THE UNIVERSITY OF NORTH CAROLINA AT CHARLOTTE

ADVANCED MANUFACTURING PROCESSES AND EQUIPMENT

Wire Drawing Simulation For Advanced High Strength Steels

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1 Introduction

Advanced high-strength steels (AHSS) are a newer generation of steel grades which exhibits both high-strength and high formability over traditional high strength steels. Increased high-strength helps in reducing part thickness, while the increased formability allows for greater part complexity, which leads to fewer individual parts (cost savings) and more manufacturing flexibility. The AHSS family includes Dual Phase (DP), Complex-Phase (CP), Ferritic-Bainitic (FB), Martensitic (MS or MART), Transformation-Induced Plasticity (TRIP), Hot-Formed (HF), and Twinning-Induced Plasticity (TWIP). DP and TRIP steels are excellent in the crash zones of the car for their high energy absorption.

The project focuses on the wire drawing simulation including friction for DP 350/600 AHSS. The data for the instantaneous strain hardening exponent, n and engineering strain, e has been extrapolated using the existing data. The corresponding drawing stress, (σ_d) and die pressure, p is calculated and plotted against drawing distance. We have calculated the maximum friction value before the drawing operation fails. The code is developed and the simulation is performed on MATLAB.

2 Literature Review

New advanced high strength sheet steels are being developed for multiple applications majorly for automobile applications to reduce the weight so as to improve the fuel efficiency of the vehicle. AHSS is also being developed to improve the crash performance of vehicles and passenger safety. Dual phase (DP), transformation induced plasticity (TRIP), high strength low alloy (HSLA), complex phase (CP), twin induced plasticity (TWIP) and martensitic steels are being developed by varying the microstructural combinations of alloys and various different combinations are being applied to build these new generations AHSS.

Other than DP steels currently other materials such as CP steels and TRIP steels are being analyzed, these are known as first generations AHSS steels. Materials induced with plasticity (L-IP) and shear band strength steels (SIP) are known as second generation AHSS steels, this includes austenitic steels, lightweight steels, and TWIP.

So, development of AHSS is required to build lightweight and fuel-efficient vehicles. These steels are being developed by closely varying microstructures of the alloys being used to produce varied level of strength.

3 Relationship Between True Strain (e) and Engineering Strain (ϵ)

True Strain,

$$\epsilon = ln\frac{L}{L_0} \tag{1}$$

$$\epsilon = 2ln\frac{D}{D_O} \tag{2}$$

Engineering Strain,

$$e = \frac{L - L_0}{L_0} = \frac{L}{L_0} - 1 \tag{3}$$

$$e = \frac{D}{D_0} - 1 \tag{4}$$

where,

L_0 and D_0 is initial length and initial diameter

L and D is final length and final diameter

From equation 1 and equation 3, we find the relationship between true strain and engineering strain.

$$\frac{L}{L_0} = e + 1$$

$$ln\frac{L}{L_0} = ln(e+1)$$

$$\boxed{\epsilon = ln(e+1)} \tag{5}$$

$$\boxed{e = exp(\epsilon) - 1} \tag{6}$$

4 Relationship Between Engineering Strain (e) and Strain Hardening Exponent (n)

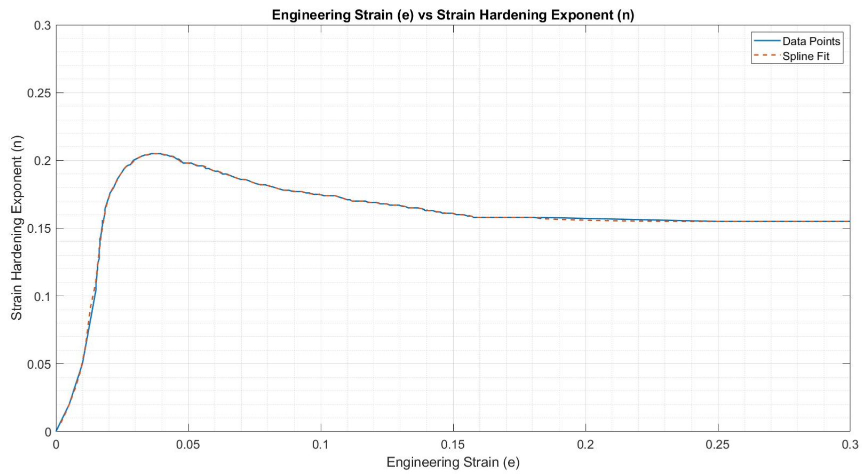

Figure 1: Extrapolation between Engineering strain (e) and Strain hardening exponent (n) at at limited span

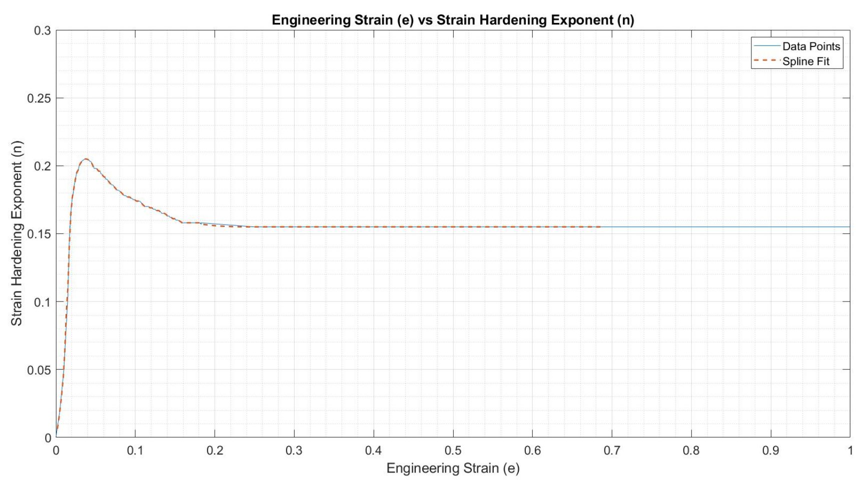

Figure 2: Extrapolation between Engineering strain (e) and Strain hardening exponent (n) at entire span

5 Drawing Stress (σ_d) and Die Pressure (p) at $\mu = 0$

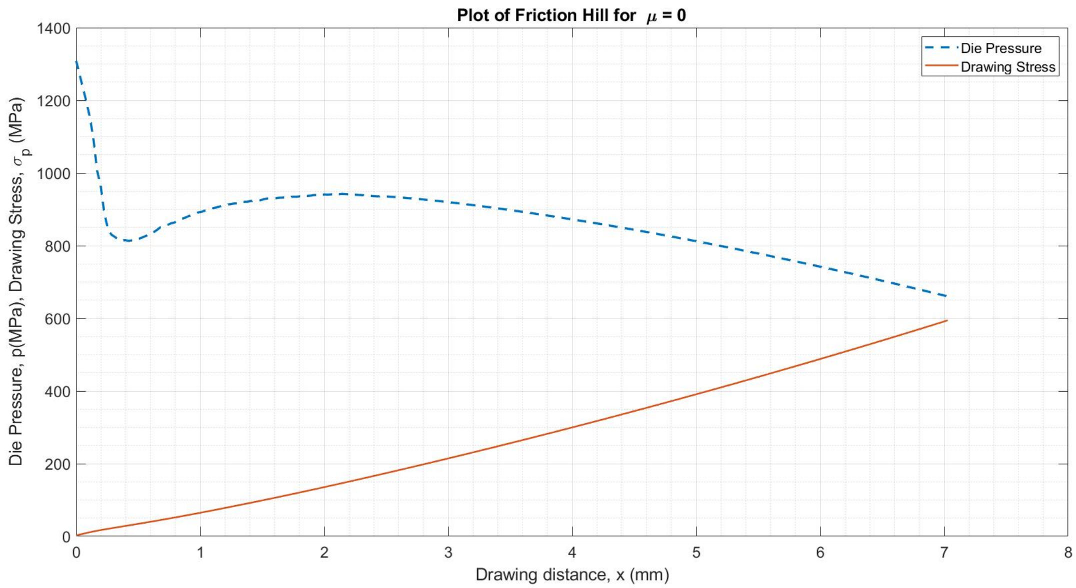

Figure 3: Drawing stress, σ_d (MPa), and die pressure, p (MPa), versus the drawing distance, x, (in mm) for $\mu = 0$

Parameter	Final Values (MPa)
Drawing Stress	594.4
Die Pressure	660.6

Table 1: Final Values of Drawing Stress (MPa) and Die Pressure (MPa) at $\mu = 0$

6 Drawing Stress (σ_d) and Die Pressure (p) at $\mu = 0.5$

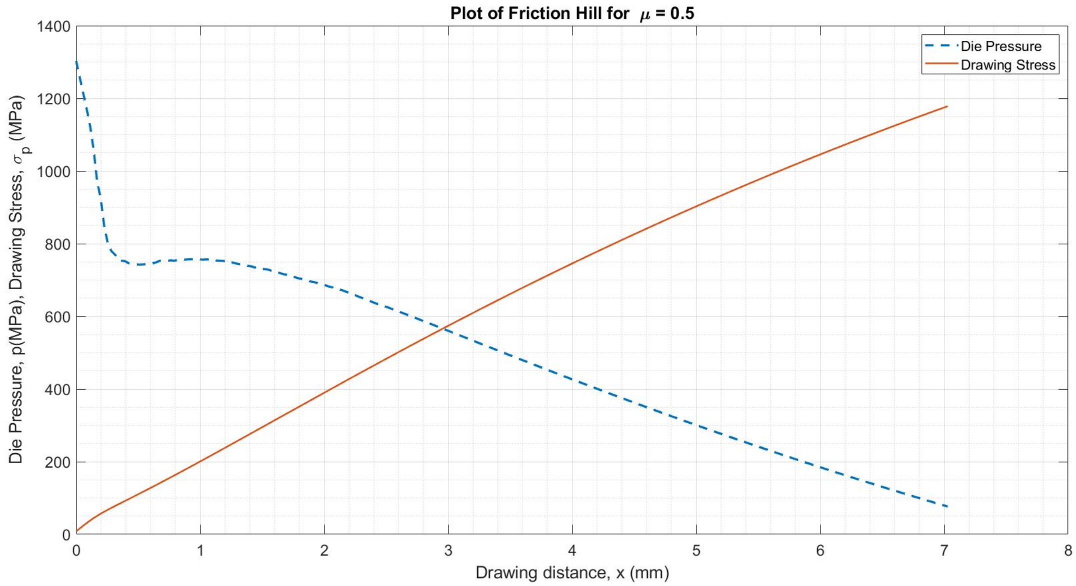

Figure 4: Drawing stress, σ_d (MPa), and die pressure, p (MPa), versus the drawing distance, x, (in mm) for $\mu = 0.5$

Parameter	Final Values (MPa)
Drawing Stress	1179
Die Pressure	76.41
Intersection Pressure	562.5

Table 2: Final Values of Drawing Stress (MPa) and Die Pressure (MPa) at $\mu = 0.5$

7 Maximum Allowable Friction Coefficient (μ_{max})

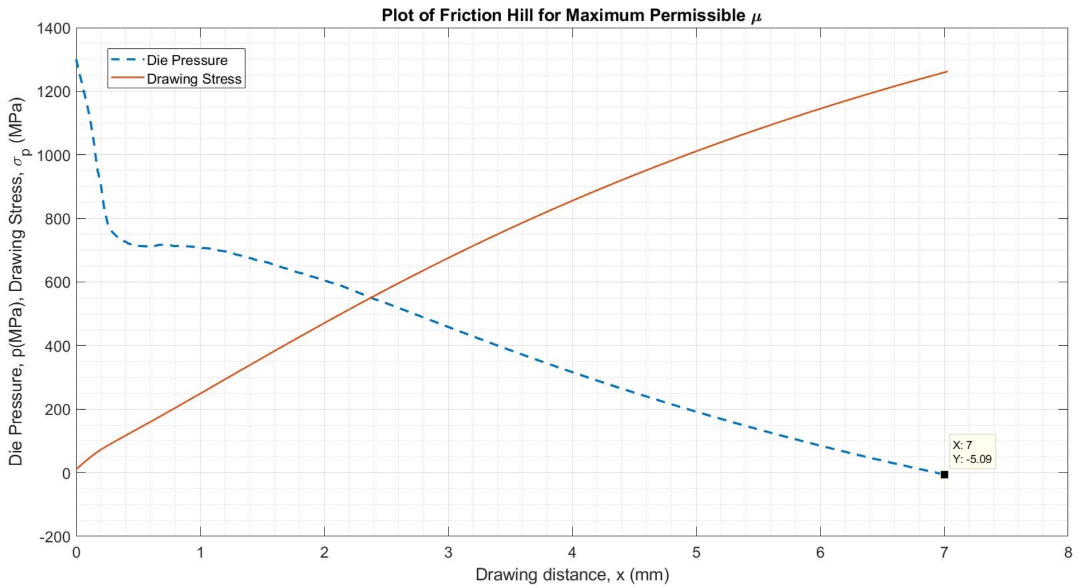

Figure 5: Drawing stress, σ_d (MPa), and die pressure, p (MPa), versus the drawing distance, x, (in mm) for maximum allowable μ

For $\mu \geq 0.7$ operation is not possible because the pressure becomes negative.

References

[1] Matlock, D.K., Speer, J.G., Moor, E., Gibbs, P.J., 2012. Recent developments in advanced high strength sheet steels for automotive applications: an overview. JESTECH 15, 1–12.

[2] Tlusty, J., 2000, Manufacturing Processes and Equipment, Prentice Hall, Upper Saddle River, NJ.

Appendix

MATLAB code

Contents

- For mu = 0;
- For mu = 0.5;
- Maximum Allowable mu

```
clc
clear all;
close all;
% Advanced Manufacturing Project Swagat Shah % Parth Thekdi
% Siddhesh Rajput

D0=13; % Initial Diameter % mm
D1=10; % Final Diameter % mm
D=D0;
steps = 250;
alpha = 12*pi/180; % Die angle % rad
dD=(D0-D1)/steps; % Increment in Diameter % mm
dx= dD/(2*tan(alpha)); % Increment in Drawing distance % mm
K = 1000; % Shape Factor
Y0 = 350; % Initial Yield Strength

% Predefine vectors used in the 'for' loop
eps=zeros(steps,1);

% Calculating the value of True Strain

for i = 1:steps
    D=D-dD; % Change in Diameter
    eps(i)=2*log(D0/D); % True Strain (Epsilon)
end

% Calculating the value of Engineering Strain

e=exp(eps)-1; % Engineering Strain

% Engineering Strain 'e' Data from Question

e_data=[0 0.5 1 1.516 1.515 1.513 1.529 1.543 1.574 1.571 1.636 1.634 1.631...
    1.664 1.662 1.66 1.693 1.725 1.724 1.756 1.753 1.771 1.82 1.852...
    1.849 1.882 1.915 1.948 1.981 2.014 2.046 2.113 2.18 2.247 2.313...
    2.38 2.447 2.515 2.582 2.683 2.819 2.92 3.124 3.226 3.363 3.466...
    3.602 3.774 3.945 4.083 4.186 4.323 4.427 4.496 4.565 4.634 4.703...
    4.807 4.978 5.116 5.219 5.323 5.426 5.563 5.667 5.77 5.874 6.011...
    6.132 6.287 6.442 6.563 6.683 6.821 6.976 7.131 7.285 7.406 7.544...
```

```
    7.716 7.905 8.077 8.266 8.421 8.61 8.799 8.954 9.108 9.28 9.435...
    9.572 9.727 9.847 9.967 10.105 10.259 10.396 10.534 10.689 10.861 10.999...
    11.102 11.188 11.308 11.411 11.548 11.685 11.788 11.926 12.029 12.132 12.235...
    12.338 12.475 12.613 12.716 12.853 12.956 13.094 13.197 13.301 13.403 13.541...
    13.678 13.884 13.953 14.091 14.228 14.365 14.503 14.606 14.743 14.846 14.984...
    15.121 15.258 15.396 15.533 15.67 15.774 15.877 15.979 16.151 16.288 16.425...
    16.597 16.7 16.837 17.077 17.214 17.42 17.523 17.66 17.797 17.934 18.071...
    18.329 18.208 25 30 40 50 75 100]/100;

% Strain Hardening Exponent 'n' data from Question

n_data=[0 0.02 0.05 0.105 0.107 0.109 0.111 0.115 0.12 0.123 0.128 0.132...
    0.135 0.137 0.14 0.142 0.144 0.148 0.149 0.152 0.156 0.154 0.158...
    0.161 0.164 0.166 0.168 0.17 0.172 0.174 0.176 0.178 0.18 0.183...
    0.186 0.188 0.19 0.192 0.194 0.196 0.197 0.2 0.202 0.203 0.204...
    0.204 0.205 0.205 0.205 0.204 0.204 0.203 0.203 0.202 0.201 0.201...
    0.2 0.198 0.198 0.198 0.197 0.196 0.196 0.196 0.194 0.194 0.193 0.192...
    0.192 0.19 0.19 0.189 0.188 0.187 0.186 0.186 0.185 0.184 0.183...
    0.182 0.182 0.181 0.18 0.179 0.178 0.178 0.177 0.177 0.177 0.176 0.176...
    0.175 0.175 0.175 0.174 0.174 0.174 0.174 0.173 0.172 0.171 0.171...
    0.17 0.17 0.17 0.17 0.17 0.169 0.169 0.169 0.169 0.168 0.168 0.168...
    0.167 0.167 0.167 0.167 0.166 0.166 0.165 0.165 0.165 0.165 0.164 0.163...
    0.163 0.163 0.162 0.162 0.161 0.161 0.161 0.161 0.16 0.16 0.16 0.159...
    0.159 0.158 0.158 0.158 0.158 0.158 0.158 0.158 0.158 0.158 0.158 0.158...
    0.158 0.158 0.158 0.158 0.158 0.158 0.157 0.158 0.155 0.155 0.155 0.155 0.155 0.155];

% Using Piecewise Cubic Hermite Interpolating Polynomial (pchip) fucntion
% to calculate Strain Hardening Exponent 'n' values

n=pchip(e_data, n_data, e);

% Plotting Engineering Strain 'e_data' & Strain Hardening Exponent 'n_data'
% values from the question given Plotting calculated Engineering Strain 'e'
% & Strain Hardening Exponent 'n' values for e values upto 1

figure(1)
plot(e_data,n_data)
hold on
plot(e,n,'--','LineWidth',1.5)
xlabel('Engineering Strain (e)')
ylabel('Strain Hardening Exponent (n)')
title('Engineering Strain (e) vs Strain Hardening Exponent (n)')
axis([0 1 0 0.3])
grid on
grid minor
legend('Data Points','Spline Fit')

% Plotting Engineering Strain 'e_data' & Strain Hardening Exponent 'n_data'
```

```
% values from the question given Plotting calculated Engineering Strain 'e'
% & Strain Hardening Exponent 'n' values for e values upto 1

figure(2)
plot(e_data,n_data,'LineWidth',1.5)
hold on
plot(e,n,'--','LineWidth',1.5)
xlabel('Engineering Strain (e)')
ylabel('Strain Hardening Exponent (n)')
title('Engineering Strain (e) vs Strain Hardening Exponent (n)')
axis([0 0.3 0 0.3])
grid on
grid minor
legend('Data Points','Spline Fit')
```

For mu = 0;

Calcuting the Die Pressure & Drawing Stress for mu=0 and Plotting the Friction Hill

```
mu = 0; % Coefficient of Friction
sigmax=0; % Stress in x-direction
D=D0;

% Predefine vectors used in the 'for' loop
YS=zeros(steps,1);
sigmad=zeros(steps,1);
dist=zeros(steps,1);
press=zeros(steps,1);

% Calculating Die Pressure & Drawing Stress at each Increment

for cnt = 1:steps
    YS(cnt) = Y0+ K*(eps(cnt)).^n(cnt); % Yield Strength % MPa
        % Change in Stress in x-direction
    dsigmax = (2*dD/D).*(YS(cnt)*(1+mu/tan(alpha))-(sigmax*mu/tan(alpha)));
    sigmax= sigmax + dsigmax;
    p = YS(cnt)-sigmax; % Die Pressure % Mpa
    D = D -dD; % Change in Diameter
    x = dx*(cnt-1); % Drawing Distance
    sigmad(cnt) = sigmax; % Final Drawing Stress at each Increment
    dist(cnt) = x; % Drawing Distance
    press(cnt) = p; % Final Die Pressure at each Increment
end

% Plotting Die Pressure & Drawing Stress vs Drawing Distance (Friction
% Hill)

figure(3)
```

```
plot(dist, press,'--','LineWidth',2)
hold on
plot(dist, sigmad,'LineWidth',1.5)
title('Plot of Friction Hill for  \mu = 0');
ylabel('Die Pressure, p(MPa), Drawing Stress, \sigma_p (MPa)')
xlabel('Drawing distance x (mm)')
legend('Die Pressure', 'Drawing Stress')
axis([0 8 0 1400])
grid on
grid minor
```

For mu = 0.5;

Calcuting the Die Pressure & Drawing Stress for mu=0.5 and Plotting the Friction Hill

```
mu = 0.5; % Coefficient of Friction
sigmax=0; % Stress in x-direction
D=D0;

% Calculating Die Pressure & Drawing Stress at each Increment

for cnt = 1:steps
    YS(cnt) = Y0+ K*(eps(cnt)).^n(cnt); % Yield Strength % MPa
        % Change in Stress in x-direction
    dsigmax = (2*dD/D).*(YS(cnt)*(1+mu/tan(alpha))-(sigmax*mu/tan(alpha)));
    % Change in Stress in x-direction
    sigmax= sigmax + dsigmax;
    p = YS(cnt)-sigmax; % Die Pressure % Mpa
    D = D -dD; % Change in Diameter
    x = dx*(cnt-1); % Drawing Distance
    sigmad(cnt) = sigmax; % Final Drawing Stress at each Increment
    dist(cnt) = x; % Drawing Distance
    press(cnt) = p; % Final Die Pressure at each Increment
end

% Plotting Die Pressure & Drawing Stress vs Drawing Distance (Friction
% Hill)

figure(4)
plot(dist, press,'--','LineWidth',2)
hold on
plot(dist, sigmad,'LineWidth',1.5)
title('Plot of Friction Hill for  \mu = 0.5');
ylabel('Die Pressure, p(MPa), Drawing Stress, \sigma_p (MPa)')
xlabel('Drawing distance x (mm)')
legend('Die Pressure', 'Drawing Stress')
axis([0 8 0 1400])
grid on
```

```
grid minor
```

Maximum Allowable mu

```
% Finding maximum allowable value of mu before the operation will fail by
% varying it from 0 to 1 in steps of 0.05

mu=0:0.05:1; % Range of mu

for i = 1:length(mu)
    sigmax=0; % Stress in x-direction
    D=D0;
    for cnt = 1:steps
        YS(cnt) = Y0+ K*(eps(cnt)).^n(cnt); % Yield Strength % MPa
                % Change in Stress in x-direction
        dsigmax = (2*dD/D).*(YS(cnt)*(1+mu(i)/tan(alpha))-(sigmax*mu(i)/tan(alpha)));
        sigmax= sigmax + dsigmax;
        p = YS(cnt)-sigmax; % Die Pressure % Mpa
        D = D -dD; % Change in Diameter
        x = dx*(cnt-1); % Drawing Distance
        sigmad(cnt) = sigmax; % Final Drawing Stress at each Increment
        dist(cnt) = x; % Drawing Distance
        press(cnt) = p; % Final Die Pressure at each Increment
    end
    if press(steps)<0
        disp({'Maximum Permissible Value of \mu is:', mu(i)})
        disp(mu(i))
        break
    end
end
figure(5)
plot(dist, press,'--','LineWidth',2)
hold on
plot(dist, sigmad,'LineWidth',1.5)
title('Plot of Friction Hill for Maximum Permissible \mu');
ylabel('Die Pressure, p(MPa), Drawing Stress, \sigma_p (MPa)')
xlabel('Drawing distance, x (mm)')
legend('Die Pressure', 'Drawing Stress')
grid on
grid minor
```

```
    'Maximum Permissible Value of mu'

    0.7000
```