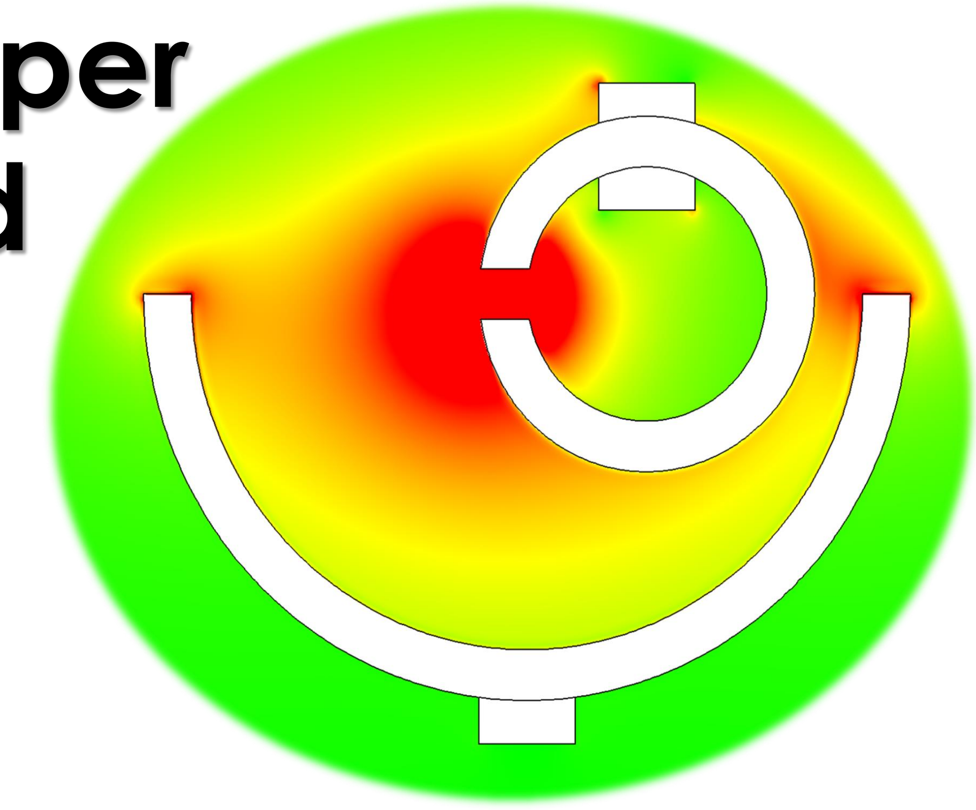
Electro-Chemical Etching & Deposition of a Super Alloy Using Tertiary Current Distribution Method

M Yeoman[1], R Damodharan[1]
1. Continuum Blue Ltd., Tredomen Innovation & Technology Park, CF82 7FQ, United Kingdom.



INTRODUCTION

The application of super-alloys has grown in numbers in many industries. The initial cost of prototyping & the selection of suitable manufacturing methods & test fixtures made by electrochemical machining (ECM) have proved to be expensive process, especially where tolerances are extremely tight on the nanometer scale. In this study, we will look at the development of a mathematical model to simulate Electrochemical Etching of a super-alloy by considering its major material constituents, using the tertiary current distribution.

AIM

The aim of this study was to develop a Electro-Chemical Etching process of a super alloy using tertiary current distribution method by considering major material constituents of Waspaloy® alloy and system optimisation

Figure 1. Model setup showing the electrodes and connector positions in the system

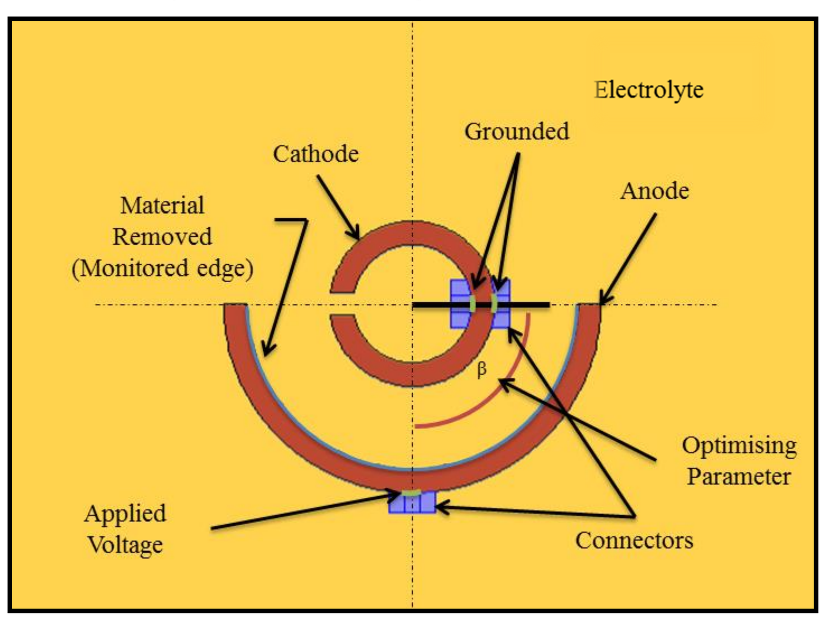


Table 1. Elemental composition of Waspaloy® [3]

Element	% Composition
Cr	21
Ni	51.58
Mo	5
Co	15
Al	1.6
Ti	3.25
B	0.01
C	0.1
Zr	0.08
Fe	2
Mn	0.1
Si	0.15
Cu	0.1

Equations 1. The chemical reactions at anode & cathode

Anode	Cathode
$Cr = Cr^{2+} + 2e^-$	$Cr^{2+} + 2e^- = Cr$
$Ni = Ni^{2+} + 2e^-$	$Ni^{2+} + 2e^- = Ni$

Equations 2. Nernst-Planck equation, current density and electroneutrality equation

Nernst-Plank equation

$$N_i = -D_i \nabla c_i - z_i u_i F c_i \nabla \emptyset_i + c_i u$$

Current density

$$i_i = F \sum_{i=1}^{n} z_i N_i$$

Electroneutrality condition

$$\sum_i z_i c_i = 0$$

Where,
c_i Concentration in the electrolyte of i^{th} species (mol·m^{-3}),
D_i Diffusion coefficient of i^{th} species (m^2/s),
z_i Ionic charge of i^{th} species,
u_i Ionic Mobility of i^{th} species (m^2·s^{-1}·J^{-1}·mol^{-1}),
F Faraday's constant (A·s·mol^{-1}),
$\emptyset_i$ Electric Potential (V)

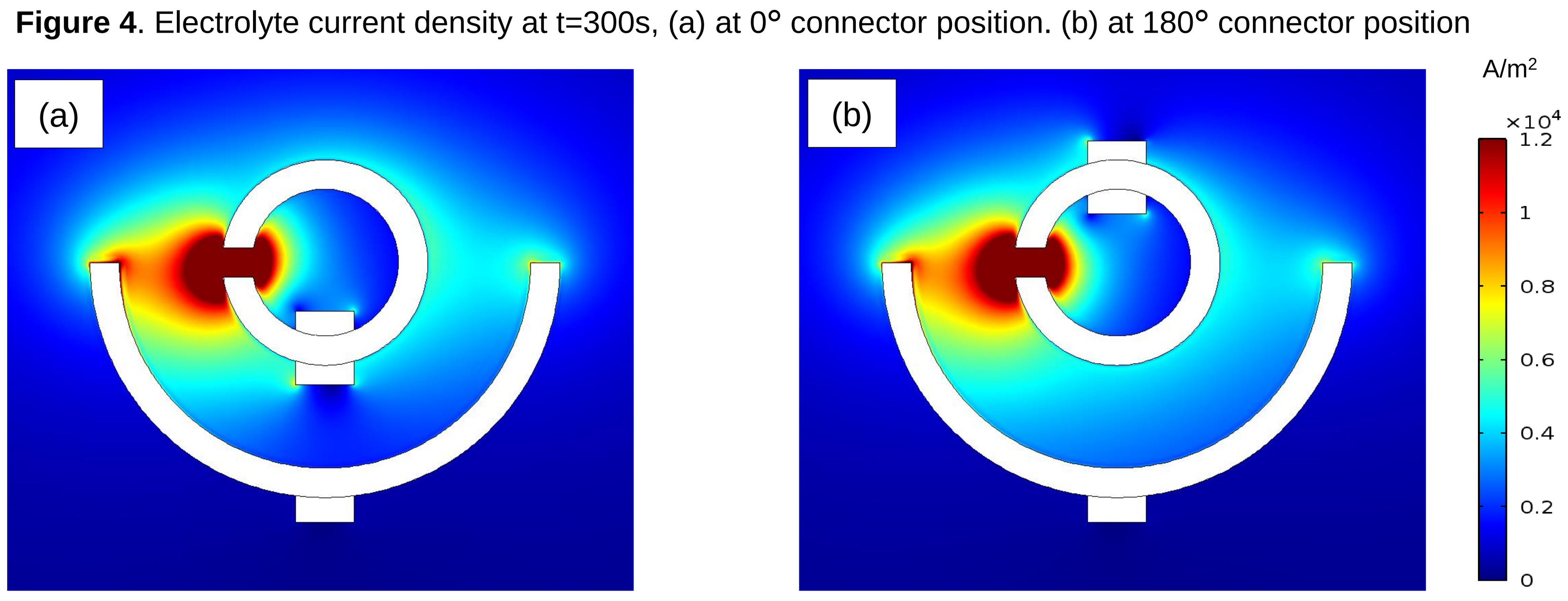
Equations 3. Electrode current density

$$i_{loc} = i_{io}\left(C_R e^{\left(\frac{\alpha_a F \eta}{RT}\right)} - C_O e^{\left(\frac{\alpha_c F \eta}{RT}\right)}\right)$$

Where,

i_o Exchange current density of the species,
α_a Anodic transfer coefficient,
α_c Cathodic transfer coefficient,
C_R Reduced species expression,
C_o Oxidized species expression,
R Universal Gas constant,
T Operating Temperature,
F Faraday constant,
η (E-E$_{eq}$), activation overpotential,
E$_{eq}$ Equilibrium (REDOX) potential for the given species,

Figure 4. Electrolyte current density at t=300s, (a) at 0° connector position. (b) at 180° connector position



METHOD

The Waspaloy® alloy was used in the current study to model Electro-Chemical Etching process. The major two constituent of Waspaloy® alloy, Chromium(29%) & Nickel(71%) were considered for modelling. Tertiary current method under Electrodeposition module in COMSOL was used to model Electro-Chemical Etching process. Tertiary current method accounts for the effect of variation in solution resistance, electrode kinetics and electrolyte compositions. The effect due to evolution of hydrogen gas on the surface of cathode and parasitic equations is not taken into account in the current study. Nernst-Plank equation was used for modelling current density, which accounts for diffusion, migration and convection to calculate the flux of the ion species participating in the electrochemical cell, with further assumption of electroneutrality condition is valid within the electrolyte. The model was ran for 300 seconds and the data's were evaluated.

References:
1 G.E. Benedict, Nontraditional Manufacturing Processes, Marcel Dekker, 1987
2 R. van Tijum & T. Pajak, The Multiphysics Approach: The Electrochemical Machining Process, COMSOL Conference Hanover (2008)
3. www.rolledalloys.com/alloys/cobalt-alloys /waspaloy/en/
4. COMSOL Multiphysics®, Electrodeposition Module Physics Interface Guide Version 4.4, COMSOL AB (2013)

RESULTS

Results obtained from COMSOL simulation shows the effect of connector and cathode position on current density and on material removal from anode. Figures 2, 3 & 4 shows the effect of connector positon on anodic dissolution distribution on the selected surface. Figures 5, 6 & 7, shows the effect due to change in the cathode position. Even anodic dissolution distribution is observed when cathode is offset position and lies in between 10mm & 15mm.

Figure 2. Anodic dissolution data along the Arc length for different cathode connector position (at 300s)

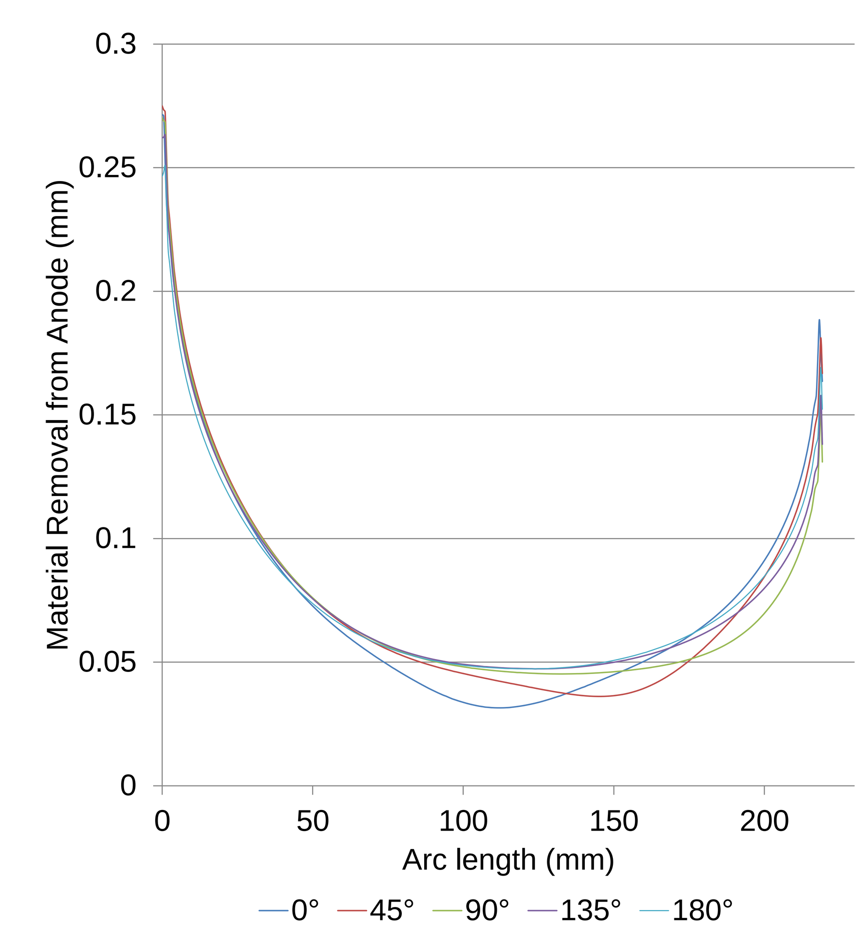


Figure 3. Maximum, minimum & average anodic dissolution data at different cathode connector position (at 300s)

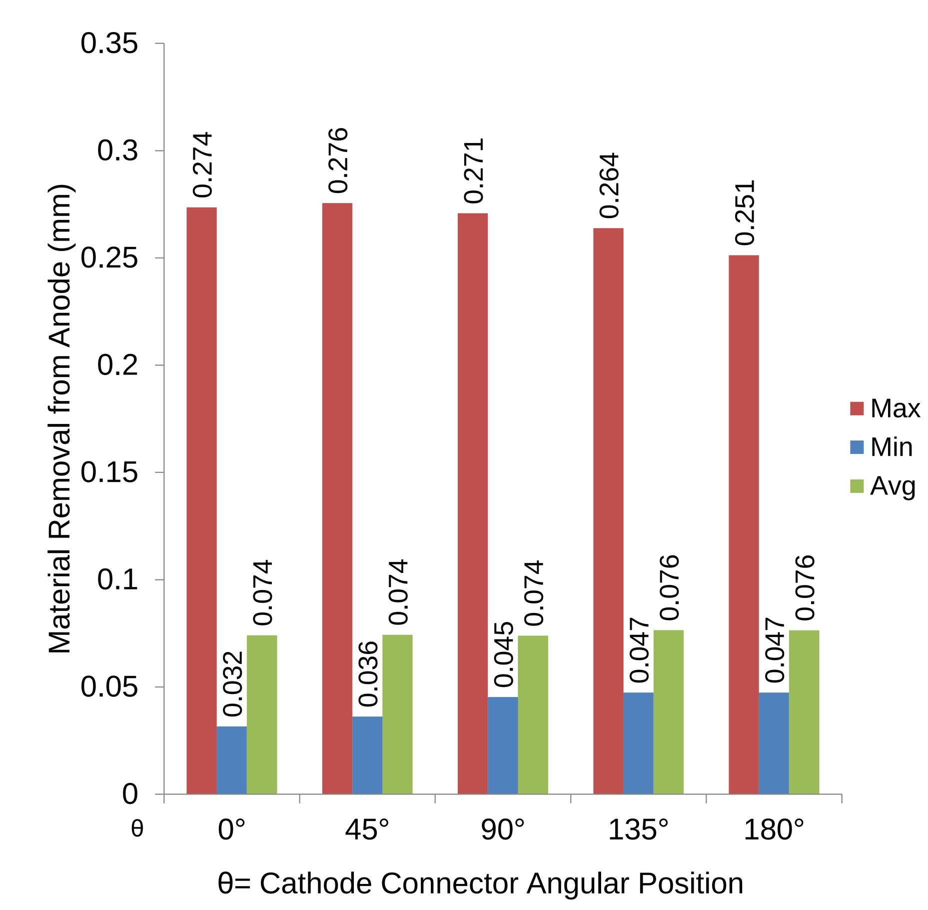


Figure 5. Anodic dissolution data along the arc length at different cathode position (at 300s)

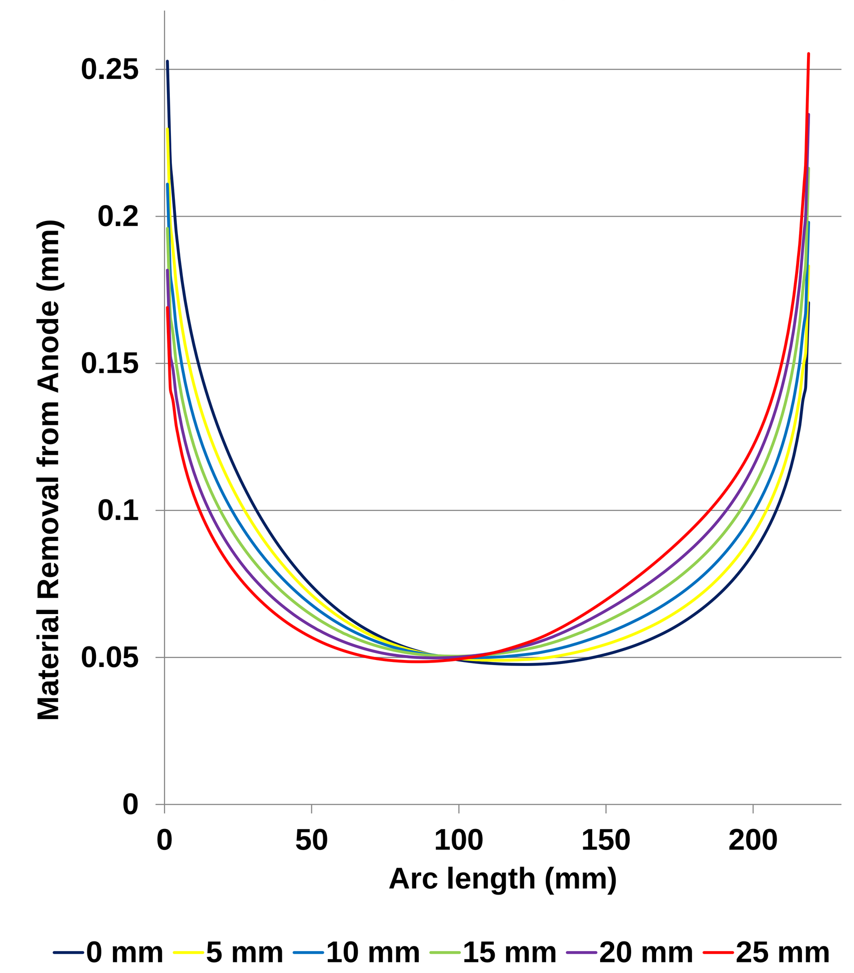


Figure 6. Maximum, minimum & average anodic dissolution data at different cathode position (at 300s)

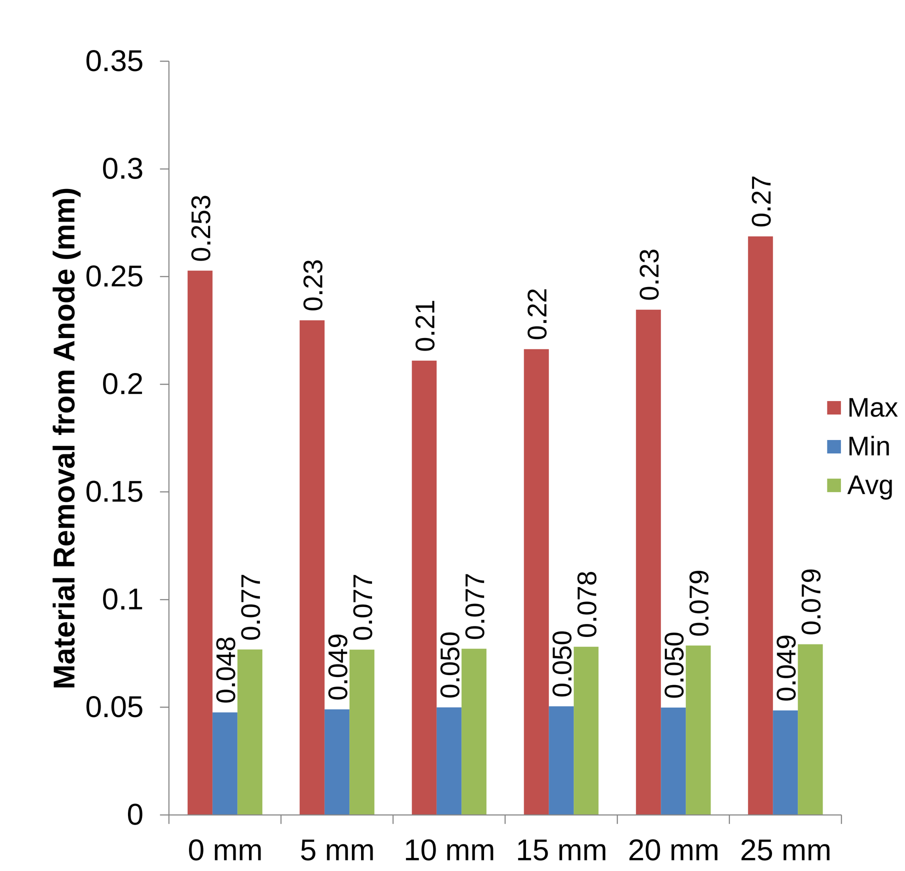
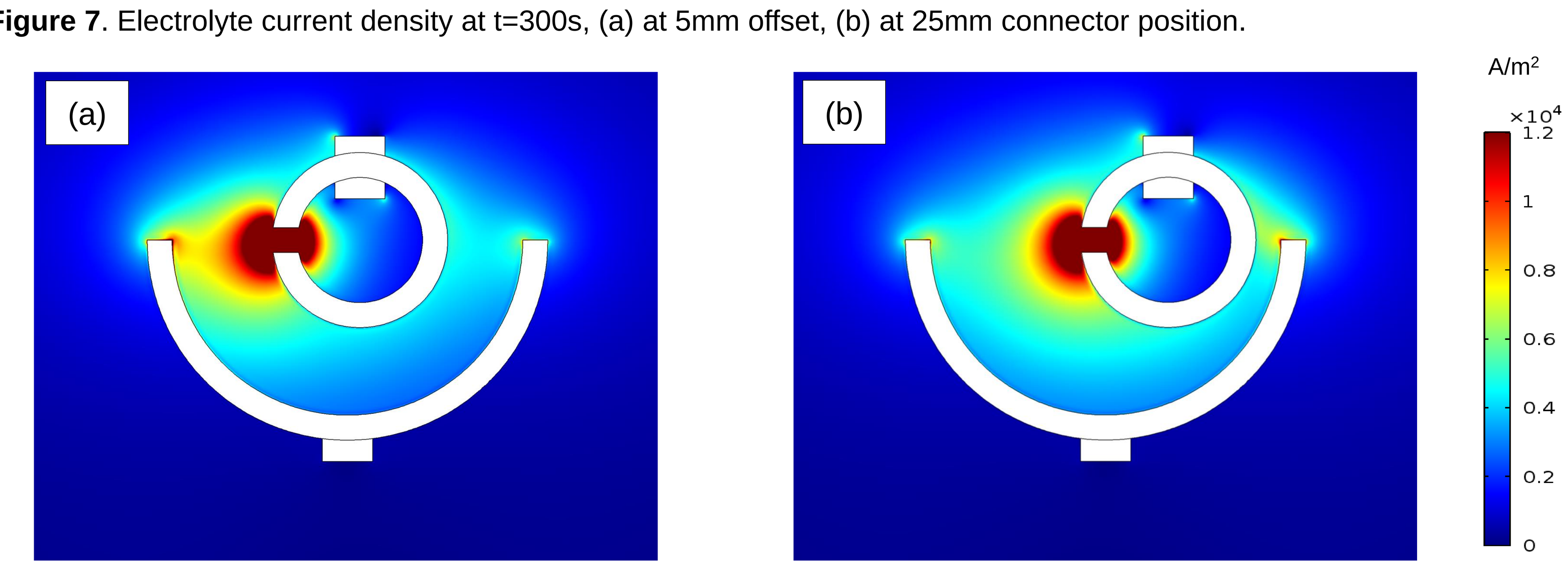


Figure 7. Electrolyte current density at t=300s, (a) at 5mm offset, (b) at 25mm connector position.



DISCUSSION & CONCLUSION

In the current paper, we have discussed about modelling of a super alloy Electrochemical Etching process using COMSOL and system optimisation. Studying of a such Multiphysics system can help in great extent to understand effect of process and model parameters. The future work involves model verification against physical test data. Furthermore, development of Multiphysics model in conjunction with fluid flow, mixing of electrolyte of varying concentrations, effect of temperature on the Electrochemical reactions and modelling the effect of H_2 gas evolution at cathode shall be conducted.

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