Study the Effects of Microwave Furnace Heat on The Mechanical Properties and Estimated Fatigue life of AA2024-T3

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ABSTRACT

This research aims to study the effect of microwave furnace heat on the mechanical properties and fatigue life of aluminum alloy (AA 2024-T3). Four conditions were used inside microwave furnace (specimens subjected to heat as dry for 30 and 60min. and specimens subjected to heat as wet (water) for 30 and 60 min.), and compared all results with original alloy (AA 2024-T3). Tensile, fatigue, hardness and surface roughness tests were used in this investigation. It is found that hardness of dry conditions is higher than wet conditions and it increases with increasing of time duration inside microwave furnace for dry and wet conditions. Also, tensile strength has the same behavior of hardness, but it increases with decreasing of time. Dry condition for 60 min. shows the higher fatigue strength than other conditions. Surface roughness parameter (Ra) of dry conditions is higher than wet conditions and it decreases with increasing of duration of time.

Key words: Microwave Furnace, Mechanical Properties, Fatigue Life.

دراسة تأثير الحرارة الناجمة عن أفران المايكروويف على الخواص الميكانيكية وعمر الكلال لسبيكة الألومنيوم 2024-T3

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الخلاصة

يهدف هذا البحث لدراسة تأثير حرارة افران المايكرويف على الخواص الميكانيكية وعمر الكلال لسبيكة الالمنيوم (AA2024-T3). تم استخدام ابرع حالات داخل افران المايكرويف (عينات جافة تتعرض الى حرارة لمدة 30 دقيقة و 60 دقيقة و عينات رطبة (الماء) تتعرض الى حرارة لمدة 30 دقيقة و 60 دقيقة). في هذا البحث تم استخدام اختبار الشد ، الكلال ، الصلادة و خشونة السطح. وجدت ان الاصلادة للحالات الجافة اعلى من الحالات الرطبة وتتناقص الصلادة بزيادة الزمن داخل فرن المايكرويف بالنسبة للحالات الجافة والرطبة. مقاومة الشد لها نفس سلوك الصلادة ايضا ولكن تزداد مقاومة الشد بنقصان

الزمن. مقاومة الكلال للحالة الجافة ولمدة 60 دقيقية ظهرت اعلى من باقي الحالات. عامل خشونة السطح للحالة الجافة ولمدة 60 دقيقة اعلى من الحالة الرطبة وتتناقص بزيادة الزمن للحالتين الجافة والرطبة.

1. INTRODUCTION

It is well known that aluminum alloy has low density with normal strength and relatively a very good resistance for corrosive ware. Both strength and hardness of the material 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. In many modern researches a microwave furnace heat 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 heat 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 period microwave furnace was used efficiently to process AA 2024-T3. In microwave furnace processing, microwave furnace energy heats the alloy at the different heat levels، which will might leads to a uniformly bulk heating, conversely in the conventional heating systems, the alloy heated from surface to the inner core which produces thermal stress and/or longer time required for homogenization. A heat-treating process by microwave furnace can be used for a wide application of surface treatments such as carburizing, carbonating, chromizing, and bronzing. 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 , **Loganatha, et al., 2014**. Conventional heat treatment process exhibits higher porosity and coarse microstructure which affect the physical and mechanical properties of alloys, therefore, a new technique of microwave heating will be removing the bad effects of conventional heat treatment. Microwave heating process enhances the alloy uniformity way of providing unique microstructure and properties as a result of selective heating, **Rajkumar, et al., 2014** and **Rajan, et al., 2014**. In addition, microwave furnace is used for plant growth not only using as heat treatment of metal alloy, **Nasher, 2014**.

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, AA 2024-T3 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**.**

2. MATERIAL AND APPARATUS

In this work, sheet metal of AA 2024-T3 is used with 3 mm thickness in order to make a standard tensile test specimen as shown as in **Fig. 1**. The tests were conducted at the Central Organization for Standardization and Quality Control (COSQC-Baghdad) according to the Iraqis Specification Quality (ISQ 1473/1989). The chemical composition tests were done at (COSQC-Baghdad) according to (ISQ 1473/1989) by the device (Spectrometer, ARC. MET 8000, 2009) as shown in **Fig.2**. These test result and standard are showed in **Table 1**.

2.1 Tensile and fatigue specimens preparation

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. Tinius Olsen tensile machine is used in this investigation as showing in **Fig. 3**. 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, **ASTM**, **2012.**
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. **Fig. 4** shows the specimen before and after polishing.

2.2 Fatigue Test Machine [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 **Fig. 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 **Fig. 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. **Table 2** is illustrated the instruction manual of the machine.

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, **ASME**, **2009**.

2.3 Other Mechanical Properties Tests

Other tests included hardness test according to refrence, **ASTM E 110 – 82, 2002**, and surface roughness test according to Mitutoyo Standard Test. The first test was done by (Rockwell Hardness Testing Machine, the values are converted from Bernill Hardness value) as showing in **Fig. 6**, while the second test was done by Mitutoyo Surface Roughness Testing Machine as illustrated in **Fig. 7**, all tests were made by the COSQC-Baghdad according to the (ISQ 1475~1476/1989).

2.4 Experimental Work

Microwave furnace type Daewoo is used to achieve a heat treatment for all specimens as showing in **Fig. 8**. **Figs. 9** and **10** are showing tensile and fatigue specimens. There are 12th

tensile specimens that using in this study and divided into four groups, three specimens each group. Firstly, dry condition for 60 min. in microwave, secondly, dry condition for 30 min. in microwave, thirdly, wet condition for 60 min. and the last, wet condition for 30 min in microwave. Temperature of microwave is 150°C. The general equation form of fatigue life is calculated by Basquin equation, **ASM Metals Handbook**, **2003,** and references, **Hantoosh, 2012, Mhesssan, 2012** and **Abdullatef, 2016,** are explained how to solve this equation according to S-N curves data, as follows:

$$\sigma_a = \sigma_f \, N^{-b} \qquad \ldots (1)$$

Where:

σ_a: The applied stress at failure

N : The number of cycles at failure due to the applied stress σ_a

σ_f & b : Material constants that can be calculated by linearizing the S-N curve by rewriting equation (1) in logarithmic form.

3. RESULTS AND DISCUSSION

3.1 Hardness results

It has been showed that hardness of dry conditions is higher than wet conditions and it decreases with increasing of time duration inside microwave furnace. Increment of first group has 16% which higher than other groups (14%, 9% and 7.5% for group 1, 2 and 3 respectively), these results are illustrated in **Table 3**. These results lead to AA2024-T3 becomes harder when using of this type of heat treatment. These results are matched with references, **Loganathan, et al., 2014, Rajkumar, et al., 2014** and **Abdullatef, 2012,** which is studied the comparison between conventional heat treatment and microwave heat treatment.

3.2 Tensile strength results

From **Fig. 11** and **Table 4** results, it has been noticed that tensile strength of group 2 has higher result with improvement of 25% as compared with original alloy (2024-T3) than other groups. As above, material is become more brittle when using of microwave furnace, this is representing in total elongation. Group 4 has a higher total elongation (11.2 %) as compared with original alloy (12%), while group 1 has a lower value of total elongation (5.5%). Also, duration of time is effecting on elongation, when time increases, total elongation is decreased and verse versa. Microwave heat produces a hardening of surface of alloy only, while the center stills the same. When the surface is cooled, grains size of surface become smaller than grains size of center due to cooling is slower. Modulus of elasticity and Poisson's ratio has little change as compared with original alloy. These results have similar behavior with references, **Loganathan, et al., 2014** and **Abdullatef, 2012,** which is reported the effect of microwave furnace on the mechanical properties of AA6061 as compared with conventional heat treatment.

3.3 Fatigue strength results

The results showed that fatigue strength of dry conditions is higher than wet conditions as compared with original alloy. Also, time duration inside microwave furnace effects on fatigue strength, dry condition for 60 min. has fatigue strength higher than dry condition for 30 min, and wet conditions have the same behavior, **Fig. 12** is illustrated that S-N curves of all groups as compared with original alloy.

For fatigue life, it has been found that group 1 has a major improvement as compared with other groups. When applying of equation (1) to produce a life of group 1, it can be written as follows in equation (2):

$$\sigma_a = 142\, N^{-0.0766} \quad \dots (2)$$

Equation (3) represents a fatigue life of group 2 and as follows:

$$\sigma_a = 123\, N^{-0.0992} \quad \dots (3)$$

Also, equation (4) represents a fatigue life form of original life and as follows:

$$\sigma_a = 165\, N^{-0.1085} \quad \dots (4)$$

It has been not seen reports about fatigue strength of microwave furnace as a heat treatment of aluminum alloy, but, according to tensile strength, it is noticed that fatigue strength also has the same behavior.

3.4 Surface roughness results

Surface roughness parameter (Ra) of all groups are representing in **Table 4**. It has been found that group 1 has higher (Ra) than other groups and surface roughness parameter decreases with increasing of duration of time in microwave furnace.

4. CONCLUSION

1. Hardness of alloy that is subjected to microwave heat is a higher than conventional heat treatment.
2. Tensile and fatigue strength of alloy that is treated by microwave furnace have higher value as compared with conventional heat treatment.
3. Using of microwave furnace heat is not effect on modulus of elasticity and Poisson' ratio.
4. Using of microwaves furnace might be useful for shorten both time and cost of changing these properties into certain levels by only using suitable method and/or duration time and amount of heat.

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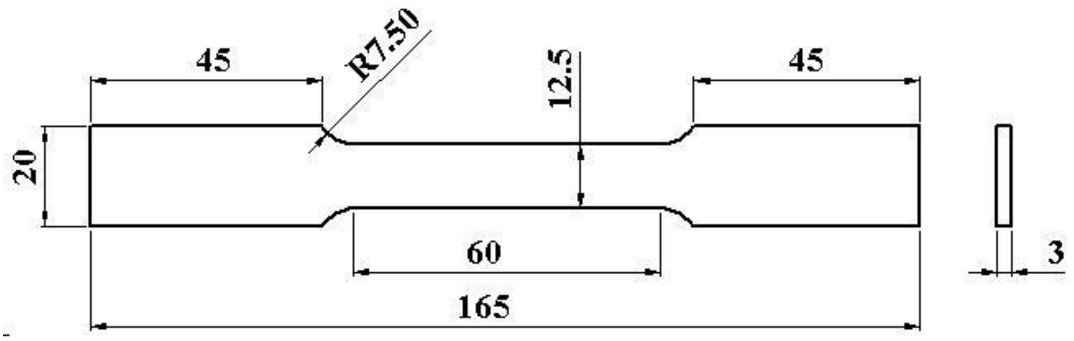

Figure 1. Tensile Test Specimen, **ASTM D 638 - 02a, 2003**. All dimensions are in mm.

Figure 2. AMETEK Material analysis division instrument**.**

Figure 3. Tensile Test Machine Type Tinius Olsen.

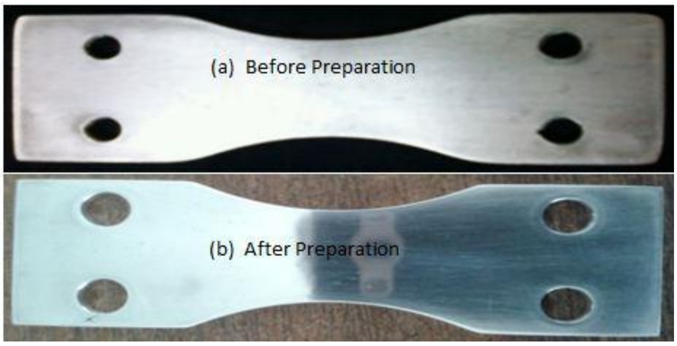

Figure 4. Standard Fatigue Test Specimen Before (a) and After (b) Preparation Steps**.**

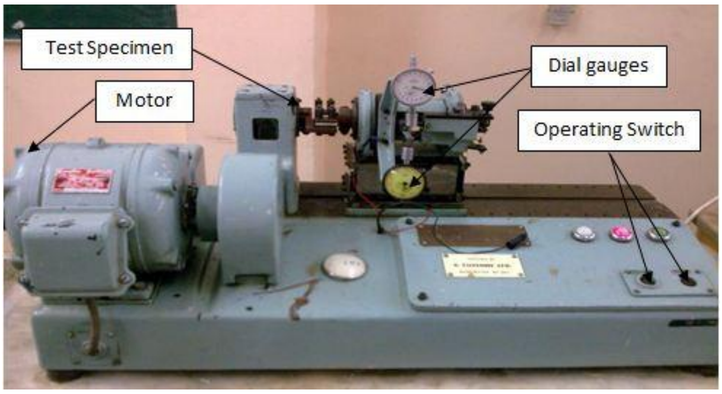

Figure 5. Bending Fatigue Testing Machine Type Avery Model 7305.


Figure 6. Rockwell Hardness Testing Machine**.**

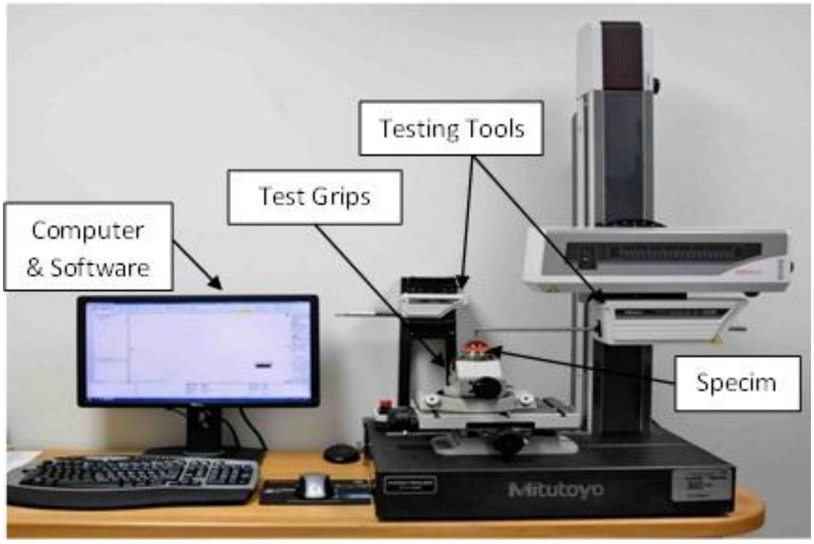

Figure 7. Surface Roughness Testing Machine Type Mitutoyo.

Figure 8. The Microwave Furnace used in this work Type Daewoo**.**

Figure 9. Tensile Test Specimens each three for specific group.

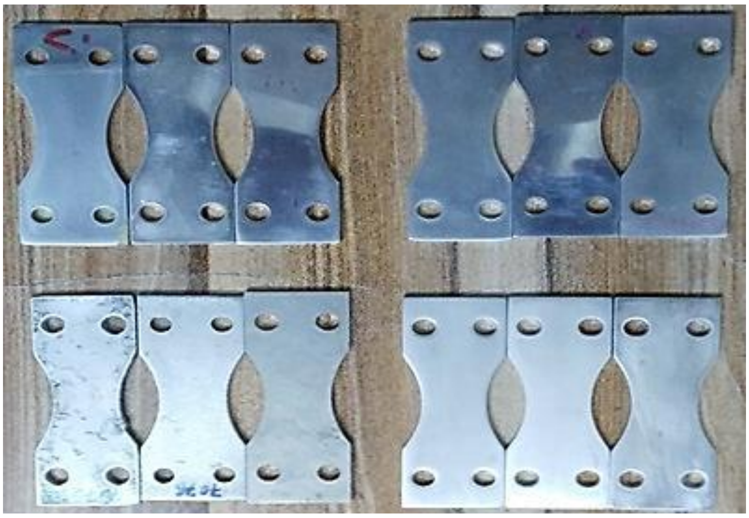

Figure 10. Fatigue Test Specimens according to Avery standard each three for specific group.

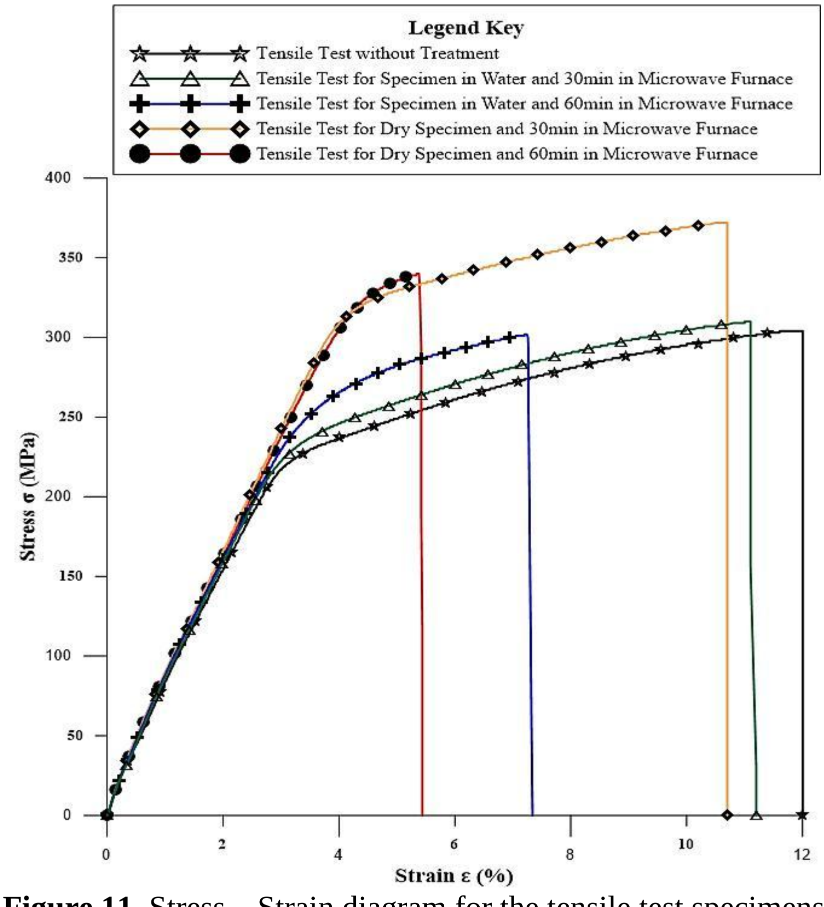

Figure 11. Stress – Strain diagram for the tensile test specimens.

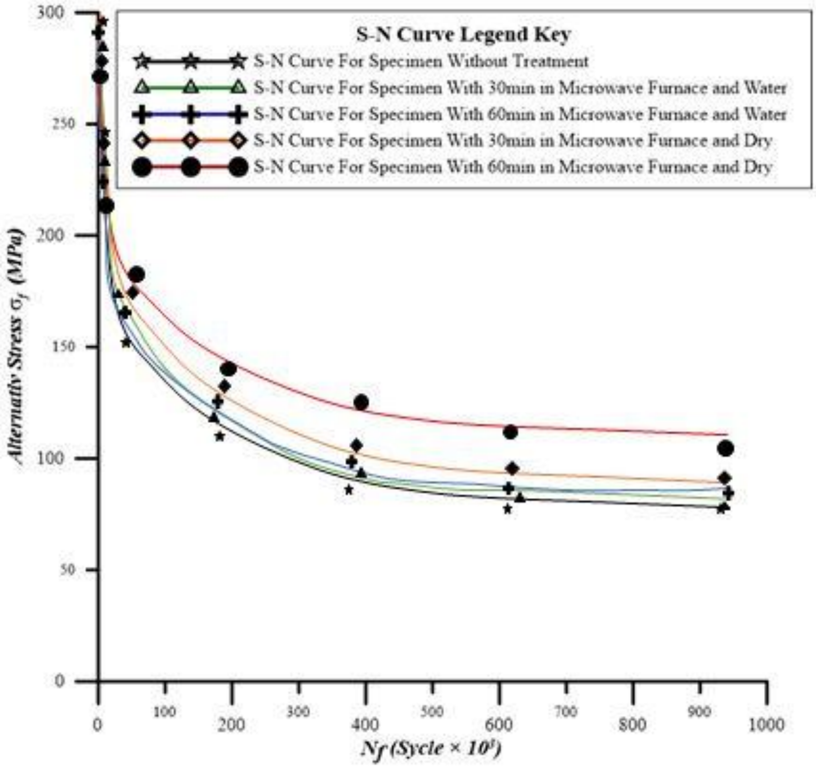

Figure 12. S – N Curves for the Fatigue test specimens.

Table 1. Chemical composition of AA2024-T3.

Component	% Si	% Fe	% Cu	% Mn	% Mg
Standard **(ASTM E 1251 – 94, 1999)**	≤ 0.5	≤ 0.5	3.8-4.9	0.3-0.9	1.2-1.8
Actual	0.25	0.09	4.53	0.81	1.51
Component	% Cr	% Zn	% Ti	% other	% Al
Standard **(ASTM E 1251 – 94, 1999)**	≤ 0.1	≤ 0.25	≤ 0.15	≤ 0.2	Reminder
Actual	0.014	0.13	0.014	0.065	Reminder

Table 2. Instruction manual of the fatigue test machine.

Power	1 HP
Maximum rating	1400 rpm
Current	2 Amperes
Voltage	380/440 Volts (3 Phases)
Frequency	50 Hz

Table 3. Mechanical Properties of all groups as compared with standard**.**

Group	Mechanical Properties	Test	Standard (ASM Metals Handbook, 1992)	Increment (%)
Group-1 Dry 60min in Microwave Furnace	Hardness, Rockwell B	93	80	16
	Ultimate Tensile Strength (MPa)	345	300	15
	Tensile Yield Strength (MPa)	325	225	44
	Modulus of Elasticity (GPa)	75.5	72	5
	Poisson's Ratio	0.333	0.35	5 (decrement)
	Fatigue Strength (MPa)	123	85	45
	Total Elongation (%)	5.5	12	54 (decrement)
Group-2 Dry 30min in Microwave Furnace	Hardness, Rockwell B	91	80	14
	Ultimate Tensile Strength (MPa)	375	300	25
	Tensile Yield Strength (MPa)	305	225	36
	Modulus of Elasticity (GPa)	74	72	4
	Poisson's Ratio	0.338	0.35	3 (decrement)
	Fatigue Strength (MPa)	105	85	24
	Total Elongation (%)	10.7	12	11 (decrement)
Group-3 Wet 60min in Microwave Furnace	Hardness, Rockwell B	87	80	9
	Ultimate Tensile Strength (MPa)	305	300	2
	Tensile Yield Strength (MPa)	265	225	18
	Modulus of Elasticity (GPa)	73	72	1
	Poisson's Ratio	0.343	0.35	2 (decrement)
	Fatigue Strength (MPa)	91	85	7
	Total Elongation (%)	7.5	12	37.5 (decrement)
Group-4 Wet 30min in Microwave Furnace	Hardness, Rockwell B	86	80	7.5
	Ultimate Tensile Strength (MPa)	315	300	5
	Tensile Yield Strength (MPa)	220	225	2 (decrement)
	Modulus of Elasticity (GPa)	72.5	72	0.7
	Poisson's Ratio	0.347	0.35	0.9 (decrement)
	Fatigue Strength (MPa)	88	85	3.5
	Total Elongation (%)	11.2	12	6.7 (decrement)

Table 4. Surface roughness results for all groups**.**

Alloys Type	AL 2024-T3			
Condition	Dry 60	Dry 30	Wet 60	Wet 30
Ra (μm) Read No.1	0.788	0.634	0.556	0.451
Ra (μm) Read No.2	0.784	0.637	0.550	0.452
Ra (μm) Read No.3	0.787	0.633	0.549	0.455
Ra (μm) Read No.4	0.785	0.630	0.547	0.454
Ra (μm) Average	0.786	0.634	0.552	0.453