Investigating the Effects of Microwave Furnaces Heat on the Mechanical Properties and Fatigue Life of AA6061-T6 Alloy

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Abstract

The objective of this research is to determine the effect of microwave furnaces heat energy on the surface of an aluminum alloy AA 6061-T6, also, to investigate the range of change in mechanical properties and the estimated fatigue life have through different medium (dry and salt solution) and duration times (0.5-1 hour). It was found that the heat generated by the energy of the microwave furnace affected the ultimate stress and the yield stress as well as surface roughness, hardness and modulus of elasticity, where degrees varied according to the time of exposure to those waves. The estimate fatigue life was also affected by heat generated through the energy of the microwave furnace. The highest range of change was when the alloy specimen was subjected to microwave heat energy for one hour. All the variation was compared with the properties of the alloy without treatments as received (ASTM Standards) in tables within the research. Also, the research aims to change the wrong idea about not using metals with the microwaves furnace and to prove it's safe to do that through controlled steps.

Key words: Microwave Furnace, Mechanical properties, Fatigue life .

الخلاصة

ان الغرض الاساسي من هذة الدراسة هي لمعرفة مدى تأثير حرارة طاقة افران المايكروويف على سطح سبيكة الألمنيوم من نوع AA6061-T6، وكذلك لبحث مدى التغير الحاصل في الخواص الميكانيكية وعمر الكلال المحسوب من خلال أوساط أختبار (وسط جاف ووسط ملحي) ولفترتين زمنيتين (نصف ساعة وساعة كاملة داخل الفرن). وجد ان الحرارة الناجمة من الطاقة موجات أفران المايكروويف اثرت في الاجهاد الاقصى وكذلك أجهاد الخضوع كما كان لها تأثير كذلك على خشونة السطح، الصلادة وكذلك معامل المرونة حيث كانت معدلات تلك التغيرات تختلف تبعاً للوقت الذي تعرضت له لموجات المايكروويف. تأثر عمر الكلال المحسوب كذلك بتلك العملية وكانت اعلى معدلات تلك التأثير هي عند التعرض لحرارة طاقة موجات المايكروويف لمدة ساعة كاملة. تمت مقارنة كافة تلك التغييرات مع النتائج الاولية المستحصلة لنفس السبيكة من دون معاملة ووفق معايير قياسية بجداول مثبتة داخل متن الدراسة. تهدف الدراسة ايضاً لدحظ المفهوم الخاطئ حول محاذيير استخدام المعادن داخل تلك الافران والاثبات انه بالامكان استعمالها وفق ضوابط متحكم بها مسبقاً.

الكلمات المفتاحية :- افران المايكروويف، خواص ميكانيكية، عمر الكلال.

1. Introduction

Microwaves are a part of the electromagnetic spectrum with frequencies ranging from 300 MHz to 300 GHz and consistent wavelengths between 1m and 1mm respectively **(Xiang *et.al.*, 2005)**.However,2.45 GHz and 915 MHz were the commonly-using microwave frequencies for study and industrial actions **(Michael, 2004) .** Heat generated within the body by the absorption of microwave furnace heat energy directly by the body and do not need substantial heating of the environment. Therefore, a temperature gradient exists in both conventional and microwave furnace heat energy because of the way heat is transferred /generated in the object **(Wai, 2015)** . Microwave furnace heat energy processing's are a green manufacturing process, significantly fast and hence tends to be highly economical and had been effectively and efficiently using for processing of ceramics and composite materials which are else hard to process through conventional processes **(Manoj, 2010)** . Microwave material processing technology had been gaining much interest due to the relatively low manufacturing costs, both energy and time saving, the fast sintering process, short soaking time, higher energy efficiency, improved product uniformity and high yields **(Penchal *et.al.*, 2016)** . A heat-treating process by microwave furnace can be used for a wide application of surface treatments such as carbonating, carburizing, bronzing and chroming **(Ahmed, 2017)** .

2. Experimental Work:

A- Material: 6XXX series aluminum alloys have been widely used as structural materials in aeronautical industries due to their attractive comprehensive properties, such as low density, acceptable strength, ductility, toughness and resistance to fatigue **(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.*,2014)**. It is general known that aluminum alloy 6061-T6 has acceptable strength and relatively a very good resistance for corrosive **(Fatima Ali Hussain, 2015).**

B-Specimen Preparation Tensile and fatigue test specimens were prepared using a CNC-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, Figures (1,2). (**ASTM E8M**).

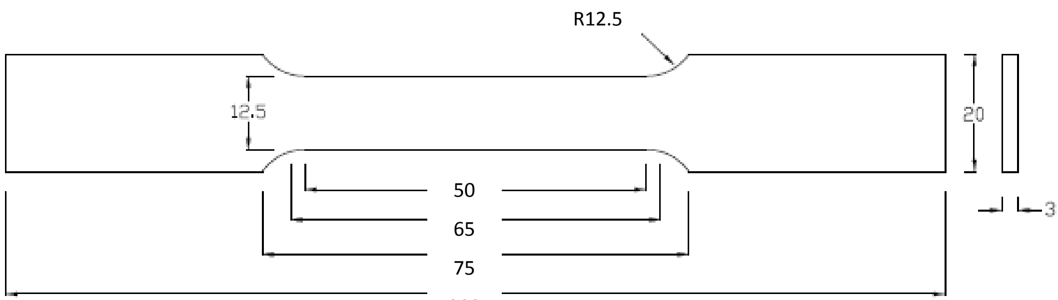


Figure (1): Standard Tensile Test Specimen. All dim. in mm for plane specimen [ASTM E8M]

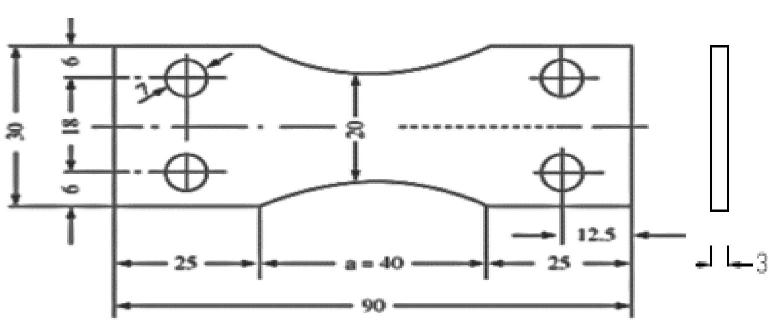


Figure (2): Standard Fatigue Test Specimen, all dim. in mm for plane specimen (Avery Manual)

C- Process Parameters

Thermal treatment was including during this study: The samples were subjected inside the microwave furnace as shown in Figure (3), with 1 liter from all the different mediums: dry and salt solution (50% salt percentage) treated in microwave furnace at different time (0.5 and 1 hr), Then the samples were cooled slowly inside the microwave furnace.

Figure (3): Microwave Furnace with Specimen

3. Tensile Test (ASTM B557M – 15):

The tensile test was carried out according **ASTM E8M**. The tensile test devise used was (50KN Tinus Olsen) testing machine as shown in Figure (4).

Figure (4): Tensile Test Machine (ASTM B557M – 15)

4. Fatigue life Test (Avery Plane Bending Fatigue Test Machine):

Afully reversed reciprocating plane bending fatigue testing machine (Bend Test) type Avery Model 7305 with stress ratio R= -1 was used, as shown in Figure (5).

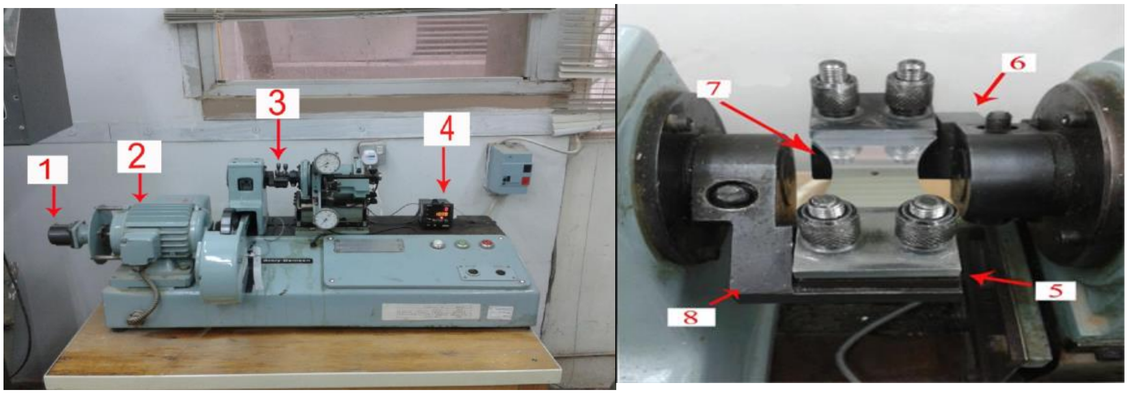


Figure (5): Fatigue testing machine (AVERY DENISON-7305).
1. Mechanical counter 2. Motor 3. Sample fixture 4. Digital counter 5. Clamp 6. Fixed grip 7. The sample 8. Movable grip

5.Hardness Test (ASTM E110 – 14):

The heat-treated samples were subjected to the Rockwell hardness testing machine as shown in Figure (6). 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.

Figure (6): Rockwell Hardness Testing Machine

6. Surface roughness Test:

It was done by (Pocket surf IV Surface Roughness Testing Machine) as shown in Figure (7).

Figure (7): Pocket surf IV Surface Roughness Testing Machine.

7. Microstructure and Surface Topographic Image:

To study the microwave furnace heat energy behavior of AA6061-T6, 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 then treated by the microwaves furnace. The microstructures were then characterized by light microscopy Figure (8), after etched by using killer solution (2.5mlHNO_3 ,1.5mlHCL,1ml HF,95ml H_2O).

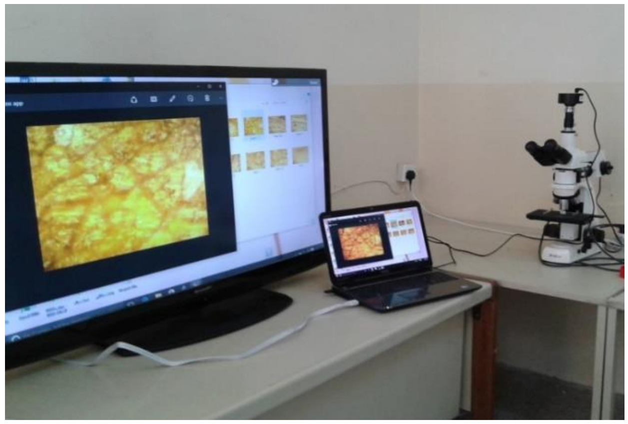
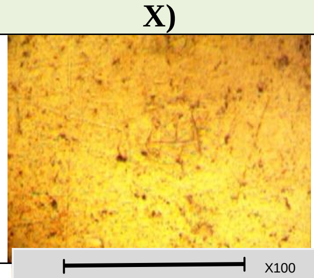
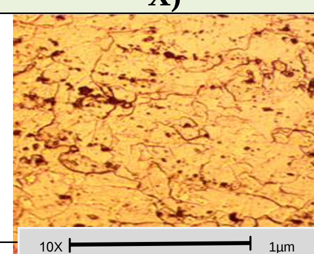
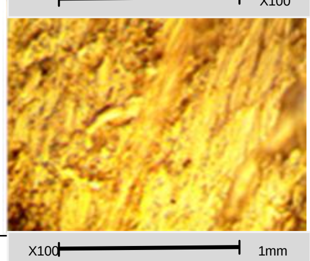
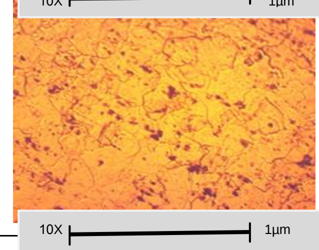


Figure (8): Light Microscope

8. Results

All the results calculated by the tests above showed in tables 1,2 and 3, also the result of tensile test, estimated fatigue life and the microstructure surface topographic was illustrated in Figures (9,10 and 11).

Topographic iamge(A) (100 X)	Type of medium	Microstructure iamge(B) (10 X)
	Without Treatment (Standard)	
	Salt Solution 0.5 hr	

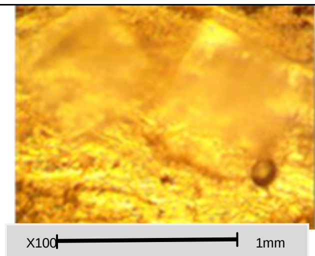
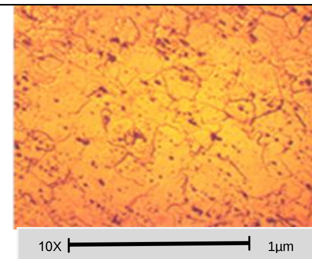
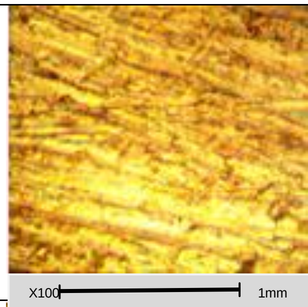
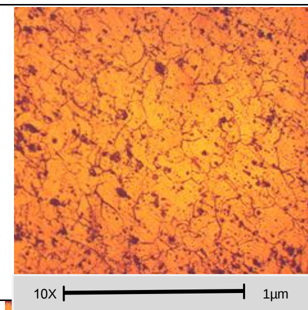
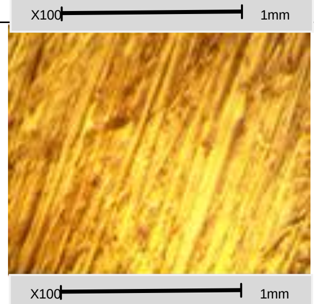
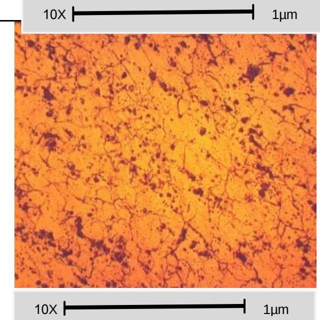
	Salt Solution 1 hr	
	Dry 0.5 hr	
	Dry 1 hr	

Figure (9): Surface topography (A) and microstructure image (B) of 1µm surface alloy

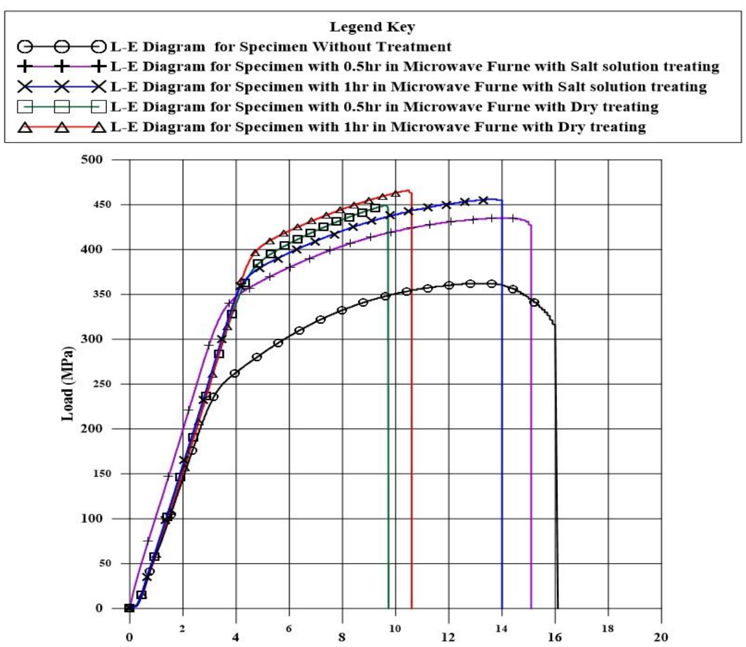


Figure (10): Load – Deflection chart for tensile test of all tests samples

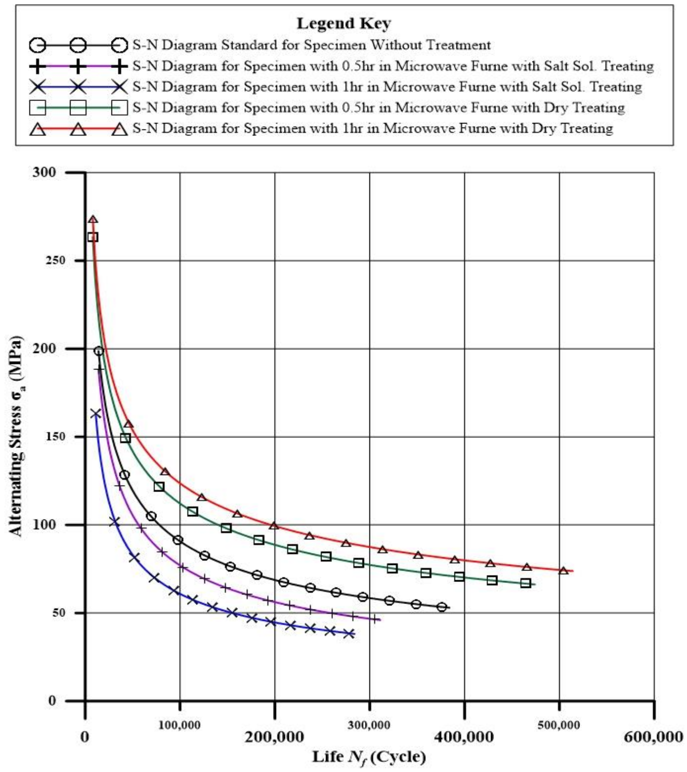


Figure (11): S – N Curves for all the Fatigue tests samples

Table (1): Material composition of aluminum alloy 6061-T6

Component	**% Si**	**% Fe**	**% Cu**	**% Mn**	**% Mg**
[ASTM] Standard	0.4-0.8	≤ 0.7	0.15-0.4	≤ 0.15	0.8-1.2
Actual	0.56	0.35	0.22	0.08	1.12
Component	**% Cr**	**% Zn**	**% Ti**	**% other**	**% Al**
[ASTM] Standard	0.04-0.35	≤ 0.25	≤ 0.15	≤ 0.15	Reminder
Actual	0.065	0.16	0.025	0.097	Reminder

Table (2). Mechanical Properties of AA 6061-T6 as taken from the COSQC-Baghdad (Central Organization for Standardization and Quality Control) according to the ISQ (Iraqis Specification Quality) 1475~1476/1989.

Mediums Cases in Microwaves Furnace		Mechanical Properties																				
		Hardness Rockwell B			Ultimate Tensile Stress value (σ_{ut}) MPa			Tensile Yield Stress value (σ_y) MPa			Modulus of Elasticity value (E) GPa			Extension (%)			Fatigue Strength value (MPa)			Surface roughness Ra (μm)		
		Test	As received WT	+/- from WT (%)	Test	As received WT	+/- from WT (%)	Test	As received WT	+/- from WT (%)	Test	As received WT	+/- from WT (%)	Test	As received WT	+/- from WT (%)	Test	As received WT	+/- from WT (%)	Test	As received WT	+/- from WT (%)
Dry	1hr	81	62	23.4	467	356	21.8	395	270	31.6	71	69	2.81	10.8	16	-48.1	109	95	12.8	0.48	0.6	-25
	0.5 hr	79	62	21.5	448	356	18.5	354	270	23.7	70.5	69	2.12	9.7	16	-64.9	102	95	6.86	0.50	0.6	-19.1
Salt Sol.	1hr	72	62	13.8	456	356	19.9	367	270	26.4	70	69	1.42	14	16	-14.2	98.5	95	3.55	0.88	0.6	32.3
	0.5 hr	68	62	8.82	439	356	16.8	342	270	21.1	69.5	69	0.71	15	16	-6.66	97	95	2.06	0.76	0.6	21.1

Table (3). Amplitude Stress σa MPa, For all medium tests

Basquin Equation		$\sigma_a = \sigma_f . N_f^{-b}$
AS received WT		$\sigma_a = \sigma_f . N_f^{-0.0885}$
Salt Solution	0.5hr	$\sigma_a = \sigma_f . N_f^{-0.0937}$
	1hr	$\sigma_a = \sigma_f . N_f^{-0.0945}$
Dry	0.5hr	$\sigma_a = \sigma_f . N_f^{-0.0794}$
	1hr	$\sigma_a = \sigma_f . N_f^{-0.737}$

9.Discussion

For the mechanical properties, the results that have been calculated after the test processes are: -

1. The ultimate tensile stress, which increased in all tests compared with standard values (see Figure (10). Where maximum increment of about 23.5% was for dry 1 hr in a microwave furnace, 21.5% for dry 0.5 hr. For salt solution medium 1 hr in a microwave furnace only about 14% increment was seen. Also, about 9% increased for dry 0.5 hr. The reason for this is due to the excessive thermal heat affecting the surface into its core of the alloy due to the microwaves heat energy arrived.
2. Also, found that the increasing of the yielding stress with decrements in extension percentage too. The reason for this phenomenon is that the thermal heat created by microwave furnace hardened the surface of the alloy, through the core of the alloy. Also, when the surface cooled, the grain cells became smaller compared with the internal grain cells which was still at its original size as it was cooled in a slower rate. So, when a sample was tested for tensile test and checked the results found increment of about 32% for dry 1 hr in microwave furnace ,24% increment for a test group of dry 0.5 hr while the increment for salt solution medium was 27% only for 1 hr and 22% increment for 0.5 hr in a microwave furnace.
3. For elongation at break, the results showed that the alloy brittleness raised due to excessive heat from the microwaves furnace with deference to duration time, which might have made some changes in phases of the alloy surface causing the grain size of alloy to decrease. The extension of this alloy is reduced generally from reference due to the same reasons above, but the major decrement was for the test group of dry media with 1 hr in a microwave furnace of about 48.5% and about 65% for a test group of dry 0.5 hr in a microwave furnace than reference, for salt solution 1 hr was about 14.5%, 7% the decrement respectively.
4. There was not a great observed variation in the modulus of elasticity for all test mediums and treated times, the increment was only 0.71 % for 0.5hr salt solution and 1.42 % for 1hr salt solution, for dry 2.8% and about 2.2% for 1hr and 0.5hr respectively, Figure (10) shows no change in the elastic zone for the slop of load-extension diagram which is identify the stress-strain one and for that reason there was almost no change in the modules of elasticity.
5. For the fatigue strength (at the point where the specimen break), it is observed that the test group of dry 1 hr in microwave furnace increased by about 13% higher than references. While for test group of dry 0.5 hr in a microwave furnace 7% and 3.5% for

salt solution 1 hr and 2% for 0.5 hr respectively. The results war reasonable since, if consider the empirical ratio between the ultimate stresses and the fatigue strength for the aluminum alloys is ($\sigma_{ult} = (0.35 \sim 0.45) S_f$).

6. For fatigue life, the high cyclic fatigue tests were applied at amplitude stress 100 MPa, the major increment in fatigue life occurred for test groups of dry (1 hr and 0.5 hr) in a microwave furnace of (80% and 72%), respectively, where salt solution medium causing insolated the surface from the environment condition, so close porosities and prevent surface oxidation. This state led to increase the surface roughness with pits or surface cracks. For salt solution with 1 hr in a microwave furnace the decrement in life was about 30% compared with its original life and the general equation form of life using (Basquin equation, $\sigma_a = \sigma_f N_f^{-b}$). The salt contains in salt solution medium led to corrosion in the surface and occurrence of pits on it. These pits are the places for the initiation of cracks, so the higher surface roughness causing increment in crake propagation, therefore decreasing the fatigue life. While for a test group of salt solution at (1 hr and 0.5 hr) group tests, the decrement in fatigue life were about 30% and 21% respectively. Table (3). Represent the fatigue equation for all mediums where we could get σ_f and N_f from S-N Curve.
7. The microstructures were characterized by light microscopy, after etched by using killer solution (2.5mlHNO_3 ,1.5mlHCL,1ml HF,95ml H_2O) it is observed that effects of microwaves heat energy on the surface of the alloy especially for salt solution 1 hr treated and 1hr dry treated.
8. The effects of specimen's position in the microwave furnace and/or temperature distribution at the surfaces and inside the furnace were out of scope of this study due to the measuring difficulty and/or limitation of time study.

10. Conclusions

From this research, the following conclusions are drawn:

1. In this research, it has been concluded that a certain microwaves furnace duration time could create major effects on one or more of the mechanical properties including fatigue life, ultimate stress and yielding stress for the alloys used.
2. Using a microwave furnace might be useful if its effects on the mechanical properties is known 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 places for the initiation of cracks, so the higher hardness of the surface and high surface roughness led to increasing in crake propagation, therefore decreasing the fatigue life.
4. In general, the dry medium with microwaves heat energy working to insulate the surface from the environment condition so oxidation the surface and close porosities. This state led to remain the surface smooth without pits or surface cracks therefore the fatigue life was longer than salt solution.
5. The great benefits of availability of microwaves furnace in industrial application was found that these microwaves furnace changes its mechanical properties in different 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 magnitude 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 when it compared with other applications.

11. References:

Ahmed Adnan AL-Qaisy, Eng. Sameh Fareed Hasan, Najmuldeen Yousif Mahmood, 2017," Study the Effects of Microwave Furnace Heat on The Mechanical Properties and Estimated Fatigue life of AA2024-T3" Journal of Engineering, No.10, Vol.23.

ASME, 2009 , "Standard Tensile Tests and Estimation of Mechanical Properties of AA7075", Chicago, Illinois, USA.

Fatima Ali Hussain" Fatigue of 7075T6 Al alloy under different conditions of corrosion" A thesis of Master Al-Mustansiriyah University, Materials Engineering Department.

LI Jin-feng, PENG Zhuo-wei, LI Chao-xing, JIA Zhi-qiang, CHEN Wen-jing and ZHENG Zi-qiao, 2008, " Mechanical properties, corrosion behaviors and microstructures of 7075 aluminum alloy with various aging treatments" Transaction of nonferrous metals society of china 18,755-762.

Manoj Gupta and Wong Wai Leong, Eugene "Microwaves and Metals "John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop, 02-01, Singapore 129809.

Michael Vollmer 2004" Physics of the microwave oven" Germany, Physical Education 39 (1).

Noboru Yoshikawa, 2010, " Fundamentals and Applications of Microwave Heating of Metals" Japan, Journal of Microwave Power and Electromagnetic Energy, 44 (1), pp. 4-13.

Penchal Reddy Matli, Rana Abdul Shakoor, Adel Mohamed Amer Mohamed and Manoj Gupta, 2016," Microwave Rapid Sintering of Al-Metal Matrix Composites: A Review on the Effect of Reinforcements, Microstructure and Mechanical Properties" MDPI Metals, 6, 143; doi:10.3390/met6070143.

Wai Leong Eugene Wong, and Manoj Gupta , 2015 , " Using Microwave Energy to Synthesize Light Weight/Energy Saving Magnesium Based Materials" Technologies, 3, 1-18; doi:10.3390/technologies3010001

Xiang Sun, Jiann-Yang Hwang, Xiaodi Huang, Bowen Li, Shangzhao Shi, 2005, " Effects of Microwave on Molten Metals with Low Melting Temperatures" Journal of Minerals & Materials Characterization & Engineering, Vol. 4, No. 2, pp 107-112.

Zabih-Alah Khansha, Mohammad R. Saeri and Sasan Otroj" Study of Stress Corrosion Cracking of AA7075-T6 Aluminum Alloy by Chromate Coatings in Aerial Industry" Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231–6345 (Online).