MAE- 503- Finite Elements in Engineering

Project-2 Report

Instructor- Prof. Jay Oswald

Team Member	Course	ASURITE
Abhijit Prekash	MAE 503	aprekash
Sherry Daniel Sajan	MAE 503	snola139
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Questions:

1. Definitions of the key element matrices:

a) Element electrical conductivity matrix-

Element Electrical Conductivity Matrix (K_E) is a matrix derived from the strong form for the electric problem and represents how electrical conductivity is distributed within each element of the material. It's influenced by electrical resistivity (ρ) and can be obtained by integrating over the element volume with respect to spatial coordinates.

$K_E^e = \int_{\Omega^e} (B^e)^T \sigma B^e d\Omega$ (ohm-mm)

where:

Ω^e- Element domain

σ-Electrical conductivity of material

B^e- Derivates of shape functions contained in strain displacement matrix

K_E^e- Electrical conductivity matrix of element

b) Element thermal conductivity matrix-

Element thermal conductivity matrix (K_T) is derived from the strong form for the heat problem and this matrix represents how heat is conducted within each element. It depends on thermal conductivity (κ) and is obtained similarly by integrating over the element volume. In the context of the welded joint, it helps us understand how heat is transferred through the material.

$K_T = \int_{\Omega^e} (B^e)^T K B^e d\Omega$ W/(mm- $°C$)

Where:

Ω^e- Element domain

K- Thermal conductivity of material

B^e- Derivates of shape functions contained in strain displacement matrix

K_T^e- Thermal conductivity matrix of element

c) Element nodal heat flux from Joule heating-

Element Nodal Heat Flux from Joule Heating (f_e) represents heat generated due to resistance to electric current flow within each element. In the welded joint, this heat generation contributes to the temperature rise.

$f_e = \int_{\Omega^e} (N^e)^T J^T E$ (J/mm^3)

Where:

Ω^e- Element domain

E- Electric Field Vector

J- Current density Vector

N^e- Shape function matrix

f_e – Nodal heat flux vector through Joule heating

d) Element Nodal electric current flux from natural boundary condition

Element Nodal Electrical Current Flux from Natural Boundary Condition (φ_e) is a vector which accounts for the uniform current flux boundary condition. Each node receives a portion of total current flux based on its share of surface area or edge length exposed to the boundary. In the given problem, the boundary condition is a uniform current flux of 3 A/mm².This boundary condition directly provides the electrical current flux (Jn) at the nodes on the boundary of the element.

$\int_{\Omega^e} N_I \, N_J d\Omega = A_{IJ}$ $\int_{\Omega} N_J q(x) d\Omega = y_J$ (A/mm^2)

$q_I = A_{IJ}{}^{-1} Y_J$ (A/mm^2)

Where:
Ω – Domain differential volume element
A_{IJ} – Element of matrix
q(x)- Heat source distribution function within the domain
$N_I N_J$ – Shape functions
Y_J- Nodal values vectors
q_I – Vector solution of current density

2. **Calculated pore area for each weld geometry input (calculate the difference between the area of your domain and a domain without any pores). (Units- mm^2)**

Ans:

	T3-R1	T3-R2	T3-R3	T3-R4	T6-R1	T6-R2	T6-R3	T6-R4
aprekash (MAE 503)	0.71417	0.71417	0.71418	0.71778	0.71999	0.71999	0.72000	0.72000
snola139 (MAE 503)	0.58357	0.58357	0.58376	0.58617	0.58357	0.58357	0.58376	0.58617
sgummara (MAE 503)	0.78506	0.78507	0.78540	0.78883	0.79132	0.79133	0.79133	0.79133
mchan28 (MAE 503)	0.70807	0.70824	0.70867	0.71165	0.71329	0.71347	0.71355	0.71356

3. **Calculated total energy dissipated in each geometry compared with total Joule energy dissipated in a domain without any pores. (Units- J/mm^3)**

<u>Ans:</u> **With pores:**

	T3-R1	T3-R2	T3-R3	T3-R4	T6-R1	T6-R2	T6-R3	T6-R4
aprekash (MAE 503)	19.6337	23.6831	34.7922	95.25347	74.5062	90.26699	134.0319	372.3766
snola139 (MAE 503)	20.2499	25.2255	38.4438	103.6463	77.028	96.6047	148.5597	405.7145
sgummara (MAE 503)	22.7057	26.5304	39.1497	97.3103	86.1953	101.3593	150.5373	379.0242
mchan28 (MAE 503)	30.8888	37.6499	62.8370	147.322	200.35	154.973	277.361	599.241

Without Pores:

	T3-R1	T3-R2	T3-R3	T3-R4	T6-R1	T6-R2	T6-R3	T6-R4
aprekash (MAE 503)	2.54667	5.38101	15.54091	54.22366	8.98179	20.23199	59.97019	213.2437
snola139 (MAE 503)	2.54667	5.38100	15.54091	54.22366	8.98178	20.23198	59.97019	213.2437
sgummara (MAE 503)	2.54667	5.3810	15.54091	54.22366	8.98178	20.23198	59.97019	213.24374
mchan28 (MAE 503)	2.54667	5.38100	15.5409	54.2236	8.98178	20.2319	59.9701	213.243

4. **Tables containing the following information for each pore geometry:**
   a) **Maximum heat generation values (per unit volume) for each mesh refinement level (With Pores). (Units- J/mm^3)**

	T3-R1	T3-R2	T3-R3	T3-R4	T6-R1	T6-R2	T6-R3	T6-R4
aprekash (MAE 503)	0.14053	0.13620	0.15119	0.16169	0.14722	0.14786	0.14903	0.14570
snola139 (MAE 503)	0.14357	0.14434	0.13686	0.13780	0.14026	0.14027	0.14008	0.13988
sgummara (MAE 503)	0.12824	0.12528	0.12574	0.13584	0.15536	0.15489	0.15473	0.16880
mchan28 (MAE 503)	0.64623	0.67775	2.96604	4.50666	68.7612	1.05740	8.85741	5.36371

Maximum heat generation values (per unit volume) for each mesh refinement level (Without Pores)

	T3-R1	T3-R2	T3-R3	T3-R4	T6-R1	T6-R2	T6-R3	T6-R4
aprekash (MAE 503)	0.05582	0.03745	0.04516	0.03974	0.03964	0.03962	0.03961	0.03922
snola139 (MAE 503)	0.05581	0.03744	0.04515	0.03974	0.03964	0.03961	0.03960	0.03922
sgummara (MAE 503)	0.05582	0.03745	0.04515	0.03974	0.03964	0.03962	0.03960	0.03922
mchan28 (MAE 503)	0.05581	0.03744	0.04515	0.03974	0.03964	0.03961	0.03960	0.03922

b) Maximum temperatures for each mesh refinement level. (With pores) (Units-°C)

	T3-R1	T3-R2	T3-R3	T3-R4	T6-R1	T6-R2	T6-R3	T6-R4
aprekash (MAE 503)	0.65802	0.65838	0.65860	0.65940	0.66002	0.66003	0.66004	0.66004
snola139 (MAE 503)	0.69086	0.69112	0.69140	0.69215	0.69276	0.69277	0.69277	0.69278
sgummara (MAE 503)	0.66766	0.66810	0.66845	0.66943	0.67033	0.67037	0.67037	0.67038
mchan28 (MAE 503)	0.69675	0.69972	0.70231	0.7049	0.70377	0.70487	0.70680	0.70696

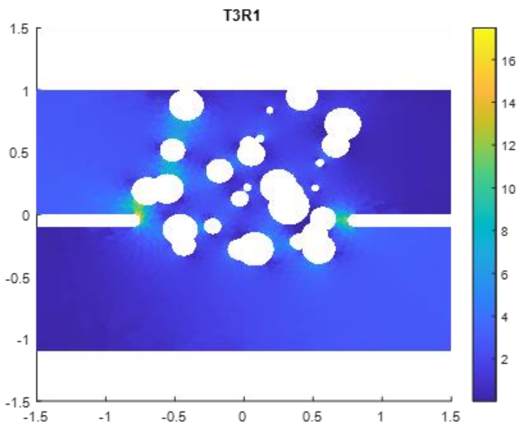
Maximum temperatures for each mesh refinement level. (Without pores)

	T3-R1	T3-R2	T3-R3	T3-R4	T6-R1	T6-R2	T6-R3	T6-R4
aprekash (MAE 503)	0.60475	0.60513	0.60530	0.60536	0.60543	0.60544	0.60544	0.60544
snola139 (MAE 503)	0.60475	0.60512	0.60530	0.60536	0.60543	0.60543	0.60543	0.60543
sgummara (MAE 503	0.60475	0.60513	0.60530	0.60536	0.60543	0.60544	0.60544	0.60544
mchan28 (MAE 503)	0.60475	0.60512	0.60530	0.60536	0.60543	0.60543	0.60543	0.60543

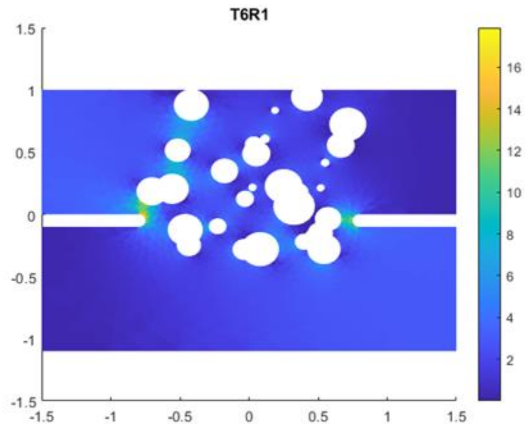
5. **Plots of current density magnitude with comparing a coarse mesh with a fine mesh. Zoom to the following bounds -1.5 < *x* < 1.5, -1.5 < *y* < 1.5.**

Ans:

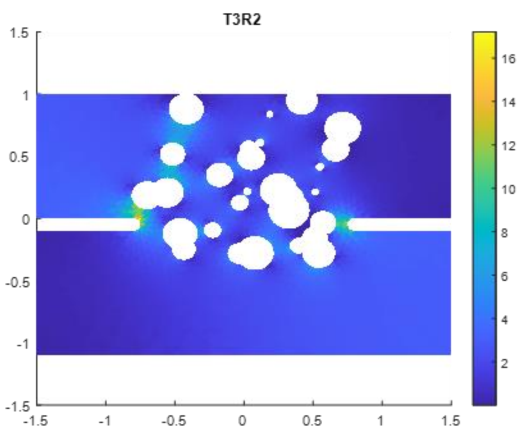
a) Plots of Current density magnitude (Comparing Coarse and Fine mesh) – **aprekash**



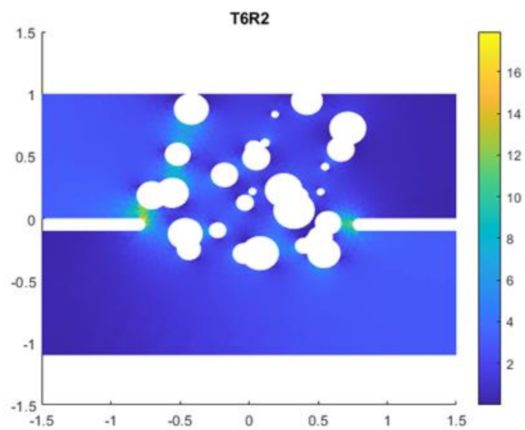
T3R1



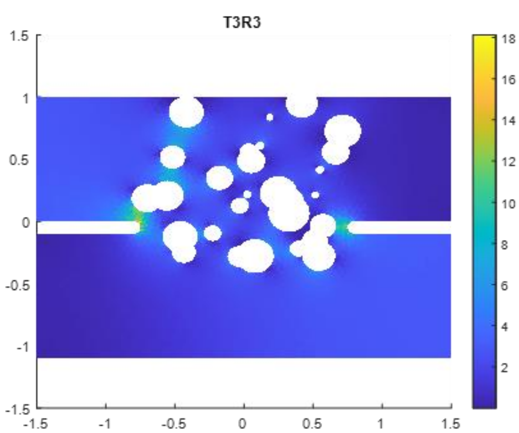
T6R1



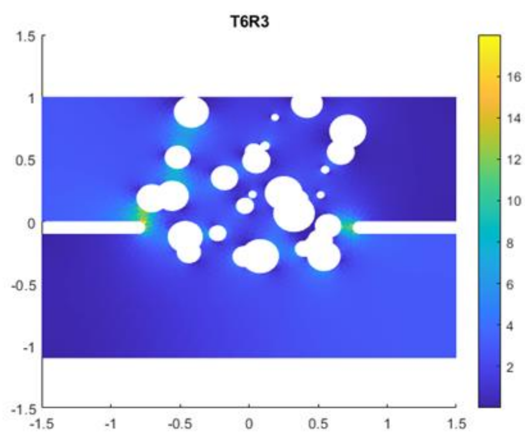
T3R2



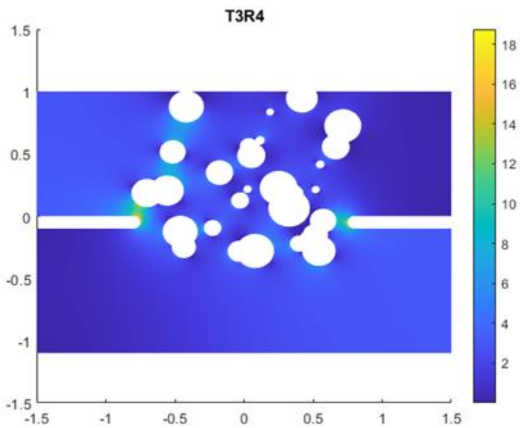
T6R2



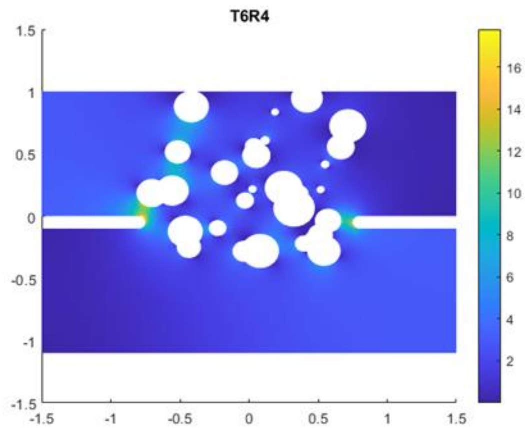
T3R3



T6R3

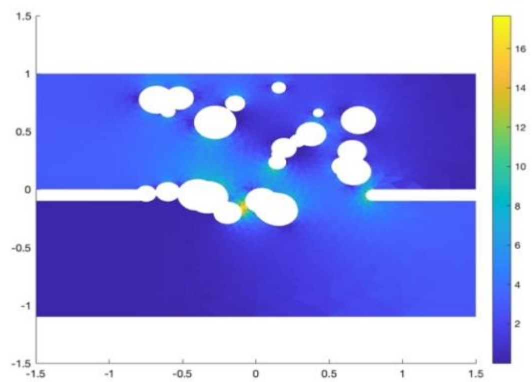


T3R4

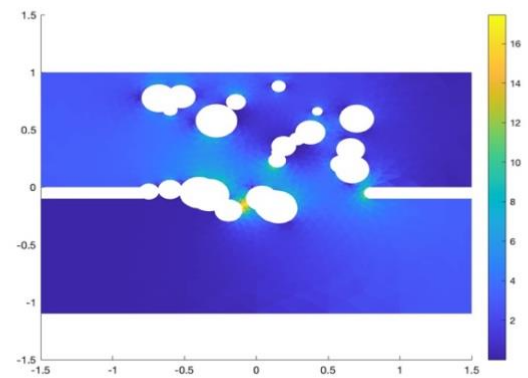


T6R4

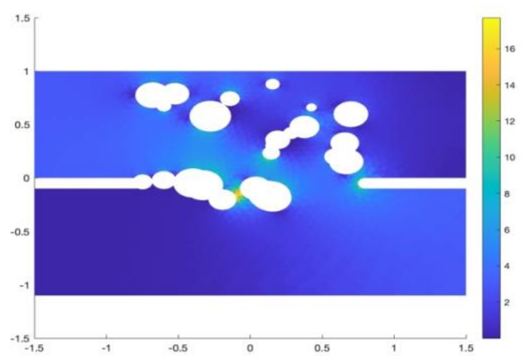
b) <u>Plots of Current density magnitude (Comparing Coarse and Fine mesh) – **snola139**</u>



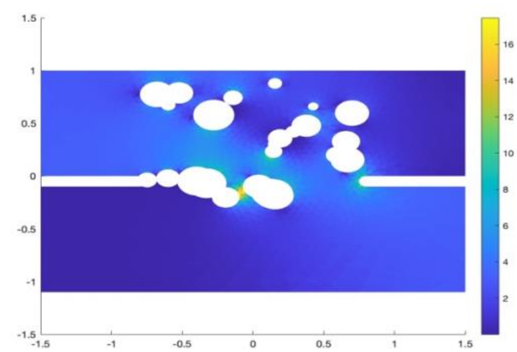
T3-R1



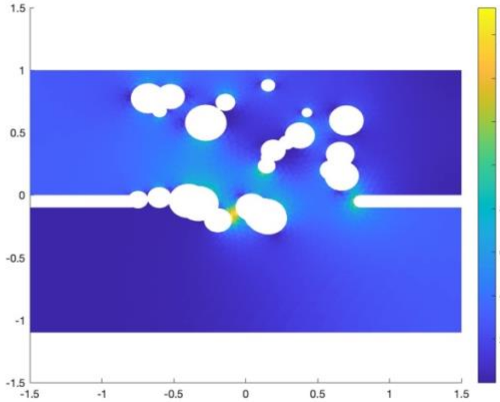
T6-R1



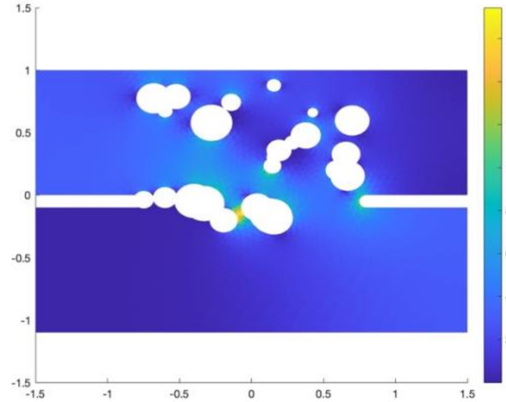
T3-R2



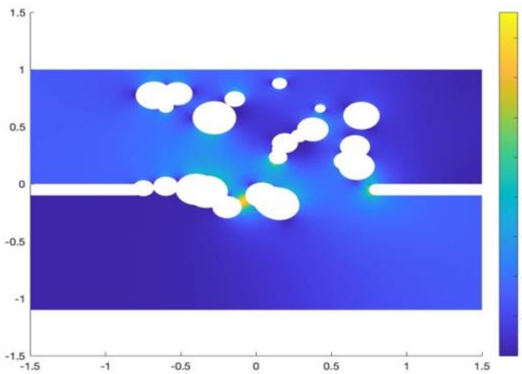
T6-R2



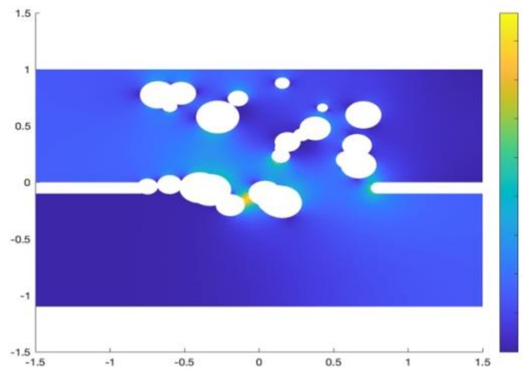
T3-R3



T6-R3

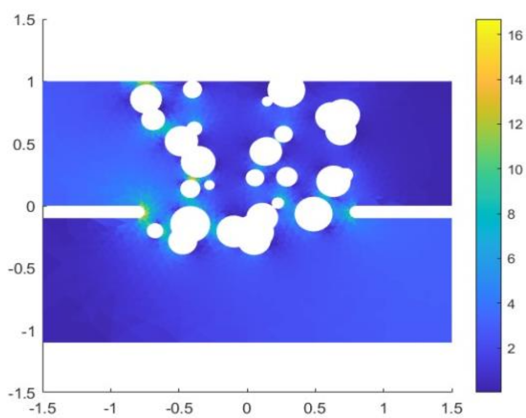


T3-R4

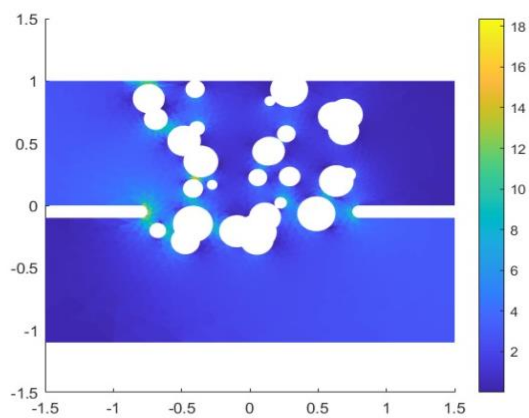


T6-R4

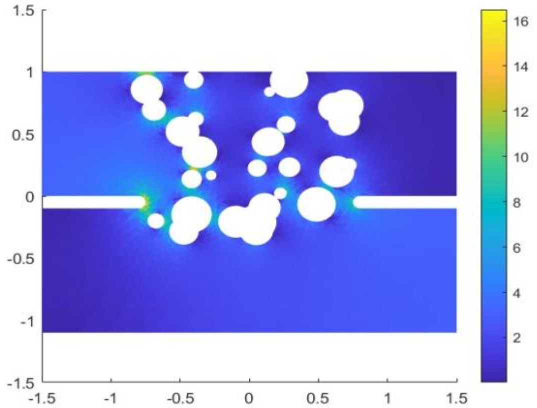
c) <u>Plots of Current density magnitude (Comparing Coarse and Fine mesh) – **sgummara**</u>



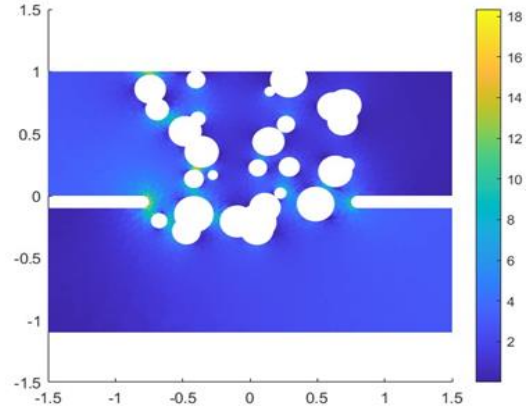
T3-R1



T6-R1



T3-R2



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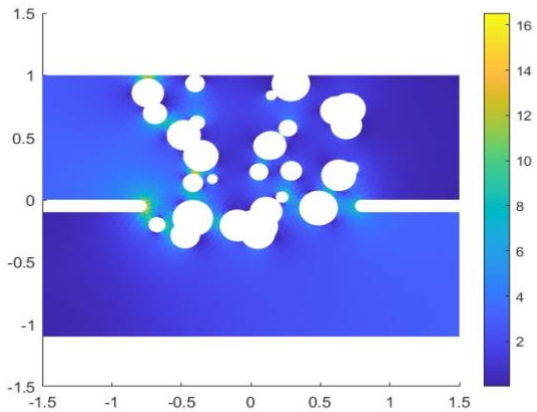
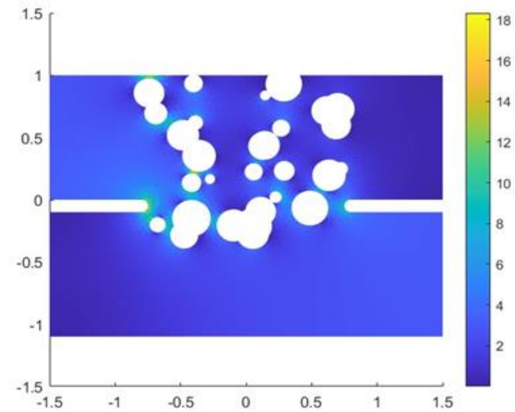
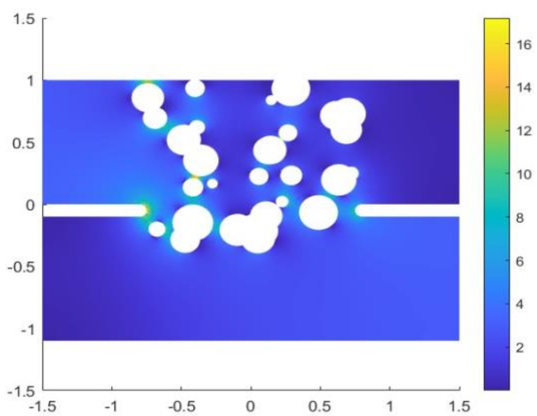


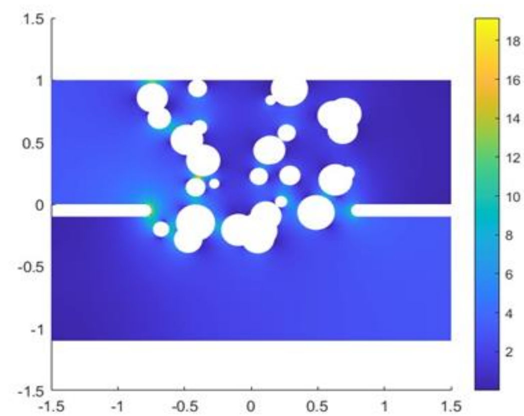
T3-R3



T6-R3

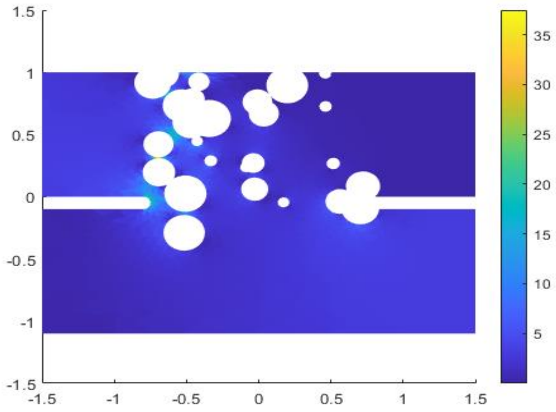


T3-R4

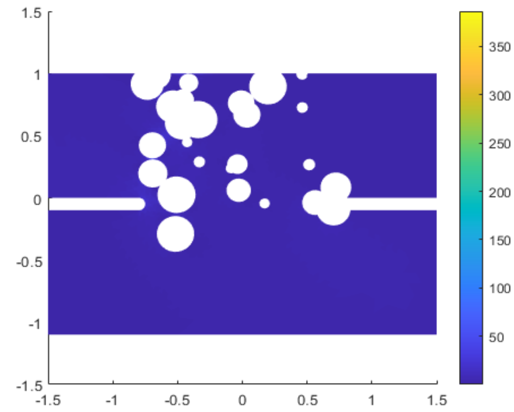


T6-R4

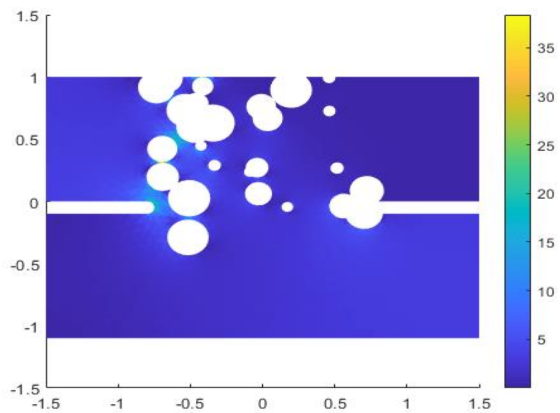
d) <u>Plots of Current density magnitude (Comparing Coarse and Fine mesh) – mchan28</u>



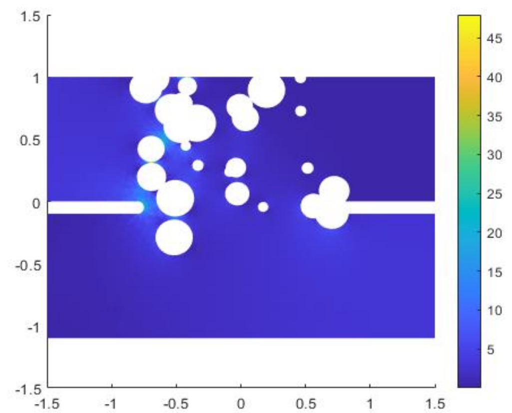
T3-R1



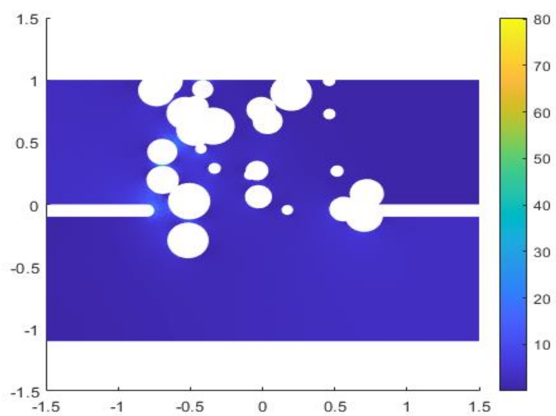
T6-R1



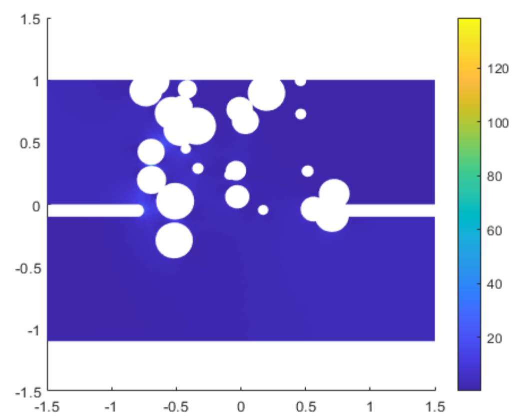
T3-R2



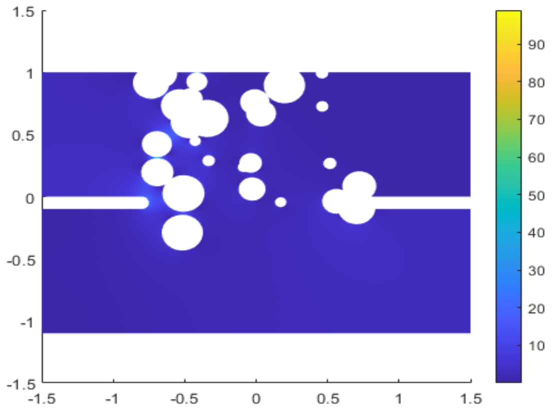
T6-R2

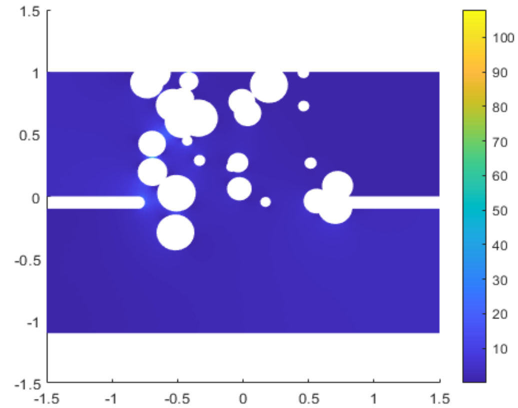


T3-R3



T6-R3





. ***T3-R4*** ***T6-R4***

6. Short answers to the questions below:

a) Does weld porosity significantly increase busbar resistance or lead to substantial battery heating?

Ans: Weld porosity refers to the presence of tiny holes or voids in a weld, often caused by gas that becomes trapped as the weld cools. These pores can interrupt the flow of electric current, effectively increasing the busbar resistance. The increased resistance leads to a rise in Joule heating. As a result, when current flows through the busbar, it encounters higher resistance at the locations of porosity, leading to localized heating. This localized heating can potentially result in hot spots, which may degrade the performance and reliability of the battery assembly over time. The extent of this heating depends on the size, number, and distribution of the pores.

b) How sensitive is the computed maximum heat generation per unit volume to the mesh resolution?

Ans: The computed maximum heat generation per unit volume is not highly sensitive to the mesh resolution with changes typically occurring after the second decimal place. This is because the maximum heat generation per unit volume is typically smooth , continuous function across the volume of the material. Finer meshes generally yield more accurate results, especially in capturing localized effects such as high current density regions and temperature gradients. In regions with sharp variations in current density or temperature, finer meshes are essential for accuracy. However, in less critical areas with smoother gradients, coarser meshes may still provide reasonable results.

c) How sensitive is the computed maximum temperature to the mesh resolution?

Ans: The maximum temperature computed is not highly sensitive to mesh resolution. Finer meshes excel in capturing temperature gradients and localized variations accurately, particularly in regions prone to hot spots and this leads to a constant result. Coarser meshes may underestimate temperature variations, especially where rapid temperature changes occur.

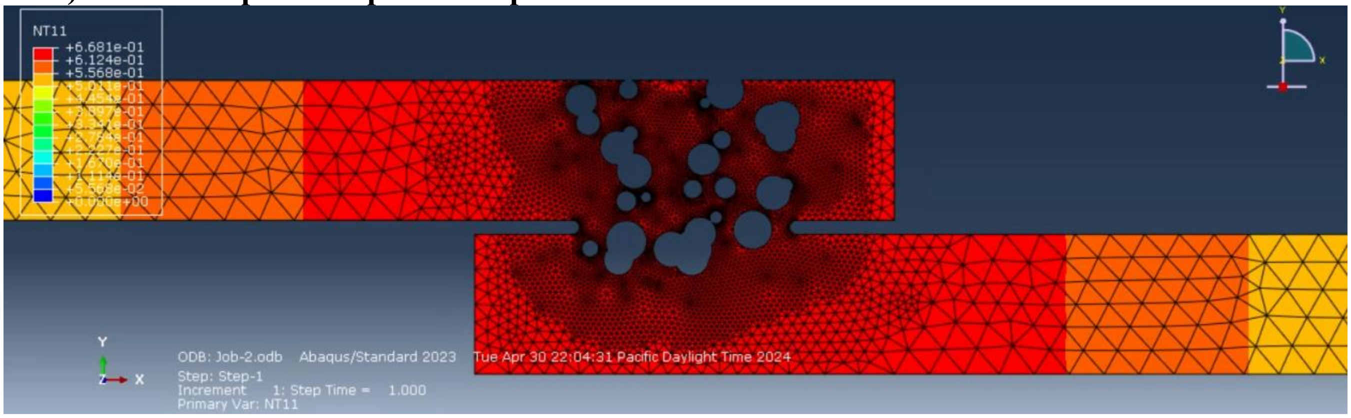
d) What are potential reasons why this problem could be nonlinear? Given the specified problem parameters, is it reasonable to assume that the problem is linear?

Ans: Potential reasons why this problem could be nonlinear include temperature-dependent material properties, non-uniform heat generation, and significant temperature gradients. For instance, if material

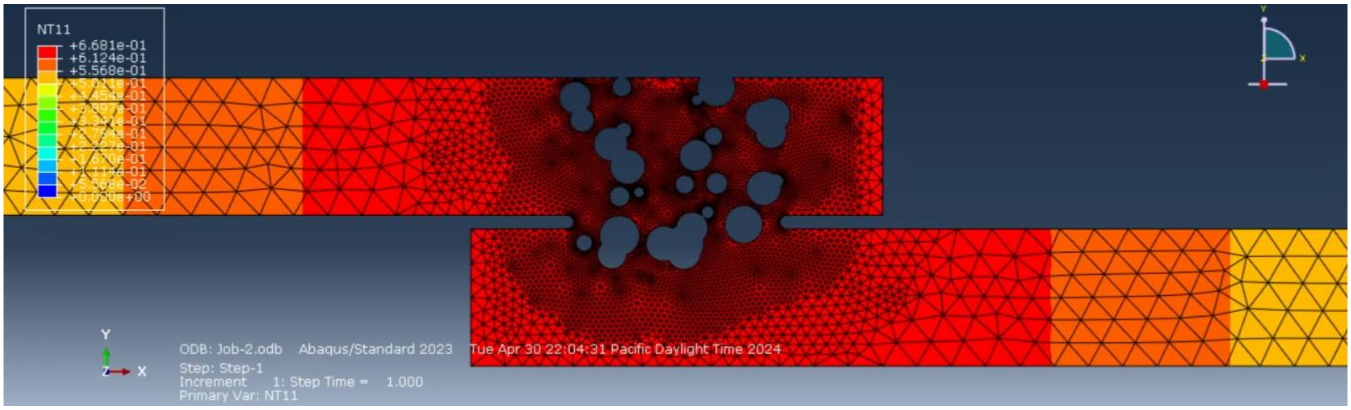
properties such as electrical resistivity or thermal conductivity vary with temperature, the problem becomes nonlinear. Additionally, large temperature gradients within the welded region can invalidate the assumption of linear behavior.
However, given the specified problem parameters of steady-state conditions and constant material properties, it is reasonable to assume linearity. The problem involves steady-state heat conduction and electrical conduction in homogeneous materials with constant properties. Under these conditions, linear analysis should provide accurate results. Nonetheless, deviations from these assumptions or changes in problem parameters could introduce nonlinear effects, which should be considered in the analysis.

ABAQUS RESULTS (sgummara):

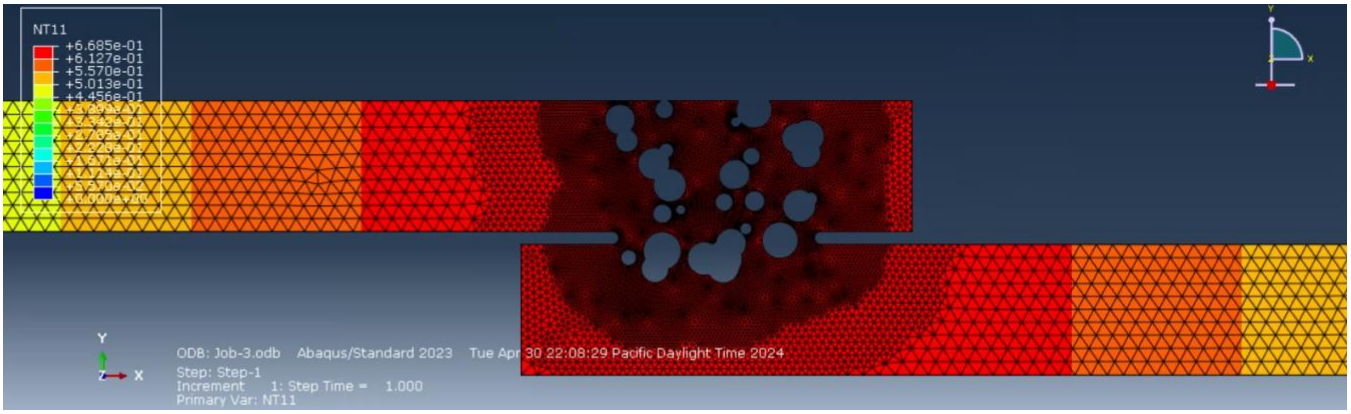
a) **Nodal temperature plots with pores**



T3R1



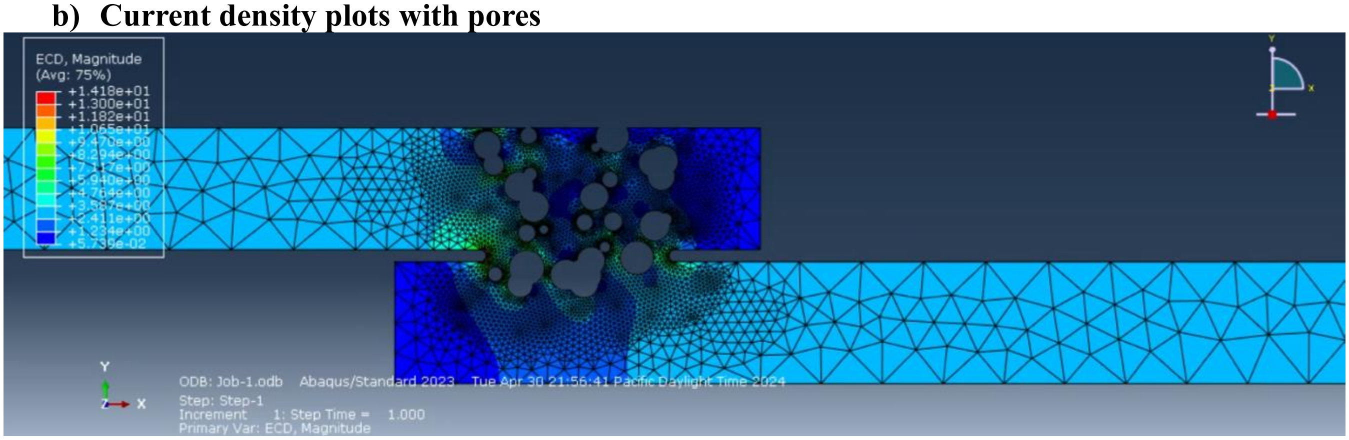
T3R2



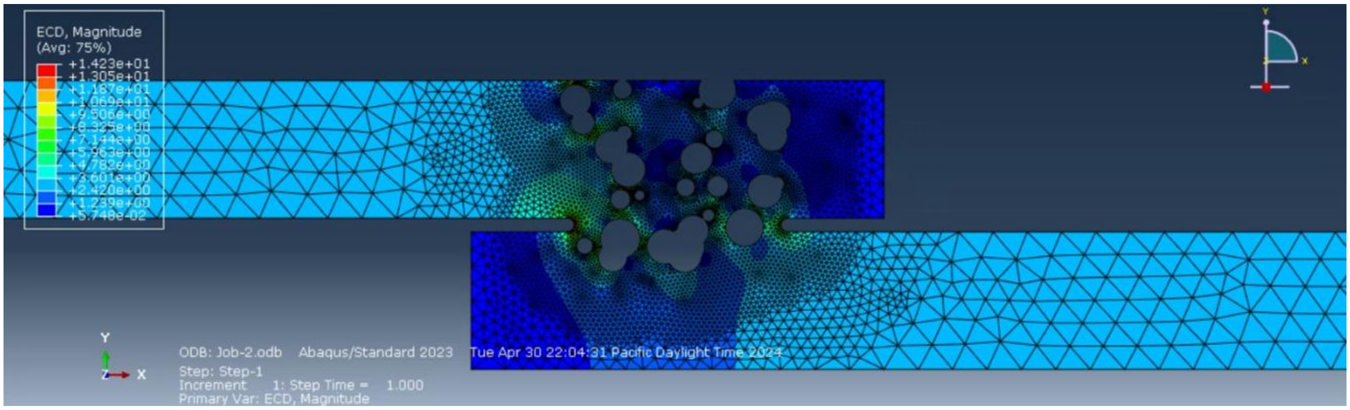
T3R3

T3R4

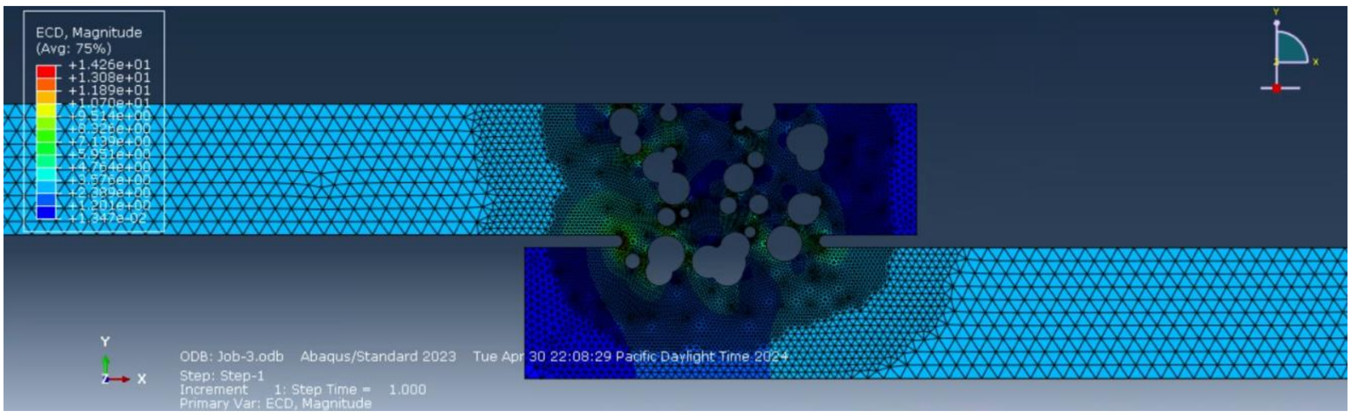
b) Current density plots with pores



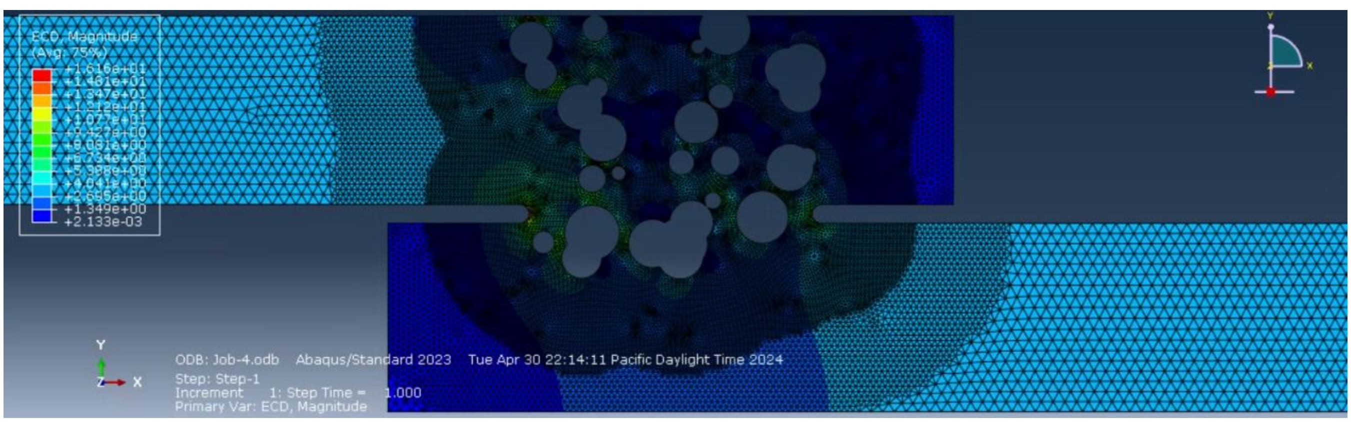
T3R1



T3R2

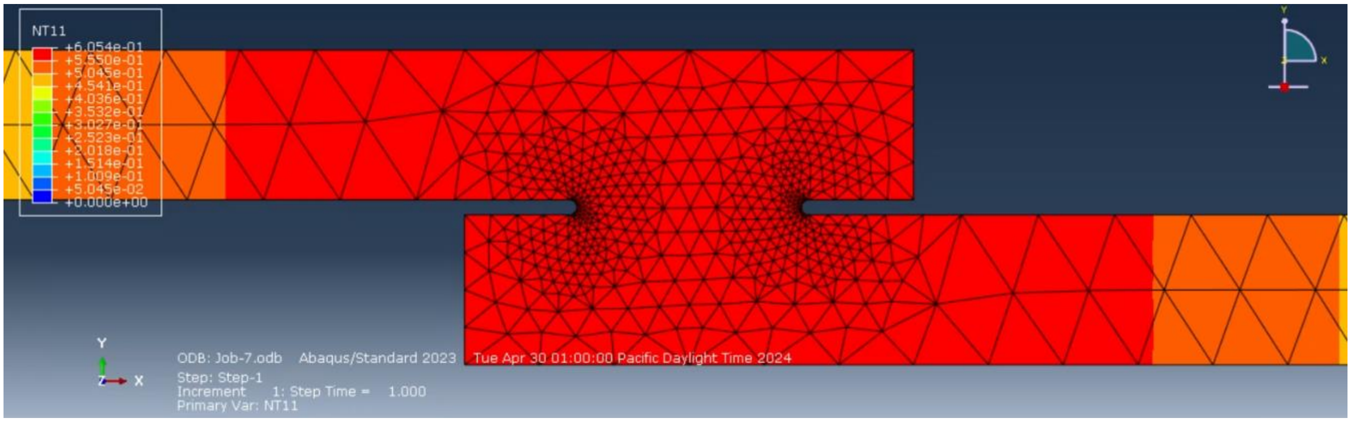


T3R3



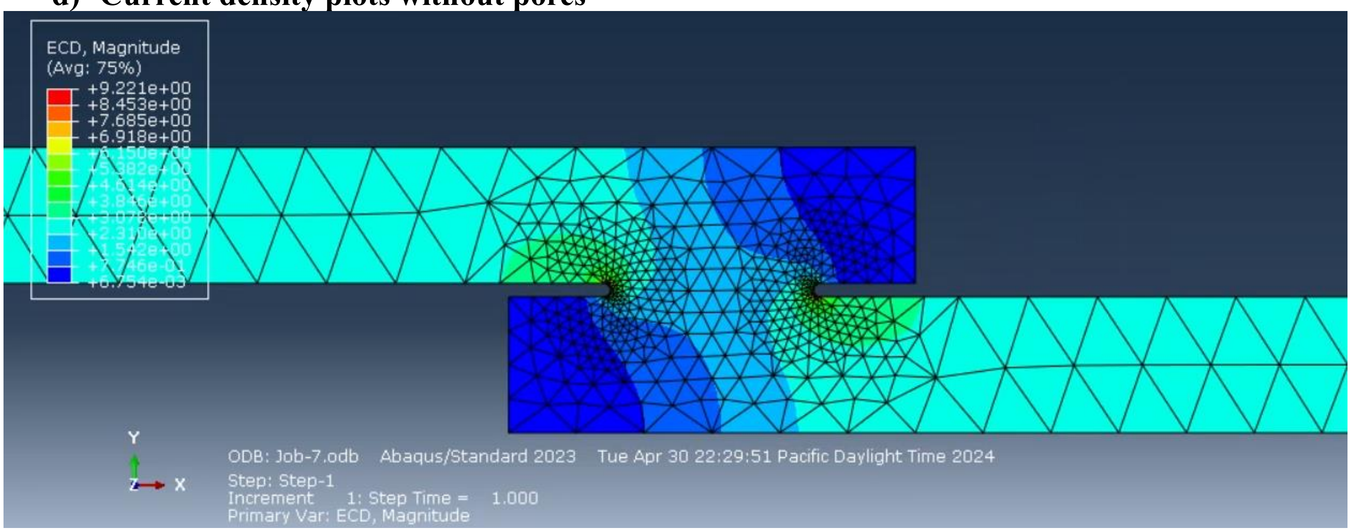
T3R4

c) Nodal temperature plots without pores



T3R1

d) Current density plots without pores



T3R1