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Influence of Machining Parameters on Surface Roughness in Chemical Machining of Silicon Carbide (SiC)

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HIGHLIGHTS

- Influence of chemical machining parameters on the surface roughness of ceramic material (silicon carbide).
- The best surface roughness value is obtained (2.933) µm experimentally and (2.958) µm at a predictable program.
- The coefficient determination (R-sq) to predict the surface roughness is ((93.7).

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ABSTRACT

This study discussed the influence of chemical machining parameters such as (machining time, type of etchant, etching temperature, and concentration of the solution) on the surface roughness of ceramic material (silicon carbide) as a workpiece in the chemical machining (CHM) process. To achieve the best value for surface roughness. In this research, four levels of factors affecting the chemical etching process were used, the values of etching temperature (60, 80, 100, and 120) °C, the etchant concentration (50, 60, 70, and 80) %, and machining time (30, 50, 70, and 90) min, and two etchant type (HBr, HCl). Experiments proved the best value of surface roughness is obtained (2.933) µm experimentally and (2.958) µm at a predictable program when using hydrochloric acid (HCl) at a temperature (80) °C, time (50) min, and etchant concentration (50) %. The coefficient determination (R-sq) to predict the surface roughness is ((93.7).

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 chemical machining process may be the oldest method of non-conventional machining applied to shape copper with citric acid in Ancient Egypt about 2300 BC [2]. Due to the development of the technological field led to the diversification of the machining processes for materials that are difficult to machine, such as fiber-reinforced composites, ceramics, stainless steel, and super alloy—these materials' properties: toughness, strength, low machinability, and high hardness [3].

Several factors are contributing to the publicity of chemical machining (CHM) processes [4]:

1) It is well established and mature.
2) Easy-to-implement process
3) No extra cleaning steps are required.
4) Inexpensive machining process.

The chemical machining (CHM) process was considered one of the machining processes after the fifties of the last century [5]. The working principle of the chemical machining process depends on chemical etching. The portion of the work material is removed when in contact with strong chemical solutions called etchant. The etchant reacts with the workpiece in the cut material and causes the solid material to be removed. Thus, the metal is removed by the chemical attack of the etchant [6]. Figure (1) shows the typical chemical etching process [7].

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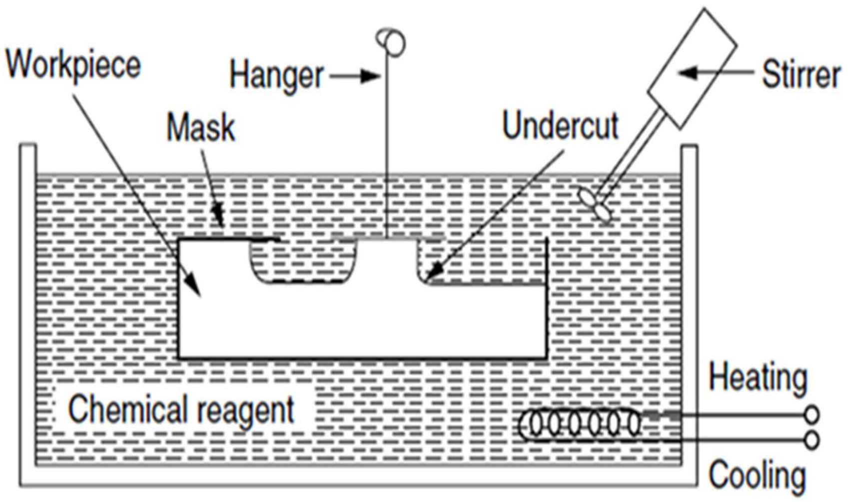

Figure 1: Typical chemical etching process [7]

2. Application of chemical etching

The material that can be chemically etched includes all common types like copper, aluminum, steel, zinc, nickel, and lead. Many strange materials such as zirconium, titanium, and molybdenum. As well as many non-metallic materials like (ceramics and glass) and some plastic materials that can be operated in this way. Chemical operation is a suitable method for machined sags and surface holes. Materials that have a very small thickness easily and do not need to be used mechanization. Materials with high hardness can be chemically etched without problems. The properties of the machined material are not affected after the chemical etching operations. The chemical etching method can be used for very brittle materials subjected to breakage when used in traditional methods [8].

3. Environmental issues

The most critical factor influencing the machining process to be used or not may be environmental concerns in chemical machining operations. Most chemicals are very dangerous liquids, such as cleaning agents, etchants, strippers, etc. Therefore, they are very difficult to be treated and disposed of. The industrial pattern of using these chemicals is to choose chemicals that are more widely acceptable [9]

4. Surface roughness

The surface roughness of the material is one of the key issues after the chemical etching process because the rough surface affects the performance of the end products. Therefore, less surface roughness is required. Therefore, studying surface roughness is to find a relationship between surface roughness and the chosen variables and get high-quality surface roughness with a faster etching rate [10].

The surface machined by CHM does not have a uniform lay pattern. Based on grain size, orientation, and heat treatment. Surface defects will not be eliminated after the CHM, and any surface irregularities previously existed, such as dents, scratches, or waviness, will be little change in the machined surface [11].

5. Materials used:

5.1 Silicon carbide (SiC)

Silicon carbide, which has numerous industrial applications, is an effective non-oxide ceramic. It has specific characteristics such as elevated hardness and strength, chemical and thermal stability, high melting point, resistance to oxidation, high resistance to erosion, etc. None of these Features make SiC an excellent candidate for electronic devices with high power, high temperature, and applications for abrasion and cutting [12]. Figure (2) shows a sample of (SiC). Silicon carbide (SIC) on a type of advanced ceramics is silicon carbide. Since 1991 silicon carbide has been known as a semiconductor and a very suitable material for machining at high temperatures, high capacity, and high radiation conditions that conventional semiconductors cannot perform adequately like silicon (Si). Silicon carbide is an advanced non-oxide ceramic type and has many industrial applications [13].

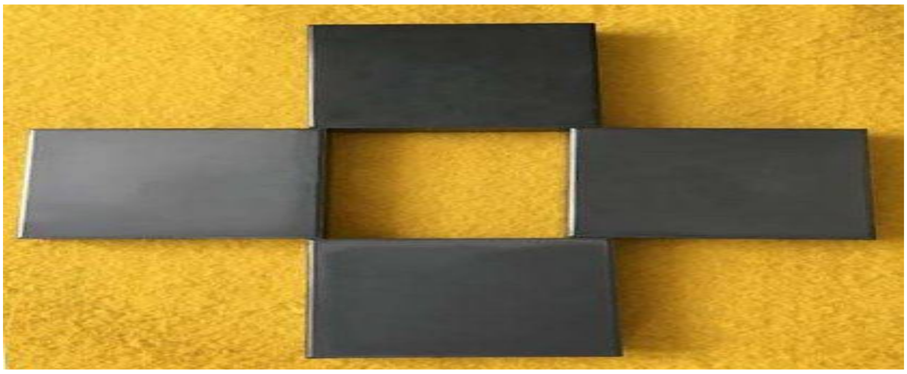

Figure 2: A specimen of silicon carbide (SiC)

Silicon carbide has good properties:

- Low density.
- High hardness.
- Oxidation resistance.
- Excellent thermal shock resistance.
- High melting temperature.
- High elastic modulus.
- High erosion resistance [14].

5.2 Chemical etchant solution

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

5.2.1 Hydrochloric acid (HCl)

Hydrochloric acid is a liquid substance, and it is a fireproof material, transparent and colorless or light yellow. HCl has a Molecular weight (of 36.46) g/mol. When hydrochloric acid is heated, it generates large quantities of hydrochloric acid fumes [15].

5.2.2 Hydrobromic acid (HBr)

Aqueous solution hydrobromic acid (HBr) is a powerful mineral acid that is an essential chemical tool in modern manufacturing. Hydrobromic acid (HBr) is a strong acid formed by dissolving hydrogen bromide in water. HBr has a Molecular Weight of 80.9119 g/mol and a Boiling Point (122 °C). In this study, four concentrations were used (50, 60, 70, and 80%).

6. Devices used

6.1 Hot and stirrer device

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

6.2 Measuring device

The surface roughness was calculated experimentally using (The Pocket Surf gauge) before and after the etching process, as shown in Figure (4). The device was calibrated by a laboratory official.

7. Parameters and their levels of chemical machining

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

Table 1: Parameters and their 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	/	/

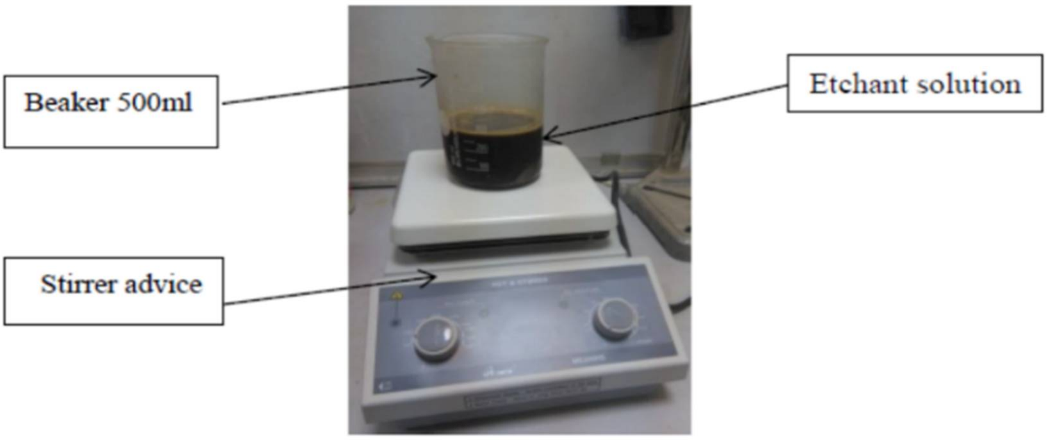

Figure 3: Hot and stirrer device

Figure 4: The Pocket Surf gauge

Table 2: Measured and predicted surface roughness

No.	Temp. (°C)	Con. (%)	Time (min	Etchant	Measured Ra (μm)	Predicted Ra(μm)
1	60	50	30	HBr	3.421	3.487
2	60	60	50	HBr	3.521	3.260
3	60	70	70	HCl	3.25	3.378
4	60	80	90	HCl	4.543	4.609
5	80	50	50	HCl	2.933	2.958
6	80	60	30	HCl	3.811	3.979
7	80	70	90	HBr	4.570	4.547
8	80	80	70	HBr	4.276	4.104
9	100	50	70	HBr	3.030	3.102
10	100	60	90	HBr	4.214	4.335
11	100	70	30	HCl	4.230	3.962
12	100	80	50	HCl	3.660	3.732
13	120	50	90	HCl	4.326	4.160
14	120	60	70	HCl	3.750	3.720
15	120	70	50	HBr	3.635	3.797
16	120	80	30	HBr	4.783	4.815

8. Results and discussions

Table (2) represents the workpiece's measured and predicted surface roughness by (Taguchi design). Figure (5) explain the Main effects plot of process parameters on the surface roughness. For each specimen, three surface roughness readings were recorded before and after the machining operation, and the average was taken for the workpiece.

The surface roughness (Ra) results were close between measured and predicted. The ability of the independent value to predict the surface roughness was (93.7%). This means that the correlation coefficient between the measured value of the dependent variable and the predicted value is good. It can be seen that the minimum surface roughness value when using hydrochloric acid (HCl) obtained is (2.933) am, which was occurred in the experience of number (5) at operating conditions etching temperature (80)°C, etchant concentration (50%), and etching time (50) min. The minimum surface roughness value when using the obtained Hydrobromic acid (HBr) is (3.030) μm, which occurred in the experience of number (9) at operating conditions etching temperature (100)°C, concentrations of solution (50%), and etching time (70) min.

Table (3) the analysis of variance (ANOVA) for the surface roughness (Ra) of the workpiece depending on Taguchi design. This table illustrates that the time, concentration, etchant type, and temperature affected the surface roughness of specimens. The effect of the etching time was more influential than other parameters. The effect of etching time was (13.24), the effect of concentration, temperature, and etchant type (8.73, 2.35, 0.92), respectively.

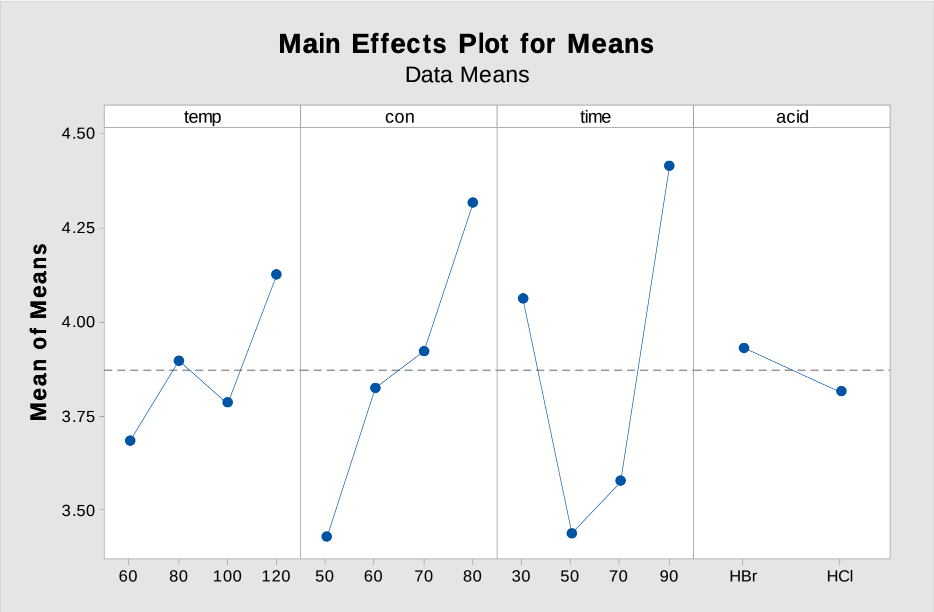

Figure 5: Main effects plot of process parameters on the surface roughness

Table 3: Analysis of variance for surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
Temperature °C	3	0.42869	0.42869	0.14290	2.35	0.190
Concentration %	3	1.59601	1.59601	0.53200	8.73	0.020
Time	3	2.42038	2.42038	0.80679	13.24	0.008
Etchant type	1	0.05605	0.05605	0.05605	0.92	0.381
Residual Error	5	0.30459	0.30459	0.06092	/	/
Total	15	4.80571	/	/	/	/

9. Conclusions

The present work has reached the following conclusions:

1) The minimum value of surface roughness (Ra) when using hydrochloric acid (HCl) is (2.933) am has occurred in the experience of number (5) at operating conditions etching temperature (80) °C, concentrations of solution (50%), and etching time (50) min.
2) The maximum value of surface roughness when using Hydrobromic acid (HBr) is (4.783) am has occurred in the experience of number (12) at operating conditions etching temperature (120) °C, concentrations of solution (80%), and etching time (30) min.
3) The coefficient determination (R-sq) using the Taguchi method to predict the surface roughness is (93.7%).

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Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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