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Chemical Machining of St37 Rod Using Etchant Substance $FeCl_3$

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Chemical machining is one of the oldest nontraditional machining processes. It applies chemical etchant to machine material. The method is very basic and economical to produce complex geometrical parts from thin sheet materials. The application of this method to cylindrical parts is not common. In this study, chemical machining process was employed to machine rod as cylindrical part. The selected material was St37 with diameter of 10 mm. The experimental study implemented ferric chloride, which is known a universal chemical etchant for iron-based materials, at three different etchant solutions in two chemical machining temperatures (30 °C and 50 °C). The experimental setup is based on upright drilling machine that has three different spindle speed values (250, 500, and 1500 rpm). It was observed that lower etchant concentration provided higher diameter reduction, surface roughness, and cylindricity. Moreover, the effect of chemical machining temperature is examined and increase of this value produced faster machining.

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PACS/topics: chemical machining, ferric chloride, diameter reduction, surface roughness

1. Introduction

Chemical machining, which is one of the non-traditional machining methods, has a special place in micro-machining applications. The method is employed to shape material's selected areas by controlled-corrosion activity. It has wide application areas in various industries such as electronics, aerospace, medical part production, and μm-sized components for MEMS. Chemical machining is mainly used to manufacture parts from thin and flat materials. The application of chemical machining method to rod or bar geometries is few [1–3].

Application of chemical machining starts with cleaning of material, and then masking is employed. The required section(s) is mentioned by cut and peel process. The next step is chemical machining by selected chemical solution, which is called "etchant". The masked part is placed in etchant and material's open areas are corroded until the desired geometry is obtained [1].

There are machining parameters in chemical machining such as etchant type, etchant concentration, and chemical machining temperature. The main machining parameter is to select optimum etchant for the chosen material. There is an excellent reference book for this purpose, providing possible etchants and process application parameters as well [4]. However, industrial application of chemical machining yield limited etchants like ferric chloride for most of materials (mainly iron-based), cupric chloride for copper and its alloys, and ammonium based etchants for copper.

Ferric chloride ($FeCl_3$) is a universal etchant containing various advantages like high etch rates, easy availability, and cost. Most of the chemical machining of iron-based alloys are operated by $FeCl_3$ with different concentrations. Chemical machining temperature is another parameter and it affects the etch rate and surface quality. It has been proved that temperature positively influences etch rate performance, but surface quality decreases with increase of it [1, 4–6].

Chemical machining is generally applied for flat and thin materials, but this study examines the chemical machining of cylindrical part. Therefore, the rod with 10 mm diameter is selected from St37 iron-based material which is chemically machined with three different etchant solution of $FeCl_3$ at two different temperatures. The performance of chemical machining of cylindrical part is determined.

2. Materials and equipments

Experimental study is aimed to examine the performance of chemical machining of cylindrical parts. The chemical machining was based on immerse chemical machining method. St37 iron-based alloy (0.17% C, 0.040% P, 0.040% S, 0.009% N) was chosen. The dimensions were: diameter 10 mm, and length 100 mm. The specimens were cleaned by ultrasonic cleaning method at 30 °C for 30 min. A drilling machine tool is used to rotate the rod part at various revolutions (250, 500, and 1500 rpm). The selected etchant was $FeCl_3$ that is prepared in three different concentrations (1.33 mol, 1.38 mol, and 1.43 mol) with distilled water. The etchant and water mixture was 100 ml of volume in total (Fig. 1).

Measurements were carried out by ±0.01 mm accuracy of micrometer for diameter control and Surtronic 3+ Taylor Surf for surface roughness. The cylindricity is checked by comparator (±0.001 mm accuracy).

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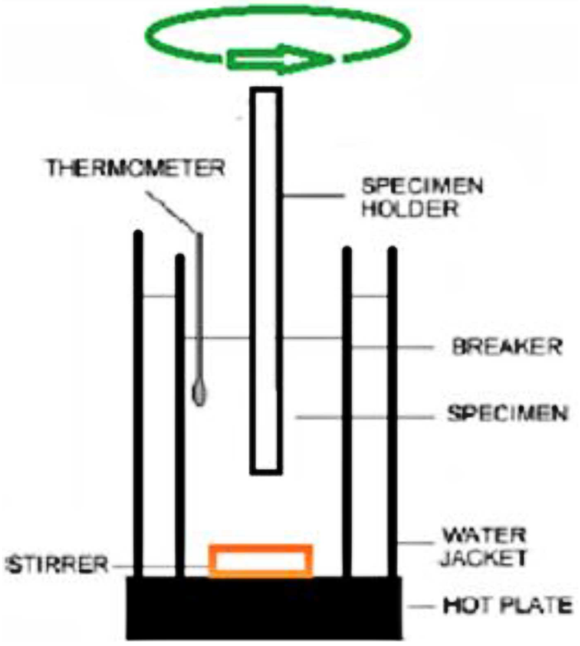

Fig. 1. Experimental setup of immerse chemical machining of rod.

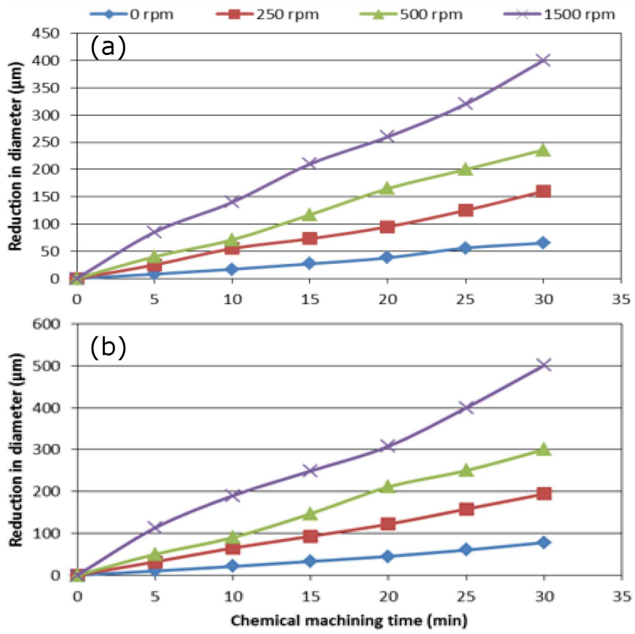

Fig. 2. Reduction in rod diameter (1.33 mol of $FeCl_3$): (a) 30 °C chemical machining temperature, (b) 50 °C chemical machining temperature.

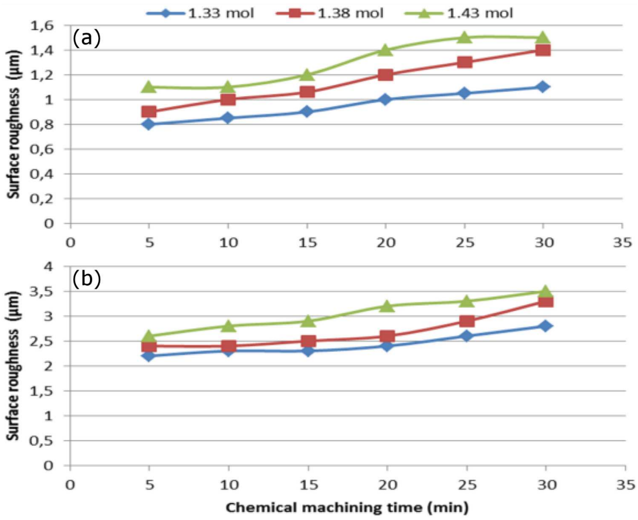

Fig. 3. Surface roughness changes at different etchant concentrations: (a) 30 °C chemical machining temperature, (b) 50 °C chemical machining temperature.

3. Results and discussion

In milling chemical machining of iron-based alloy with $FeCl_3$ etchant can be written as chemical reaction

$$2FeCl_3 + Fe \rightarrow 3FeCl_2.$$

When $FeCl_3$ attacks material surface, electron transfer starts and ferric ion oxidizes iron to ferrous chloride. Corroded iron and other materials spread in the etchant.

The changes on rod diameter were first examined. It was clearly observed that lower etchant concentration provided faster reduction on diameter. 1.33 mol of etchant solution provided the highest diameter reduction at three rotation speeds. The maximum reduction was obtained at 1500 rpm. The reduction was the lowest when the rod was stationary (0 rpm). The medium rotation speeds (250 rpm and 500 rpm) caused more diameter reduction comparing to stationary condition. The etchant concentration was influential parameter because increase of the etchant concentration reduced diameter reduction. Each high etchant concentration reduced around 10–15% of diameter reduction. Therefore, it was clearly observed that lower etchant concentration provided better chemical machining performance (Fig. 2a,b). Moreover, this figure indicates clear experimental results about the effect of chemical machining temperature when St37 rod was machined. Temperature is an influential parameter in corrosion and chemical machining is a typical corrosion controlled process. Higher temperature improved the performance of chemical machining of rod around 30% in reduction of diameter. It is noted that the chemical machining temperature would give a better governing on the shaping operation when high temperature is selected.

The surface quality is another output when chemical machining of any material is examined. The effects of etchant concentration in the chemical machining of St37 material was clearly observed, lower etchant concentration (1.33 mol) produced smoother surfaces comparing to two other etchant concentrations (1.38 mol and 1.43 mol). These results were given in Fig. 3a,b.

Another important output of chemical machining of cylindrical parts is change in cylindricity. The effects of etchant concentration at two different temperatures were delivered in Table I. Etchant concentration presented an important factor — higher concentration reduced cylindricity deviations compared to lower concentrations. Moreover, the rotation speed improved cylindricity and deviation became more stable. The influence of chemical machining temperature exhibited slight differences, but low temperature reduced cylindricity deviations.

TABLE I

Changes in cylindricity (30 °C chemical machining temperature).

Concentration	Cylindricity (maximum and minimum deviations [μm])							
	0 rpm		250 rpm		500 rpm		1500 rpm	
1.33 mol	13	39	20	22	24	29	14	25
1.38 mol	11	36	25	23	14	20	21	31
1.43 mol	10	34	10	13	13	26	11	14

4. Conclusion

The experimental study of chemical machining of St37 rod with FeCl3 etchant was carried out and some conclusions can be mentioned. $FeCl_3$ is a very suitable etchant for iron-based alloys and suitable for most of metals. The concentration of $FeCl_3$ is an effective factor as higher concentration increases the etch rate, but uncontrollable chemical machining process is observed. Therefore, the etchant concentration should be kept around 1.3 mol. Temperature should be selected according to the expectation from machining method. High temperature (50 °C) produces faster diameter reduction, but reduces surface quality. As a result, machining step in the end should be at low chemical temperature to obtain low surface roughness. Rotation speed improved chemical machining performance, and increase in rotations resulted in quicker diameter reduction. Cylindricity is an important output when rod parts are chemically machined. The lowest deviations should be gained. Therefore the process speed should be reduced.

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