Anodic Dissolution Model Parameterization for Pulsed Electrochemical Machining Coupled with a Magnetic Field

C. Bradley

U.S. Army RDECOM-ARDEC, Benét Laboratories, Watervliet, NY 12189, USA

INTRODUCTION: Magnetically assisted pulsed electrochemical machining (PECM) extends the capabilities of traditional ECM for tungsten carbide and super alloys. Magnetic fields can increase the material removal rate (MRR), but also complicates material removal prediction [1].

	Value	Units
Anode	7075	Al
Electrolyte	$NaNO_3$	20%
IEG	110	μm
B-Field	370	mT
E-Field Frequency	4	kHz

Table 1. PECM Conditions

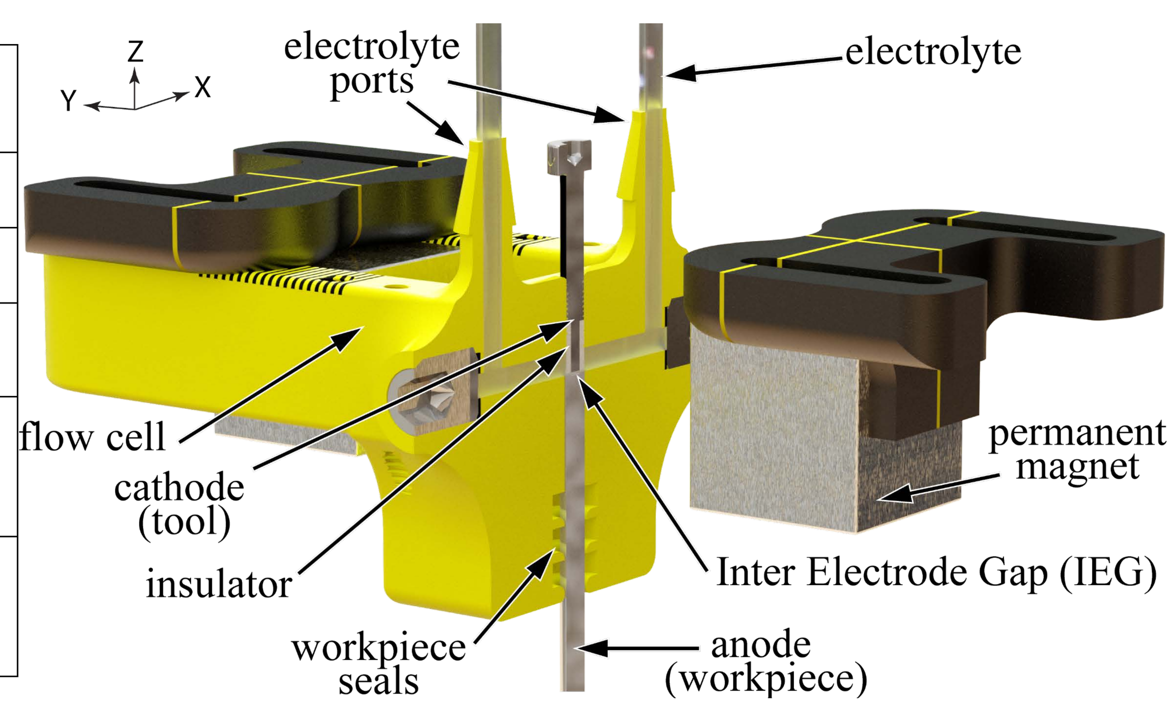

Figure 1. PECM Flow Cell w/ Magnets

Bipolar current pulses occurring on a small time scale determine the anodic dissolution (AD) rate that defines the geometry on a much larger total machining time scale. Parameters that capture machining performance are necessary to bridge these time scales to allow prediction.

COMPUTATIONAL METHODS: The concentration-dependent current distribution has upper and lower current limits and is solved simultaneously with mesh deformation which simulates AD using the arbitrary Lagrangian-Eulerian (ALE) method. Additionally, the convection-diffusion equation is solved for the transport of dissolved metal ions which limits the current distribution. A sweep of surface current limits was simulated to asses parameterization. Average pulse conductivity (Y_{ave}) and Faraday efficiency (θ) were chosen to parameterize magnetically assisted PECM machining as ECM in the simulation.

$$\frac{\partial c}{\partial t} = \nabla\cdot(D\nabla c) - \mathbf{u}\cdot\nabla c + \frac{\theta m}{M_{\mathrm{eqv}}}\,\mathrm{dt}$$

The deformed mesh from the COMSOL 5.2™ simulation is shown in Fig. 2.

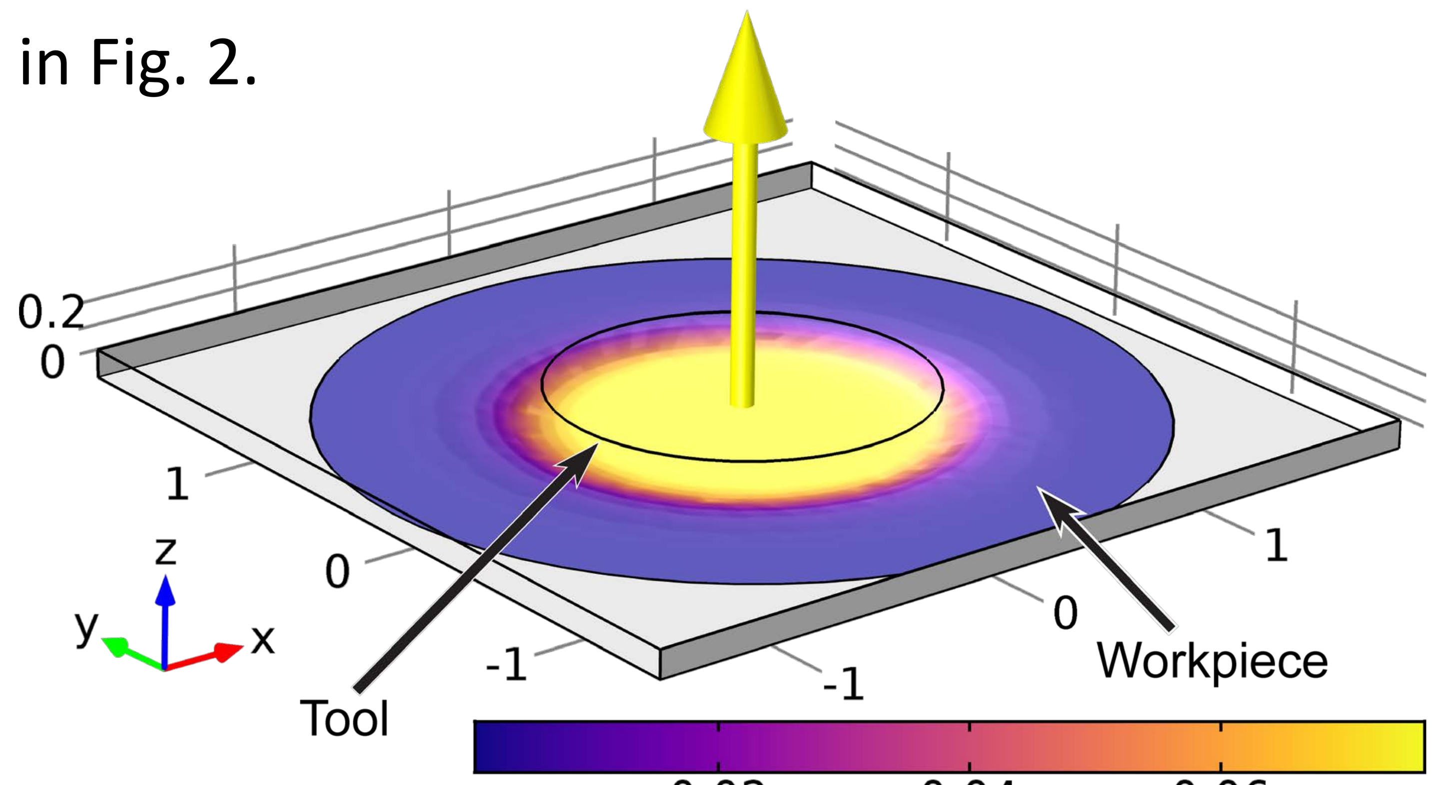

Figure 2. Workpiece current density, ***i**, with arrow indicating current flow*

This parameterization is defined by Faraday's Laws and total charge and is computationally efficient as compared to simulating each pulse over a large time scale.

$$m = \theta\left(\frac{Q}{F}\right)\left(\frac{M_{\mathrm{eqv}}}{z_{\mathrm{eqv}}}\right)\quad,\quad Q = \int_0^{t_{\mathrm{final}}} Y_{\mathrm{ave}}\cdot V\,\mathrm{dt}$$

RESULTS: The machined hole was captured using a structured light surface scanner. The total volume error for the two experiments had a mean of *4%* regardless of current limit. This indicates the volume and MRR are well parameterized by the Y_{ave} and θ. Separately, the alpha shape combines the simulated hole from Fig. 3 and experimental hole scan in Fig. 4. The alpha shape represents the XOR of the holes, the volume of this alpha shape is shown in Fig. 5. When the XOR volume is divided by the total scanned hole volume it is a robust measure that quantifies morphological simulation error, shown in Fig. 6 [2]. The best 1σ error in Fig. 6 is at a surface current limit of 0.08 A/mm^2.

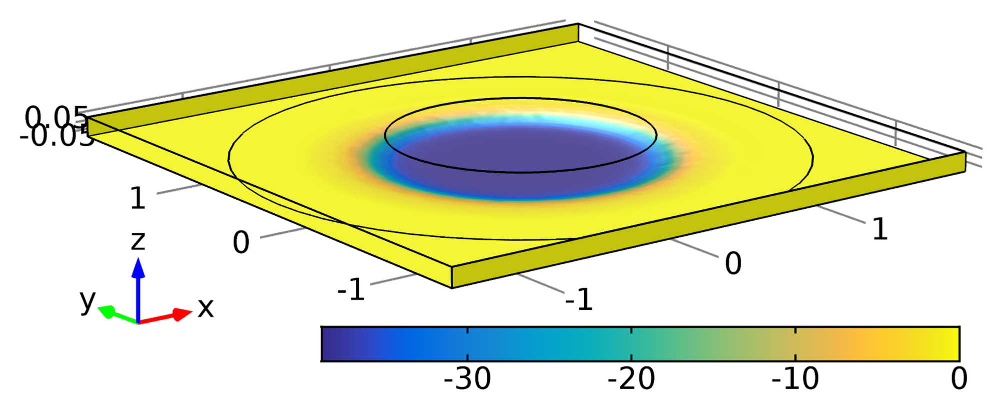

Figure 3. Displacement surface of simulation

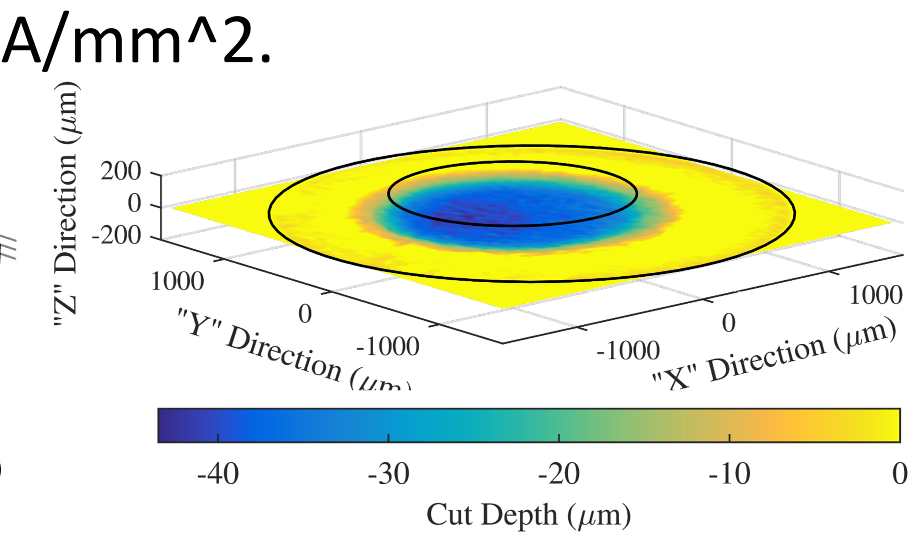

Figure 4. Surface scan from experiment

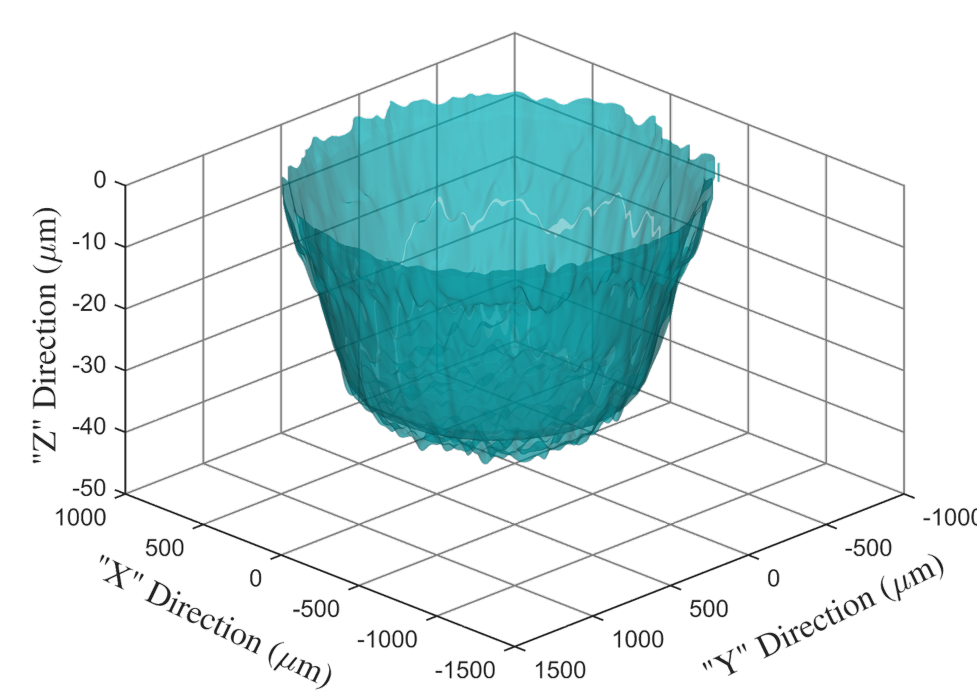

Figure 5. XOR of simulation and experimental holes at *i* limit 0.08 A/mm^2

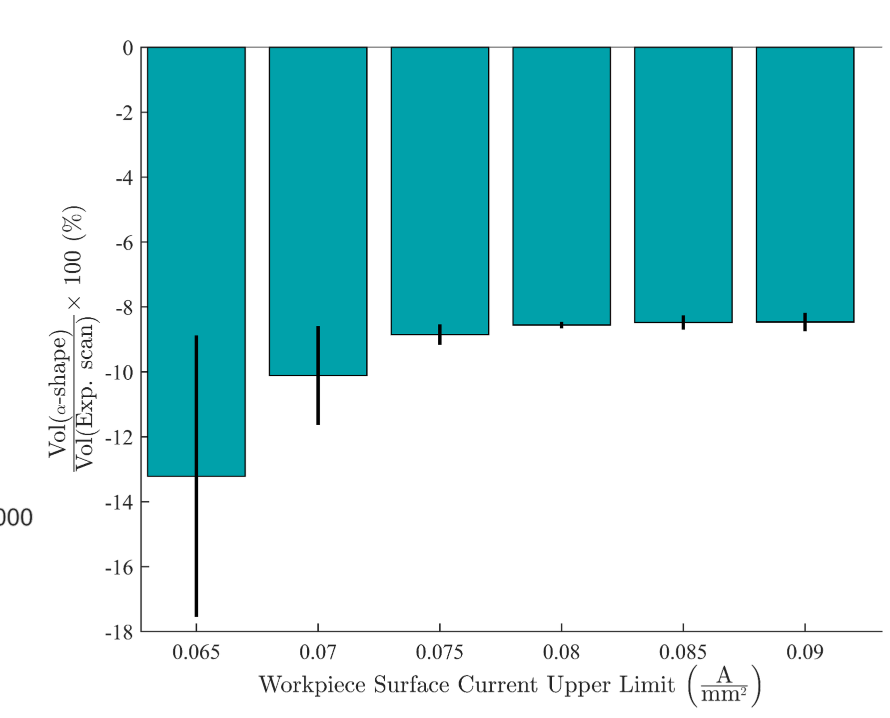

Figure 6. XOR volume error versus current limit, 1σ bars

The total volume was near constant, independent of the current limit, whereas the morphology is highly affected by the current limit, seen in Fig. 6.

CONCLUSIONS: By parameterizing machining performance the total volume and MRR could be accurately simulated from a measured Y_{ave} and θ. However, the morphology requires additional measures to parameterize the machining conditions including the current limit and possibly other parameters. The machining environment parameters of magnetic field flux density and PECM current frequency interact in a complex manner that is difficult to predict, but MRR is characterized using Y_{ave} and θ. This parameterization has the potential to simplify navigating and optimizing within the complex parameter space of magnetically assisted PECM.

REFERENCES:

1. Yin, Liang, et al., "Study of electrochemical finishing with magnetic field and high-frequency group pulse.", 2010 International Conference on Digital Manufacturing and Automation, 2, (2010)
2. Jiang, Xiangqian, et al., "Morphological method for surface metrology and dimensional metrology based on the alpha shape.", Measurement science and technology, 23.1, 015003, (2012)