CFD Analysis of L-Shaped ECM Tool

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Abstract:
In electrochemical machining, due to improper tool design of complicated shapes, there are chances of passivation of electrolyte that cause poor machining. Predicting the flow pattern is also important to prevent boiling tendency of electrolyte is due to overheating of electrolyte. This research work is an endeavour to optimise the design of L-shaped tool and to study the flow pattern, current density distribution, velocity profile and temperature pattern by CFD analysis using ANSYS-CFX software. The model is simulated with various inlet velocities and the major findings are: the maximum temperature of electrolyte in inter electrode gap decreases with increase in inlet velocity. The current density and material removal rate has increasing tendency with respect to increase in inlet velocity. The tendency of passivation decreases with increasing inlet velocity.

Keywords: CFD; ECM; flow pattern; IEG; MRR; passivation; temperature profile

1. Introduction

In case of complicated shapes of workpiece, it is very difficult to know the machining variables within the Inter Electrode Gap (IEG) while machining in ECM. Passivation is one of the major difficulties in ECM process in the case of complicated tool shapes. There is an uttermost need to understand these parameters and visualize the flow pattern to avoid passivation. This is the main motivation behind this work. Also, the temperature variation of the electrolyte in IEG has immense bearing on MRR in ECM. Thorpe and Zerkle [1] discussed about the effect of void fraction and temperature variation of the electrolyte, it limited to one dimensional flow. Prediction of shape in ECM depends up on current density. Variation in current density depends up on the change in inter electrode gap. Kozak et al. [2] discussed about the computer simulation electrochemical shaping using a universal tool electrode; its application is limited in flexible manufacturing system. Wang et al. [3] used ANSYS-CFX for 3-D modelling of thermo-fluid and electrochemical for planar SOFC. ECM is a nonlinear and complex process so it is very difficult to develop a mathematical model. Kozak [4] proposed a mathematical model for computer simulation of electrochemical machining process. In this paper the physical and mathematical model based on simulation module are presented. Most recent development in this area is Boundary Element Method (BEM) method where computational domains are boundary surface. Purcar et al. [5] developed BEM software to model 3D ECM process and they predicted the workpiece shape by trial and error method. Pattavanitch et al. [6] discussed about modelling of the electro- chemical machining process by the boundary element method. Dabrowski and Paczkowski [7] published paper related to the two dimensional electrolyte flows in ECM. They used vibrating type tool for machining. They found out that the usage of vibrating tool helped to increase accuracy and stability of machining. During machining the IEG alter from minimum to maximum according to the current density. The physical phenomena in IEG are described by using differential equation and partial derivatives. Ratkovich et al. [8] analyses the evolution of nitrogen gas and the ways to minimise the fouling effects using CFD analysis in a tubular membrane.

Many of the researchers presented experimental and analytical studies about material removal mechanism and current density distribution in ECM using different tool shapes and different software, but they couldn‘t predict the flow pattern accurately. In case of complicated shapes of workpieces, it‘s very difficult to know the machining variables within the IEG. So there is a need to understand about the parameters related to flow pattern. Once the flow pattern is known, then it‘s easy to design the tool and avoid passivation. The salient objectives of the present study have been identified as follows: To optimize the design of L-shaped tool and study the flow pattern among four different tool design. Secondly, to evaluate the above tool models for efficient machining and determining minimum inlet velocity to avoid boiling of electrolyte.

2. Modelling and Analysis

In the present simulation, a tool designs are considered for Computational Fluid Dynamics (CFD) analysis. The modelling is done with ANSYS Design Modeller and the model is an L shaped tool having a central hole connected to an intermediate chamber and grooves without sharp corners (Figure 1). The tool is having the foot print of 30x15mm length. There is an inlet hole of diameter 3mm on the tool for electrolyte flow. Electrolyte starts flowing from the inlet, passes through IEG and comes out sideways between the tool and work piece. Electrolyte used for this simulation is 20% brine solution. A cylindrical mild steel work piece is used for all models with 60mm diameter and 20mm height.

The models are meshed using ANSYS Mesh module and patch independent meshing method is adopted. The number of nodes generated is 344130 for the model and are shown in Figure 2. The quality of mesh is relevant for accurate results and with orthogonal quality approaching unity, yields better results (ANSYS team [9]). These models have orthogonal quality more than 0.98 for tetrahedral elements, which are used for meshing these geometries and the elements are have a minimum edge length 5×10^{-4} m.

4. Analysis

This analysis is done with ANSYS-CFX software as a steady state problem. The assumptions made are

1. The inter electrode gap is constant.
2. Material property of the tool and workpiece never change throughout the analysis.
3. Tool and workpiece material are homogeneous.
4. Heat generation is due to Joule‘s heating.
5. The electrolyte is in liquid state and no H_2 gas is evolved.
6. Material removal only depends on current density.

4.1. Boundary Conditions

The computational domains are specified earlier. In this simulation, two solid and a fluid domains are used. The workpiece and tool are the two solid domains that are considered as pure continuous solids. Mild steel is used as workpiece material with valancy = 2. Electric potential model with automatic value is selected from Electromagnetic model. The potential difference between tool and workpiece is 10V for anodic dissolution. The reference temperature is assumed as 300K and the heat transfer is through Conjugate Heat Transfer (CHT). Boundary conditions used for these simulations are given as follows. Fluid domain is constructed for electrolyte and morphology for fluid domain is taken as continuous fluid. The inlet flow is in subsonic regime and all these models are analysed with three different inlet velocities, v= 36 m/s, 43m/s and 48 m/s. These velocities are chosen to maintain the minimum flow rate of 15 to 20 L/min to avoid passivation. The outlet pressure is 3MPa and the direction is normal to the exit boundary. The turbulence of fractional intensity = 0.06 and auto computation length is assumed. The temperature depended conductivity of electrolyte is assumed as shown by Equation 1 whereas all the other properties are kept constant. This equation is written as CEL expression and directly assigned it as material property. The coefficient of electrical conductivity of electrolyte, κ is taken as 0.02 and boiling temperature as 373K.

$$\kappa = \kappa_0(1 + \alpha(T_0 - T)) \qquad (1)$$

Where κ_0 = the conductivity of electrolyte at room temperature T_0, α = coefficient of electrical conductivity of electrolyte, and T = node temperature. The convection heat transfer coefficient = 100W/m^2K is used for electrolyte-air. The same between electrodes and electrolyte is 1000 W/m^2K. Material properties used for this simulation are available in McCleskey et al. [10].

General Grid Interface (GGI) type mesh connection is used to connect meshes at the interfaces of brine Brine - Tool and Brine - Workpiece. After imposing the boundary conditions, the solver control parameters are setup. For advection and turbulence high resolution is enabled. The minimum iteration of one step was enforced with a limit of maximum of 600 steps while simulation. Fluid time scale control is set as physical time scale with 0.1s. Root Mean Square (RMS) value of 10^{-5} is set as convergence criteria and run mode selected is HP MPI distributed parallel.

5. Results and Discussions

5.1. Velocity profile

Figure 3 is the velocity profile within the IEG of the model obtained for the stimulation. In the figure, the velocity is approximately 30 m/s near the central through hole and the surrounding of the central through hole has a small variation of velocity due to stagnation. The incoming electrolyte enters IEG with high velocity, first makes contact with the workpiece, where it releases most of the kinetic energy. This region is called stagnation region and the velocity is called stagnation velocity. After that, the velocity is decreasing smoothly, but it is less than 5m/s in some region towards the tip of the tool (shown in Figure 3 with blue colour). According to ECM theory, passivation occurs due to deposition of sludge on the workpiece and tool surfaces because of insufficiency flow of electrolyte within the IEG. If velocity less than 5m/s, then it is more likely to the surface will passivate and prevent further machining (Ghosh and Mallik [11]). It can be easily understood that the velocity variation is smooth and a very small region is having velocity less than 5 m/s. Here stagnation effect is less because first the electrolyte entering in to a small chamber and then it coming out through the grooves.

5.2. Temperature Distribution

Figure 4 is the temperature distribution in the IEG with an inlet velocity of 36 m/s. The conductivity of the electrolyte reduces with increase in temperature in IEG. Since, the boiling point of brine solution is 373K, if temperature at any point goes beyond this limit, the electrolyte start to boil. This effect is more pronounce near the edges of the tool in the direction of the flow. In the model, the temperature variation is very much less, which is because of good flow pattern and uniform current density distribution. Maximum temperature obtained in this model is 315K. So here there is no chance of electrolyte boiling.

5.2.1. Influence of inlet velocity on maximum temperature

The maximum temperature of the electrolyte for various the inlet velocities are plotted in Figure 5 that shows the temperature decreases gradually from 315K to 312K then to 311K. Here, the flow is smooth and turbulence also less, hence the variations in the maximum temperature is less. The threshold inlet velocity required to prevent the electrolyte from boiling depends on the tool design. It can understand that the maximum temperature in model is much less than the boiling temperature (373K).

5.3. Current density distribution

In ECM process, the current density distribution is having immense importance because MRR is purely depended on the current density within the IEG and Figure 6 depicts that for inlet velocity 36 m/s. The Current density distribution in the workpiece is uniform throughout the tool foot print area. The reason being better the velocity profile that having no passivation and there is no eddy formation, as well as turbulence is much less for the tool design, resulting in less temperature variation in the IEG .

5.4. Influence on MRR

Figure 7 is the graph plotted MRR against inlet velocity for various models. From the graph it is understood that MRR slightly increases with inlet velocity because with uniformity and higher current density more metal can be dissolved. MRR is increasing from $0.0319\times10^{-6}\text{m}^3/\text{s}$ to $0.0327\times10^{-6}\text{m}^3/\text{s}$ and finally to $0.0333\times10^{-6}\text{m}^3/\text{s}$.

6. Conclusion

The present study is an attempt to visualises the velocity profile, current density and temperature variation in the inter electrode gap in ECM for an L-shaped tool design. The material removal can be estimate by CFD analysis. The tendency of passivation is decreasing with increasing inlet velocity. The maximum temperature in IEG has a decreasing tendency with respect to the increase in inlet velocity. The current density has increasing tendency with respect to increase in inlet velocities. The results show that higher current density, hence, it has higher MRR. The CFD evaluation method can be helpful to the tool designers to design more complicated tools with better efficiency.

7. References

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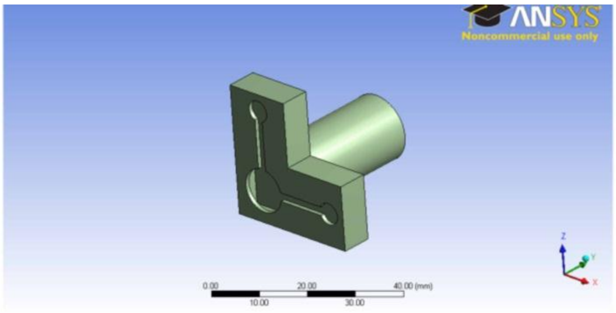

Figure 1 Tool bottom view

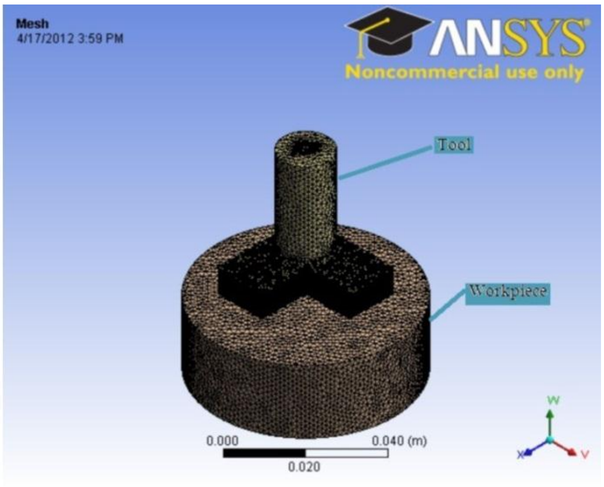

Figure 2 Meshing of the model

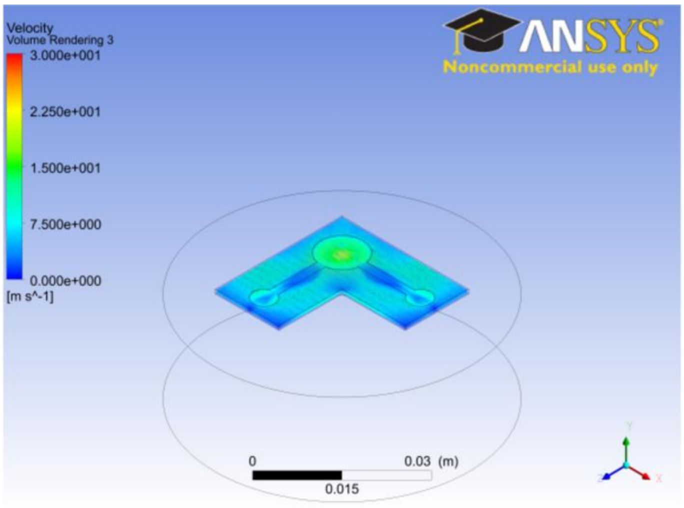

Figure 3 Velocity profile in IEG

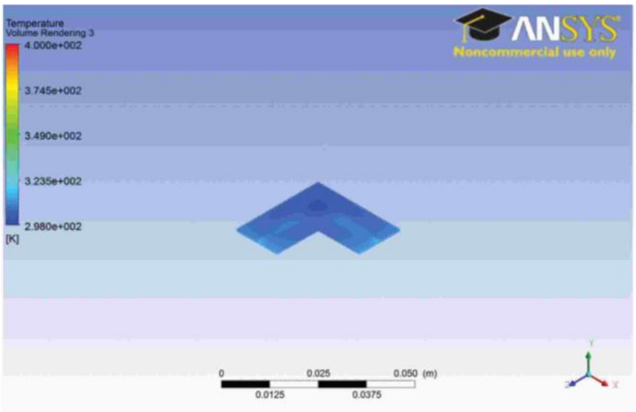

Figure 4 Temperature profile in IEG

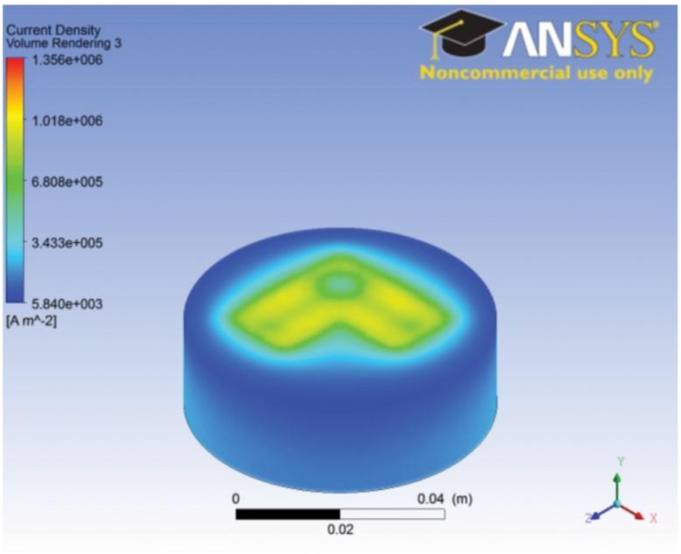

Figure 5 Current density on the work piece

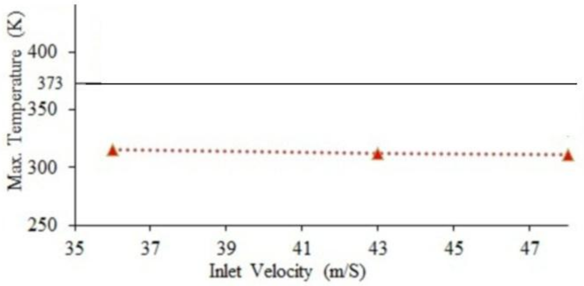

Figure 6 Variation of maximum temperature with inlet velocity

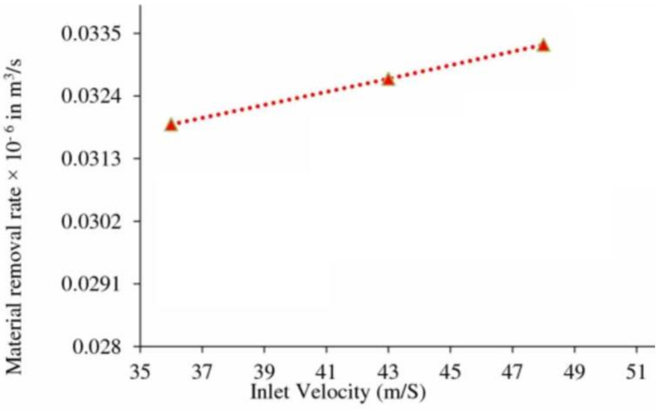

Figure 7 MRR vrs inlet velocity