Albert Wiryawan
MSE 404 MAC
11/30/2020

OOF2 Module

Part A – MATLAB finite element code for 1D steady state heat conduction

A1. Steady-state temperature profile

In appendix at the bottom of the report

A2. Temperature Profile

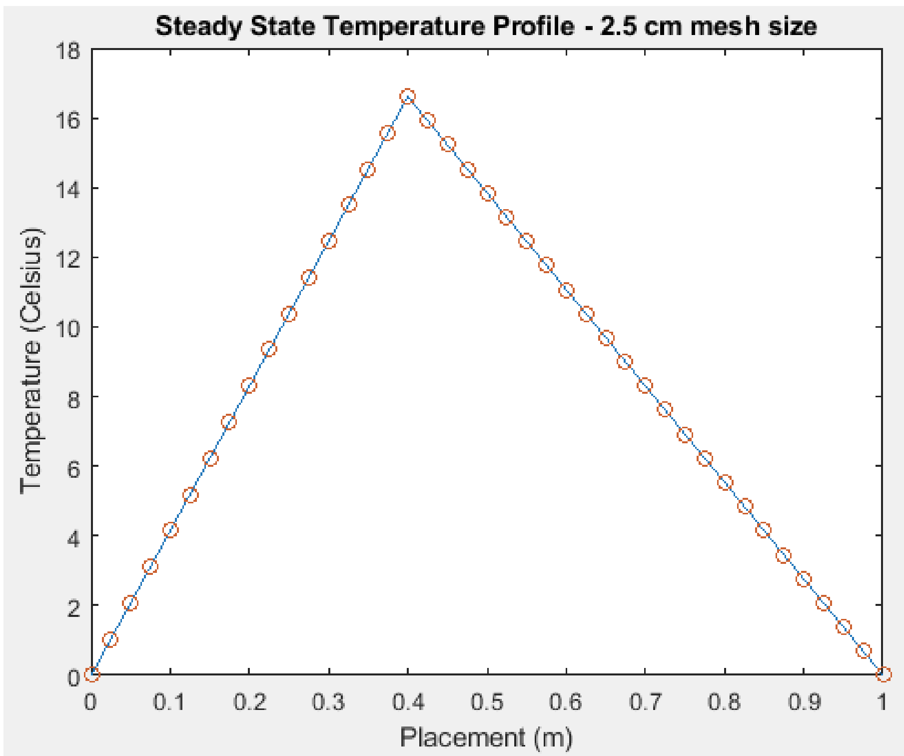

Figure 1. Steady state temperature profile with uniform mesh and element size of 2.5cm

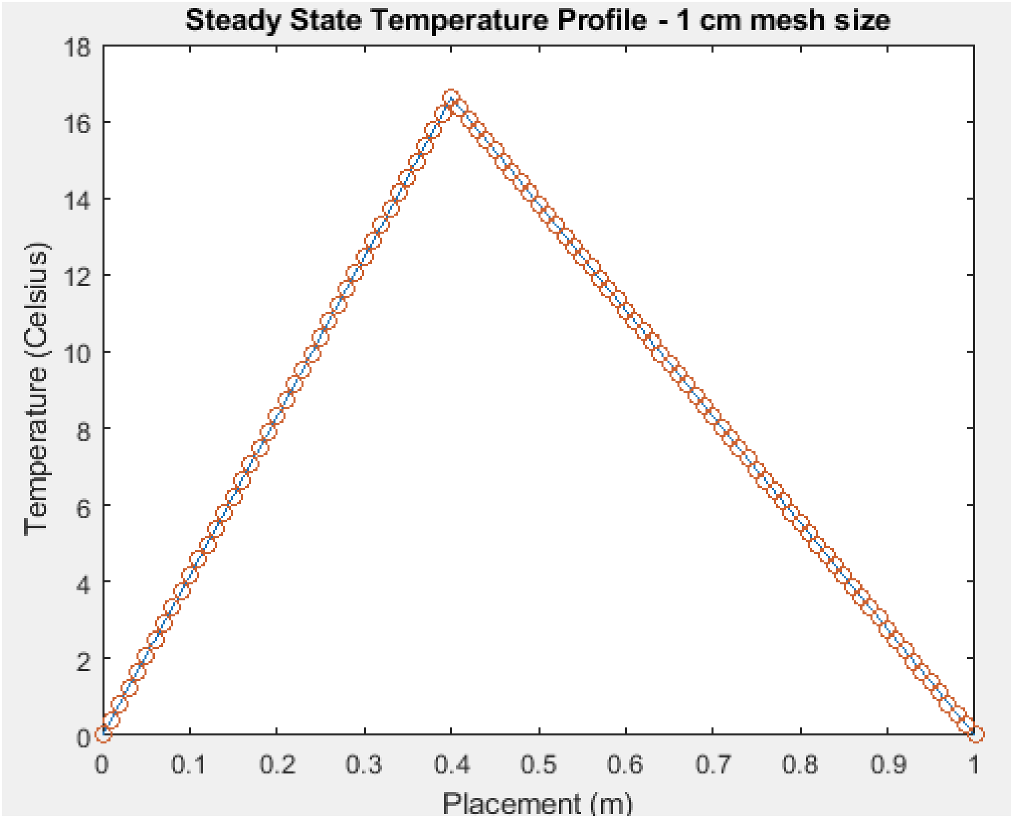

Figure 2. Steady state temperature profile with uniform mesh and element size of 1cm

The L matrix or b vector is not dependent on the mesh size. Due to this, there will be no quantitative difference between the two solutions shown from the two different figures above

A3. Modified system temperature profile

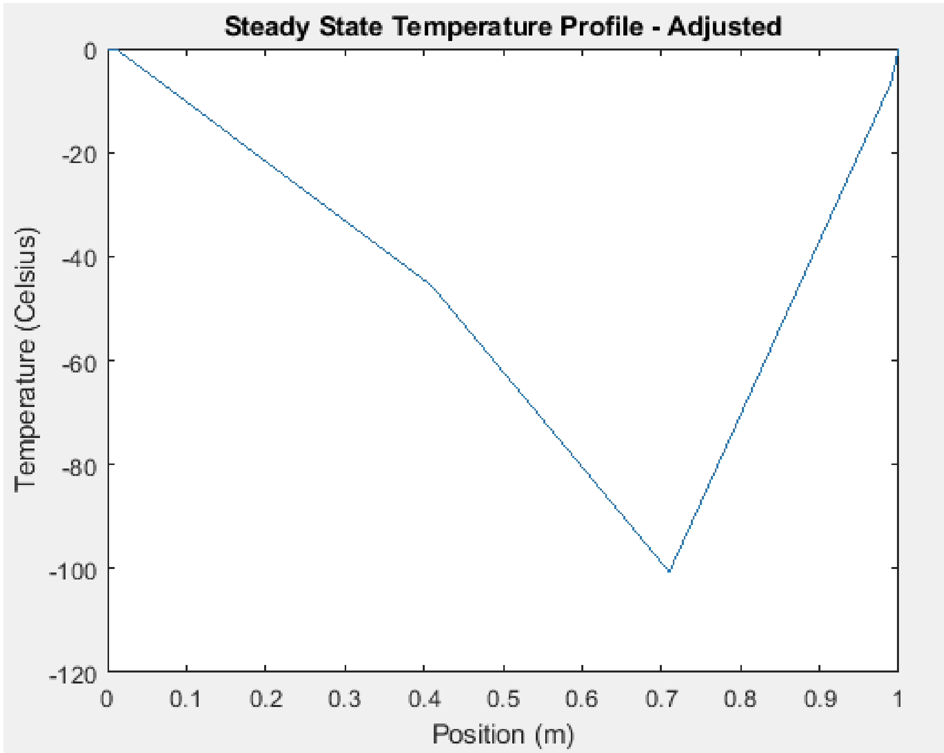

Figure 3. Steady state temperature profile in the modified system

Part B – OOF2 analysis of stress field around a crack tip in Al

B1. Upload Micrograph

Figure 4. Crack Tip Sample of Al with height 5mm given with pixel dimensions of 720x540

X-dimension of figure is 720 pixels and Y-dimension is 540 pixels. This also means that the x-dimension is 6.67mm and the y-dimension is 5mm as given by the proportion found from the pixels.

B2. Pixel Goups

There are 382017 pixels that belong to this phase.

B3. Materials Properties

Given information on the aluminum sample:

Table 1. Aluminum sample various material properties data

Young's Modulus (GPa)	62
Poisson's Ratio, *v*	0.35
Thermal Conductivity, κ (W/m°C)	237
Thermal Expansion Coeff., α @ T0=25°C (C-1)	2.31*10-5
Color [R, G, B]	[1, 0, 0]

B4. Skeleton

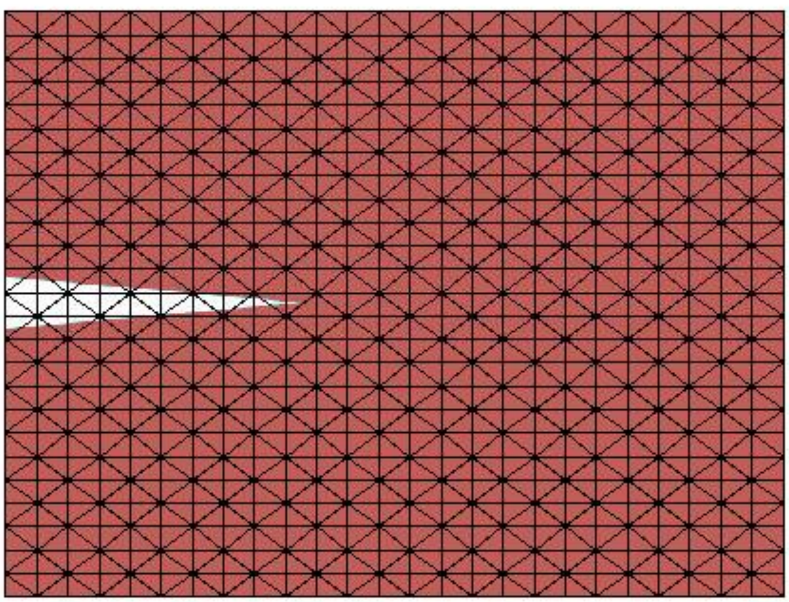

Figure 5. Screenshot of skeleton over the micrograph.

The reported homogeneity index is 0.994718484225. Since the homogeneity index of 1 signifies a specimen that is perfectly aligned with its phase boundaries, it is observed that the specimen under question has its phase boundaries close to perfectly aligned. This deviation from one can be attributed to the observable spaces made by Al and empty space from the crack tip

B5. Skeleton Adjustment

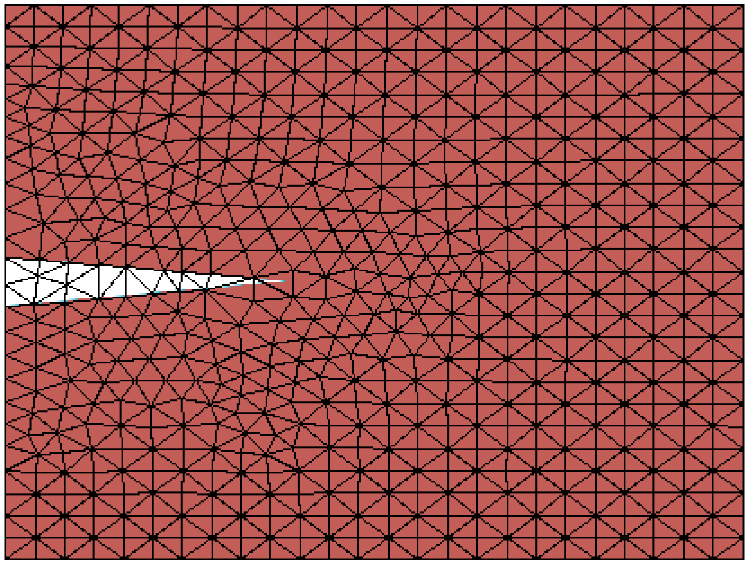

Figure 6. Screenshot of the adjusted skeleton over the aluminum crack tip micrograph

After adjustment, the reported homogeneity index increases to 0.998911028491. By adjusting the triangles near the crack tip, there is better separation of the two different phases of both aluminum and empty space. As such, the homogeneity index will increase.

B6. Generate mesh

(i) 667 nodes
(ii) 1350 elements
(iii) 100 2-cornered elements
(iv) 1250 3-cornered elements

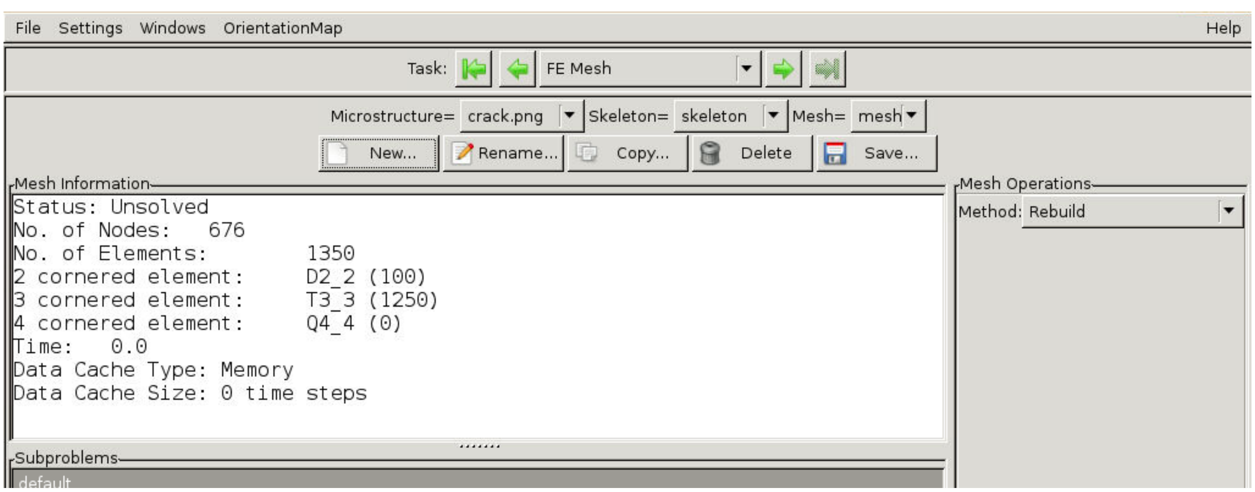

Figure 7. Mesh data

B7. Equation and boundary conditions

Enable	Name	Boundary	Condition
☑	bc	top	Dirichlet / Displacement[y] / Force_Balance[y] / 0.0
☑	bc<2>	bottom	Dirichlet / Displacement[y] / Force_Balance[y] / 0.0
☑	bc<3>	right	Dirichlet / Displacement[x] / Force_Balance[x] / 0.0
☑	bc<4>	top	Dirichlet / Temperature[] / Heat_Eqn[] / 25
☑	bc<5>	bottom	Dirichlet / Temperature[] / Heat_Eqn[] / 25
☑	bc<6>	right	Dirichlet / Temperature[] / Heat_Eqn[] / 25
☑	bc<7>	left	Dirichlet / Temperature[] / Heat_Eqn[] / 25

Figure 8. Screen shot of boundary conditions set through the instructions given.

B8. Solve

```
1842x1842 matrix solution statistics
 # of solutions: 1
      iterations: 69
        residual: 3.885967870818515e-12
Matrices were built 1 time.
```

Figure 9. Screenshot of the number of iterations required and the final residual after solving the FEM problem at a tolerance of 1*10^-11. 69 iterations were required to solve the problem with residual of 3.886*10^-12.

B9. Analysis

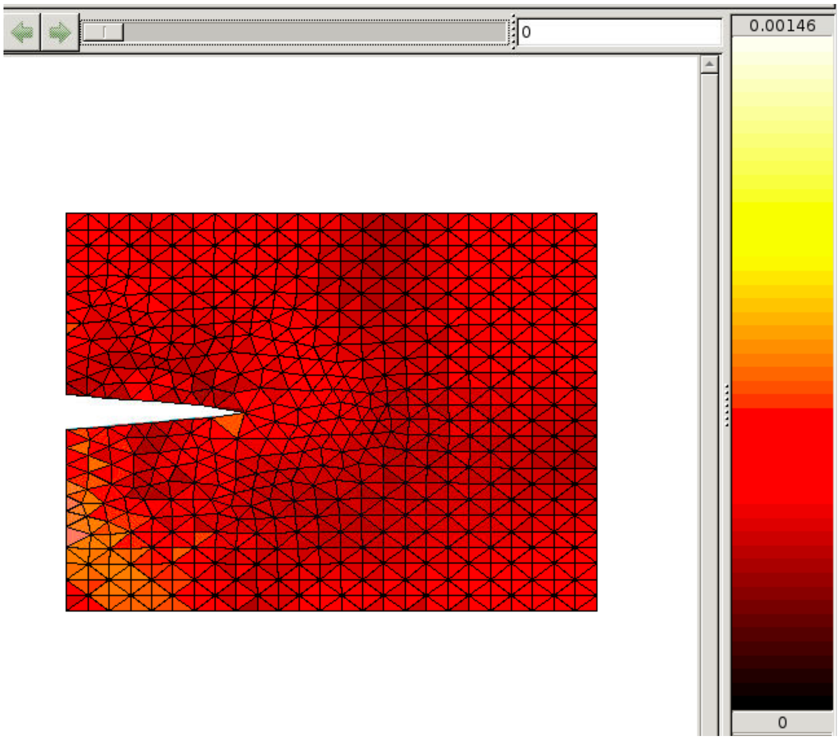

Figure 10. Screen shot with scale bar of the resulting stress distribution over the micrograph.

From observation, the max stress is located in the left corners of the specimen (yellow shade) with a magnitude of 0.00146 Pa. If the yield stress of Al is 11MPa, the crack tip will not propagate through the aluminum specimen. This is because 0.00146 Pa is negligible in comparison to 11MPa.

B10. Re-solving with temperature gradient

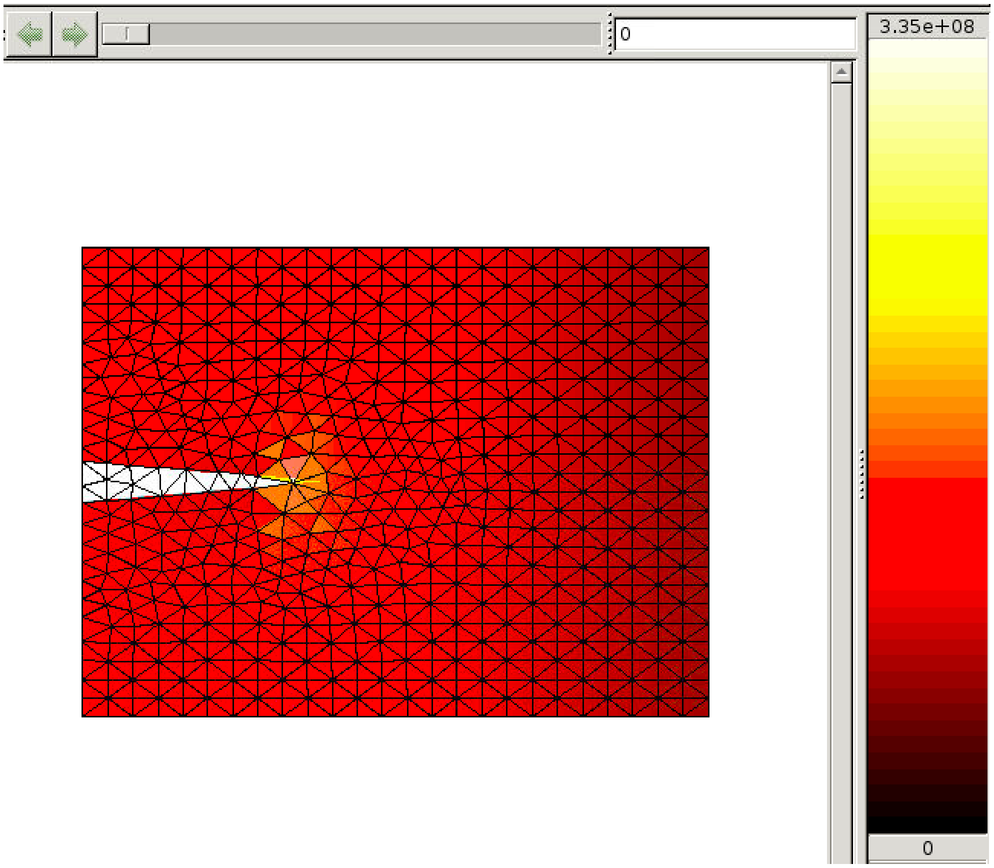

Figure 10. Screen shot with scale bar of the resulting stress distribution over the micrograph.

The magnitude of the maximum stress is 3.35*10^8 Pa (335MPa) and located at the crack tip (as given by the yellow shading). Assuming a yield stress of 11MPa, the crack tip will propagate this time since the maximum stress is larger than this. In the previous problem there was no temperature gradient. Due to this temperature gradient, there will be different parts of the specimen heating to different temperatures. This will cause the sample to expand differently throughout the specimen resulting in varying thermal expansion coefficients in different locations of the specimen. As a result, thermal stress and strain is seen and will result in the micrograph seen above. If no temperature gradient is applied, like in the previous problem, the micrograph has negligible stress without the varying of thermal expansion throughout the specimen body.

B11. Mesh refinement

My collogues answer is more accurate than my own. Increasing mesh refinement will better fit the phase boundaries to increase the index of homogeneity thereby increasing the accuracy of the analysis. To improve this solution, however, we can implement nonlinear equations to better model complex interaction.

Appendix

```
%Given global parametes
k = 57.8;
C = 4e3;
xs = 0.4;
dx = 1e-2;
n = (1/dx) + 1;

%Declare L and b
X = (0:dx:1);
L = zeros(n - 2);
b = zeros(n - 2, 1);

%Populate l matrix
for i = 2:n - 1
    for j = 2:n - 1
        if i == j
            L(i - 1, j - 1) = (1/(X(j) - X(j - 1))) + (1/(X(j + 1) - X(j)));
        elseif i == (j - 1)
            L(i - 1, j - 1) = -1/(X(j) - X(j - 1));
        elseif i == (j + 1)
            L(i - 1, j - 1) = -1/(X(j + 1) - X(j));
        end
    end
end

%Populate b vector

for j = 2:n - 1
    if X(j) >= xs && X(j - 1) <= xs
        b(j - 1) = (-C/k)*((xs - X(j - 1))/(X(j) - X(j - 1)));
    elseif X(j) <= xs && X(j + 1) >= xs
        b(j - 1) = (-C/k)*((X(j + 1) - xs)/(X(j + 1) - X(j)));
    end
end

%solveß
temp_u = -L\b;
```