Nanomanufacturing through Electrophotochemical Machining

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Abstract---There are various techniques which can be used for the manufacture of microproducts, micro electromechanical systems (MEMS) based manufacturing .Broadly these techniques are photolithography, chemical etching, plating, laser fabrication. Micro machining may be seen as an ultra precision material removal process and by this process it is able to achieve micro form accuracy and nanometers finish. There are still some challenging issues to be addressed from precision machining to micro machining. To achieve3 D micro components mechanical micro machining is not the suitable technique. Electro physical and chemical micro machining processes play an important role in micromachining due to their special materials removal mechanisms. Electrical discharge machining (EDM) is especially suitable for manufacturing micro components due to its thermal material removal mechanisms. High precision micro EDM can process functional materials like hardened steel, cemented carbide and electrically conductive ceramics with sub micron precision. It applications are far beyond dies, moulds fabrication such as micro gears, micro fluidic devices medical implants. In this tool electrodes are miniaturized compared to conventional EDM. Discharge energy is also minimized and by this a very small material removal at one single discharge is made possible and hence extremely small gap width 1.5 to 5 μm holes are made possible. High surface roughness, relatively poor fatigue properties, difficult to make sharp corners etc will be the negative features during the micro manufacturing. For precision manufacturing a pulsed power of relatively short duration has to be used. Development of hybrid processes seem now another focus for micro/ nano manufacturing related research. Micro EDM and laser assembly were combined to fabricate 3 D metal micro structures. Combining ECM and EDM the so called hybrid ECM-EDM is another example of improving material processing efficiency, Electro photochemical machining is a hybrid of photo chemical machining and electro chemical machining. This technique has been attempted first time by the present authors is a unique one. It is essentially a non traditional machining in which the removal of metal is accomplished by electrochemical reactions. The desired pattern to be etched on the surface is formed by photo lithography technique. This includes cleaning of the sample, the preparation of the photographic mask, and application of the photo resist on the work piece and the generation of pattern to be etched on the piece on exposure to suitable UV radiations. This method is thus used to cover the work piece with the mask in such a way that only the portions to be etched remain exposed. The etching is done by electro polishing. This is an electrolytic method in which the metal removal is achieved by electrochemical dissolution of anodically polarized work piece. The principle is the reverse of electro plating. In addition to etching it is possible to get good surface finish. Thus this method is popular for the production of complex configurations in thin materials and for production of delicate parts that could be easily damaged by the forces of conventional cutting tools. This method is also applied for high strength and high resistant alloys and materials that are difficult to cut by the conventional methods. The details of the process are discussed in the paper

I. INTRODUCTION

ICRO and nano manufacturing processes: For micro and M nano manufacturing processes numbers of technologies are available. Some examples are Physical vapor deposition,chemical vapor deposition, electroplating, injection molding, embossing Electrical discharge machining, micro electrochemical machining. This depends on manufacturing flexibility and also economical viability.EDM is the process of removing material from two electrodes, the work-piece and the tool. When these electrodes are submerged in a liquid dielectric bath, pulses of voltage applied to them. This causes a sequence of breadowns and recoveries of the in-between dielectric. This is the basic principle of EDM. Numerous EDM developments are now focusing on machining micro features like die sinking, micro drilling, and micro milling micro grinding.

One bottleneck in the research in micro and nano technology is the problem in getting low cost machining technique when the resolution is in the 100nm to 1 μm range. At this level of resolution it is not proper to combine conventional UV photolithography and wet or dry etching techniques like reactive ion etching or deep reactive ion etching. But these techniques require long machining time. These are not only expensive but skilled personals are needed to operate.One advantage of EDM is it can be used to machine very hard materials if they are electrically conductive or semi conductive. Micro EDM is the miniaturization of EDM has the potential to target its application related to rototyping or manufacturing a master piece even though it takes a long machining time as the process is flexible, cost efficient and fully automatic.Different types of EDM machining are available for 20-100µm resolution. The main ones are a die sinking with a complex 3 D electrode, a wire cutting electrode with a circulating wire electrode EDM and a hole drilling with an electrode tip like a tube. Another facility available is EDM milling. This consists in using a tip electrode to perform the machining by computer numerical control. Even though this process is having flexibility to machine parts with complex geometry and high aspect ratio from CAD CAM data, EDM milling is a process rarely used because it is difficult to prepare thin electrode tools and it is necessary to compensate the wear of the electrode. At the afore mentioned resolution EDM milling is less competitive than CNC milling at present.A micro EDM machine with high resolution can be easily developed as it is done in AFM-STM where a combination of micrometric and nanometric positioning actuators and this is needed to achieve large working volume and high accuracy.

TABLE I COMPARISON OF CAPABILITIES OF THE ADVANCED METHODS OF DEEP DRILLING

SL	Parameter	EDM	STEM	ESD	LBM	EBM
1	Hole size (mm)	0.125-6.25	0.75-2.5	0.125-0.875	0.125 -1.25	0.025-1.0
2	Hole depth (mm) i. Common max ii. Ultimate	3.125 62.5	125 900	18.75 25	5.0 17.5	2.5 7.5
3	Aspect ratio i. Typical ii. Maximum	10:1 20:1	16:1 300:1	16:1 40:1	16:1 75:1	6:1 100:1
4	Cutting rate (mm/sec)	0.0125	0.025	0.025	<1	0.25
5	Finish (µ in AA)	63-125	32-125	10-63	32-25	32-250
6	Operating voltage	30-100	5-25	150-850	30kV	150kV

It is clear from Table 1 that for the drilling of deep holes used n turbine blades; Shaped Tube Electrolytic Machining (STEM) is the preferred technique in terms of:
1. The required physical dimensions of the hole.
2. The maximum drilling depth.
3. The surface finish and integrity.
4. Power consumption because of the low operating voltage compared to Electro Discharge Machining (EDM) and electro stream drilling (ESD).
being restricted to about 18 mm. EDM suffers in comparison to STEM because it can drill holes only of relatively lower aspect ratio and shallower depths, and

II. METHODOLOGY
For deep drilling, there are specialised techniques of ECM such as Shaped Tube Electrolytic Machining (STEM)
2.1 Shaped Tube Electrolytic Machining (STEM)
The basic process is illustrated in Fig.1. This technique uses a hollow titanium or copper tube coated with an electrically insulating chemically resistant resin. The electrolyte is fed down the center of the tube. This technique has been used to drill holes with diameter of 0.1-4.0 mm (the ratio of hole depth to diameter 600:1).

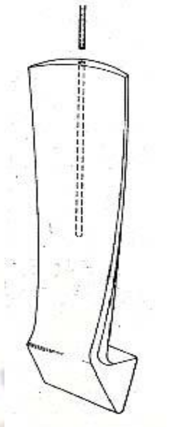


Fig.1 Turbine Blades

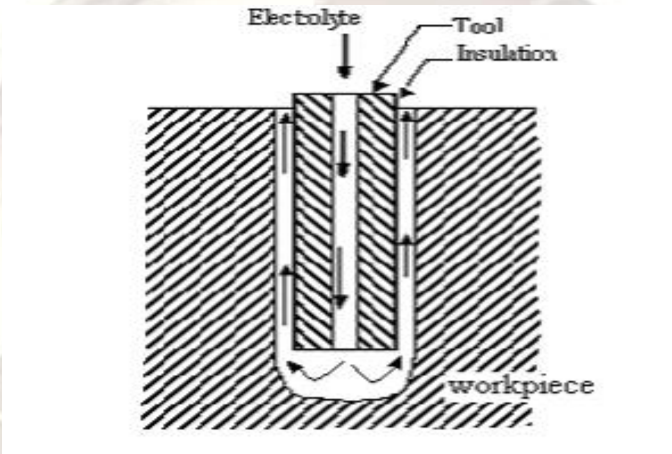


Fig. 2 STEM Method of Drilling

Current industrial applications for STEM mostly involve drilling in difficult-to-cut super alloys, such as cooling holes in turbine blades Fig. (2). For example, holes of diameter 0.35 in ( ) can be drilled to depths 200 mm [3]. The straightness of the hole depends upon the straightness of the tool, which is usually supported close to the surface of work.

III. CRITICAL FACTORS IN DEEP DRILLING

The six critical factors for achieving high accuracy and good surface quality are.

3.1 Sludge Formation

Salt electrolytes such as sodium chlorate ($NaClO_3$), sodium chloride (NaCl) and sodium nitrate ($NaNO_3$) are commonly used in ECM. They generate sludge, which either restricts or clogs the flow of electrolyte; it limits the minimum diameter of the hole that can be drilled. Consequently, acids are used for drilling deep holes. For example, dilute hydrochloric acid has been used for drilling materials such as IN100, aluminum and Ti-6Al-4V. Dilute sulphuric acid is the preferred electrolyte for carbon steels, cobalt alloys, and 300 and 400 stainless steels. The problem with acid electrolytes is corrosion and (possibly) poor surface finish, especially with hydrochloric acid.

3.2 Over Cut

Minimising over cut is an important consideration in hole making (Fig.3). This is minimised by insulating the tool right up to the tip but may still result in hole of diameter 0.01-0.02 mm larger than that of the tool [8]. Over cut depends on feed rate. For example a reduced feed rate gives a larger over cut.

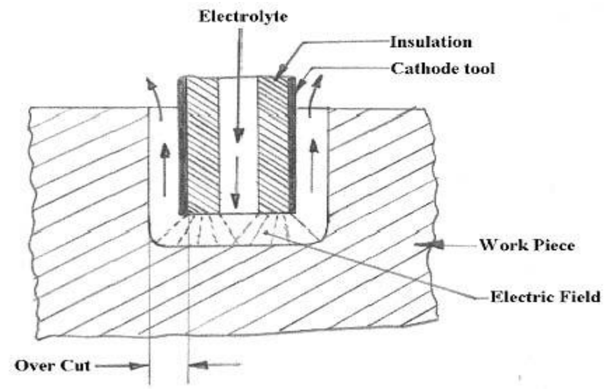


Figure 3 Over Cutting in Electrochemical Drilling [7]

3.3 Feed Rate

Feed control is a great challenge to determine the quality and shape of the deep hole. If feed rate is too low, then more over cut and if too high, it may touch the work piece causing short circuit. The non-uniform feed rate gives non-uniform diameter of holes. For example, by suitable control of feed rate (i.e. uniformly increasing or decreasing feed) gives tapered holes. And if feed is stopped and the tool is allowed to dwell for some time when the correct depth has been reached, a hole of the shape is produced.

3.4 Length and Rigidity of Tool

In electrochemical drilling very long tools (up to 600 mm) can be used. If tool is too long, then tool will vibrate under electrolytic pressures. So tool should be rigid against the vibrations. However in some cases long tools are supported at the surface of work by some guiding mechanism. However cathode tube should always be as smooth as possible especially inside hollow portion of the hole for proper electrolyte circulation. Rough surface causes more pressure drop leading to insufficient electrolyte flow.

3.5 Gap Control

Gap control is important from the point of view of efficient machining. If the gap between tool and work piece is too large the machining will be too slow and if the gap is too small there is a danger of short circuits. Moving rams and slides should be free from stick-slip-motion to provide constant feed rates.

3.6 Surface Finish of Hole

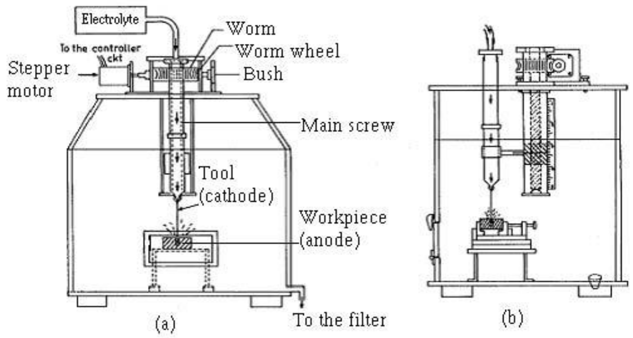
The surface finish, or roughness, of the hole may have an impact on the heat transfer coefficient, e.g. the rate of cooling of the turbine blades. In fact, the relation between surface roughness and heat transfer coefficient is complex. For a given Reynolds number, in the turbulent flow regime, the heat transfer coefficient, increases with surface roughness. If the surface is too rough, then more pressure drop takes place that means more pumping loss. Thus rough surface gives good heat transfer, but more pumping loss. Smooth surface reduces pumping loss but poor heat transfer. By FEM simulation, Noot.M.J [6] investigated and found that the waveform holes are preferable and provide good heat transfer and low pumping loss.

IV. EXPERIMENTAL SETUP

4.1 Shaped Tube Electrolytic Machining (STEM)

Figure 4 is a schematic diagram of the experimental set-up for STEM. The major elements are:

1. Cathode “tool”.
2. Work piece.
3. Electrolyte
4. Cathode feed mechanism
5. Control panel board
6. Electrolyte flow system



(a) Front view, (b) Side view [7]
Figure: 4. Schematic Diagram showing the Set-Up of Electrochemical Drilling

4.2 Cathode Tool

Cathode material must be good conductor of electricity and have adequate mechanical strength against pressure of electrolyte. In this experiment copper tube used as good conductor of electricity and strength is enough for moderate pepths.

Fig. 5 (a) shows a tool with a tool bit soldered at one end; however, its larger diameter produced a larger over cut. The tool shown in Fig. 5 (b) was not satisfactory as there was no insulation at the tip. The tool shown in Fig. 5 (c) produced less over cut.

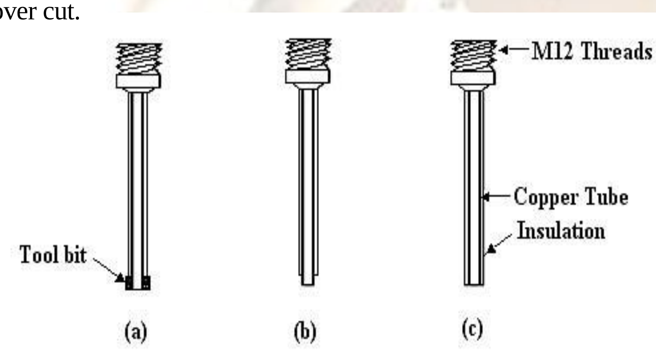


Figure 5 Electrodes used for EC Drilling, (a) Tool Bit Type Electrode, (b) Partially Coated Electrode (ce Fully cathode [9]s

tool was coated with insulating resin over the Coated Electrode To minimize over cut and to get straight holes the ecasidewall of the tool.

V. CONCLUSION

Thus the electrochemical machining of large plane microstructures with accuracies in the nanometer range sets strict demands on process control. As discussed in this paper one process is classical electrochemical discharge machining where in pulse can be applied and accuracies can be improved. Another method that is upcoming is μ-PECM (micro pulse Electrochemical machining). Advantage of pulse electrochemical machining over the EDM is high material removal rate and the big machining surface. This must be weighed against the small accuracy caused by the big gap widths. The μ-PECM will not have this disadvantage since it has very high accuracy and this is made possible because of the double layer reloading with very small gaps. It provides only a small material removal rate in relation to PECM. The aim is first to decrease the gap width by adjusting the electrical pulse parameters and then apply μ- PECM for substantially larger surfaces by increasing the effective energy brought in per pulse. Thus in this communication how a shaped tool electrochemical machining can be done which is a special kind of EDM and also it indicated the future of EDM lies in the modification of applying energy through pulse methods wherein μ pulse will take over as it has more control parameters to achieve very specific objectives.

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