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DOI: 10.13140/RG.2.2.32964.94081

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Study the Effects of Microwave Furnace Heat on The Mechanical Properties and Estimated Fatigue life of AA 7075-T73 with Oil and salt solution Treatments

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Abstract

The aim of this study is known the difference that will occur when heat treating of the height strength aluminum alloys AA7075-T73 in a microwave furnace within different mediums (salt solution and oil) at different times (30 and 60) minute, where the heat occurs due to microwave furnace energy effect on the surface of the alloy, changing occur of its properties such as resistance to fatigue and the different mechanical properties. The experimental results of microwave furnace heat energy were showed that there were varied in the mechanical properties. The ultimate stress, yielding stress and fatigue strength were decreased for all states compared with standard values. With reference to fatigue life, the results were showed that the major increment in fatigue life occurred for test states of oil (30 and 60) min in microwave furnace were (83% and 75%) respectively., the increment in hardness range was reached for test state of salt solution medium in 60 min only about 3% from state without treatment samples.

Key words: Microwave Furnace, Mechanical properties, Fatigue life

الخلاصة

الهدف من هذه الدراسة هو معرفه التأثيرات التي سوف تحدث عند المعاملة الحرارية لسبيكة الالمنيوم عالية المقاومة AA7075-T73 في فرن المايكرويف وبأوساط مختلفة (محلول ملحي (ماء بحر) وزيت) عند اوقات مختلف(30,60) دقيقة. حيث ان تلك الحرارة المتولدة من موجات أفران المايكرويف تؤثر على سطح السبيكة مما يغير من بعض خواصها وكذلك من مقاومتها للكلال ومختلف الخواص الميكانيكية. أظهرت النتائج العملية للطاقة الحرارية لفرن الموجات الدقيقة أن هناك اختلافات في الخواص الميكانيكية. انخفض كل من الإجهاد الاقصى، اجهاد الخضوع ومقاومة الكلال لجميع الحالات مقارنة مع القيم القياسية. وفيما يتعلق بعمر الكلال، أظهرت النتائج أن الزيادة الكبيرة في عمر الكلال لحالات اختبار الزيت (30 و60) دقيقة في فرن الموجات الدقيقة كانت (83% و 75%)على التوالي. تم التوصل إلى زيادة في مدى صلابة لاختبار حالة لوسط محلول الملح في 60 دقيقة فقط حوالي 3% من حالة العينات بدون معاملة.

الكلمات المفتاحية: فرن المايكرويف، الخواص الميكانيكية ,عمر الكلل

1. Introduction

Microwaves are portion of the electromagnetic field with ranging of frequencies from 300 MHz to 300 GHz and equivalent wavelengths between 1 m and 1 mm respectively **(Xiang *et.al.*,2005)**. However, the widely-used microwave frequencies for studies and industrial actions were about 2.45 GHz and 915 MHz (**Michael , 2004**) Microwave furnace heat energy is rapidly emerging as an active and efficient tool in various technological and scientific fields (**Jing *et.al.*,2016)**. Heat is generated from inside the object by the absorption of microwave energy directly through the object and does not need considerable heating of the surrounding. Therefore, a temperature distribution exists in both conventional and microwave furnace heating as a product of the method heat is transferred /generated in the object (**Wai and Manoj Gupta, 2015**). Microwave furnace heat energy processing is a green manufacturing process, considerably fast and hence tends to be highly energy consumption saving. Microwaves have been effectively and efficiently applied for processing of ceramics and composite materials which are else hard to process through conventional processes, its fine microstructures and improved mechanical properties are observed with reduced processing duration time **(Manoj and Wong ,2007)**. When a material absorbs microwaves, heat can be generated inside the material and heating is direct with the introduction of power**.** Additional benefit of microwave furnace heating is that it can hurry reaction rates and decrease reaction temperatures through reducing activation energy **(Xiang *et.al.*,2005)**., microwave material processing technology has increased greatly interest because of the relatively low industrial costs, both energy and time saving, the fast sintering process, higher energy efficiency, short soaking time, improved product homogeneity and high yields **(Penchal *et.al.*,2016)**. There are numbers of reports related with microwave furnace heat energy of metals in various fields: Sintering, Joining, Metal glass and composite materials **(Noboru , 2010)**. In microwave furnace heat energy processing, microwave furnace energy heats the alloy at the differs heat planes، which will might leads to a homogeneously majority heating, conversely in the conventional heating systems, the alloy heated from inner core to the surface which produces thermal stress and/or longer time required for homogenization **(Wai and Manoj ,2015).** The fracture strength, toughness and hardness arrived from microwave furnace energy of treated specimen components were reported to be higher than others conventionally heat-treated application ones **(Ahmed *et.al.*, 2017)**. A heat-treating process by microwave furnace can be used for a varied application of surface treatments such as carbonating, carburizing, bronzing and chroming **(Satnam *et.al.*, 2015)**. Penetration depths of microwaves in water description of the frequency apply, the energy would be absorbed in a thin surface layer. Therefore, it may be possible to heat salty water more rapidly than pure water **(Michael ,2004).** It had been believe that oil models heat faster in a microwave furnace than do water models of the similar mass **(Barringer *et. al.*,1994)**.

There is a common misconception about the use of minerals in microwave ovens and the concept is unscientific and based on false grounds and simplest proof of that is that most of these ovens are built from the inside metal fully, how dangerous this is consistent? This research aims to focus on and remove those problematic and misconceptions.

In this work, a newer technique including microwave furnace post heat treatment of specimen surface were employed. Period microwave oven was used efficiently to process AA7075-T73. The research concentrated on the mechanical properties and estimated fatigue life affected by the microwave furnace energy heat treatment of the alloy used. In this work, the sheet material was heat treated using microwave furnace energy at 2450MHz and 900W and the estimated fatigue life as long as its effect on mechanical properties is discussed in this work in details.

2. Experimental Work:

A- Material selection:

7XXX series aluminum alloys have been widely used as structural materials in aeronautical industries due to their attractive comprehensive properties, such as low density, high strength, ductility, toughness and resistance to fatigue **(LI Jin-Feng *et.al.*,2008)**, Also it is attracting much attention because of their favorable strength-to-weight ratio and corrosion resistance compared to conventional stainless steels **(Zabih-Alah *et.al.*,2015)**. The 7xxx-series alloys have zinc as their primary alloying agent, with a small amount of magnesium added. Some alloys also contain copper or chromium **(Adeyemi *et.al.*, 2013)**. It is general known that aluminum alloy 7075-T73 has high strength and relatively a very good resistance for corrosive **(Fatima ,2016).** This group of alloys exhibits the highest strength as far as aluminum is concerned and in many cases, they are superior to that of high tensile steels. These alloys are heat treatable and can acquire very high strengths. Though other 7XXX alloys had been emerging with improved specific properties, alloy 7075 stall the standard with a good balance of properties necessary for aerospace applications **(Teng-Shih *et.al.*, 2014)**. Both hardness and strength of the metal were extremely needed to be improved in any engineering applications. So, to apply this suitable heat treatment process is needed in order to improve the mechanical properties of such alloys **(Ahmed *et.al.*, 2017)**.

B-Specimen Preparation

Tensile and fatigue test specimens were prepared using a milling machine as follow: The sample profile was obtained using a milling machine with a special fixture to achieve specimen geometry in accordance with the standard [ASTM E9M]. 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 has been used.

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 sample because it might be affecting on the results.

Other preparation concludes:

1. Grinding the sample faces and sides with grinding papers (Silicon Carbide) initially from 400, 800, 1000, 1500 and 2000 type.
2. Polishing the sample by polishing instrument (Diamond Paste of a grain size 3 μm and lubricant).
3. Washing the sample by water, oil soap and alcohol to clean grinding and polishing stick particles.
4. Finally, smoothly clean the sample by soft silky fabric until you should almost see yourself in it.

C- Process Parameters

The study investigation was carried out on AA 7075 composition. The tests of were conducted 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). The effects of the test are shown in Table **(1)** together with the standard materials for comparison resolves. material used is plat of AA7075-T73 with thickness (3mm) formed to a standard test specimen (tensile) by CNC machine after that Thermal treatment In this study, the samples are placed inside the microwave furnace type (Lifetec mikrowelle 2450 MHZ, 900W) as shown in Figure-1, in 1 litter from different mediums: salt solution (50% salt percentage) and sunflower oil treated in microwave furnace at different time (30 and 60 min) Figure (1).

Component	% Si	% Fe	% Cu	% Mn	% Mg
Standard **[ASTM]**	≤0.4	≤0.5	1.2-2.0	≤ 0.3	2.1-2.9
Used	0.28	0.26	1.51	0.21	2.24
Component	% Cr	% Zn	% Ti	% other	% Al
Standard **[ASTM]**	0.18-0.28	5.1-6.1	≤0.2	≤0.15	Reminder
Used	0.265	5.18	0.03	0.098	Reminder

Table (1): Material composition of aluminum alloy 7075-T73

Figure (1): Microwave Furnace with Specimen

Note: 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.

3. Tensile Test [ASTM B557M - 15]:

The tensile test was carried out according to American Society for Testing Material **(ASTM)**. Plate tensile specimens were of the geometry and dimensions shown in Figure (2). The tensile test was used (50KN Tinus Olsen) testing machine Figure (3). The average value of three tests is recorded and used to draw the stress-strain curve. 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 has been used.

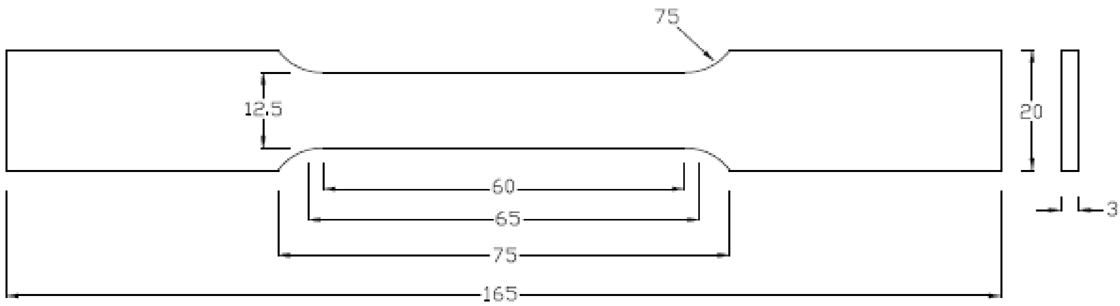


Figure (2): Standard Tensile Test Specimen. All dimensions in mm for plane specimen [ASTM E9M]

Figure (3): Tensile Test Machine

4. Hardness Test: [ASTM E110 - 14]

Hardness is known that resistance the material from scratch and penetration. The heat-treated samples were subjected to the Rockwell hardness test after the samples were polished and mounted on the machine applied a dwell time of 15 seconds. The diameter of the hollow left by the ball was then measured using the Rockwell hardness number was determined. (Rockwell Hardness Testing Machine). Figure (4).

Figure (4): Rockwell Hardness Testing Machine

5. Surface roughness Tests:

Roughness is an important part in calculating how an actual thing will interact with its surrounding. Rough surface samples usually wear more rapidly and have friction coefficients higher than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical part, since indiscretions on the surface may form nucleation positions for cracks or corrosion. On the other side, roughness may help to adhesion .It was done by (Pocket surf IV Surface Roughness Testing Machine) Figure (5).

Figure (5): Pocket surf IV Surface Roughness Testing Machine.

6. Microstructure and Surface Topographic Image:

In order to study the microwave furnace heat energy behavior of AA7075-T73, light microscope images were taken for different regions in the samples surface. Where cut samples with (1*1) cm^2 selection, mounting, grinding, polishing and etching. The microstructures were then characterized by light microscopy Figure (6), after etched by using killer solution (2.5mlHNO_3 ,1.5mlHCL,1ml HF,95ml H_2O).

Figure (6): Light Microscope

7 . Results and Discussion

For the mechanical properties, the results that have been calculated after the four test processes is as shown as in, Table (2).

1. The ultimate tensile stress, there were reduced to occur in all groups compared with stander values. Where a little effect for a test group of salt solution 30 min in a microwave furnace of about 2%, while for other test groups, there were less of 17% for a test group of salt solution 60 min in microwave furnace, But noticed major effect for oil 60 and oil 30 group tests about 44.5% and 25.6 % respectively. Figure (9).
2. Also, found in this work that decreasing the yielding with decrements in extension percentage too. When sample had been tested for tensile test and check the result, it was found that a decrement of about 65% for a test group of oil 60 min in a microwave furnace and a decrement of about 40% for a test group of oil 30 min while the decrement for group of 60 min in microwave furnace and with salt solution was 31% and only about 1% of the last group.
3. Elongation at break, the calculated results 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 make some changes in phases of the alloy surfaces leads the gran size of both alloys to decrease. The extension of these alloys is decreased generally from references due to the same reasons above, but the major decrement was for the test group of salt solution 60 min in a microwave furnace of about 41.6% and about 25.5% of a test group of oil 60 min in a microwave furnace than reference, while there was little decrement of about 15% for test group of oil 30 min in microwave furnace and only 8% for the last group, all than its references.

4. There was not a great noticed change in the modulus of elasticity for all test groups.
5. It is also noticed that, for the fatigue strength test group of oil 60 min in microwave furnace was decreased its value of about 44.5% lower than references, while for test a group of oil 30 min in a microwave furnace there was decrement of about 25.6%. But in salt solution 60 and 30 min in mediums test shows very little effect 17% and 2% respectively, decrement percentage.
6. Fatigue life, a high cyclic fatigue tests were used .at amplitude stress 100 MPa the major increment in fatigue life was for test groups of oil with 30 min and 60 min in a microwave furnace 83% and 75% respectively, compared with its original life and the general equation form of life using *(Basquin equation,* $\sigma_a = \sigma_f N_f^{-b}$) Table-3. While for test groups of salt solution 60 the decrement was about 41.7 %, last for 30 min group test the decrement in fatigue life was only about 25%. Figure (10).
7. Surface roughness, noticed that when time increasing the surface roughness increase. The majority effects were at 60min with salt solution mediums test 47.8%, while the salt solution 30 test shows 26.7% and the minimum effect was occurring at oil 30 min test about 16 % and only about 1.7% decrement occurred in oil 60 min group. Figure (11. (A))
8. Hardness, it has been noticed that the major value was for a test group of salt solution 60 min in a microwave furnace with an increment of about 3% from standard without treatment samples, while the decrement in hardness for groups oil 30 min and oil 60 min in a microwave furnace were 11.7% and 9.5% respectively, for salt solution 30 min group the decrement was only about 2.8%.

8. Conclusion

1. 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. Using a microwave furnace might be useful if known 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.
3. In general, the salt contains in salt solution medium led to corrosion in the surface and occurrence of pits on it, these pits are the place for the initiation of cracks and the higher hardness of the surface and high surface roughness led to increasing in crake propagation, So decrement in fatigue life was occurred .But in the oil medium made to insolated the surface of the heating samples , this led to reducing the oxidation of surface so surface roughness was less while fatigue life increase.
4. From this work, it can be found that using a microwaves fern 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.

5. The great benefits of availability of microwaves furnace in industrial application was 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.

Table (2). Mechanical Properties of AA 7075-T73 as taken from the COSQC.

Group-1 Oil 60min in Microwave Furnace		
Mechanical Properties	Test	Standard
Hardness Rockwell B Value	81	89.5
Ultimate Tensile Stress value MPa	275	496
Tensile Yield Stress value MPa	135	385
Modulus of Elasticity value (E) GPa	77	76.3
Extension (%)	13.4	18
Fatigue Strength value (MPa)	124	223.2
Surface roughness Ra(µm)	0.56	0.6
Group-2 Oil 30 min in Microwave Furnace		
Mechanical Properties	Test	Standard
Hardness Rockwell B Value	79	89.5
Ultimate Tensile Stress value MPa	369	496
Tensile Yield Stress value MPa	230	385
Modulus of Elasticity value (E) GPa	75.37	76.3
Extension (%)	15.3	18
Fatigue Strength value (MPa)	166	223.2
Surface roughness Ra(µm)	0.504	0.6
Group 3- Salt Solution 60 min in Microwave Furnace		
Mechanical Properties	Test	Standard
Hardness Rockwell B Value	92	89.5
Ultimate Tensile Stress value MPa	411	496
Tensile Yield Stress value MPa	265	385
Modulus of Elasticity value (E) GPa	75	76.3
Extension (%)	10.5	18
Fatigue Strength value (MPa)	185	223.2
Surface roughness Ra(µm)	0.887	0.6
Group 4- Salt Solution 30 min in Microwave Furnace		
Mechanical Properties	Test	Standard
Hardness Rockwell B Value	87	89.5
Ultimate Tensile Stress value MPa	485	496
Tensile Yield Stress value MPa	380	385
Modulus of Elasticity value(E) GPa	75.3	76.3
Extension (%)	16.5	18
Fatigue Strength value (MPa)	218.2	223.2
Surface roughness Ra(µm)	0.76	0.6

Table (3). Amplitude Stress σa MPa

State		$\sigma_a = \sigma_f . N_f^{-b}$
Stander		$\sigma_a = \sigma_f . N_f^{-0.079}$
Salt Solution	***30min***	$\sigma_a = \sigma_f . N_f^{-0.0912}$
	60min	$\sigma_a = \sigma_f . N_f^{-0.096}$
Oil	***30min***	$\sigma_a = \sigma_f . N_f^{-0.0614}$
	60min	$\sigma_a = \sigma_f . N_f^{-0.067}$

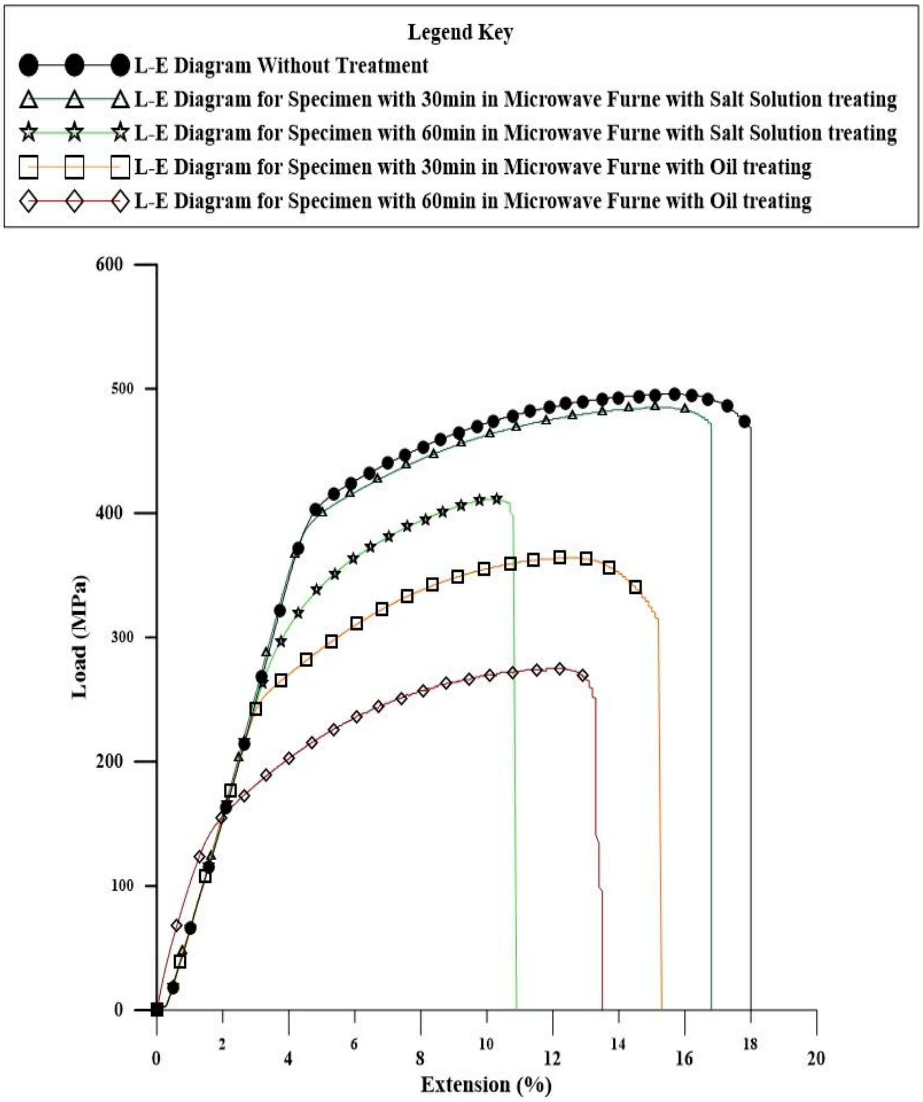
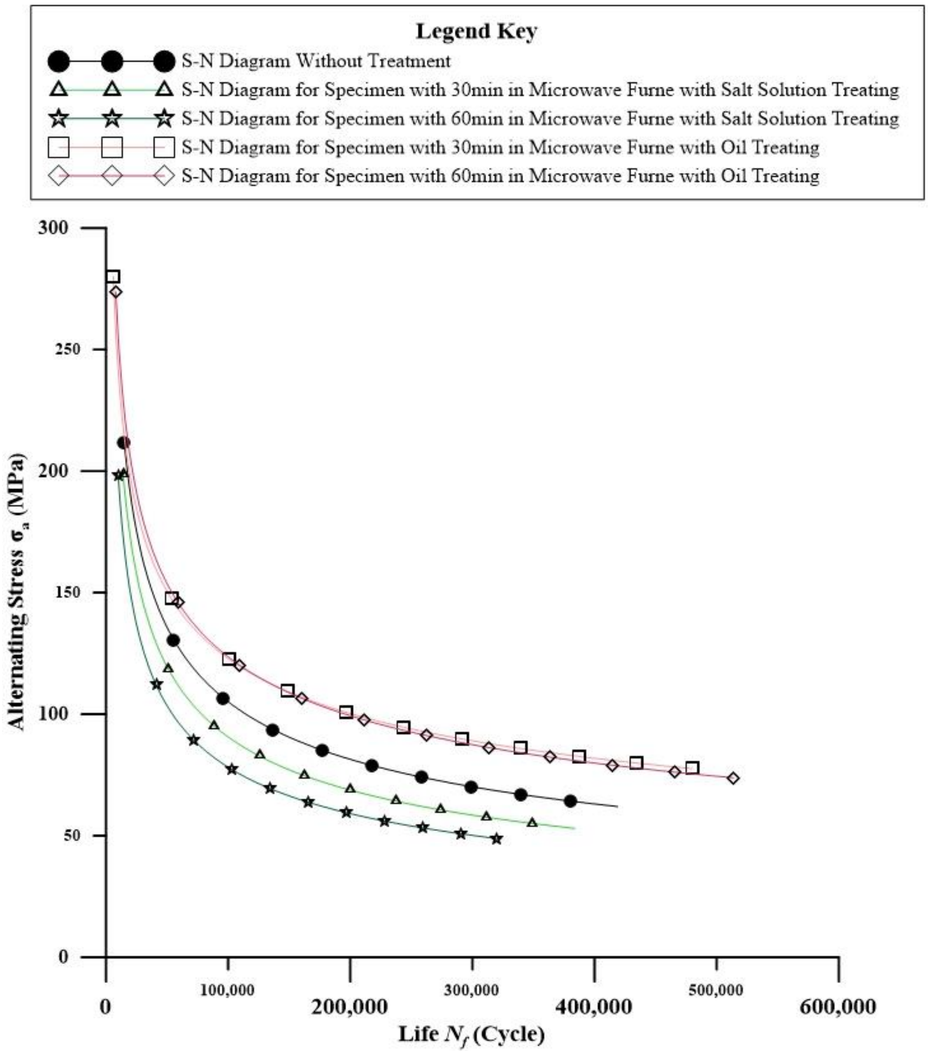
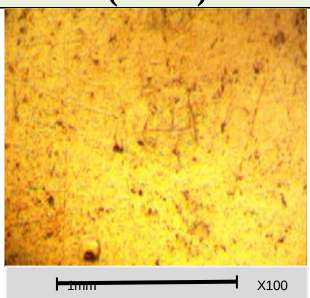
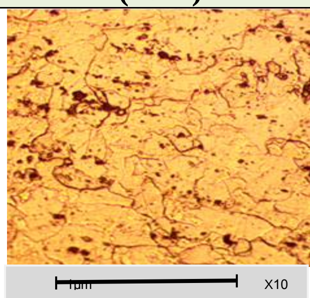
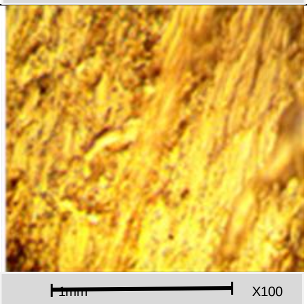
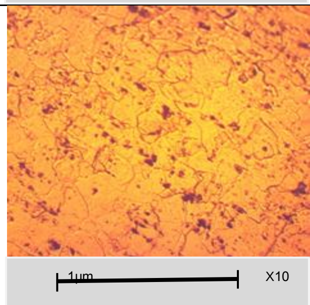


Figure (9): Stress – Strain chart for tensile test of all tests samples



Topographic iamge(A) (100 X)	Type of medium	Microstructure iamge(B) (10 X)
	Without Treatment (Standard)	
	Salt Solution 30 min	

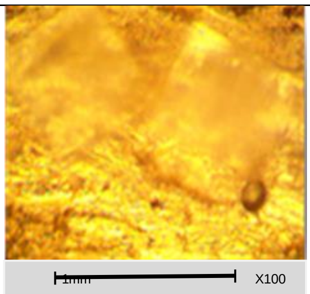
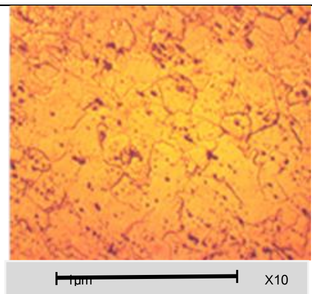
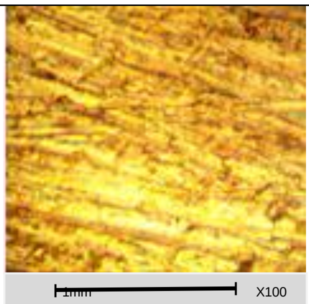
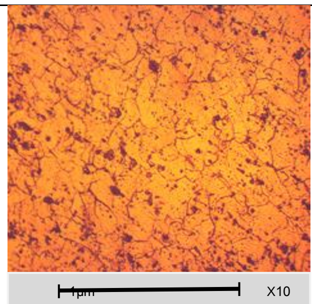
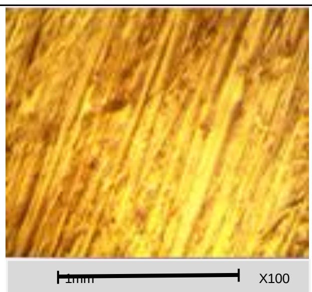
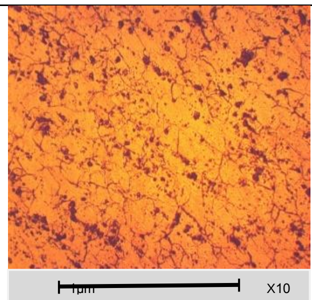
	Salt Solution 60 min	
	Oil 30 min	
	Oil 60 min	

Figure (10): S – N Curves for all the Fatigue tests samples

Figure (11): Surface topography (A) and microstructure image (B)

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