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Effect of static etchant concentration of chemical machining on surface roughness and metal removal rate of AL 6063 alloy

تاثير تركيز المحلول الساكن في عملية التشغيل الكيميائي على الخشونة السطحية و معدل الازالة المعدنية لسبيكة المنيوم 6063

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Abstract

Chemical machining process is one of non traditional machining methods. There is a need to study the basics of this process to control the variables affecting this important method of machining. In this work some logic arrangement for achieving a required metal removal rate with a higher surface smoothness was stated for machining one widely used aluminum alloys. Aluminum (6063) alloy was used to be chemically machined using an ferric etchants ($FeCl_3$). The affecting parameters were used: machining time and concentration of etchant. Three concentrations of etchant (30, 50 and 60%) were considered. Each sample was machined in different machining times of (2, 4, 6, 8 and 10 min). Metal removal rate was calculated based on the weight loss due to corrosion.

The results showed that a minimum surface roughness of (Ra = 0.00240 µm) was recorded in the sample machined with 60% concentration of etchant at 2 min. Among the variables under study, concentration of etchant has the important effect on the metal removal rate and the surface roughness of the machined surface.

الخلاصة

عملية التشغيل الكيميائي هي احدى طرق التشغيل اللاتقليدية. وهناك حاجة الى دراسة اساسيات الطريقة للتحكم بالعوامل المؤثرة على طريقة التشغيل المهمة هذه. في هذا العمل بعض الترتيبات المنطقية للوصول الى اعلى نعومة سطحية و باقل معدل تاكل عند تشغيل احد سبائك الالمنيوم الواسعة الاستخدام. تم استخدام سبيكة Al(6063) لتشغيلها كيميائيا باستخدام ($FeCl_3$). العوامل المؤثرة التي تم استخدامها : زمن التشغيل وتركيز المظهر. تم دراسة ثلاث تراكيز للمظهر (30, 50 and 60%). كل نموذج تم تشغيله في ازمان مختلفة (2, 4, 6, 8 and 10 دقيقة). معدل الازالة المعدنية تم حسابه بالاعتماد على الفقدان بالوزن بسبب التاكل.

اوضحت النتائج ان اقل خشونة سطحية سجلت في النموذج المشغل كيميائيا عند تركيز المظهر (60%) و زمن (2) دقيقة .من بين العوامل المستخدمة في الدراسة تركيز المظهر كان التاثير الاهم على معدل الازالة المعدنية والخشونة السطحية للسطح المشغل.

1. Introduction

Non-traditional manufacturing processes is defined as a group of processes that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use a sharp cutting tools as it needs to be used for traditional manufacturing processes.

Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Non traditional machining processes, also called advanced manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons as outlined below [1].

- Very hard fragile materials difficult to clamp for traditional machining.
- When the work piece is too flexible or slender.
- When the shape of the part is too complex.

Several types of non-traditional machining processes have been developed to meet extra required machining conditions. When these processes are employed properly, they offer many advantages over non-traditional machining processes. The common non-traditional machining processes are [2]:

- Mechanical Processes
- Electrochemical Processes
- Electro-Thermal Processes
- Chemical Processes

The non-traditional machining processes are generally characterized by low material removal rate and high specific energies relative to conventional machining operations. The capabilities for dimensional control and surface finish of the non traditional processes vary widely, with some of these processes providing high accuracies and good finishes and others yielding poor accuracies and finishes. Surface damage is also a consideration. Some of these processes produce very little metallurgical damage at end immediately below the work surface, whereas others (mostly the thermal based processes) do considerable damage to the surface [3].

Non-traditional machining processes are widely used to manufacture geometrically complex and precision parts for aerospace, electronics and automotive industries. There are different geometrically designed parts, such as deep internal cavities, miniaturized microelectronics and fine quality components may only be produced by non-traditional machining processes. The process used to produce pockets and contour the machining method is widely used to produce micro-components for various industrial applications such as electromechanical systems and all the common metals including aluminium, copper, zinc, steel, lead, and nickel can be chemically machined [4]. CHM applications range from large aluminium alloy airplane wing parts to minute integrated circuit chips. The practical depth of cut ranges between 2.54 to 12.27 mm. Shallow cuts in large thin sheets are of the most popular application especially for weight reduction of aerospace components. Multiple designs can be machined from the same sheet at the same time.CHM is used to thin out walls webs and ribs of parts that have been produced by forging, casting or sheet metal forming.

The main objective of this work is to study factors influencing chemical machining of aluminium alloy in etchant ($Fecl_3$). Factors to be studied are concentration of etchant and time of etching. Each factor takes several levels to study the effect of them on the process [5].

2. Materials Used In The Present Study

A. Alloy Under Study

An aluminum 6063 alloy with chemical composition shown in table (1) was used. The analyses of the chemical composition was carried out in Faculty of Medicine in University of Kufa .

Table (1) Chemical composition of the alloy under study.

AL 6063 alloy	Si	Fe	Mg	Cr	Zn	Cu	Mn	AL
	0.4	0.3	0.9	0.1	0.1	0.1	0.1	Bal

B. Maskant Material
The selected maskent was prepared from (Polymer) depending on the used alloy [6].

C. Etchant Solution
The used etchant was $FeCl_3$ with three concentrations because the used alloy is one of the aluminum alloys [7], which demonstrated in table (2).

Table (2) Chemical composition and concentrations of the used etchant solution.

Chemical composition	Etchant concentrations (ml)
$FeCl_3$	30% 50% 60%

3. Samples Preparation
- **Basic Alloy**

Aluminum 6063 alloy sheet was cutting to samples with dimensions of (3.5*3.5*1mm).
- **Samples Preparation For CHM**

Before coating with maskant material, the samples were cleaned from dirt, dust, fats, oils and organic compounds using alcohol (ethanol 98%) then dried with air dryer and rinsed with water and dried with air dryer again. A specially designed glass mold was used to carry out the coating of the samples. Vaseline was used to ease removing the sample from the mold. Maxing (5) of polymer with (0.25) of accelerator. After pouring the polymeric masking material, the mold was kept in room at 25 ºC for 60 min for drying. Only one side (face) of samples was left without coating. This face represents the area to be chemically machined.
A hole of 2 mm diameter was drilled in each sample for the purpose of suspension in the etchant solution by using plastic tongs during the machining process. Figure (1) shows specimens before and after the coating.

a. Sample before coating. b. Sample after coating.

Figure (1) Samples before and after coating.

The machining process was achieved via magnetic stirrer thermostat which contains a thermostat to regulate the temperature of etchant during the machining operation and controller on velocity as shown in Fig (2).

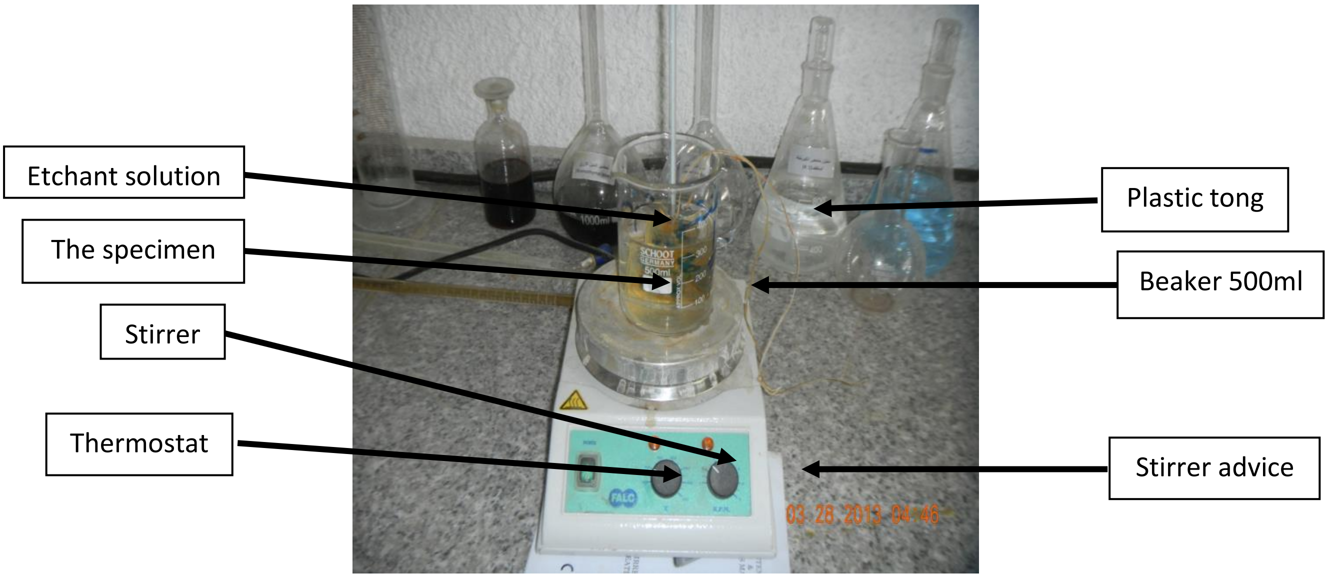


Figure (2) Chemical machining system.

4. Chemical Machining Program

The alloy samples were chemically machined depending on a program contains different machining conditions. Three etchant concentrations (30, 50 and 60%) for each of which five machining times (2, 4, 6, 8 and 10 min) were used as the machining conditions. The surface roughness (Ra), weight loss and the metal removal rate (MRR), were recorded after each machining process. The metal removal rate (MRR) was calculated basing on the weight loss after each experiment. The weight was measured via Sensitive weighing balance with accuracy ±0.0001 (ACCULAB Balance). As shown in tables (3, 4 and 5).

Table (3) Chemical machining results for concentration 30 (g/l) at 25 ºC

No	time (min)	Surface roughness (μm)	Metal removal rate (g/min)
1	2	0.0029	0.03
2	4	0.004	0.009
3	6	0.19	0.005
4	8	0.5	0.02
5	10	1.019	0.002

Table (4) Chemical machining results for concentration 50 (g/l) at 25 ºC

No	time (min)	Surface roughness (μm)	Metal removal rate (g/min)
1	2	0.008	0.07
2	4	0.092	0.0643
3	6	0.488	0.0389
4	8	1.365	0.052
5	10	2.07	0.0042

Table (5) Chemical machining results for concentration 60 (g/l) at 25 ºC

No	time (min)	Surface roughness (μm)	Metal removal rate (g/min)
1	2	0.09	0.09
2	4	0.23	0.082
3	6	0.91	0.054
4	8	1.81	0.061
5	10	2.4	0.01

5. Results and Discussion

A. Results of The Hardness Tests:

The hardness tests were carried out for the alloy samples before and after the machining process with machining conditions of etching concentrations (30%, 50% and 60%) and machining time of (2,4,6,8 and 10 min). These tests indicate the following results:

- Vickers hardness of samples before chemical machining is closed to its standard value.
- The hardness of all samples is not affected or very little difference by the chemical machining process, because of no change in crystalline structure of sample and process temperature not change the sample structure which change mechanical properties.

B. Effect of Machining Time on Ra and MRR:

Figures (3,4) indicate the effect of the machining time on the surface roughness and metal removal rate of the machined samples with different concentrations of etchant at room temperature.

The two figures indicate the following :

- For all samples, it is apparent that increasing machining time leads to increase in surface roughness (Ra). This can be refer to the basis of the variety of the element in the composition of the alloy. Increasing the machining time leads to increase dissolving the alloy to ions, active metal (the anode) corrode at a faster rate and the more noble metal (the cathode) corrodes at a slower rate and both share in the chemical reaction with the components of the etchant.
- Metal removal rate decreases with machining time and then suddenly rises and fall again for a certain temperature and a certain concentration of etchant due to increase dissolve of metal ions and its concentrations in the etchant.

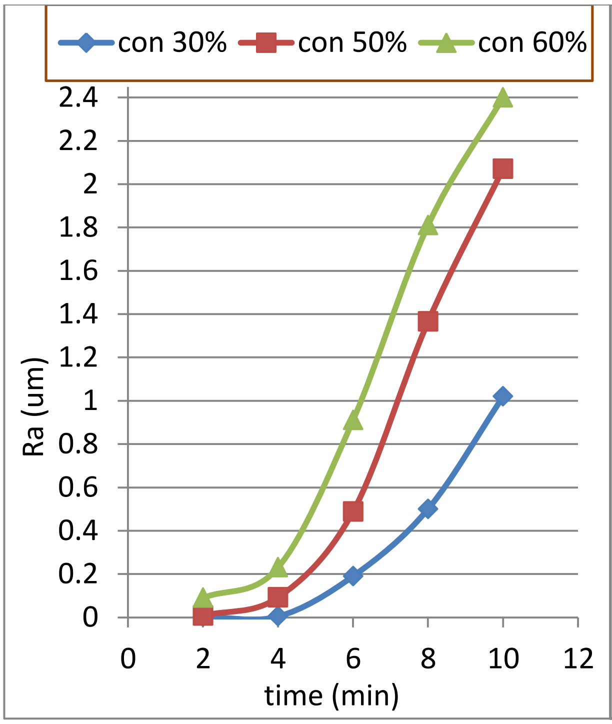


Figure (3) Effect of machining time on Ra

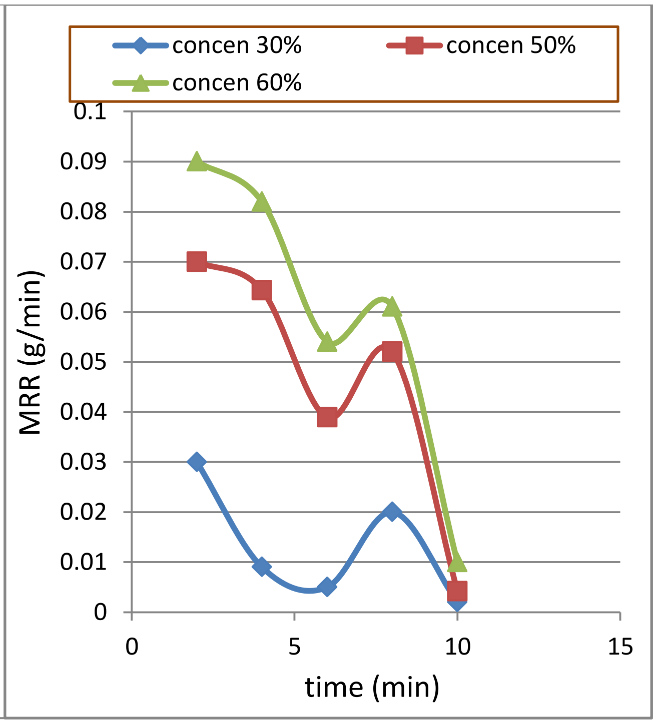


Figure (4) Effect of machining time on MRR

C. Effect of Etchant Concentration on Ra and MRR

Figures (5,6) illustrate the effect of etchant concentration on surface roughness and metal removal rate of the machined samples at different machining times. The figures show the following:

- Increasing in etchant concentration leads to increase in surface roughness. In other words, an increase in etchant concentration leads to increase in corrosion rate as a result of high power oxidizing agent and the mobility of ions will increase and the lowest etchant concentration provided the lowest etch rate.
- At a certain etchant concentration, surface roughness increases with the machining time.
- Increase in metal removal rate with an increase in etchant concentration for a certain machining time that because of using a higher etchant concentration produced a better and the best surface finish because the etch rate was higher in comparison to a low concentration.
- For a certain etchant concentration metal removal rate decrease with machining time then suddenly rises and falls again.

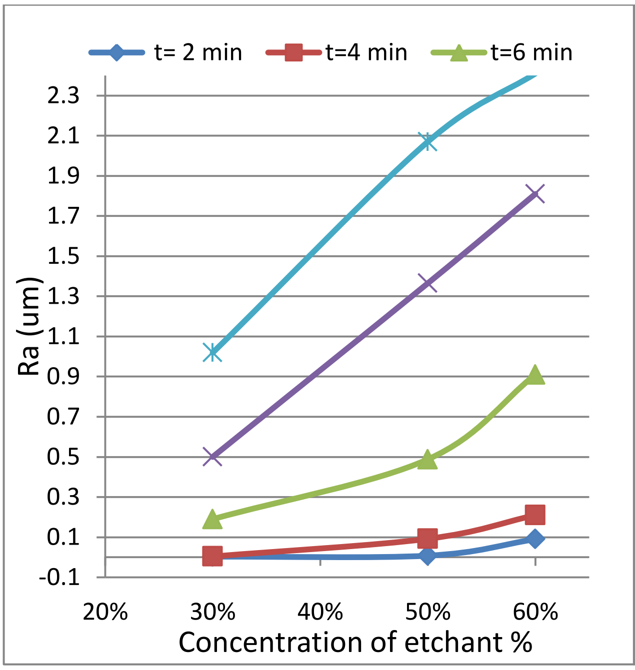


Figure (5) Effect of etchant concentration on Ra

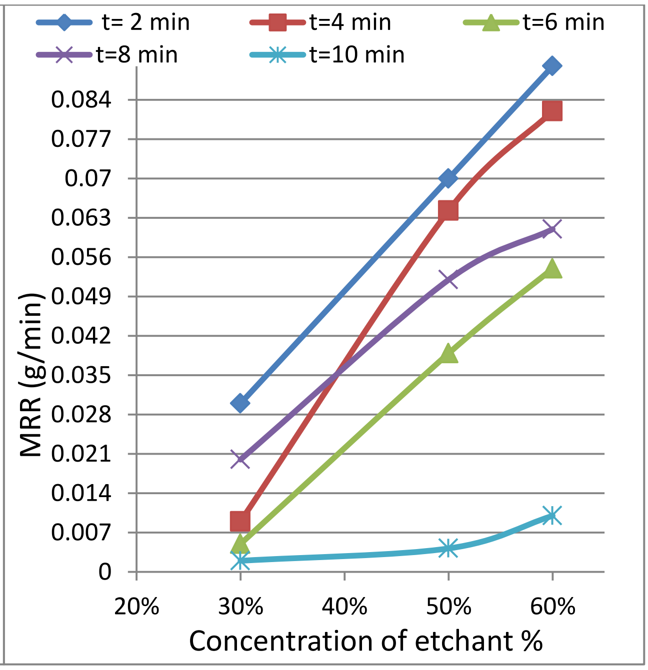


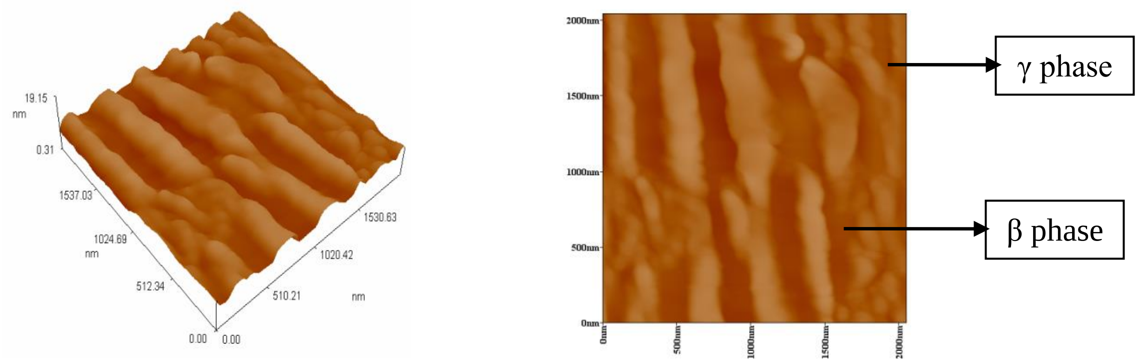
Figure (6) Effect of etchant concentration on MRR

E. Scanning Probe Microscope Tests

Microstructure, topography and surface roughness was gotten by using Scanning Probe Microscope for the tested samples before and after the chemical machining for each sample as shown in Figures (7 – 10) with different concentration (0, 30, 50 and 60%). The image size is 2049×2041 nm. The figures show the following:

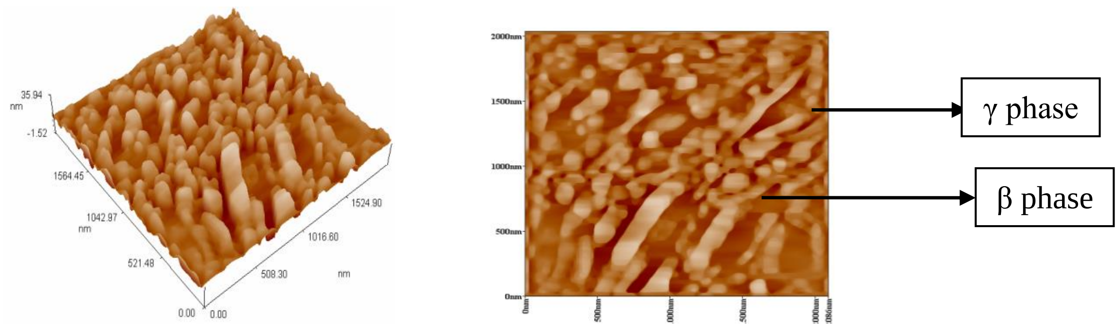
- The grains in crystals lattice of samples structure which measured by SPM before chemical machining. After chemical machining, as shown in SPM, chemical machining don't change structure of samples.
- Average surface roughness for samples before chemical machining by using SPM technique is (1.15 µm) compared with experimental results (Ra =1.19 µm). While average surface roughness for samples with 30% concentration of etchant after chemical machining by using SPM is (3.9 µm) compared with experimental results (Ra = 1.019 µm). Average surface roughness for samples with 50% concentration of etchant after chemical machining surface roughness by using SPM is (6.08 µm) compared with experimental results (Ra = 2.07 µm). For samples with 60% concentration of etchant average surface roughness by using SPM technique is (7.12 µm) compared with experimental results (Ra = 2.4 µm).

- Chemical machining process improve the metallurgical structure of samples, therefore are not found any metallurgical defects.
- Microstructure consisting of two phases (γ +β), for samples before chemical machining. In other words, structure contains grains (β) within matrix of (γ); after chemical machining no change in microstructure of samples. For samples with 30% , 50% and 60% concentration of etchant the microstructure after chemical machining no change in microstructure of samples.



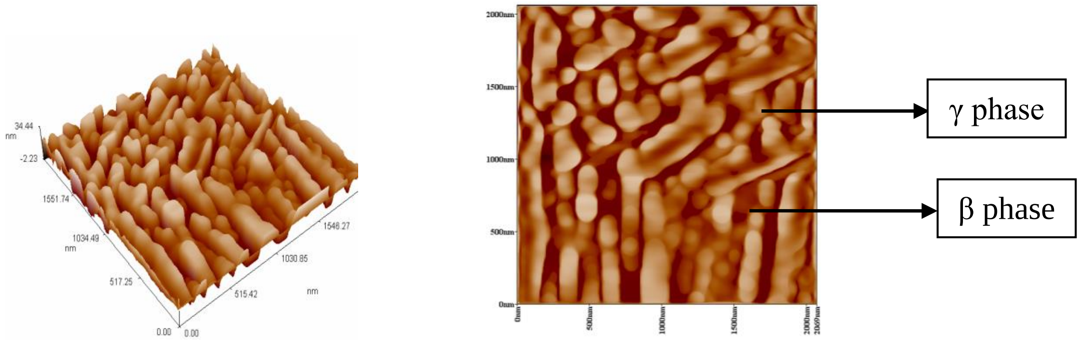
3D cross section and roughness microstructure

Figure (7) Surface roughness and microstructure for the samples before CHM



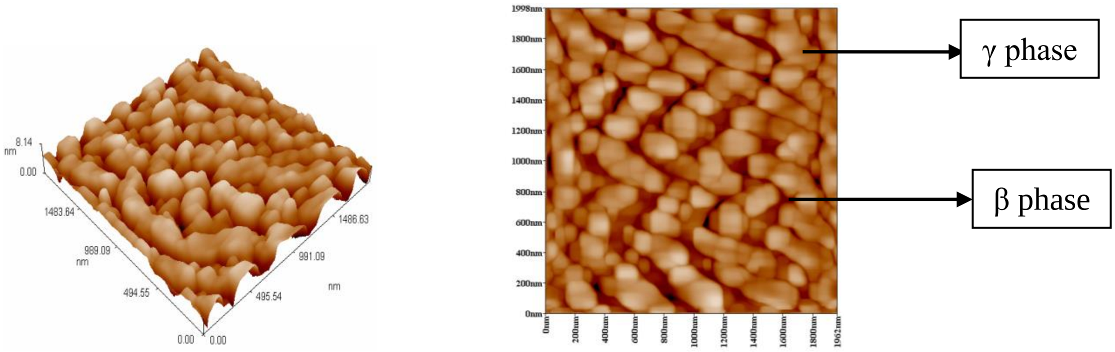
3D cross section and roughness Microstructure

Figure (8) Surface roughness and microstructure for the samples after CHM with concentration 30%



3D cross section and roughness microstructure

Figure (9) Surface roughness and microstructure for the samples after CHM with concentration 50%



3D cross section and roughness microstructure

Figure (10) Surface roughness and microstructure for the samples after CHM with concentration 60%

F. Conclusions

Can be state the following results:

1. Machining time and concentration of etchant are important variables that effect chemical machining products and concentration of etchant has larger affect than other variables.
2. Surface roughness of chemically machined parts increases with machining time and etchant concentration of the sample.
3. Metal removal rate of parts that chemically machined decreases with machining time and increases rapidly then decreases, metal removal rate increases with etchant concentration.

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