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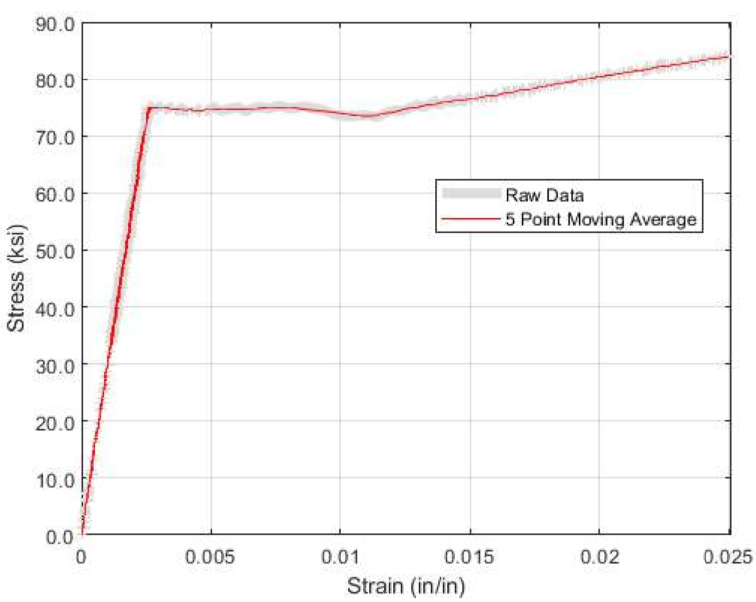
Part(I) Modeling Tensile Stress-Strain Response of Mild Steel Reinforcement

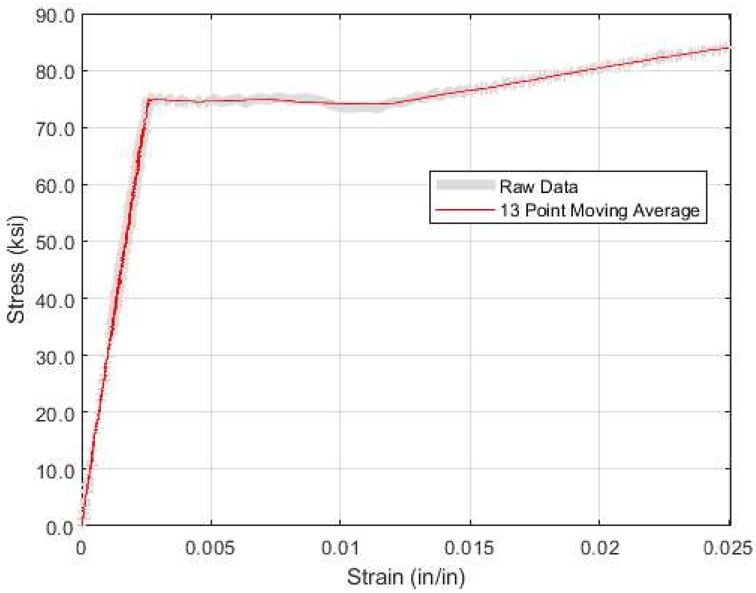
Question 1. Use the data and determine the Young’s modulus, the yield strength, the onset of strain hardening, the tensile strength, and the uniform strain

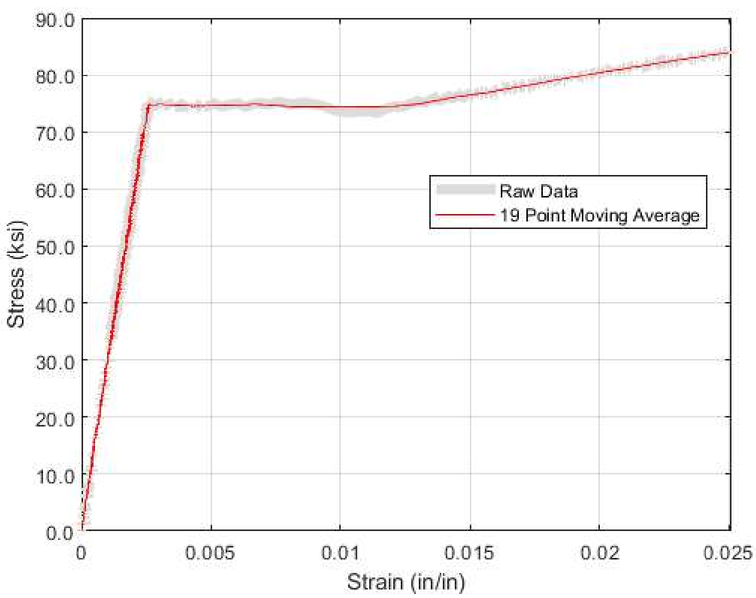
Using the data from the excel sheet the young's Young’s modulus E_s, the onset of strain hardening ϵ_{sh}, the tensile strength f_y, and unform strain ϵ_u.

Part (i) Determining Yeidling Stress and Onset of Strain Hardening

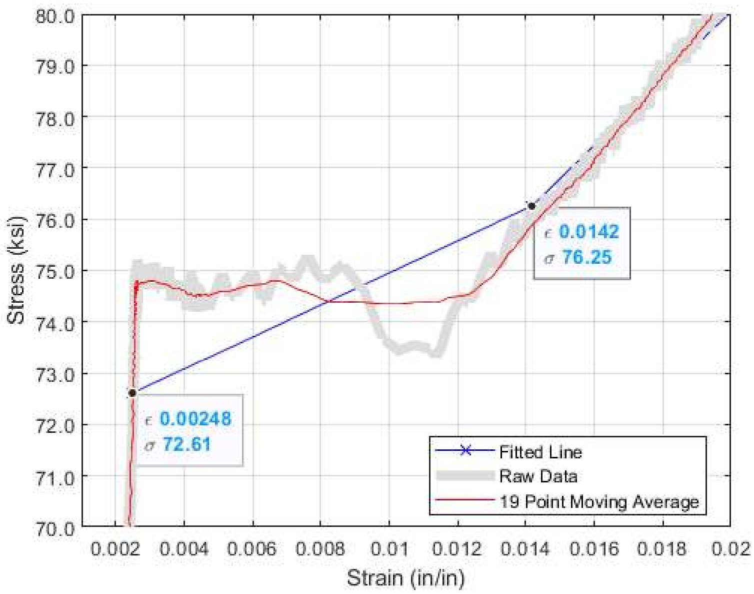
```
close all;
strain_range = [0, 0.025]; % As specified
[stress, strain] = get_data_for_range(strain_range); % Gets the data from the range

avg_values = [5, 13, 19]; % The number of samples that need to be taken for the moving average
for i = 1:length(avg_values) % Loops through the avg values
    figure(i); % Set up Figure
    mov_pt_avg = avg_values(i); % Sets the sampling size
    plot_raw_data(strain, stress) % Plots raw data
    int2str(mov_pt_avg) + " Point Moving Average"; % Title of plot, just set as a temp variable
    plot(strain, movmean(stress,mov_pt_avg),'r','DisplayName',ans); % Filtered Data
    print_figure(i) % Saves the figure as a pdf
end
```








```
strain_range = [0, 0.13]; % As specified
[stress, strain] = get_data_for_range(strain_range); % Gets the data from the range

close all;
idx_pts = findchangepts(stress,'Statistic','linear','MaxNumChanges',7); % Signal processing add-on
pts = plot(strain(idx_pts),stress(idx_pts),'x-b',"DisplayName",'Fitted Line'); % Fitted Line
plot_datatips(pts, strain, stress, idx_pts, (3:4)) % Using these two points
plot_raw_data(strain, stress); % Raw Data
plot(strain, movmean(stress,19),'r','DisplayName','19 Point Moving Average'); % Filtered Data
xlim([0.001 0.02]); ylim([70 80]);
print_figure('3a') % Saves figure as PDF
```




```
fy = min(stress(idx_pts(3:4))) % Finds the fy as the minimum stress in the yield plateau
```

```
fy = 72.6104
```

```
e_sh = strain(idx_pts(4)) % Strain where strain hardening is consistent
```

```
e_sh = 0.0142
```

```
f_sh = stress(idx_pts(4)) % Stress where strain hardening is consistent
```

```
f_sh = 76.2543
```

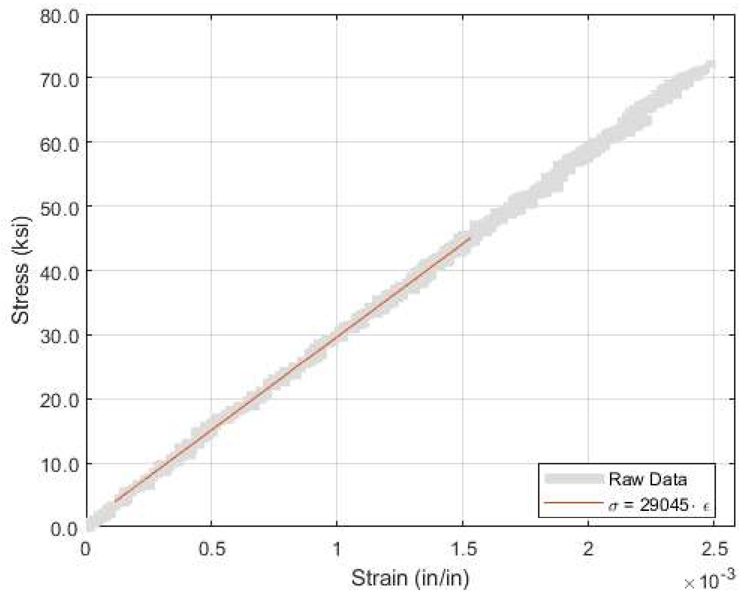
Using the signal processing toolkit, I was able to segment the data in seven linear portions. From there, using the indices as located by the algorithm, the strains at the boundaries of the Lüders yeild plateau were found. The yeild stress was taken as the minimum stress between the two corresponding stresses.

Part (ii) Determining Young's Modulus, E_s

```
strain_range = [0, 0.0025]; % As specified
[stress, strain] = get_data_for_range(strain_range);% Gets the data from the range

close all;
[~, idx1] = min(abs(0.05*fy- stress)); % Finds the index where the stress is equal to 0.05*fy
[~, idx2] = min(abs(0.6*fy- stress)); % Finds the index where the stress is equal to 0.6*fy
range = (idx1:idx2); % The ids where the two strains are met
coefs = polyfit(strain(range),stress(range),1); % Use a linear fit to find best fit the data
Es = coefs(1) % Modulus is just the slope of this line
```

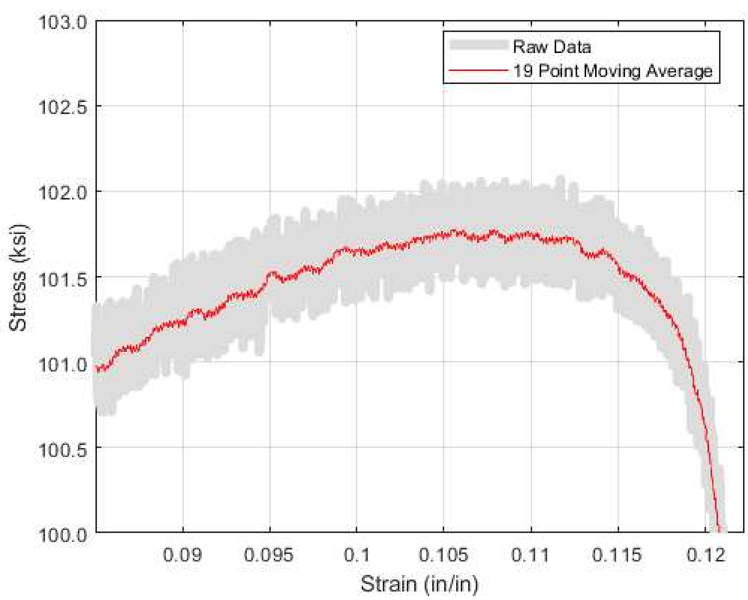
```
Es = 2.9045e+04
```

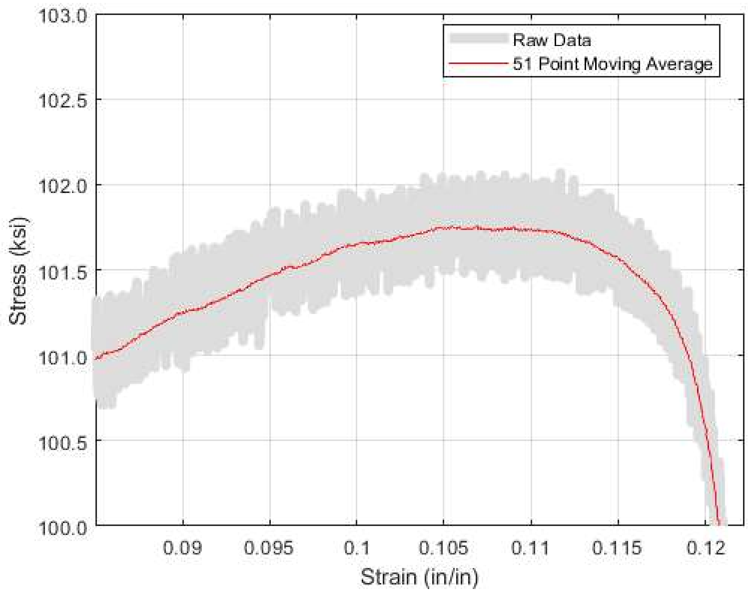
```
figure % Plot
plot_raw_data(strain, stress); % Plots raw data from start to 0.025 strain
"\sigma = " + sprintf("%5.0f", coefs(1)) + "\cdot \epsilon"; % Text for the plot name- stored as temporary variable
plot(strain(range), polyval(coefs,strain(range)),'-',"DisplayName", ans); % Plots the fitted line between 0.05fy and 0.6fy
print_figure(4)
```

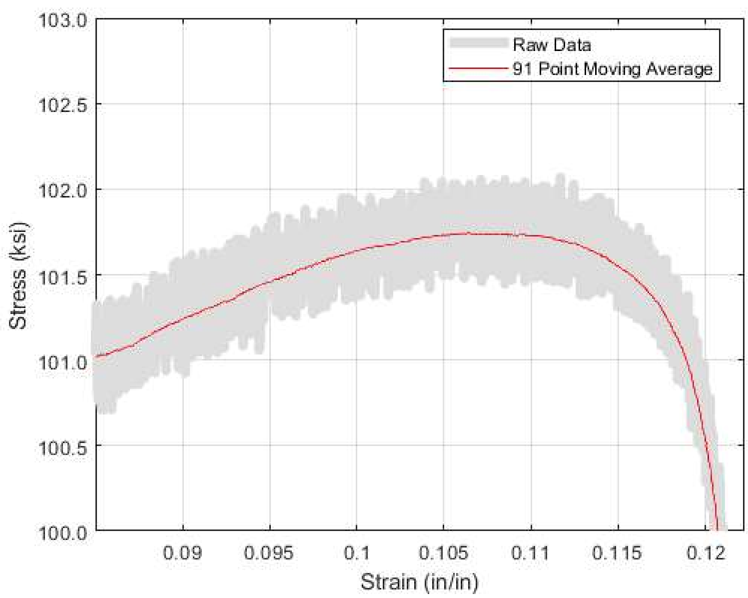


Part (iii) Determine Ultimate Stress f_{su} and Ultimate Strain ϵ_{su}

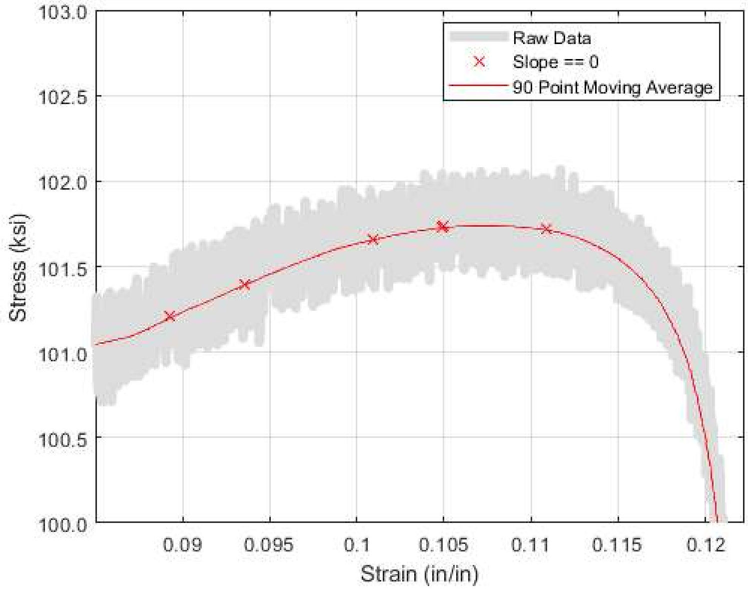
```
strain_range = [0.085, 0.125]; % As specified
[stress, strain] = get_data_for_range(strain_range); % Gets the data from the range

close all
avg_values = [19, 51, 91]; % The number of samples that need to be taken for the moving average
for i = 1:length(avg_values) % Loops through the avg values
    figure; % Set up figure, adjusted for figure numbers
    mov_pt_avg = avg_values(i); % Sets the sampling size
    plot_raw_data(strain, stress) % Plots raw data
    int2str(mov_pt_avg) + " Point Moving Average"; % Title for plot- temporary variable
    plot(strain, movmean(stress,mov_pt_avg),'r','DisplayName',ans); % Filtered Data
    ylim([100,103]); % Per office hours
    print_figure(i+4) % Save figure as PDF
end
```








```
strain_range = [0.085, 0.125]; % As specified
[stress, strain] = get_data_for_range(strain_range); % Gets data

close all
plot_raw_data(strain, stress) % Plots raw data
mov_pt_avg = 90; % Arbitrary
stress = movmean(stress,mov_pt_avg); % Filtered by moving average
slopes = diff(stress) ./ diff(strain); % Finds the slope of at various points
slopes(isinf(slopes)) = 10^-10; % Remove the inf from data
pt = find(slopes == 0); % Finds where the plot has 0 slope
plt = scatter(strain(pt),stress(pt),"Marker",'x',"MarkerEdgeColor","Red","DisplayName","Slope == 0"); % Plot thse points
string(mov_pt_avg) + " Point Moving Average"; % Title for plot- temporary variable
plot(strain, movmean(stress,mov_pt_avg),'r','DisplayName',ans); % Filtered Data
ylim([100,103]);
print_figure('7a')
```




```
e_su = mean(strain(pt(3:6))) % Start of the admissible range for strain
```

```
e_su = 0.1054
```

```
f_su = mean(stress(pt(3:6))) % Admissible Fsu
```

```
f_su = 101.7103
```

Question 2. Fit a Tri-Linear Model to the Processed Data

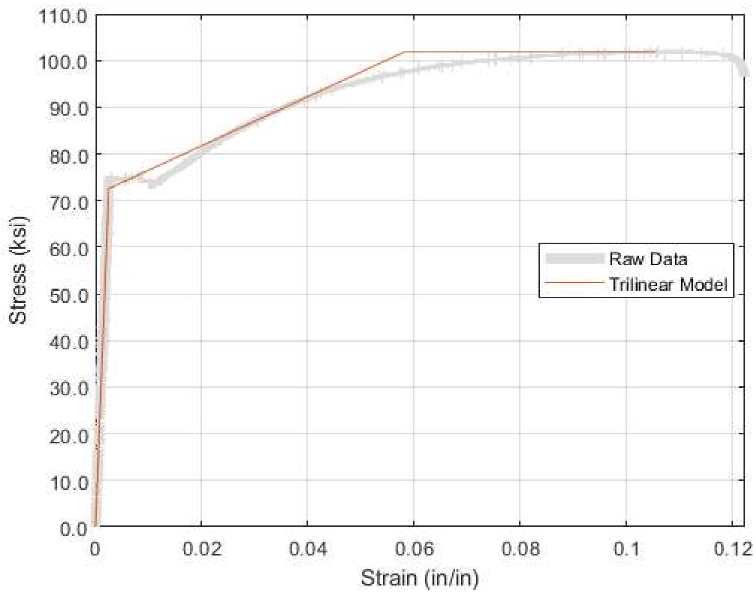
Plot the complete stress strain relationship to point (ϵ_{su}, f_{su}).

Compare the model and the processed data and show the value computed for the hardening ratio r.

```
strain_range = [0, 0.13]; % As specified
[stress, strain] = get_data_for_range(strain_range); % Get data for range

close all
plot_raw_data(strain, stress) % Plot raw data
zeta = 0.55; % As specifiec
e_y = fy/Es;
strain_pt = [0, e_y, zeta*e_su, e_su]; % As specifiec
stress_pt = [0, fy, f_su, f_su]; % As specifiec
plot(strain_pt,stress_pt,"DisplayName","Trilinear Model") % Plot
r = (f_su/fy - 1) / (zeta*e_su/e_y - 1) % Strain hardening example
```

```
r = 0.0181
```

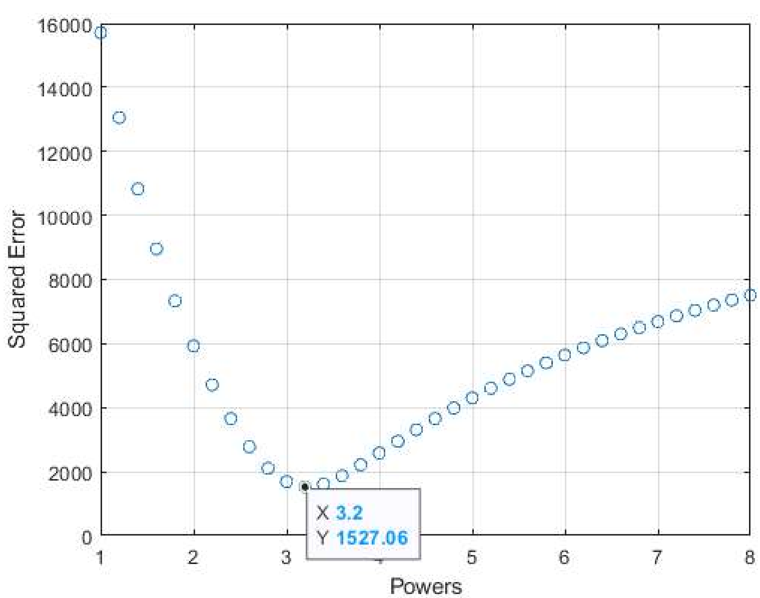
```
print_figure(8)
```



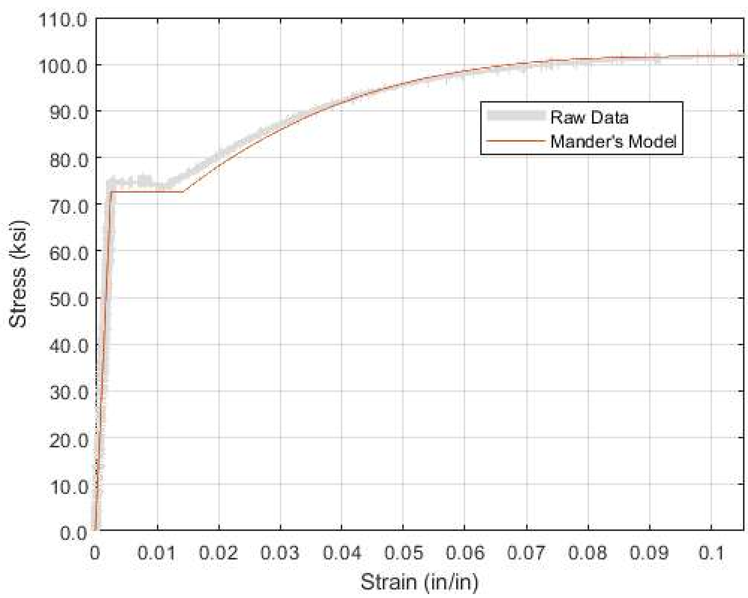
Question 3. Fit the Data to the Modified Mander's Model

Determine the power factor, P>1, through a least square error minimization procedure.

```
strain_range = [e_sh, e_su]; % Data range is from 0 to esu
[stress, strain] = get_data_for_range(strain_range);  % Get data

stress = movmean(stress, 91); % Assumed stress values; Varying this did not affect the P

P_trials = 1:0.2:8; % Selected powers for trial
sq_error = zeros(1,length(P_trials)); % Initialized sq erorr for results
i = 1; % Double loop counter- limitation of MATLAB (I'm joking)
for P = P_trials
    stress_guess = f_su - (f_su -fy) * ((e_su - strain)/(e_su- e_sh)).^P; % Generates the stress
    sq_error(i) = sum(sqrt((stress - stress_guess).^2)); % Calculates the sq. error
    i = i+1; % counter ++
end
P = P_trials(sq_error == min(sq_error));
close all;
plt = scatter(P_trials,sq_error); % As needed
datatip(plt,'DataIndex',find(sq_error == min(sq_error)),"Location","southeast"); % Min Point
xlabel("Powers"); ylabel("Squared Error");box on, grid on;
print_figure(9)
```



```
[model_stress, model_strain] = deal(linspace(0,e_su,1000)); % Initialize model strain range
i = 1;  % Double loop counter- limitation of MATLAB (I'm joking)
for epsilon = model_strain
    if epsilon <= e_sh % If the strain is before the start of the strain hardending
      model_stress(i) = min(fy, Es*epsilon); % Linear Function
      i = i+1;  % counter ++
    elseif epsilon >= e_sh && epsilon <= e_su % Else use the power function
      model_stress(i) = f_su - (f_su -fy) * ((e_su - epsilon)/(e_su- e_sh)).^P; % Mander's Model
      i = i+1; % counter ++
    end
end

close all
strain_range = [0, e_su]; % Data range
[stress, strain] = get_data_for_range(strain_range); % Get Data
plot_raw_data(strain, stress) % Plot
plot(model_strain, model_stress,"DisplayName","Mander's Model"); % Model data
print_figure(10)
```



Functions

```
function plot_datatips(pts, strain,stress,idx,range)
    % For that one figure ... spent too much time on this one
    pts.DataTipTemplate.Interpreter = 'tex';
    pts.DataTipTemplate.DataTipRows(1).Format = '%0.3g';
    pts.DataTipTemplate.DataTipRows(1).Label = '\epsilon';
    pts.DataTipTemplate.DataTipRows(2).Format = '%.2f';
    pts.DataTipTemplate.DataTipRows(2).Label = '\sigma';
    for pt = idx(range)'
        datatip(pts,strain(pt),stress(pt),"location","southeast");
    end
end

function [stress, strain] = get_data_for_range(range_)
    % Import the data but also cuts it into the range that I need
    opts = spreadsheetImportOptions("NumVariables", 4);
    opts.Sheet = "Data 2021";
    opts.DataRange = "A7:D5116";
    opts.VariableNames = ["Var1", "Stress", "Var3", "Strain"];
    opts.SelectedVariableNames = ["Stress", "Strain"];
    opts.VariableTypes = ["char", "double", "char", "double"];
    opts = setvaropts(opts, ["Var1", "Var3"], "WhitespaceRule", "preserve");
    opts = setvaropts(opts, ["Var1", "Var3"], "EmptyFieldRule", "auto");
    file = "C:\Users\Louis Lin\Workspace\Academic\UCSD\SE 211\Homework\HW 1\data\No 11 Bar Tensile Test 2021.xlsx";
    No11BarTensileTest2021 = readtable(file, opts, "UseExcel", false);

    % For the range I need
    stress = No11BarTensileTest2021.Stress; % Saves the stress data
```

```
    strain = No11BarTensileTest2021.Strain; % Saves the strain data
    strain_range = and(strain >= range_(1), strain<=range_(2)); % Selects a data range as specified
    stress = stress(strain_range);
    strain = strain(strain_range);
end

function plot_raw_data(strain, stress)
    % Formats the raw data plot consistently
    hold on; grid on; box on; % Per choice
    ylabel("Stress (ksi)"); xlabel("Strain (in/in)"); ytickformat('%.1f');
    axis([max(0,min(strain)),max(strain)+0.0001,max(0,round(min(stress),-1)-10),round(max(stress),-1)+10]) % Per choice
    raw_data = plot(strain,stress,"Color",[220,220,220]/255,'LineWidth', 5,'DisplayName',"Raw Data");
    raw_data.Color(4) = 0.3;% Raw Data alpha
    legend('Location',"best","Interpreter","tex");
end

function print_figure(no)
    % Saves the figures in a consistent manner
    orient(gcf,'landscape');
    folder = '..\figures\';
    name = 'Figure' +string(no);
    print(folder+name,'-dpdf','-PMicrosoft Print to PDF','-fillpage','-r600','-painters')
end
```