

Flow Controlled Chemical Machining

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Abstract: This paper presents a new method of manufacturing 3D components by using Flow-Controlled Chemical Machining (FCCM). FCCM can be used for fabrication of 3D components using flow control set-up (or pattern) and suitable etchant. In this investigation, pattern used is perforated and having wettability which is made up of the cotton material. The pattern material has etchant resistant properties. During machining, the pattern is placed on a workpiece and etchant is passed over the pattern. Due to wettability of pattern, a thin layer of etchant is formed below the pattern and etching of work piece is done in the direction of pattern in a stepwise. This investigation is useful in fabrication of various 3D free-form surface components. Since, the chemical etching processes have a very low material removal rate; by optimizing machining parameters such as flow rate of etchant, etchant concentration, temperature etc.; machining rate can be improved.

Keywords: *Chemical; machining; 3D Components; Fluid flow*

1 Introduction

Now-a-days in the industries, traditional and non-traditional manufacturing processes are widely used for the fabrication of various products. Non-traditional processes include Ultrasonic Machining (USM), Electro-Discharge Machining (EDM), Laser Beam Machining (LBM), and Electron Beam Machining (EBM), Electro-Chemical Machining (ECM), and Photochemical Machining (PCM). These processes are having high setup and operating cost and also require a high electric power supply except PCM [1]. Thus, only the PCM process doesn't require a high electric power supply and it has low tooling cost.

In the literature, D.M.Allen (2004) explained the photochemical machining with their wide applications in micro-engineering[1-4]. Cakir (2008) found that ferric chloride (FeCl_3) was a suitable etchant for aluminum etching. The chemical reaction is simple which makes the process easy to control. Cakir (2006) studied copper etching with cupric chloride (CuCl_2) etchant simultaneously with the waste etchant. It has made the overall manufacturing cost slower and also it has made the etching process a more environmentally friendly[7]. Allen et. al (2004) studied the characterization of the aqueous ferric chloride etchants used in an industrial photochemical machining. FeCl_3 is the most commonly used etchant but there are a variety of grades of FeCl_3 [8]. Roy et al. (2004) investigated a cost model for PCM which defines standards for an industrial etchants and methods to analyze and to monitor them. Allen et al. (1983) studied the manufacture of stainless steel edge filters: an application of electrolytic photo polishing and stated two methods for manufacturing of an edge filter. Also the surface textures and process characteristics of the electrolytic photoetching of annealed AISI304 stainless steel in hydrochloric acid was studied [8]. Muhl et al. (1995) studied direct printing of the etch masks under computer control in which all the stages of photo-processing and mask making was covered [2].

Basically, PCM process is a 2D process in which material is removed by means of the chemical reaction of etchant on the material. In this process, the masking is done by photographic technique to avoid unwanted area from etching. Moreover, in this process etching is controlled in the directions of a plane surface area and perpendicular to surface area (that is depth wise). But for producing 3D components, controlling the flow of etchant in angular direction is necessary. Controlling the flow in angular direction is difficult in PCM because the workpiece is completely dipped in the etchant [4]. Therefore, etching is done vertically as well as horizontally at the same time. Due to this reason, PCM is difficult to use for manufacturing of 3D components. To eliminate these problems, etching of a selective area in particular direction is required. Hence, FCCM is utilized in this research.

In FCCM, all the problems related to 3D PCM get eliminated as etching was done only on the area under the pattern or the area which was in contact with the pattern. In this process, the tools used were pattern and etchant. The pattern materials were having property of wettability and plastic (as etchant resistant material) was used for making a frame of the required shape. Both these materials are easily available and are of low cost. Therefore, in an economical manufacturing point of view, this research is useful. This research thus provides the large applications in an industrial area since the tooling cost is low and it does not require electric power supply in large amount [8].

This research relates to the process of manufacturing for different 3D components by the chemical etching process. More particularly, this fundamental concept relates to the control of etching direction with the help of flow-control set-up of a desired product shape. By using this process, the different free-form surface products can be manufactured.

2 Experimental work

The Set-up for FCCM is shown in Figure 1 which contains workpiece, pattern of required shape, etchant sprayer, workpiece table and etchant collecting tray.

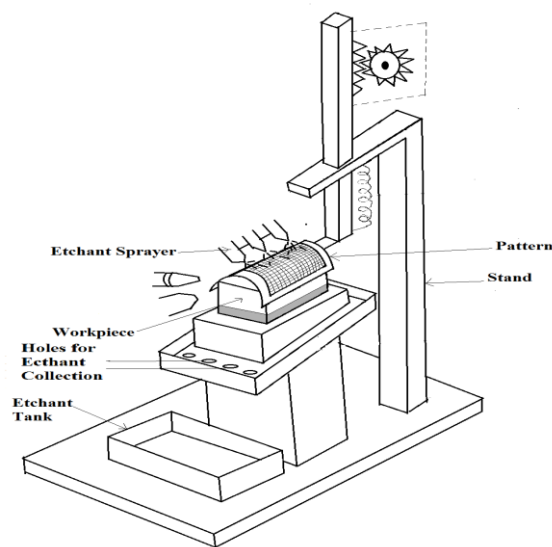


Fig. 1. Schematic diagram of set-up of the Flow-Controlled Chemical Machining (FCCM)



Fig. 2. Aluminium workpiece and machining set-up

The procedure of making pattern of required shape is illustrated below. In this investigation, the desired shape of a plastic frame was taken and then cotton was tightly wound on the frame. The experimentation was carried out for manufacturing of the chamfer or semi-cylindrical shape on square block. For making this shape, hollow plastic workpiece of a semi-cylindrical shape was taken and then the rectangular section was cut from it. Also slots were made on the both sides below the rectangular cut section as shown in Figure 3.

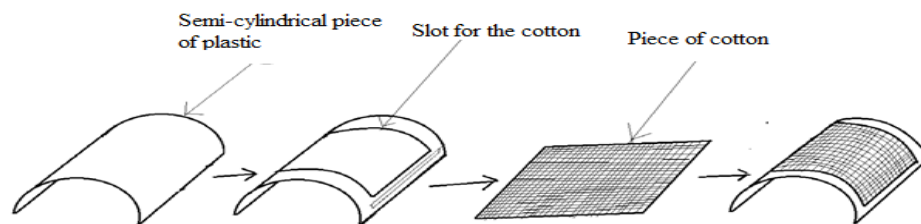


Fig. 3. Procedure for making pattern

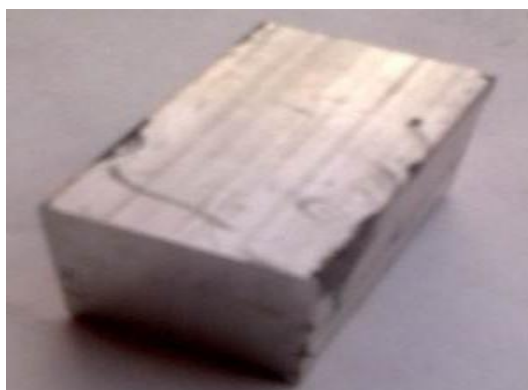


Fig. 4. Workpiece before machining

During the operation of FCCM, the etchant was getting dropped downward from the pattern and there may be possibility that the etchant may come into contact with the workpiece at the bottom side. Therefore, to avoid etching action at bottom of the workpiece, etchant resistant coating was applied at the bottom of the workpiece. In the set-up of the FCCM, worktable was made so that its upper surface was horizontal and lower side was tilted to collect the etchant at one side. Also the holes were provided on downward stream for collecting the etchant in a tray.



Fig. 5. Workpiece after machining

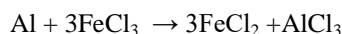
In this experiment, at first the pattern was placed on the workpiece as shown in Figure 1 and Figure 2. It was then slowly flowed the etchant over periphery of the pattern and this etchant was observed by the cotton which is present on the pattern. The thin layer of etchant gets formed below the cotton pattern. Only those parts of workpiece was etched continuously which was in contact with the pattern and stepwise etching was done in the direction of pattern. During machining, the etched material was flown with an extra etchant and it was automatically get removed. When the pattern contains free-form shape or concave shape, the pattern should get lifted because it was difficult to remove the etched material with an extra etchant in concave shape pattern. Also, in this case etchant was flown slowly over the pattern so that it can only wet to the cotton otherwise an extra etchant get collected at concave shape.

For lifting the pattern, a square cross-sectional area slider was attached to the pattern. A square hole was provided on the stand so that the slider slides through the stand as shown in Figure 1. To make the lifting time to time, a cam follower arrangement was provided to the slider as shown in Figure 1. Also in this set-up, spring was provided to the slider to place the pattern automatically always in contact with workpiece when the pattern was returned after the lifting by self-weight.

In this process, pattern was used as a tool which is made up of cotton and a plastic was used for making a frame of required shape. Both these materials are easily available at low cost. Therefore, for economical manufacturing point of view, this process is beneficial. This process thus provides the large applications in an industrial area as the tooling cost is low and it does not require electric power supply in large amount.

3 Results and Discussion

The chemical reaction of aluminium and ferric chloride during the etching can be written as:



From Figure 5, it is clear that a black layer (smut) is formed on the surface of Aluminium. This smut decreases the etch rate of Aluminium machining.

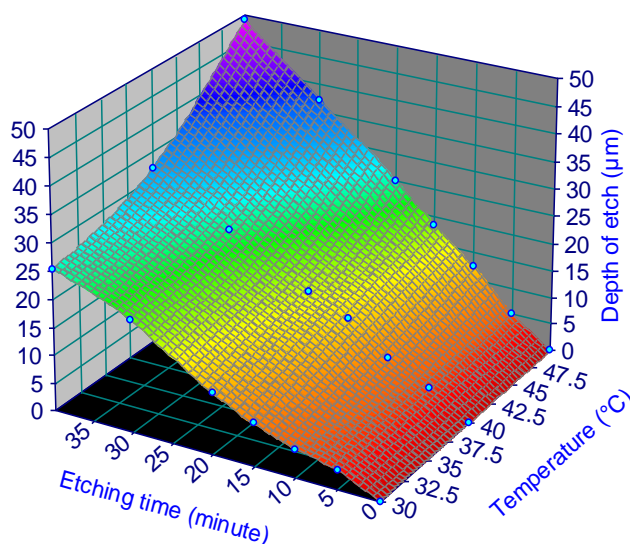


Fig. 6. Effect of etching time and temperature on the depth of etch

The solution of FeCl_3 was prepared with the concentration of 600 gm/litre. The machining was carried out at 30°C, 40°C, 50°C and 60°C respectively. The etching times were 10, 20, 25, 30 and 40 minutes respectively. From Figure 6, it is clear that as temperature and etching time increases the depth of etch also increases. It also shows that due to increase in temperature, the reaction rate between aluminium and ferric chloride increases. Flow controlled chemical machining consists of continuous laminar flow of etchant over the workpiece surface. The main advantage of this process is it provides fresh etchant for the reaction every time. From Figure 5, it can be observed that the depth of etch increases with increase in temperature in FCCM process. This is because the molecules in ferric chloride excited with increase in temperature. Due to which the velocity and kinetic energy of ferric chloride molecules increase with temperature. Material removal in FCCM usually requires collision between material and etchant molecules/ atoms. Bond formation between two molecules requires atoms to come in contact with each other. In some atomic collisions, the atoms simply collide and then rebound, leaving no energy for bond formation. These collisions are known as Ineffective collisions. These occur more in low temperature due less kinetic energy and velocity of etchant molecule. Collisions that lead to new bond formations among atoms/molecules are called as effective collisions. Enough amount of energy must be involved in collision in order to break old bonds and form new ones. A higher temperature produces violent collisions (due to high kinetic energy and velocity) which mean immense amount of energy is produced during the process. Frequency of collisions increases with temperature. Higher frequency of collisions and greater violence ensures effective collisions. Hence the depth of etch can be increased by increasing the temperature and it can be decreased by lowering the temperature.

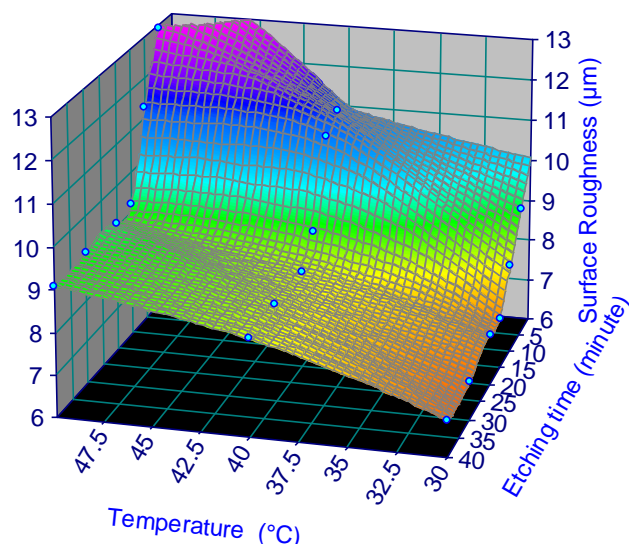


Fig. 7. Effect of etching time and temperature on the surface roughness

The Figure 7 shows that the etching temperature was the most effective parameter as compared to the etching time in case of the surface roughness. It was also seen that the depth of etch was high at high temperature but it resulted in higher R_a value. From the experimental results, it was clear that due to controlled flow of the etchant the undercut was not produced during FCCM. Figure 8 shows one more free-form surface manufactured by FCCM.



Fig. 8. Photograph of free-form formation on copper plate by using FCCM

4 Conclusions

From the experimental results, it is clear that different types of shapes can be produced by flow control chemical etching. Tolerance of the product depends upon accuracy of the pattern and the process control parameters. The process parameters includes spraying of the etchant, uniform wetting ability of the pattern, uniform concentration of the etchant, temperature and etching time etc. By controlling these parameters, it can produce more accurate and better surface finish products. This new technique also produces undercut free components as the result of the controlled flow of an etchant.

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