Experimental investigation of machining parameters on material removal rate and surface roughness in chemical machining

IOP Conf. Series: Materials Science and Engineering **518** (2019) 032029 doi:10.1088/1757-899X/518/3/032029

Experimental investigation of machining parameters on material removal rate and surface roughness in chemical machining

Abbas Fadhil Ibrahim[1] and Ali Mundher Mustafa[1]
[1]University of Technology, Baghdad, Iraq

Abstract. Chemical machining is oldest of non-traditional machining processes employed as micromachining process to produce micron-size components. The technique is broadly applied to machine geometrically complex parts of thin and flat materials. Etchants (namely Fe Cl3 +HNO3) affected by it is initial concentration, machining time and machining temperature on the surface finish of stainless steel 304. Three machining variables temperatures (40, 45 and 50 ^{o}C) for every one of which three machining times (4, 7, and 10 min) were utilized as machining parameters. Rate of Metal removal was determined based on weight loss due to corrosion. Design of experimental by Taguchi, L 9 (3×3) mixed orthogonal array is used to determine the material removal rate, surface roughness, analysis of variance, and to optimize the process parameters. R Square pieces was predicted by the analysis of independent values to portend the dependent values, and were 100% and 93% for mean material removal rate and surface roughness, individually.

Keywords: CHM, Cold Working, Stainless Steel, Rate of Material Removal, Roughness of Surface, Taguchi Method.

1. Introduction

The progression for manufacturing processes lead to made many hard to machine materials according to its high toughness, strength, hardness, brittleness and little or low machining properties. Chemical machining (CHM) consider the oldest of the non-traditional machining processes. Prior it was utilized for engraving hard stones and metals. The microscopic electrochemical cell action was used to removed material, occurs by corrosion of metal or chemical dissolution [1].

In this procedure, the testing piece that machined is dissolved in aqueous solutions that content salt, acids or alkali's such as Fe Cl_3, NaOH, HNO_3, H_2SO_4 and KOH. These solutions are termed as an etchant. Process of the chemical machining will be affected by several parameters on the performance; the more remarkable of which are: the type of etchant of the solution and concentration, and its application, temperature of machining, and time of machining. Geometrically complex parts can be produced by repeating masking and machining alternatively several times until the desired shape is achieved. These parameters have an immediate effect on the machining processes, and the characteristics of the machined parts concerning the machining rate, production tolerance, and particularly the surface finish. So, proper identification of an effective surface finishing process to achieve the required quality of surfaces represents a serious challenge to the user of the chemical machining [2].

Yuan et al (2003) [3]: indicated the variation between etchant concentrations through the heights of the micro-protuberance. This study found the heights of micro-protuberance increase with increasing concentration. The Water content in low concentration etchant effects etch rate dramatically.

Çakir O. et.al. (2007) [4] process of the chemical machining was studied to describe the importance of the non-traditional machining process. The process was display in detail of the tolerances of machined parts and the examinations. The operation of machining should be carried out carefully for producing the desired geometry. Environmental laws have important effects when chemical machining is used.

Al-Ethari H.A.H.et.al. (2014) [5] study several parameters (previous cold working, machining time, and machining temperature) on the MRR and the finish of the surface on the samples of chemically machined for stainless steel 420 using a composition of acids "(H_2O , HCl , HNO_3 , HF and HCOOH)" for etchant. The results showed a significant effect on chemical machining products for the three parameters, among the three variables the temperature of machining has the beast effect. Increases Ra; time of machining; temperature of machining; will decreases the cold working. MRR will decreases with previous cold working and with increases machining temperature.

G.A. El-Awadi et.al (2016) [6] the effect of etchants (namely, $FeCl_3$ and $FeCl_3$+HNO_3) were studied , the temperature and initial concentration on Rate of Metal Removal (MRR) for examined the stainless steel, aluminum and copper sheets. The results showed at 33% concentration of $FeCl_3$ with 50±2 ºC for all metals were achieved and that are the highest values of MRR, which were 0.287 mm^3/min for copper, 0.738 mm^3/min for aluminum and 0.224 mm^3/min for stainless steel.

Abbas Fadhil Ibrahim et.al. (2018) [7] studied the effect of machining temperature, machining time, etching solution concentration on the rate of material removal, and surface roughness of aluminum alloy using mixed of acid $FeCl_3$. Three machining temperatures (25, 30 and 35 ºC) for each three machining times (4, 8, and 12 min) and etching solution concentration (25%, 50%, and 75%) were used as machining conditions. time of Machining , temperature of machining and etchant concentration are the most variables important that affect finishing performance of chemically machined aluminum alloy.

The main objective of this work is to study factors affecting of the chemical machining for stainless steel 304 in the etchant (Fe cl_3 +HNO_3). Factors studied are the concentration of etchant, time and temperature of etching as input factors, roughness and material removal rate as output factors. Then study the effect of them on the process.

2. Experimental Procedure

2.1. Experimental design and execution

Taguchi Strategy was submitted by Genichi Taguchi, a quality administration expert in Japan. The point of TM is to lessen the quantity of analyses to think about the whole space parameter. The results then change into a flag to-clamor (S/N) proportion, an assurance of nearing to the ideal qualities or value qualities veering off from. Three classes of value attributes in the examination S/N proportion, i.e., the lower is the better, the higher is the better, and the ostensible is the better [8].

To calculate the S/N ratio by using the smallest Ra is:

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

The-higher-the-better type used to the quality characteristic for material removal rate (MRR). Therefore, the S/N ratio is given by:

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

Where y_i: value of observed response, n: number of replications.

2.2 workpiece material

Table (1) shows the chemical composition for stainless steel 304 with (30x30x1) mm dimensions was used. The chemical composition is achieved by Spectrometer device in the State Organization for Examination and Engineering Rehabilitation and the table is given below.

Table 1. Workpiece Material Composition (stainless steel 304)

Elements	C%	Si%	Mn%	Cr%	P%	Mo%	S%	Ni%	Al%	Fe%
Stainless steel 304	0.06	0.33	1.30	17.26	0.04	0.018	0.02	8.6	0.003	remain

2.3 Etchant Solution

The etchant used was $FeCl_3$++HNO_3 with three concentrations, as shown in Table (2).

Table 2. Chemical composition and concentrations of etchant solution

Chemical Composition	**Etchant Concentration (ml)**
$FeCl_3$ + HNO_3	20%
	30%
	40%

2.4 Chemical machining system.

Attractive stirrer indoor regulator was utilized as machining process, which contains a sensor of the indoor regulator which used to direct the etchant temperature amid in the activity of machining and speed control as appeared in Figure 1.

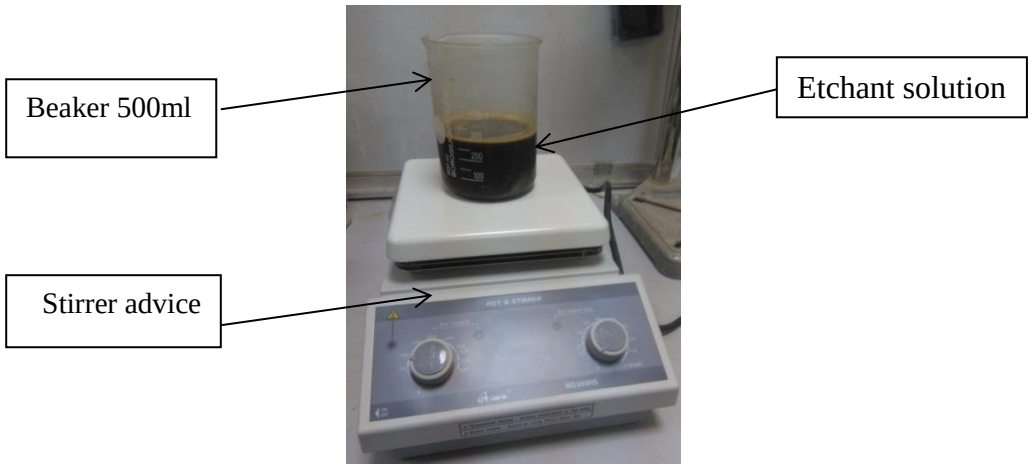

Figure 1. Chemical machining system

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 (Ra) calculated by using (The Pocket Surf gauge), as shown in figures (2 and 3).

Figure 2. Mettler Toledo Balance

Figure 3. Pocket Surf gauge

3. Experiment Analysis

The alloy was chemically machined depending on different machining conditions. Three input parameters as time with three values are (4, 7, 10 minutes), temperature with values are (40, 45 and 50 Celsius) and etchant concentrations are (20, 30 and 40 ml) and the output parameters of these process are roughness of the surface and rate of material removal. Design of experiments via Taguchi method and L_9 (3×3) combined orthogonal array was utilized for the design of parametric. Table 3 demonstrates the parameters with their levels for conducting the machining experiments were studded.

Table 3. Input Parameters and their Levels

Parameter	Level 1	Level 2	Level 3
Time (min)	4	7	10
Temperature (Celsius)	40	45	50
Etchant Concentration %	20	30	40

4. Result and discussion

The investigated results of the minimum overcut area obtained during the etching process of stainless steel 304. Table 4 showed the results were obtained at the variation of concentration, temperature, and time.

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) mg		Surface roughness (Ra) µm	
			Measured	Predicted	Measured	Predicted
4	40	20	6.25	6.23333	1.97	1.79000
4	45	30	6.87	6.88000	2.15	1.93667
4	50	40	8.36	8.36667	2.10	2.11333
7	40	30	7.14	7.14667	2.13	2.06333
7	45	40	8.19	8.17333	1.99	2.20000
7	50	20	6.97	6.98000	2.44	1.95667
10	40	40	9.16	9.17000	2.16	2.40667
10	45	20	7.51	7.51667	2.24	2.12333
10	50	30	8.64	8.62333	2.39	2.31000

The results of the material removal rate were very close between measured and predicted. The ability of independent value to predict MRR was 100% so that for results surface roughness the relation between measured and predicted Ra was close, and the ability of independent value to predict MRR was 93%.The average (mean) of these characteristics is shown for each characteristic. From examination of change (ANOVA) as shown in Tables (5,6) The "P%" changing in the value appear as effectiveness' of each parameter toward influencing the related response characteristics within the specified range. It is concluded from Table 5, that concentration is most significant parameter for maximum MRR, and next significant parameter is time. plot of the means of material removal rate s shows in Figure 4; it's clear that the optimal parametric combination for higher MRR is $A_{3;}$ $B_{3;}$ C_3; i.e.; at 10 min time; but at 50 C^o temperature and 40g/l etchant concentration, it's clear that the parametric blend inside the considered range as referenced above gives the biggest rate of material evacuation. From Table 6; it is inferred that the time (An) is the most noteworthy parameter for least Ra, the focus is the following huge parameter for least Ra. Figure 5 demonstrates the plot of the methods for the surface harshness. The ideal parametric for least surface harshness is $A_{1;}$ $B_{1;}$ C_1; i.e., at 4 min time; 40 C^o temperature and 20g/l etchant fixation.

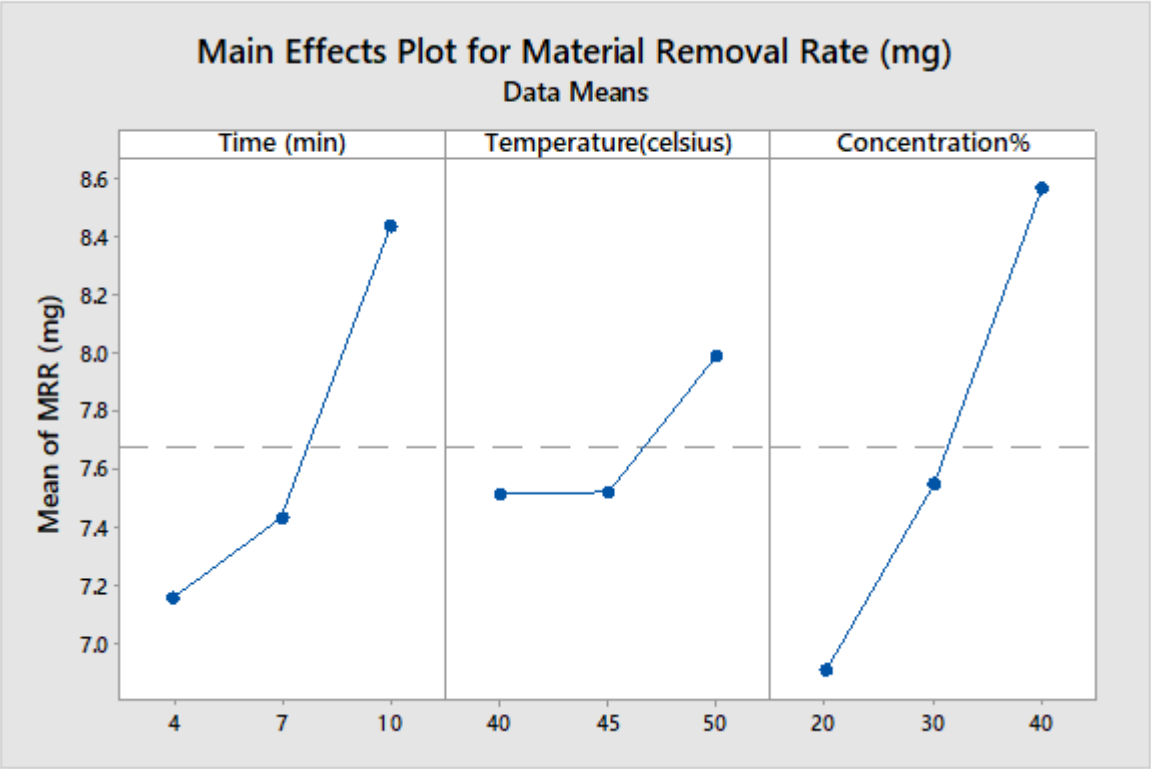

Figure 4. Plot of main effects for means material removal rate

Table 5. Analysis of Variance for means material removal rate

Source	DF	Adj.SS	Adj.MS	F%	P%
Time (min) A	2	2.71127	1.35563	2140.47	0.000
Temperature (Celsius) B	2	0.44187	0.22093	348.84	0.003
Etchant Concentration C	2	4.20560	2.10280	3320.21	0.000
Residual Error	2	0.00127	0.00063	/	/
Total	8	/	/	/	/

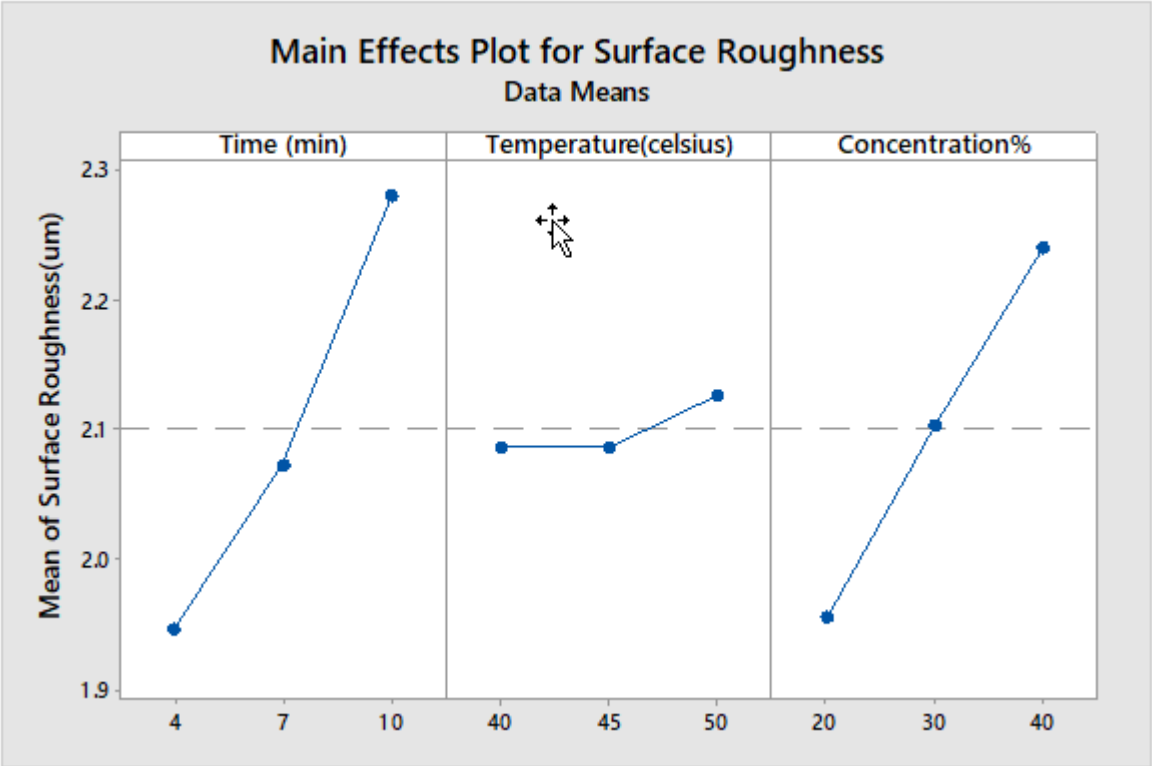

Figure 5. Main effects plot for means surface roughness

Table 6. Analysis of Variance for means surface roughness

Source	DF	Adj.SS	Adj.MS	F%	P%
Time (min) A	2	0.169867	0.084933	7.70	0.115
Temperature (Celsius) B	2	0.003200	0.001600	0.15	0.873
Etchant Concentration C	2	0.120467	0.060233	5.46	0.155
Residual Error	2	0.022067	0.011033	/	/
Total	8	/	/	/	/

5. Conclusions:

The major conclusions from this work can be outlined as follows:

1- Machine time, temperatures and concentration of etchant were the most variables that important and effect finishing performance of chemically machined of aluminum alloy. Between these variables machining time has the beast effect.

2- The R Square pieces (to predict the dependent values the independent values had the ability to predict) and they are 100% and 93% for average, surface roughness, material removal rate, respectively.

3- The ideal parametric combination for greatest MRR is A_3; B_3; C_3; i.e., at time 10 min and 50 C^o for temperature and 40g/l for etchant concentration.

4- The perfect parametric for minimal roughness of the surface is A_1; B_1; C_1; i.e.; at time 4 min, 40 C^o for temperature and 20g/l for etchant concentration.

5- The concentration is the most significant parameter for greatest MRR, and the time is the next significant parameter for greatest MRR

6- The (A) time is the important significant parameter for minimal Ra, and the next parameter is concentration.

References

[1] Haydar A H Al-Ethari, Kadhim F A, Nasree D F 2013 Variables Affecting the Chemical Machining of Stainless Steel 420 *International Journal of Engineering and Innovative Technology* **3** 210-216.
[2] Haydar A H Al-Ethari, Kadhim F A, Nesreen D F 2014 optimization of chemical machining conditions of cold worked stainless steel 420 using Taguchi method *IJMET* **5** 57-65.
[3] Yuan G Y, Feny and Liang C 2004 Micro fabrication of crystalline silicon by controlled alkali etching *Journal of Materials Processing Technology* **149** 567-572.
[4] Çakir O, Yardimeden A, Özben T 2007 Chemical machining, Archives of Materials Science and Engineering **28** 499-502.
[5] Al-Ethari H A H, Alsultani K F, Nesreen D F 2014 Optimization of Chemical Machining Conditions of Cold Worked Stainless Steel 420 Using Taguchi Method *International Journal of Mechanical Engineering and Technology* **5** 57-65.
[6] El-Awadi G A, Enb T A, Abdel-Samad S and El-Halawany M M 2016 Chemical Machining for Stainless Steel, Aluminum and Copper Sheets at Different Etchant Conditions *Arab Journal of Nuclear Science and Applications* **94** 132-139.
[7] Abbas F I, Ahmed B and Alaa H S 2018 Influence FeCl3 on material removal rate and surface roughness in chemical machining process *Kufa Journal of Engineering* **10** No.1.
[8] Abbas F I Prediction of Surface Roughness and Material Removal Rate in Electrochemical Machining Using Taguchi Method *Al-Khwarizmi Engineering*