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Challenges in Electrochemical Machining

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ABSTRACT

This review paper has been undertaken to investigate challenges in Electrochemical Machining Process (ECM) which is one of the most suitable AMP for machining of advanced and smart materials. Electrochemical machining (ECM) is one of the Progressive Machining Process which is used for machining of High-Strength Temperature-Resistant Materials (HSTR) with many surprising abilities. ECM is the most advantages Advanced Machining Process recently introduced and not yet fully discovered. It has the number of advantages over other Advanced Machining Processes. ECM provides stress free products without a direct mechanical interaction between the workpiece and the tool and high material removal rates.

1. Introduction

A literature review of Advanced Machining Processes shows that Electro Chemical Machining is more advantages and capable method for machining of materials with poor machinability and Shaped Tube Electrolytic Machining (STEM) is particularly applicable for drilling small diameter holes in advanced and smart materials such as Nickel-based super alloys, stainless steel and tool steel[1]–[14]

Electrochemical machining is one of the most recently applied methods of metal removal. It was developed originally for processing the High Strength Temperature Resisting Materials (HSTR), which are used in aircraft industry. It has the advantage that the part being machined is completely stress free. The process can give high degree of accuracy on a routine production basis and this, together with its suitability for processing components of slender nature, makes it applicable to range of precision parts. [15], [16]

In the present review paper the ECM process is chosen for investigation for the following reasons. [1], [5], [15], [17]–[30]

- EDM & ECM are two of the modern machining processes which are competing with conventional machine tools.
- EDM is widely used in Indian industries and machine tools for EDM are being manufactured in India and exported.
- ECM is still largely unexplored process in India.
- Development of aircraft industry in India necessitates development of micro hole drilling on turbine blade for drilling of coolant holes.
- ECM like EDM can be economically used for the machining of small holes.
- An outstanding example of ECM is drilling of long slender holes in aero engine's gas turbine blades to provide passage for cooling air.
- Holes up to 200 mm long and 1mm diameter are produced in tough nickel based alloy which are impossible to produce conventionally.
- Considerable economy in jet engine fuel consumption at improved performance is achieved as a result of cooling holes.
- ECM can also extend freedom of the designer and provide flexibility to introduce innovative features in the design of the produced.
- Parameters such as tool geometry, electrolyte concentration, tool feed rate, inter electrode gap and applied voltage are not much explored.
- So far a little work is reported on the dimensional control and quality of drilled holes.
- Quantitative relationship between process parameters and quality of holes is to be explored.
- Significant factors affecting the quality of hole are to be found and optimized for enhancing the performance of the process.

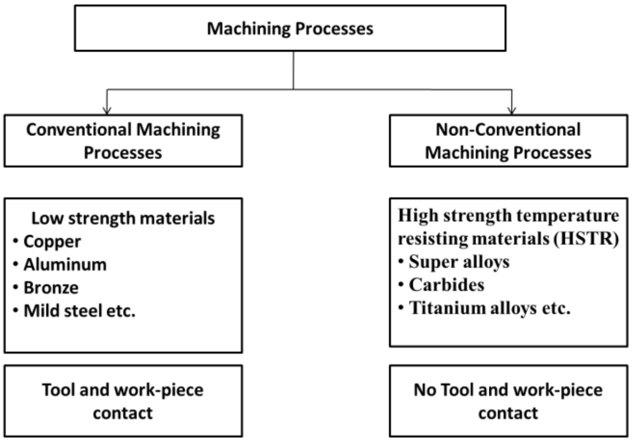


Figure 1 Machining Processes Classification
[1], [15], [25]–[28], [17]–[24]

2. ECM process

ECM is described as "the controlled removal of metal by anodic dissolution of work piece in an electric cell in which the work piece act as an anode and the tool as a cathode". The tool electrode has to be of suitable shape to get the required contour on the work piece.[4], [31]

D. S. Bilgi [18] designed and developed a versatile Shaped tube electrolytic machining (STEM) for drilling deep, high aspect ratio holes. A mathematical model using STEM operating parameters such as voltage, tool diameter and feed rate, bare tip length and electrolyte composition is proposed to predict radial overcut. Predictions from the proposed radial overcut model are compared to experimental data.

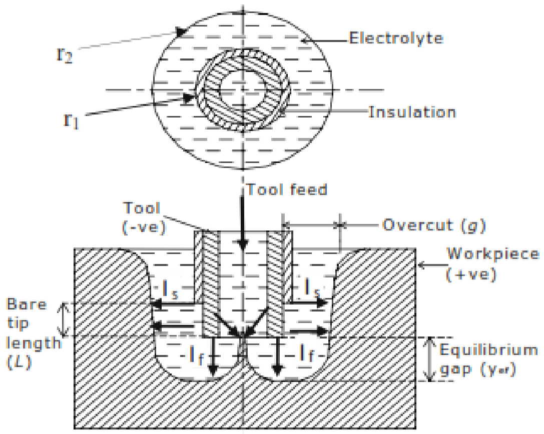


Figure 2. Schematic diagram of STEM [18]

The quality of a drilled hole (i.e. profile, overcut, surface roughness, out-of-roundness) is of prime importance for cooling holes of turbine blades. Since the radius of a drilled hole (r_2) is the sum of the tool radius (r_1) and radial overcut (g), one crucial aspect of dimensional accuracy is radial overcut. Sharma et al.[32] and Bilgi et.al.[13] have conducted extensive experiments to study radial overcut in "deep" holes made by STEM in High Speed Steel and Inconel. In their experiments, through holes were drilled in samples ranging in thickness from 26 mm to 120 mm. The aspect ratio of the drilled holes varied from 11 to 52.2. Four operating parameters were selected for the experiments: voltage (V), tool feed rate (f), bare tip length (L), and electrolyte composition. Sharma et al. [32] and Bilgi et al. [13] have also shown that overcut may vary significantly with hole depth. Consequently, Bilgi et al. [13] have suggested that the depth-averaged radial overcut is a more appropriate parameter for overcut in deep holes:

$$DAROC = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{D_{hi} - D_t}{2}\right)$$

Here, n is the number of locations along the depth of the hole, where the hole diameter (D_{hi}) has been measured. The tool diameter, D_t is known. Studies of Sharma et al. [32] and Bilgi et al. [13] have provided good insight into the effect of STEM operating parameters on DAROC. However, their applicability in accurately predicting DAROC in industrial applications is limited to the materials and the range of STEM parameters used in their experimental studies. The mathematical model that can predict radial overcut as a function of the STEM operating parameters: voltage, tool diameter and feed rate, bare tip length, and electrolyte composition is proposed.

$$\left\{\frac{(r_1 + g)^2}{2} ln \frac{(r_1 + g)}{r_1} - [0.25((r_1 + g)^2 - {r_1}^2)]\right\} = \frac{EVk_e t}{F\rho_a}$$

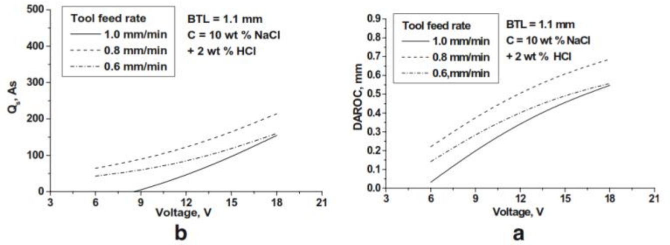
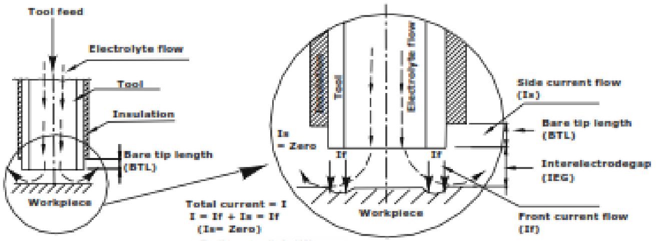
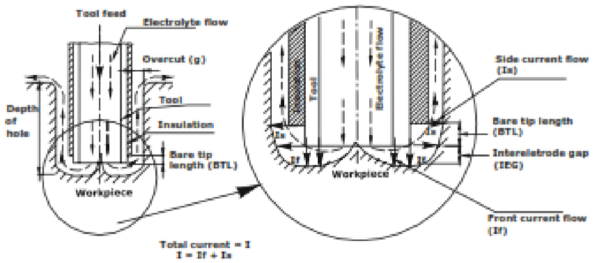


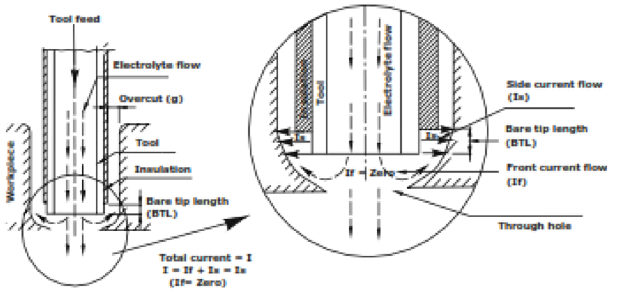
Figure 3. Comparison of the Q and experimentally measured DAROC as a function of voltage and tool feed rates[18].



a Start of drilling



b Hole depth > bare tip length



c Hole puncture

Figure 4. Electrolyte and current flow during different stages of STEM [18]

The work piece and tool are anode and cathode respectively, separated by an electrolyte [1], [24]–[28], [33]. When an electric current of high density and low voltage is passed through the electrolyte, the anode work piece dissolves locally. So the final shape of the generated work piece is approximately a negative mirror image of the tool. These results are embodied in Faraday's two laws of electrolysis:

- The amount of any substance dissolved or deposited is directly proportional to the amount of current passing through an electrolyte.
- The amount of different substances deposited or dissolved by the same quantity of current are proportional to their chemical equivalent weights.

The electrolyte, which is generally a salt solution flows through the Inter Electrode Gap (IEG) with high velocity to intensify the mass and charge transfer through the sub layer near anode and to remove the sludge, heat and gas bubbles generated in the gap. Machining performance in

ECM is governed by the anodic behavior of the work piece material in a given electrolyte. The salt is not consumed in the electro chemical processes; therefore, for keeping constant concentration of electrolyte, it is necessary to add water. With this metal-electrolyte combination, electrolysis has involved the dissolution of metal from the anode, and the generation of hydrogen at the cathode. In typical manufacturing operations, tool is fed towards the work piece while maintaining a small gap[21], [34]–[37].

The ECM techniques allow to accomplish some difficult machining operations (complex shaping, boring, turning, milling, polishing, etc.), without a direct contact between the tool and the workpiece, with high stock removal rates, regardless of the mechanical properties of the workpiece. Although conventional drilling of circular holes is the most common manufacturing process today, it is estimated on the basis of limited surveys that 5% of all holes are produced by non-traditional techniques. These 5% includes most of the more difficult, deep holes in the more difficult to machine materials.

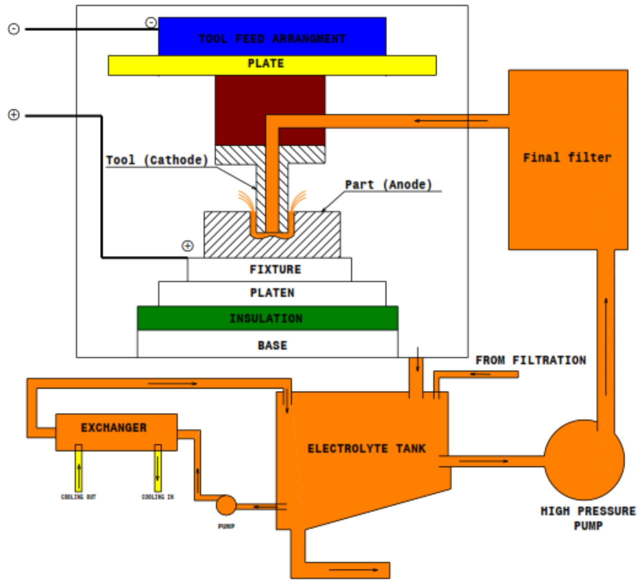


Figure 5. Electrochemical Machining (Shaped tube electrolytic machining -STEM).

- Material dissolves, atom by atom, from anode workpiece (positive pole).
- Flow of electrolyte removes the sludge and reaction products produced during the process.
- Electrode materials: Cu, brass, or stainless steel.
- Literature survey shows that STEM is extensively utilized for drilling cooling holes in turbine blades [13], [18], [38].

3. Advantages of ECM Process

ECM offers numerous advantages over other advanced machining processes (AMP's). These advantages have made ECM the best choice for a variety of applications[1], [5], [29], [30], [39]–[42], [15], [20], [21], [24]–[28][43], [44].

- Hard materials can be easily machined irrespective of their hardness.
- Burr free product.
- No direct contact of tool and workpiece.
- The product is without thermal or physical stress.
- Upper-layer deformation is absent in the product.
- 3-D processing in single step.
- High surface quality level achievable depending on material.
- High dimensional accuracy achievable.
- No local rust formation on the surface of the workpiece.
- Gives more freedom to designer to design a product.
- High machining speed at low costs.
- Tooling and running cost is low.
- The hardness, toughness and thermal resistance has no effect.
- MRR is comparatively high.
- MRR is almost independent on the material type.
- Speed for machining of Hard and tough alloys is same.
- Electrolyte can be reused.
- The produced sludge can often be recycled, depending on composition and hence environmentally acceptable.
- No possibilities of work distortion; holes in very thin sheet metals can be cut without stressing or distorting them.
- Components or jobs with very small wall thickness can be machined easily (e.g. A honey comb structure of 0.025 mm wall thickness in stainless steel material can be machined easily).
- Work materials suffer no metallurgical changes and are free from surface and sub-surface cracks.
- No tool wear occurs and the same tool can be used for any number of components or impressions.
- Unlike conventional machining method, components can be machined after heat-treatment thus eliminating the distortion and errors that may be introduced due to heat treatment.
- Surface finish produced is better on many materials eliminating operations like lapping.
- Complex shapes can be produced in one operation eliminating a sequence of processes like milling, grinding, deburring etc.
- High rate of metal removal, which becomes particularly evident when very hard materials are being machining. The time required for completing a job by ECM is sometimes very short compared which the conventional methods.
- No problem of disposal of chips as in conventional machining.
- Components machining by ECM method have better wear, friction and corrosion resistant properties.
- By using suitable transfer mechanisms, ECM can be automated for mass production.

4. Conclusion

In spite of various advantages, ECM has few challenges. The process cannot be used for non – conducting materials such as plastics and ceramics. It also has a few other challenges as follows.

- Every new product and design require new research for optimization.

- Higher production numbers are needed, as a special electrode must be designed for each product.
- Difficulty in designing a proper tooling system.
- Design of cathode tool is complicated and exclusive, it can however be used for difficult-to-machine materials cost effectively.
- The equipment required is relatively costly.
- Problems encountered in its use are not yet fully familiar to those more accustomed to conventional metal working processes.
- The process is not economical for small quantity productions of dies and work pieces.
- Specific power consumption is high.
- Tooling costs are relatively high.
- The design and manufacturing of tool electrode is very difficult and time consuming.
- If the feeding of the tool is stopped abruptly, due to the stagnation of the electrolyte, a small pip is left on the work piece.

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