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INFLUENCE OF FECL3 ON MATERIAL REMOVAL RATE AND SURFACE ROUGHNESS IN CHEMICAL MACHINING PROCESS

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ABSTRACT

Non-traditional machining process is more used to manufacture geometrically complicated and an accurate parts for electronics, aerospace and automotive industries. Chemical machining process is one of non-traditional machining methods, it is as well named as chemical etching. The current research is aimed to study the influence of the machining time, machining temperature, etching solution concentration on the material removal rate and surface roughness of aluminum alloy by using mix of acid $FeCl_3$. There are three of machining temperatures (25, 30 and 35 ºC) with three machining times (4, 8, and 12min) and etching solution concentration (25%, 50%, and 75%) were used as machining conditions. These conditions are significant variables that have effect on finishing performance of chemically machined aluminum alloy. Machining time has the greatest effect among these variables. The time is the most important parameter for maximum Material Removal Rate (MRR), and the interaction between temperature and etchant concentration is the next important parameter for maximum MRR. The time is the greatest parameter for minimum Ra, the interaction between time and temperature is the next significant parameter for less Ra.

KEYWORDS: CHM, Al alloy, MRR, Ra, $FeCl_3$

1. INTRODUCTION

Non-traditional machining process is widely used to produce geometrically difficult and exactitude parts from materials in different industries as aerospace, electronics and automotive manufacturing (McGeough, 1988). Many machined elements need to dimensional accuracy and high surface finish, special size and complex shape which cannot be performed with the conventional machining processes (Benedict, 1987). Non traditional machining process is recognize as a group of operations that remove surplus material by different techniques including mechanical, electrical, chemical or thermal energy or combinations of these energies but don't use a sharp cutting tools as it required to be using for traditional manufacturing processes. Exceedingly brittle and hard materials are hard to machine by conventional machining processes such as turning, drilling, milling and shaping (Çakır et al., 2005). Non-traditional machining processes, as well called advanced manufacturing processes, are used where conventional machining processes aren't suitable, satisfactory or economical due to special reasons as outlined below:

- Easy clamping of the brittle and fragile materials.
- Flexibility in workpiece machining.
- Machining the complicated shape.

There are many types of non-conventional machining process have been advanced to meet extra needed machining conditions. When these operations are used correctly, they show many features over non-conventional machining processes (Nesreen 2016). Chemical machining explain practically unlimited field for engineering and design intelligence, to win the most from its unrivaled characteristics, it must be approach with the thought that this industrial tool can do jobs not practical or potential with another metal working methods (Cakir, 2008). Chemical Machining (CHM) applications field from large aluminum aircraft wing parts to tiny integrated circuit chips. The actual depth of cut ranges between 2.54 to 12.27mm. In large thin sheets that have shallow cuts are of the most common application particularly in weight reduction of aerospace elements. Various designs maybe machined from the same sheets at the same time."(CHM) is used to thin out walls grids and ribs of part that have been produced by forging, casting or sheet metal forming (El-Hofy, 2005).

Yuan et al., 2003 indicated the variation between etchant concentrations through the height for the micro-protuberance. This study illustrate increasing concentration with increase of micro-protuberance. Water includes in low concentration etchant effects etch rate dramatically.

Çakir et al., 2007 study chemical machining processes that exhibited its significance as non-conventional machining process. The steps of operation were discussed in detail. It's found the machining process may be carried out accurately to produce a required geometry. Environmental laws have significant effects when chemical machining is used." Al-Ethari et al., 2013 explained in their study the influence of machining time, cold working and machining temperature on the surface finish and material removal rate of chemical machining of stainless steel 420 by using a mix of acids as etchant (H_2O"+ HNO_3 + HCOOH + HCl +"HF). The outcome of the study showed that the machining temperature, machining time and previous cold working has important influence on chemical machining product, these variables as the temperature of machining has the greatest effecting. The increasing of surface roughness lead to increasing of machining time and machining temperature, MRR increases with the machining temperature and decreases with the previous cold working.

El-Awadi et al., 2016 study the influence of the concentration and temperature of the etchants such as $FeCl_3$ and $FeCl_3$+HNO_3 on metal removal rate of copper, aluminum and stainless steel sheets. The resuls explaned that the highest value of MRR achieve when using the etchants of $FeCl_3$ at 50±2 ^oC for all metals.

The main object of this research is to study factors effecting the chemical machining for aluminum alloy in etchant ($FeCl_3$). Factors studied are concentration of etchant, temperature of etching and machining time as input factors and takes each one of them in three levels, and these factors effecting on roughness and material removal rate as output factors. Then study the effect of them on the process.

2. MATERIALS AND METHOD

2.1. Workpiece material

The chemical composition of aluminum alloy is shown in the Table 1 that used in experimental work. The chemical compositions are achieved by Spectrometer device in the State Company for Inspection and Engineering Rehabilitation.

Table 1. Chemical composition of the workpiece.

Material	Mg%	Si%	Fe%	Ni%	Si%	Mn%	Mg%	Cr%	Cu%	Zn%	Al%
Al Zn Mg Cu 1.5DW 1725-1	2.17	0.059	0.206	0.001	0.059	0.206	2.17	0.190	1.84	5.57	Remain

2.2. Etchant Solution

The $FeCl_3$ etchant was used with three concentrations, as shown in the Table 2.

Table 2. Chemical composition and concentrations of etchant solution.

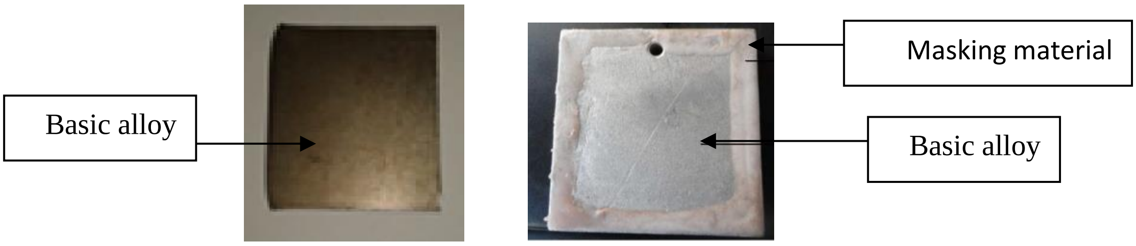
Chemical composition	Etchant concentrations (ml)
$FeCl_3$	25% 50% 75%

2.3. Samples preparation

1- Basic material: Al Zn Mg Cu 1.5DW 1725-1 alloy sheet was cut to samples with dimensions of (30x30x1 mm).

2- Preparation of the samples for CHM: Firstly, the sample was cleaned from the dust, oils and rust by using maskant material with alcohol (ethanol 98%) then it was dried with dryer of air then swill with water and dry with air dryer again. A specially designed glass bowl was used to carry out the coating of the samples. Vaseline was used to ease removing the sample from the mold. Mixing (5) of polymer with (0.25) of accelerator. After decant the polymeric masking material, the bowl was kept in room at 25ºC for 60 min for drying. Only one face of samples was left without coating. This face represents the part to be chemically machined.

A hole diameter of 2mm was drilled in all samples for purpose of holding inside of the etchant solution by using tongs of plastic through the machining process, workpiece before and after machining in Fig. 1 is given bellow.



(A) (B)

Fig. 1. Workpiece (A) before and (B) after coating.

2.4. System of chemical machining.

A magnetic stirrer thermostat was used to achieve the machining process. It is included a thermostat in order to set the temperature parameter of etchant and velocity controller during the machining process; Fig. 2 is showing it.

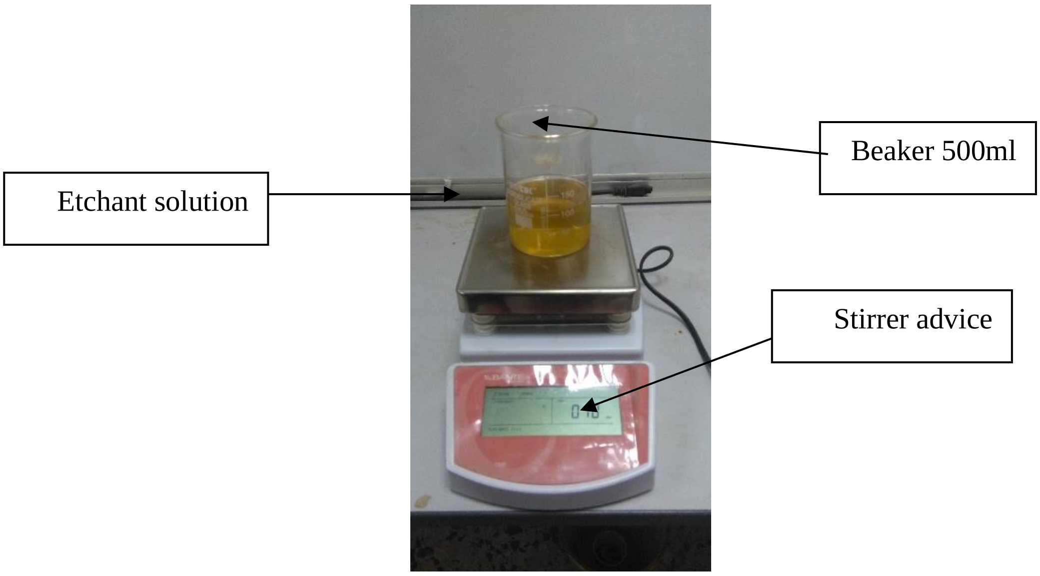


Fig. 2. Chemical machining apparatus.

2.5. Measuring devices

The metal removal rate (MRR) was calculated experimentally by (Mettler Toledo Analytical Balance Sensitive weighing) with accuracy ±0.0001, and measuring the weight difference before and after the machining. The surface roughness roughness (Ra) was measured by using (The Pocket Surf gauge), as shown in Figs. 3 and 4.

Fig. 3. Mettler Toledo Balance.

Fig. 4. Pocket Surf gauge.

3. EXPERIMENT ANALYSIS

The workpiece that chemically machined depending by Minitab program that contains various machining conditions, depending on three input parameters as time with three values are (4, 8, 12 minutes), temperature with values are (25, 30 and 35 Celsius) and etchant concentration are (25, 50 and 75 ml) and the output parameters of application are surface roughness (Ra) and material removal rate (MRR). Experiments design with Taguchi method and L9 (3×3) mixed orthogonal array is utilized for the parametric design. Table 3 demonstrates the studied parameters with their levels for conducting the machining experiments.

Table 3. The study parameters, their values and their levels.

Parameter	Level 1	Level 2	Level 3
Time (minutes)	4	8	12
Temperature (Celsius)	25	30	35
Etchant concentration %	25	50	75

Results of the experimental were then turned to a signal to noise ratio (S/N), determination the features of quality deviate from or nearing to the required value. There are three of quality categories feature in the analysis of the S/N ratio, i.e. , Nominal is the better , the lower is the better and higher is the better.

The equation applied for calculating signal-to-noise ratio for getting the smallest Ra is:

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i^{\,2})\right] \qquad 1$$

The characteristic of quality for MRR higher is the better type. Therefore, the S/N ratio is given by:

$$S/N = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\left(1/y_i^{\,2}\right)\right] \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ i = 1, 2, \ldots n \ldots \qquad 2$$

Where n: is the number of the replications.

y_i: spotted value of response

4. RESULTS AND DISCUSSION

In the Table 4 show the results of the experiment and indicated to the material removal rate (MRR) and “surface roughness” (Ra) according to the machining time, temperature, and etchant concentration. The average of features and signal-to-noise ratio (in decibels) is offered for all the characteristic. Studied the value of S/N ratio by detaching the total variability of S/N ratio for all control parameters. The analysis supports to find out the proportional contribution of parameter finishing in controlling the response of the chemical machining operation. Tables 5 and 6 show the analysis of the variance for MRR Means. In these table, the value of P% illustrates the response features relative to machining parameters (time, temperature, and etchant concentration). In the Table 5, it is deduced that the time (A) is the most important parameter for max. MRR, and the interaction between temperature and etchant concentration (B*C) is the next important parameter for max. MRR. In the Table 6, it is deduced that the time (A) is the most important parameter for min. Ra. The interaction between time and temperature (A*B) is the next important parameters for minimum Ra.

Table 4. Results of the machining experiments conducted according to Taguchi L_9 (3×3) mixed orthogonal array.

Time (minutes) A	Temperature (Celsius) B	Etchant concentration C	Material removal rate (MRR)	Surface roughness (Ra)
4	25	25	4.63	0.027
4	30	50	5.32	0.038
4	35	75	7.06	0.039
8	25	50	6.14	0.063
8	30	75	7.27	0.079
8	35	25	4.51	0.035
12	25	75	6.14	0.088
12	30	25	7.54	0.049
12	35	50	8.79	0.076

Table 5. Analysis of the Variance for (MRR) Means.

Sources	DOF	SS	MS	F%	P%
Time (minutes) A	1	10.383	10.3834	35.35	0.004
Temperature (Celsius) B	1	1.984	1.9838	6.75	0.060
Etchant concentration C	1	2.394	2.3940	8.15	0.046
Temperature (Celsius) B* Etchant concentration C	1	5.685	5.6852	19.36	0.012
Residual error	4	1.175	0.2937	/	/
Total	8	/	/	/	/

Table 6. Analysis of the Variance for (Ra) Means.

Sources	DOF	SS	MS	F%	P%
Time (minutes) A	1	0.000453	0.000453	4757.85	0.009
Temperature (Celsius) B	1	0.000066	0.000066	696.05	0.024
Etchant concentration C	1	0.001056	0.001056	11088.47	0.006
[Time (minutes) A]^2	1	0.000015	0.000015	161.33	0.050
Time (minutes) A* Temperature (Celsius) B	1	0.000127	0.000127	1333.52	0.017
Time (minutes) A* Etchant concentration C	1	0.000002	0.000002	24.08	0.128
Temperature (Celsius) B * Etchant concentration C	1	0.000017	0.000017	175.00	0.048
Residual error	1	1.175	0.2937	/	/
Total	8	/	/	/	/

Figs. 5 and 6 clarify the plot of the means of MRR s and the means of signal-to-noise ratio. In this figures it is obvious that the optimal combination of parametric for max. MRR is A3 B3 C3, i.e., in 12 min time, 35 ºC heat and 75 ml etchant concentration. It is proposed that the parametric combination into the considered range like reminded above gives the greatest material removal rate. The Figs. 8 and 9 explain the plot of the average of the surface roughness and means of signal-to-noise ratio". The optimal parameter for min. surface roughness is A1 B2 C1, i. e., at 4min time, 30 ºC temperature and 25 ml etchant concentration.

In Figs. 7 and 10 show the normal likelihood plots of the residuals response for material removal rate and surface roughness respectively, a check on these plots in figures reveal that the residuals generally drop on a straight line inclusion that errors are spreaded normally.

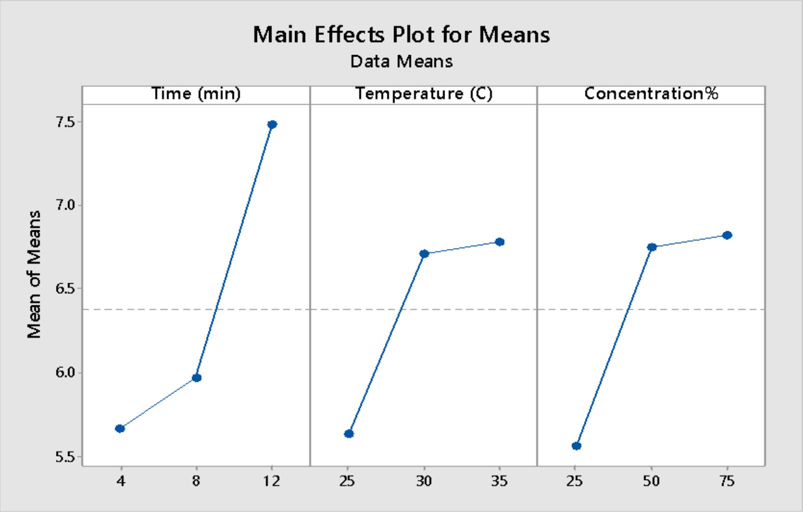


Fig. 5. Major effects Plot for (MRR) means.

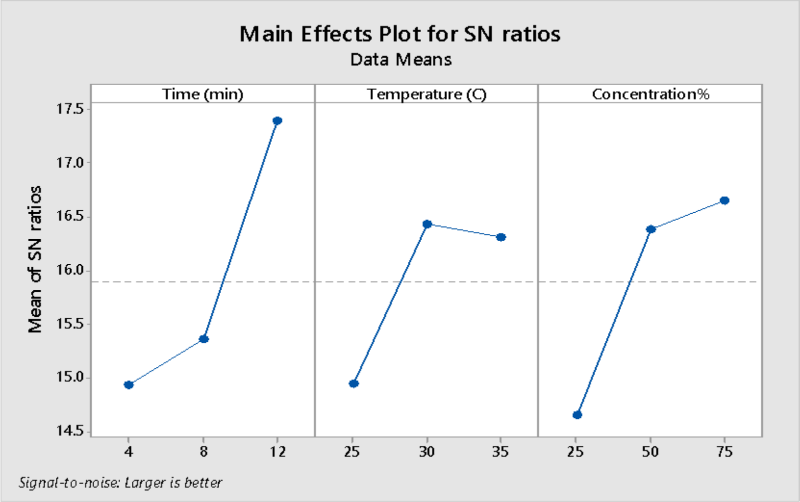


Fig. 6. Average S/N ratio plot for (MRR).

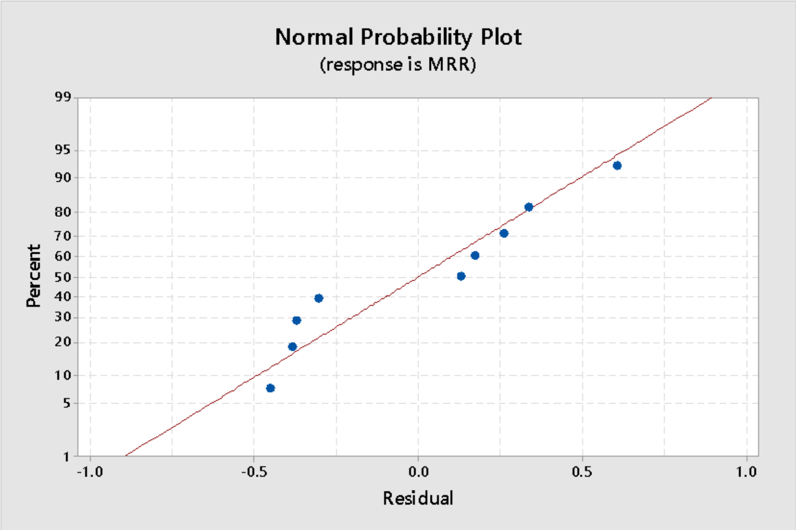


Fig. 7. Normal Probability Plot response for improvement of average material removal rate.

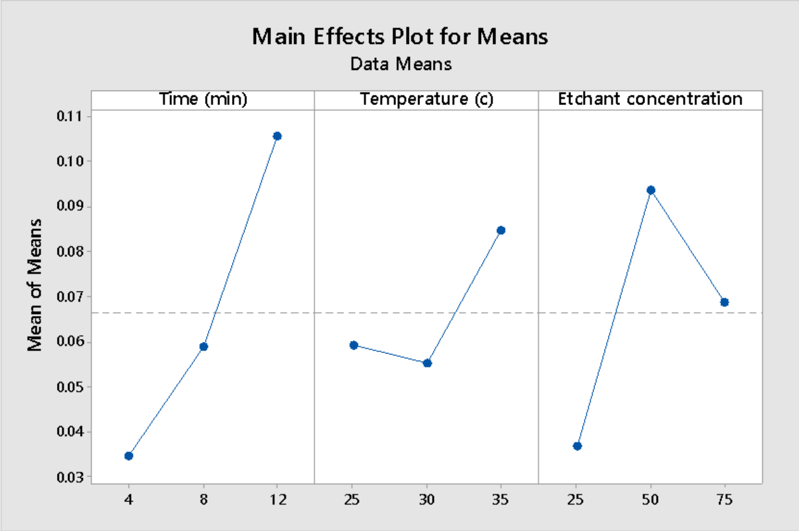


Fig. 8. Major effects Plot for (Ra) means.

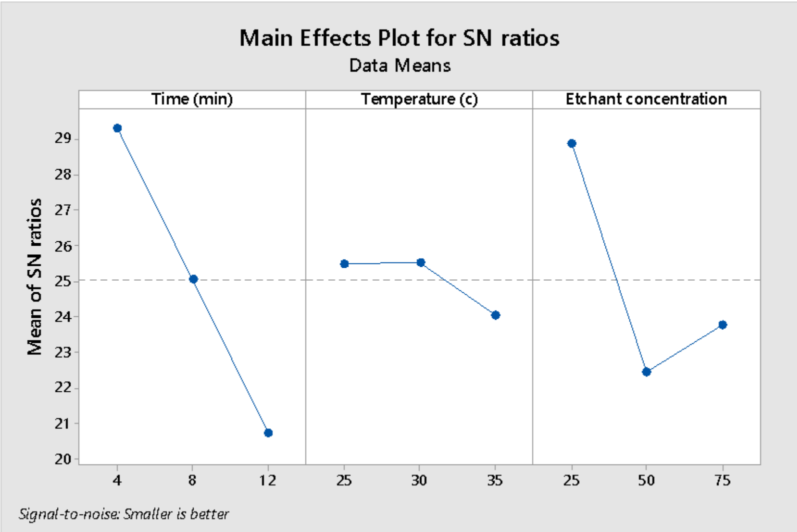


Fig. 9. The average of S/N ratio plot for (Ra).

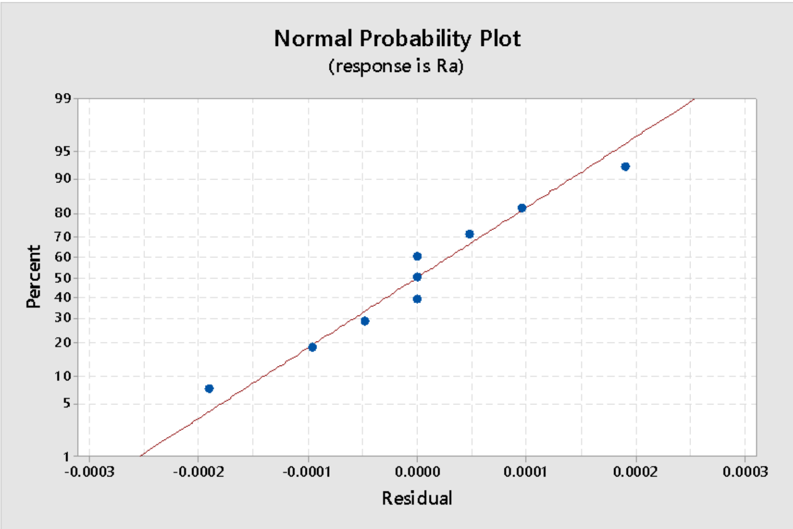


Fig. 10. Normal prospect Plot response for improvement for mean of surface roughness.

5. CONCLUSIONS

The current study has reached to the below conclusions:

1. Machining temperature, machining time and etchant concentration are significant variables
2. That impact on finishing performance of chemically machined aluminum alloy. Machining time has the largest effecting among these variables.
3. The best parameter combination for max. Material removal rate is A3, B3 and C3, i.e., at 12min time, 35 ºC temperature and 75g/l etchant concentration.
4. The superior parametric for min. surface roughness at 4 min time, 30 ºC temperature and 25 ml etchant concentration.
5. The time (A) is the most important parameter for max. MRR, and the interaction between temperature and etchant concentration (B*C) is the next important parameter for max. MRR.
6. The time (A) is the most important parameter for min. Ra, the interaction between time and temperature (A*B) is the next important parameter for min. Ra.

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