Influence of machining parameters on material removal rate in chemical machining of silicon carbide (SIC).

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Abstract this study aims to discuss the effect of chemical etching parameters such as (machining temperature, machining time, etchant type, and concentration of the solution) on the material removal rate and surface roughness of ceramic materials (silicon carbide) as a specimen in chemical machining (CHM) process. This study aims to achieve the best value for the removal rate of the material as well as to obtain the best value for the surface roughness. Four levels of chemical machining process parameters were used in this study; the values of machining time (30, 50, 70, and 90) min, the etchant concentration (50, 60, 70, and 80) % and etching temperature (60, 80, 100, and 120) °C, and two etchant type (HCl, HBr). The results showed that the Taguchi method that has been performed using MINITAB 17 software gave results with good accuracy. The best value of material removal rate is obtained (0.5102) mg/min at experimentally and (0.4816) mg/min at the predictable program, when using hydrochloric acid (HCl) at temperature (100) °C, time (30) min, and etchant concentration (70) %. The best value of surface roughness is obtained (2.933) µm at experimentally and (2.9589) µm at the predictable program, when using Hydrobromic acid (HBr) at temperature (80) °C, time (50) min, and etchant concentration (50) %. The coefficient determination (R-sq.) to predict the material removal rate (MRR) and surface roughness are (91.6) and (93.7) respectively. This means the model is perfect and fit.

1. INTRODUCTION
Chemical machining (CHM) is one type of non-conventional machining process. (CHM) is a controlled chemical process of a workpiece material by immersion with a specific concentration of acid or alkaline [1]. The development in technological sciences has led to the development of machining processes for materials that are difficult to machine such as ceramics, stainless steel, fiber-reinforced composites, and super alloy because of these materials properties: high hardness, toughness, brittleness, strength, and low machinability [2]. This process was accepted as one of the manufacturing processes after the 1950 s, one company North American Aviation Inc., USA etched aluminum to produce rocket parts [3]. Chemical etching is used to remove a layer from the workpiece material. either deep or shallow.
There are many main types of chemical machining: Chemical engraving for producing nameplate and other flat plate; Chemical blanking used to the machining sheet metal of small thickness up to (0.025 mm); Chemical milling used to remove a large amount of the material from panels or large plates; Photochemical machining: used for mineral materials working when complex patterns and accuracy are required for flat parts[4][5]. Figure (1-1) showing typically the chemical etching process.

![Figure (1) Typical chemical etching process](image)

2. Material removal rate

Nowadays, manufacturing industries required high productivity. Thus, the etching rate has become an important issue. Previous works summarized that the etch rate varies as a function of temperature, elapsed time from the start of etching and etching period, solution type and concentration, agitation method and substrate to be etched [6].

When designing a micromachining process, it is necessary to know the etching rate for each material being etched. To achieve good material selectivity a high ratio of the etching rate for the workpiece material to the etching rate for other materials. Experimentally, the material removal rate can be calculated using the weight difference method before and after the chemical etching process [7]. The MRR is defined as:

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\text{MRR (gm/min) = } \frac{W_b - W_a}{T} \text{ (mg) } \text{ (min)}
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Wb: represent the weight of the workpiece before the machining process (mg).
Wa: represent the weight of the workpiece after the machining process (mg).
T: represent the time of etching (min)

3. Materials used for experimental work:

In this study the materials that were used in the chemical etching process

3.1 Silicon carbide (SIC):

Silicon carbide is a non-oxide ceramic which has various industrial applications. In fact, it has good properties such as high melting point, high hardness and strength, high erosion resistance, thermal and chemical stability, oxidation resistance, etc. All of these qualities make Silicon carbide a perfect candidate for high power, cutting and abrasion applications as well as high-temperature electronic devices [8]. Figure (2) showing a sample of (SIC).
Figure (2) shows a specimen of silicon carbide (SIC)

3.2 Chemical etchant solution

Two types of acids were used in the chemical etching process: Hydrochloric acid (HCl) and Hydrobromic acid (HBr).

4. Devices used for experimental work:

4.1 Hot & stirrer device:

hot plate and magnetic stirrer were used in this study as shown in Figure (3)

4.2 Measuring devices

The material removal rate (MRR) was calculated experimentally by (Weight sensitive device) with accuracy ±0.0001 and measuring the difference in the weight before and after the etching. The surface roughness (Ra) was calculated by using (The Pocket Surf gauge), as shown in figures (4 and 5).
5. Parameters and levels of chemical machining.

Four parameters were used (etching temperature, a type of etchant, etching time, concentration of the solution) with four levels for each parameter. Table (1) shows the machining parameters and their levels.

Table (1): Parameters and levels of chemical etching.

| Parameters          | Level 1 | Level 2 | Level 3 | Level 4 |
|---------------------|---------|---------|---------|---------|
| etching time (min)  | 30      | 50      | 70      | 90      |
| Machining temperature (ºC) | 60      | 80      | 100     | 120     |
| Concentration %     | 50      | 60      | 70      | 80      |
| Etchant type        | HBr     | HCl     | /       | /       |

6. Result and discussion

Table (2) represents the measured and predicted material removal rate for the workpiece by (Taguchi design). figure (4.8) explain the Main effects plot of process parameters on the material removal rate.

Table (2): Measured and predicted material removal rate

| No. | Temp. (ºC) | Con. (%) | time (min) | Etchant | ΔW (mg) | MRR (mg/min) | Predicted MRR (mg/min) |
|-----|------------|----------|------------|---------|---------|--------------|------------------------|
| 1   | 60         | 50       | 30         | HBr     | 5       | 0.1666       | 0.1909                 |
| 2   | 60         | 60       | 50         | HBr     | 13      | 0.1714       | 0.1344                 |
| 3   | 60         | 70       | 70         | HCl     | 11      | 0.1571       | 0.2168                 |
| 4   | 60         | 80       | 90         | HCl     | 15      | 0.1666       | 0.1362                 |
| 5   | 80         | 50       | 50         | HCl     | 12      | 0.2415       | 0.3124                 |
| 6   | 80         | 60       | 30         | HCl     | 14      | 0.4666       | 0.4235                 |
| 7   | 80         | 70       | 90         | HBr     | 7       | 0.0777       | 0.0609                 |
| 8   | 80         | 80       | 70         | HBr     | 14      | 0.2127       | 0.1875                 |
| 9   | 100        | 50       | 70         | HBr     | 16      | 0.2285       | 0.1795                 |
| 10  | 100        | 60       | 90         | HBr     | 3       | 0.0333       | 0.1116                 |
| 11  | 100        | 70       | 30         | HCl     | 15      | 0.5102       | 0.4816                 |
| 12  | 100        | 80       | 50         | HCl     | 22      | 0.4412       | 0.4290                 |
| 13  | 120        | 50       | 90         | HCl     | 29      | 0.3222       | 0.2911                 |
| 14  | 120        | 60       | 70         | HCl     | 30      | 0.4285       | 0.4303                 |
| 15  | 120        | 70       | 50         | HBr     | 19      | 0.3814       | 0.3554                 |
| 16  | 120        | 80       | 30         | HBr     | 12      | 0.4143       | 0.4538                 |
Figure (6) Main effects plot of process parameters on the material removal rate.

The results of the material removal rate (MRR) were close between measured and predicted. The ability of independent value to predict the material removal rate was (91.6%). This means that the correlation coefficient between the observed value of the dependent variable and predicted value based on the regression model is good.

Table (3) explain the analysis of variance (ANOVA) for the material removal rate (MRR) of the workpiece -based on Taguchi design. This table illustrates that the time, concentration, etchant type, and temperature affected the material removal rate of specimens. The effect of the etchant type was more influential than other parameters. The effect of etchant type was (13.13), the effect of time, temperature, and concentration (7.16, 6.21, 0.49) respectively.

Table (3): Analysis of variance for material removal rate

| Source          | DF | Adj SS      | Adj MS      | Adj MS      | F-Value | P-Value |
|-----------------|----|-------------|-------------|-------------|---------|---------|
| Temperature °C  | 3  | 0.100291    | 0.100291    | 0.033430    | 6.21    | 0.039   |
| Concentration % | 3  | 0.007952    | 0.007952    | 0.002651    | 0.49    | 0.703   |
| Time            | 3  | 0.115570    | 0.115570    | 0.038523    | 7.16    | 0.029   |
| Etchant type    | 1  | 0.070692    | 0.070692    | 0.070692    | 13.13   | 0.015   |
| Residual Error  | 5  | 0.026918    | 0.026918    | 0.005384    |         |         |
| Total           | 15 | 0.321423    |             |             |         |         |
Conclusions

1. The maximum material removal rate (MRR) for silicon carbide when used hydrochloric acid (HCl) is (0.5102) mg/min occurred in the experience of number (11) at operating conditions etching temperature (100) °C, etching time (30) min and concentrations of solution (70%).
2. The maximum material removal rate (MRR) for silicon carbide when used Hydrobromic acid (HBr) is (0.4143) mg/min occurred in the experience of number (16) at operating conditions etching temperature (120)°C, concentrations (80%) and etching time (30) min.
3. The ability of independent value to predict the material removal rate was (91.6%).

References:

[1] O. Çakir, A. Yardimed, T. Özben, "Chemical machining", International Scientific Journal, Vol. 28, Issue 8, P.P. 499-502, 2007.
[2] Saad K. Shather, Ali Ibrahim, "Influence of Machining Parameters on Surface Roughness in Chemical Machining of Stainless Steel 304", Eng. &Tech. Journal, Vol. 33, Part (A), No. 6, P.P. 1377-1388, 2015.
[3] O. Çakir, “Study of Etch Rate and Surface Roughness in Chemical Etching of Stainless Steel,” Key Eng. Mater., vol. 364–366, pp. 837–842, 2007, 10.4028/www.scientific.net/kem.364-366.837.
[4] A. Raj, A. V, and T. S. Nanjundeswaraswany, “Chemical Machining Process - An Overview,” vol. 3, no. December, pp. 37–39, 2019.
[5] M. Groover, “Fundamentals of Modern Manufacturing Materials, Processes and Systems,” John Wiley Sons, p. 493, 2010.
[6] KINDER B M, TANSLEY T L. A comparative study of photoenhanced wet chemical etching and relative ion etching of GaN epilayers grown on various substrates [J]. Optoelectronic and Microelectronic Materials Devices, 1998, 1: 195–198.
[7] Hassan El-Hofy, "Advanced machining processes", McGraw-Hill, 2005.
[8] H. Abderrazak and E. S. B. H. Hmida, “Properties of application of silicon carbide,” Silicon Carbide Synth. Prop., no. C, pp. 361–389, 2008