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STUDY THE MICROWAVE ENERGY EFFECTS ON MECHANICAL PROPERTIES AND ESTIMATED FATIGUE LIFE OF AA7075-T6

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Abstract: This study is concerned with the effect of microwave heat treatment of AA7075-T6 on the mechanical properties and fatigue life. Specimens were divided into four groups, firstly, specimens were subjected for 60 min. of microwave heat as a dry, secondly, specimens were subjected for 30 min. of microwave heat as a dry, thirdly, specimens were subjected for 60 min. of microwave heat as a wet, and fourthly, specimens were subjected for 30 min. of microwave heat as a wet condition. Then, it is compared with original alloy (AA7075-T6). The mechanical tests that used in this research are tensile, hardness, surface roughness and fatigue. It is found that hardness of dry specimens is higher than wet specimens, and hardness of dry condition for 60 min. has higher enhancement (15%) as compared with original alloy. Hardness is increased with increasing of time inside the microwave. However, tensile strength of wet conditions has higher than dry conditions; also, tensile strength is increased with decreasing of time inside microwave furnace. Ultimate and yield strength of wet condition for 30 min. have 55% and 99% respectively, enhancement as compared with AA7075-T6. Surface roughness parameter (Ra) of dry conditions has higher than wet conditions and the decreases as decreasing of time inside microwave furnace. Fatigue strength results showed that decreasing as compared with original alloy.

Keywords: *Microwave, Mechanical Properties, Fatigue Life.*

دراسة تأثير طاقة المايكروويف على الخواص الميكانيكية وعمر الكلال لسبيكة الألومنيوم 7075-T6

الخلاصة: تتعلق هذه الدراسة بتأثير المعاملة الحرارية للمايكرويف لسبيكة الالمنيوم AA7075-T6 على الخواص الميكانيكية وعمر الكلال. تم تقسيم العينات الى اربعة مجموعات ، الاولى ، عينات الجافة تتعرض لحرارة المايكرويف لمدة 60 دقيقة ، الثانية ، عينات جافة تتعرض لحرارة المايكرويف لمدة 30 دقيقة ، الثالثة ، عينات رطبة تتعرض لحرارة المايكرويف لمدة 60 دقيقة ، والرابعة ، عينات رطبة تتعرض لحرارة المايكرويف لمدة 30 دقيقة. ومن ثم تتم مقارنتها مع السبيكة الاصلية (7075-T6). تم استخدام اختبارات الشد والصلادة وخشونة السطح والكلال في هذا البحث. وجد انه صلادة العينات الجافة اكبر من العينات الرطبة وصلادة العينات الجافة ولمدة 60 دقيقة لها نسبة تحسين (15%) مقارنة مع السبيكة الاصلية. تزداد الصلادة بزيادة الزمن داخل فرن المايكرويف. بينما مقاومة الشد للعينات الرطبة اكبر من العينات الجافة. مقاومة الشد القصوى والخضوع للحالة الرطبة ولمدة 30 دقيقة لها 55% و 99% على التوالي نسبة

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تحسين مقارنة مع سبيكة AA7075-T6. معامل خشونة السطح (Ra) للحالة الجافة اعلى من الحالة الرطبة ويتناقص بنقصان الزمن داخل فرن المايكرويف. اظهرت مقاومة الكلال نقصان مقارنة بالسبيكة الاصلية.

1. Introduction

Aluminum alloy has low density with normal strength and relatively a very good resistance for corrosive. Both strength and hardness of the material were extremely needed to be improved in any engineering applications. So, to apply this heat treatment process is needed in order to improve the mechanical properties of such alloys. In many modern researches a microwave furnace energy has been used in a wide range of applications like medical therapy industrial modern application and food keeping processing etc. In this work, microwave furnace energy has been used, as one of the most modern applications and one of the greatest material processing techniques to improve mechanical properties of metals. At this work, a newer technique including microwave furnace post heat treatment of specimen surface were employed. A microwave furnace was utilized efficiently to treat AA7075-T6. In microwave furnace treating, microwave furnace heats the alloy at the different heat levels, which will might leads to a uniformly heating, conversely in the traditional heating furnaces, the alloy heated from the surface to inner core which produces thermal stress and/or longer time required for homogenization.

A heat-treating process by microwave furnace can be utilized for an extensive application of surface treatments such as, carbonating, carburizing, bronzing, and chromizing. The fracture strength, toughness and hardness arrived from microwave furnace energy of treated specimen components were investigated to be higher than others traditional heat treated application ones [1].

Heat treatment process demonstrates coarse microstructures which affect the physical and mechanical properties of alloys, therefore, a new process of microwave heating will be excluding the bad results of traditional heat treatment. Microwave heating technique develops the alloy microstructure and properties [2, 3, 4 & 5]. Also, microwave process is used for plant growth not only using as a heat treatment of alloys [6].

The research is concentrated on the mechanical properties and estimated fatigue life affected by the microwave furnace energy heat treatment of the alloy used. In this paper AA-7075-T6 sheet was heat treated using microwave furnace energy at 4GHz and 1500W and the estimated fatigue life as long as its effect on mechanical properties is discussed in this work in details.

2. Tests and Material Selection

In this work, the material used was, AA 7075-T6 of sheet metal with 3 mm thickness in order to make a standard tensile test specimen of standard dimension is as shown as in Figure-1. The tests were taken at the COSQC-Baghdad (Central Organization for Standardization and Quality Control) according to the ISQ (Iraqis Specification Quality) 1473/1989.

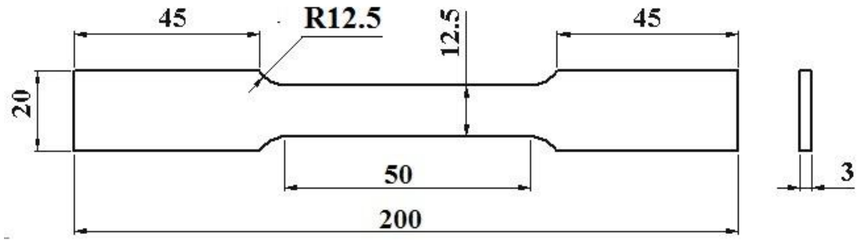

Figure-1: Standard Tensile Test Specimen (ASTM E8M)

The chemical composition tests were done at the COSQC-Baghdad (Central Organization for Standardization and Quality Control) according to the ISQ (Iraqis Specification Quality) 1473/1989 by the device (Spectrometer, ARC. MET 8000, 2009) shown in Figure-2. These tests result and standard are shown in Table-1. Tinius Olsen tensile machine is used in this work as showing in Figure-3.

Figure-2: AMETEK Material analysis division instrument

Table-1: Chemical composition of AA7075-T6 comparison with standard

Component	% Si	% Fe	% Cu	% Mn	% Mg
Standard [7]	≤ 0.4	≤ 0.5	1.2-2.0	≤ 0.3	2.1-2.9
Actual	0.26	0.24	1.81	0.11	2.15
Component	% Cr	% Zn	% Ti	% other	% Al
Standard [7]	0.18-0.28	5.1-6.1	≤ 0.2	≤ 0.15	Reminder
Actual	0.183	5.52	0.028	0.089	Reminder

Figure-3: Tensile Test Machine Type Tinius Olsen

3. Tensile Test [ASTM B557M - 15]

The most important component of tensile testing test is specimen, because it could determine the actual physical and mechanical properties of the material which had been tested. The selected specimen for such tests must conform to exact physical dimensions and it must be free of heat distortion or induced cold working. Specimen must be personnel and accurately calibrated as long as the tensile machines and this is very important before applying the test, because these test results were based on the accuracy and quality of the test specimen that been used. A preparation steps including a precision milling machine, highly skilled machinist and considerably highly skills hand finishing can achieve the required configurations of the test specimen needed **[8]**. To achieve accurate results, a test specimen must be prepared accurately and properly. The following rules are suggested for general guidance:

a. Using Standard dimensions and sizes such as ASTM standards and like.
b. Surface finishing is very important in preparing tensile test specimens because it might be affecting on the results.

Other preparation concludes:

1. Grinding the specimen faces and sides with grinding papers (Silicon Carbide) starting from 120, 320, 500, 1000 and 2000 type .
2. Polishing the specimen by polishing instrument (Alumina Powder) of a grain size 0.5 µm.
3. Washing the specimen by water, oil soap and alcohol to remove grinding and polishing remained particles .
4. Finally, smoothly clean the specimen by soft silky fabric until you should almost see yourself on it. Figure-4 shows the specimen before and after polishing.

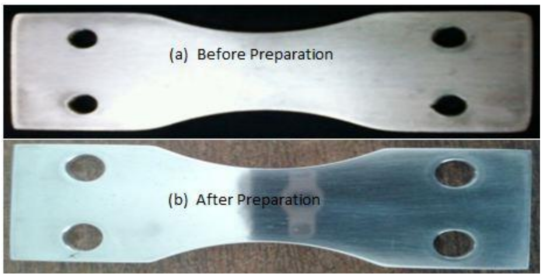

Figure-4: Fatigue Test Specimen (a) Before and (b) After Preparation Steps.

4. Fatigue Test [Avery Standard Test]

In this research, a fully reversed reciprocating plane bending fatigue testing machine (Bend Test) type Avery Model 7305 with stress ratio R = -1 was used, see Figure-5. To perform the tests, the following steps should be followed:

Step 1: Preparing the Machine:

As said, the machine should be calibrated to stress ratio R = -1 and for that two dial gages were used as shown in Figure-5.

Step 2: Machine Calibration:

Static Calibration: In machines, it is importance to know exactly the speed of the machine, as an error in its speed corresponds might be to a doubled error in the applied load where the load is produced by centrifugal forces or by reciprocating masses. Therefore, the motor speed must be checked and calibrated with the standard, specified in the instruction manual of the machine. These are: 1 HP constant and maximum rating, 1400 rpm, 2 Amperes at start and 380/440 volts, 3 phases, 50 Hz.

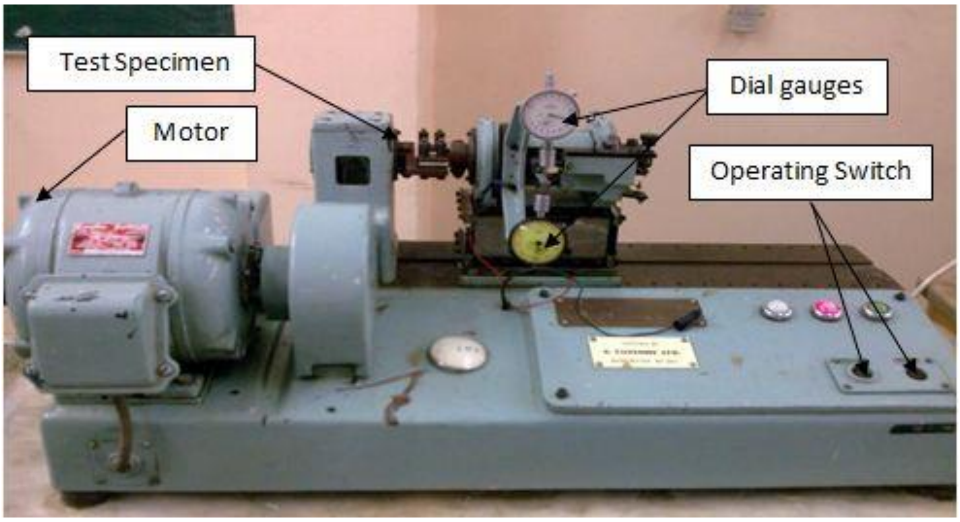

Figure-5: Plane Bending Fatigue Testing Machine Type Avery Model 7305

Dynamic Calibration: During the operation of the testing machine, a new source of error sometimes appears; these errors come from the arrived vibration of rotating parts of the machine, which might lead to errors in the estimated results of the test. In the present work, a rubber isolator was used between the machine and the grand table to eliminate the inertia effects [9].

5. Other Mechanical Properties Tests

Other tests included hardening test as in [10] and surface roughness test [Mitutoyo Standard Test]. The first test was done by (Rockwell Hardness Testing Machine) Figure-6, while the second test was done by (Mitutoyo Surface Roughness Testing Machine) Figure-7, all test was made by the COSQC-Baghdad (Central Organization for Standardization and Quality Control) according to the ISQ (Iraqis Specification Quality) 1475~1476/1989.


Figure-6: Rockwell Hardness Testing Machine

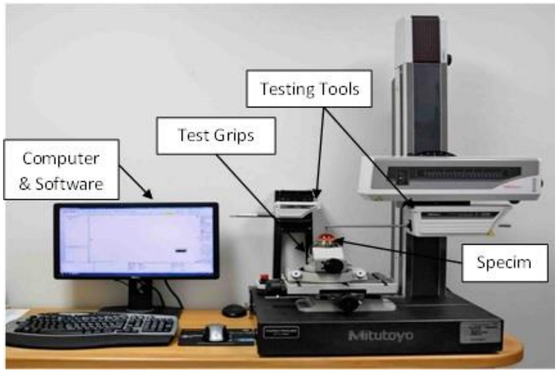

Figure-7: Surface Roughness Testing Machine Type Mitutoyo

6. Experimental Work

According to above a 20th tensile and fatigue specimens model [ASTM D-638-I] and [Avery Standard Fatigue Specimen] should been made and divided into four groups of 5 specimens each, the 1st group were tested dryly for 60 min in the microwaves furnace, Figures-8, 9 and 10, while the 2nd one were tested for 30 min, a wet test using waterbed for 60 min were used to made the 3rd group, and finally the same waterbed test for 30 min were made the last group.

Figure-8: The Microwave furnace used in this work Type Daewoo

Figure-9: Tensile Test Specimens each three for specific test from right to left (Water 30min, Water 60min, Dry 30min and Dry 60min)

Figure-10: Fatigue Test Specimens each three for specific test from left to right (Water 30min, Water 60min, Dry 30min and Dry 60min)

7. Results And Discussion

From the results of the present work, the following outcomes can be drawn.

1. For Hardness, it has been noticed that the major value was for test group of dry 60 min in microwave furnace with increment of about 15% from standard without treatment specimen, while the miner value was for test group of wet test with 30 min in microwaves furnace of only about 7%. This increasing of hardness according to microwave heat treatment is matching with references [1, 2, 14 & 18]. This increasing in hardness is corresponding with increasing of time inside microwave.
2. Table-1 and figure-11 have showed yield and ultimate strength of present test groups as compared with condition of without treatment (AA7075-T6). Yield and ultimate strength of wet conditions are higher than dry conditions. The major improvement is showed in 4th group with 55% and 99% for ultimate and yield strength respectively. While, the minor enhancement is in 1st group with 31% and 92% for ultimate and yield strength respectively. When time of treatment in microwave furnace is increased, yield and ultimate are decreased. Generally, ultimate strength has noticed improvement as compared with yield strength when using microwave as a heat treatment.

Table-2: Mechanical Properties results as compared with AA7075-T6

Groups	Mechanical Properties	Test	Without treatment	Increment %
1st	Hardness, Rockwell B	98	85	15
	Ultimate Tensile Strength	418 MPa	320 MPa	31
	Tensile Yield Strength	395 MPa	206 MPa	92
	Modulus of Elasticity	76.5 GPa	74 GPa	3.4
	Poisson's Ratio	0.363	0.35	3.7
	Fatigue Strength (S_F)	128 MPa	90 MPa	42
2nd	Hardness, Rockwell B	96	85	13
	Ultimate Tensile Strength	475 MPa	320 MPa	48
	Tensile Yield Strength	401 MPa	206 MPa	95
	Modulus of Elasticity	75 GPa	74 GPa	1.3
	Poisson's Ratio	0.348	0.35	0.5 decrement
	Fatigue Strength (S_F)	110 MPa	90 MPa	22
3rd	Hardness, Rockwell B	92	85	8.2
	Ultimate Tensile Strength	480 MPa	320 MPa	50
	Tensile Yield Strength	405 MPa	206 MPa	97
	Modulus of Elasticity	74 GPa	74 GPa	---
	Poisson's Ratio	0.333	0.35	5 decrement
	Fatigue Strength (S_F)	95 MPa	90 MPa	6
4th	Hardness, Rockwell B	91	85	7
	Ultimate Tensile Strength	495 MPa	320 MPa	55
	Tensile Yield Strength	410 MPa	206 MPa	99
	Modulus of Elasticity	73 GPa	74 GPa	1 decrement
	Poisson's Ratio	0.337	0.35	3.7 decrement
	Fatigue Strength (S_F)	92 MPa	90 MPa	2.2

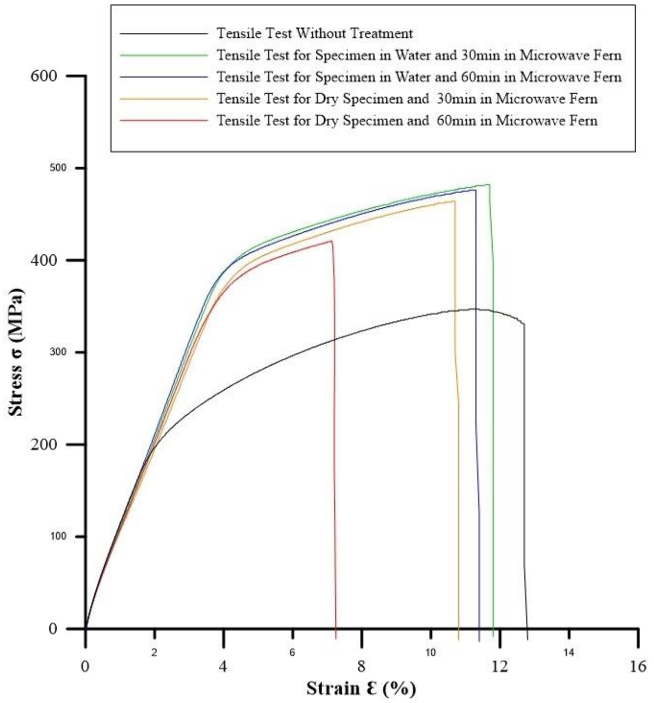

Figure-11: Stress – Strain diagram for tensile test of all tests specimens

3. For Elongation at break, the results are indicated that the alloys brittleness is increased due to the excessive heat from the microwaves furnace with respect to duration time, which is maybe or might made some changes in phases of the alloys surfaces leads the gran size of both alloys to decrease. The extension of these alloys is decreased generally from original alloy and references [1, 12, 13, 14, & 17] due to the same reasons.
4. It is also noticed that, for the fatigue strength test group of dry 60 min in microwave furnace was increased its value of about 29.5% higher than references [1, 12, 13, 14 & 17], while for test group of dry 30 min in microwave furnace there was increment of about 18.2%. Other test shows very little effect almost not noticed for that parameter.
5. For surface roughness, the majority effects were at 60min dry test while the 30min wet test shows minimum effect as shown in Table-3. Surface roughness parameter (Ra) is decreased when decreasing of time duration inside microwave furnace and the dry condition has greater (Ra) than wet condition.

Table-3: Surface roughness results of all groups

Alloys Type	AL 7075-T6			
Condition	Dry 60	Dry 30	Wet 60	Wet 30
Ra (µm) Read No.1	0.795	0.652	0.567	0.481
Ra (µm) Read No.2	0.792	0.648	0.562	0.478
Ra (µm) Read No.3	0.796	0.645	0.569	0.479
Ra (µm) Read No.4	0.797	0.655	0.565	0.480
Ra (µm) Average	0.794	0.650	0.566	0.479

6. There was not a great noticed change in the modulus of elasticity and Poisson's ratio for all tests groups.
7. For fatigue life, a high cyclic fatigue tests were used and the major decrement was also for test group of dry with 60 min in microwave furnace of about 42% from its original life. Wet conditions have not noticed change in fatigue life as compared with

dry conditions. The general equation form of fatigue life using Basquin equation [11] as following:

$$\sigma_a = \sigma_f N_f^{-b} \qquad (1)$$

Where:
σ_a : Applied stress to failure
N : The number of cycles at failure due to the applied stress
σ_f & b : Material constants that can be calculated by linearizing the S-N curve by rewriting equation (1) in logarithmic form. References [12, 13, 14, 16 & 17] are explained how to measuring the constants of equation (1).
After calculation the Basquin equation for 1st group, it is found that in equation (2):

$$\sigma_a = 156\ N_f^{-0.0655} \qquad (2)$$

While for test group of dry and 30 min in microwave furnace the decrement was about 22% only with equation life in equation (3) as following:

$$\sigma_a = 138\ N_f^{-0.0931} \qquad (3)$$

Other conditions were less affected on this criterion. Figure-12 shows the S-N curves of all groups as compared with the original alloy.

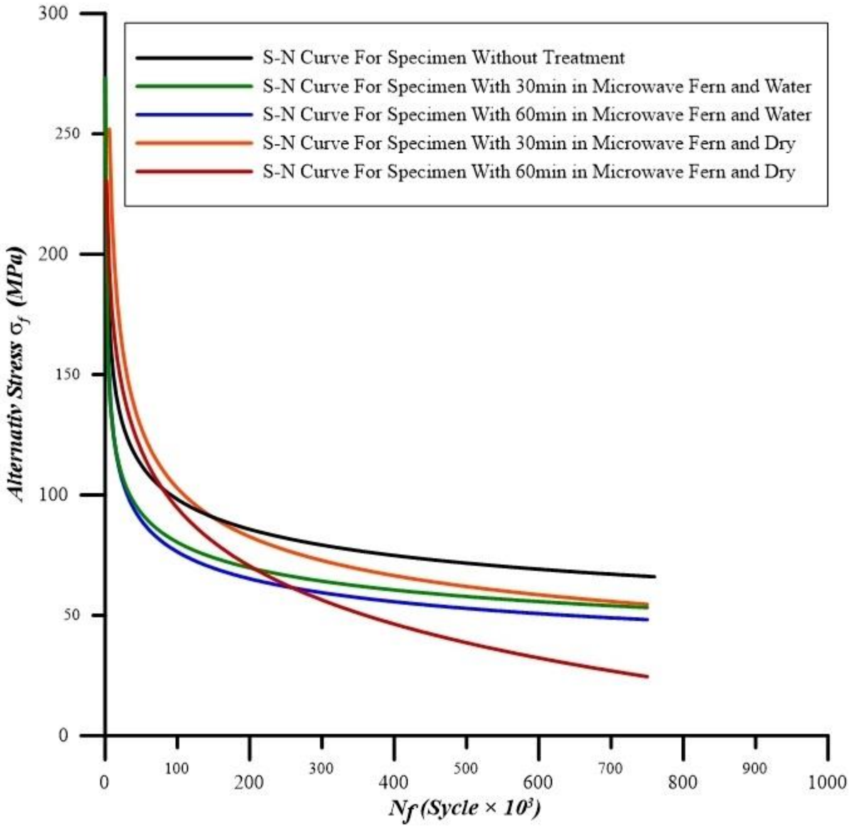

Figure-12: S – N Curves for all the Fatigue tests specimens

7. Conclusions

1. It is well-known that the yielding dependent upon nature of the material or alloy, also known that if the yielding increased this leads the materials to became more brittle which decreases the extension percentage at the tensile test and verse versa. Inscrutably in this work it has been found that a certain microwaves furnace duration time could make major effects on one or more of the mechanical properties including fatigue life, ultimate stresses and yielding stress for the alloys used.
2. Also, found in this work that increasing the yielding with decrement in extension percentage too. The explanation of this criterion is that the heat produces from microwave furnace hardened the surface of the alloy only, while the center of the alloy stills the same. Then, when the surface cooled, its grain cells became smaller in size with respect to the internal grin cells which remains at its original size because it cooled slower.
3. From this work, it can be found that using a microwaves furnace might be useful if knowing its effects on the mechanical properties because that will shorten both the time and cost of changing these properties into certain levels by only using suitable method and/or duration time and amount of heat.
4. There is no how in this experiments, the set of groups tests were made by the researchers, so for farther investigation it's extremely recommended using different duration times and or another environment to investigate its effects on the mechanical properties of the alloys.
5. The great benefits of availability of microwaves furnace in industrial application were found that these microwaves furnace changes it's mechanical properties in deferent levels than that for classical heat treatment methods, this change depends upon the parameters applied from changing the time duration to heat amount and different conditions, the amount of mechanical properties that changed even if it was not huge in some properties but clearly noticed especially if we know that this application is safe and cheap with respect to other applications which gives this processes privilege as the other applications doesn't optimize the material beater, so for those how need quick not expensive easily handled safe and with acceptable change of mechanical properties, the microwaves furnace is the best choice for them.

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