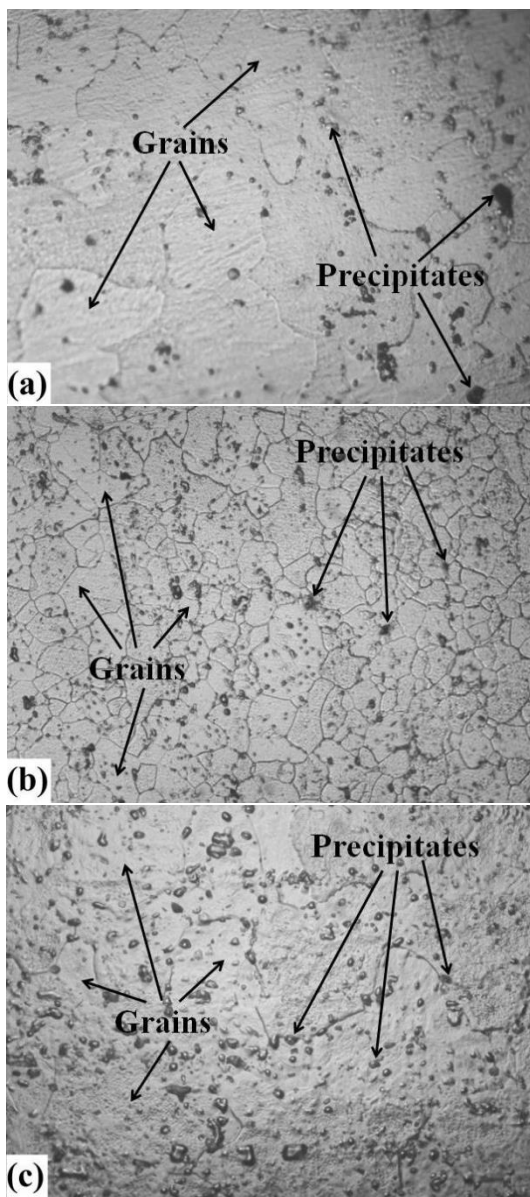


Figure (7): Optical Microscope results for: a) one cycle; b) four cycles; c) eight cycles and d) twelve cycles. (40X of magnification for all samples)

4. Conclusions

The concluding remarks from the present work are following:

- Hardness of utilized alloy increased with repeating solution heat treatment.
- Hardness of 8 cycles has a major value as compared with other cycles and it's decreased after that.
- Yield strength is not affect with cycles.
- Tensile strength is improved with increasing of cycles up to 8 cycles and decreasing after that.

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