TENSILE TEST - CODING ASSIGNMENT (C++).

MM 668 - COMPUTATIONAL METHODS FOR METAL FORMING ANALYSIS

Report Submitted

By

K Anand Naik

(Roll no: 213110031)

Supervisors:

Prof: K. Narasimhan

Metallurgical Engineering and Material Science Department

INDIAN INSTITUTE OF TECHNOLOGY, BOMBAY

(The year 2022)

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1. AIM

Designing a 1-Dimensional model to predict the Load Vs Elongation curve in a long metal rod using computer programming. Using this simulated model also predicts the effects of various parameters like n (strain hardening exponent), m (strain-rate sensitivity), heterogeneity factor and effect of nodes/mesh to get convergency, also validating them by changing their values.

2. DISCRETIZATION OF FLOW STRESS IN 1-DIMENSION

For the discretization, consider flow stress ($\boldsymbol{\sigma}$) which is a function of strain ($\boldsymbol{\epsilon}$), strain-rate ($\dot{\boldsymbol{\varepsilon}}$), strain hardening exponent (**n**) and strain-rate sensitivity (**m**) which is described below.

$$\boldsymbol{\sigma} = \mathbf{K}\, \boldsymbol{\epsilon}^{\boldsymbol{n}}\, \dot{\boldsymbol{\varepsilon}}^{\boldsymbol{m}} \quad \textbf{(1)}$$

3. ASSUMPTIONS

1. Rigid plastic material.

2. uniform strain throughout the sample while deforming (Under tensile loading).

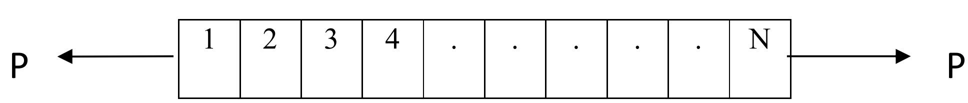
Note:

1. If the strain is uniform in the sample or test specimen, we will not observe any necking. thus, should be non-uniformity in strain throughout the sample to initiate the necking.

4. SIMULATING THE MODEL

4.1. TENSILE SAMPLE

Considering the power law equation and simulating to obtain the load vs extension curve in the plastic region only.



Here we have taken N = 100, i.e., number of steps or finite elements in the tensile sample with weakness factor f = 0.98-0.99.

4.2. GOVERNING EQUATION FOR BOTH STRAIN RATE EXPONENT (ϵ) AND STRAIN RATE SENSITIVITY ($\dot{\varepsilon}$) DEPENDENCY FOR STRESS.

Relation between initial area (a_i) and final area (A_i) of finite element at **i^th^** position.

Volume constancy: Volume of every or i^{th} element remain constant throughout the deformation.

$$a_i\, l_i = A_i\, L_j$$

$$a_i = A_i \left(\frac{L_j}{l_j}\right)$$

$$\ln a_i = \ln A_i + \ln \left(\frac{L_j}{l_j}\right)$$

$$\ln \left(\frac{a_i}{A_i}\right) = -\, \epsilon_i$$

$$\left(\frac{a_i}{A_i}\right) = \exp\,(-\,\epsilon_i)$$

$$a_i = A_i \exp\,(-\,\epsilon_i)$$

In the process of discretization, initially considered during the tensile test force in each element (N) will be equal. i.e.,

$$F_i = F_j$$

$$\boldsymbol{\sigma}_i\, a_i = \boldsymbol{\sigma}_j\, a_j$$

$$a_i\, \mathbf{K}\, \epsilon_{\boldsymbol{i}}^{\boldsymbol{n}}\, \dot{\varepsilon}_{\boldsymbol{i}}^{\boldsymbol{m}} = a_j\, \mathbf{K}\, \epsilon_{\boldsymbol{j}}^{\boldsymbol{n}}\, \dot{\varepsilon}_{\boldsymbol{j}}^{\boldsymbol{m}}$$

$$A_i \exp\,(-\,\epsilon_i)\;\; \epsilon_{\boldsymbol{i}}^{\boldsymbol{n}}\, \dot{\varepsilon}_{\boldsymbol{i}}^{\boldsymbol{m}} = A_j \exp\,(-\,\epsilon_j)\, a_j\;\; \epsilon_{\boldsymbol{j}}^{\boldsymbol{n}}\, \dot{\varepsilon}_{\boldsymbol{j}}^{\boldsymbol{m}}$$

a_i = instantaneous cross-section,

A_i= Initial cross-section,

L_j = Original length,

l_i = Instantaneous length,

K = Strength coefficient,

m = strain rate sensitivity,

n = strain hardening exponent,

Weakness factor f = $\left(\frac{A_N}{A_1}\right)$,

N = Number of Nodes or Number of finite elements.

Initial conditions:

1. Change in strain of (i) and (i+1) element will be same throughout the sample. That is

$$\mathbf{d\epsilon_i = constant.}$$

Boundary conditions:

1. Governing equation relates the quantities from 1st element to any other element by considering the absence initial elastic region. From the above governing equation, we can know the strain of 1st from which we can calculate any strain of ith element from **2 to N.**

5. TENSILE TEST CODING.

5.1. ASSUMING STRAIN RATE EFFECT (n ≠ 0 and m = 0).

$$A_i \exp(-\epsilon_i)\ \ \epsilon_i^n\ \dot{\epsilon}_i^m = A_j \exp(-\epsilon_j)\ a_j\ \ \epsilon_j^n\ \dot{\epsilon}_j^m$$

$$A_i \exp(-\epsilon_i)\ \ \epsilon_i^n = A_j \exp(-\epsilon_j)\ a_j\ \ \epsilon_j^n$$

$$\epsilon_j^n = \frac{A_i \exp(-\epsilon_i)\ \ \epsilon_i^n}{A_j \exp(-\epsilon_j)\ a_j}$$

So, from the data of load (P) and extension (e) obtained from the below C++ code we can construct the plot Load (P) vs Extension (e), which are mentioned below

```
#include<bits/stdc++.h>
// The above header file has all functions in it to simplify each task.

using namespace std;
double root (double q, double a)
// Bisection Method for calculation of Roots
{
   double x1=0, x2=0.2, x3, fx1, fx2, fx3, n=0.2;
   for (int j=0; j<50; j++)
   {
      x3=(x1+x2)/2;
      fx1 = pow (x1, n) *a*exp(-x1)-q;
      fx2 = pow (x2, n) *a*exp(-x2)-q;
      fx3 = pow (x3, n) *a*exp(-x3)-q;
      if(fx3==0)
      {
         break;
      }
      else if (fx1 * fx3 <0)
      {
         x2=x3;
      }
      else
      {
         x1=x3;
      }
   }
   return(x3);
```

```
}
int main()
{
        double f=0.99,
        edot[50],
        e[50],
        dt=0.01,
        a[50],
        q,
        n=0.2,
        gl=50,
        delta,
        fl[50],
        p,
        int N=50,i,j,t;
        a[50]=40;
// Calculating the area of each element
   for(i=1;i<50;i++)
      a[i]=a[50]*(((i/50)*(1-f))+f);
      edot[50]=0.001;
   for(t=1;t<=2000;t++)
   {
      e[50]=edot[50]*dt*t;
      q=pow(e[50],n)*a[50]*exp(-e[50]);
      delta=0;
// Load Calculation
      p=200*pow(e[50],n)*a[50];
// Calculating the elongation
      for(j=1;j<50;j++)
      {
        e[j]=root(q,a[i]);
        fl[j]=e[j];
        delta=delta+fl[j];
      }
   }
return (0);
}
```

Plots of Load (P) Vs Extension (e) from the data obtained from the above C++ code.

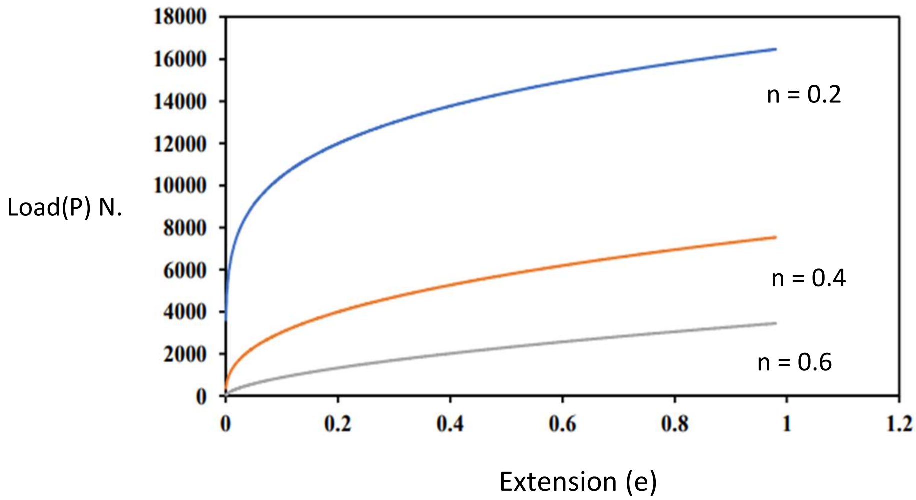


Figure 1. Load (P) Vs Elongation (e) plot with various n values.

1. RESULT: As the value of **n increases** the Load (P) vs Elongation (e) curve will shifts down. The above curves were illustrated at n = 0.2, 0.4 and 0.6.

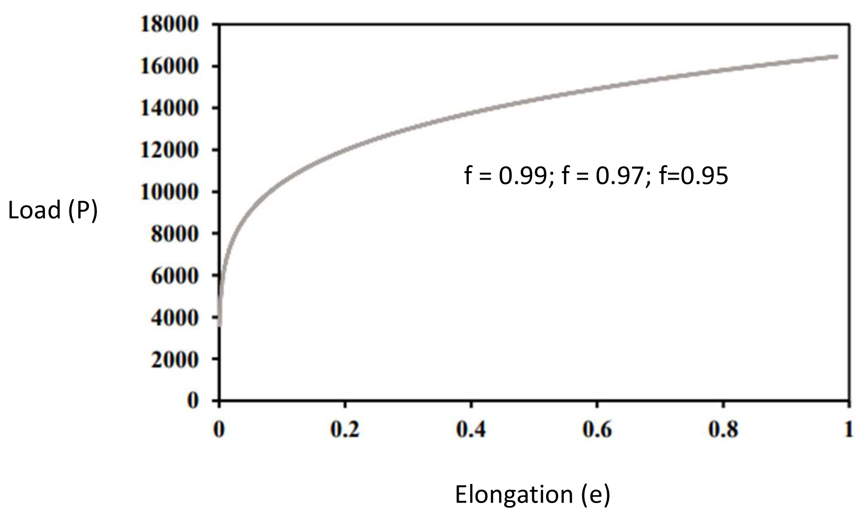


Figure 2. Load (P) Vs Elongation (e) plot with various weakness (f) factors.

2. RESULT: There will be no significant change in the Load (P) Vs Extension (e) curve as the value of weakness factor (f). The above curves were illustrated at f = 0.99, 0.97 and 0.95.

5.2. ASSUMING BOTH STRAIN-RATE SENSITIVITY (M) AND STRAIN RATE EXPONENT (N).

$$A_i \exp(-\epsilon_i)\ \ \epsilon_i^{n}\ \dot{\varepsilon}_i^{m} = A_j \exp(-\epsilon_j)\, a_j\ \ \epsilon_j^{n}\ \dot{\varepsilon}_j^{m}$$

$$\dot{\varepsilon}_j^{m} = \frac{A_i \exp(-\epsilon_i)\ \ \epsilon_i^{n}\ \dot{\varepsilon}_i^{m}}{A_j \exp(-\epsilon_j)\, a_j\ \ \epsilon_j^{n}}$$

$$\dot{\varepsilon}_j = \left[\frac{A_i \exp(-\epsilon_i)\ \ \epsilon_i^{n}\ \dot{\varepsilon}_i^{m}}{A_j \exp(-\epsilon_j)\, a_j\ \ \epsilon_j^{n}}\right]^{\frac{1}{m}}$$

Similarly, as done in the case of stain-rate dependency, from the data of load (P) and extension (e) obtained from the below C++ code we can construct the plot Load (P) vs Extension (e), which are mentioned below.

```
#include<bits/stdc++.h>
// The above header file has all functions in it to simplify each task.
using namespace std;
int main()
{
    float n=0.2,m=0.2,k=200,gl=50,f=0.99,N=50;
    int i,len=2000;
    float t[len],
          A[50],
          te[len],tp[len],e[len][50],edot[len][50],el[len][50],
          l[len][50],p[len] [50],x[50];

// Calculating the Load (P) values.
   for(i=1;i<len+1;i++)
   {
   t[i]=i;
   }
   for(i=1;i<(N+1);i++)
   {
      x[i]=((i)/gl)*(1-f);
      A[i]=40*(x[i]+f);

   int j=1;
      for (i=j+1;i<N+1;i++)
```

```
        {
            e[j][i]=0;
            e[1][1]=0;
            edot[1][1]=0.000125;
            edot[j][i]=edot[j][i-1]*pow((A[i-1]/A[i]),(1/m));
            p[j][i]=k*pow(e[j][i],n)*pow(edot[j][i],m)*A[i];
        }
    }

// Calculating the Elongation values.
    for (j=2;j<len+1;j++)
    {
        for (i=2;i<N+1;i++)
        {
        edot[j][1]=0.000125;
        e[j][1]=edot[j][1]*t[j];
        e[j][i]=(edot[j-1][i]*(t[j]-t[j-1]))+e[j-1][i];
        edot[j][i]=edot[j][i-1]*pow((A[i-1]/A[i]),(1/m))*pow((e[j][i-1]/e[j][i]) ,
(n/m))*pow((exp(e[j][i]-e[j][i-1])),(1/m));
        p[j][i]=k*pow(e[j][i],n)*pow(edot[j][i],m)*A[i]*exp(-e[j][i]);
        }
    }
    for (j=1;j<len+1;j++)
        {
        for (i=1;i<N+1;i++)
        {
            l[j][i]=exp(e[j][i])*gl;
            el[j][i]=(l[j][i]-gl)/gl;
        }
    }
    for (j=1;j<len+1;j++)
    {
        i=2;
        tp[j]=p[j][i];
    }
    for (j=1;j<len+1;j++)
        for (i=1;i<N+1;i++)
            te[j]=te[j]+el[j][i];
            for(j=1;j<len+1;j++)
                ob<<tp[j]<<"\t"<<te[j]<<endl;

}
```

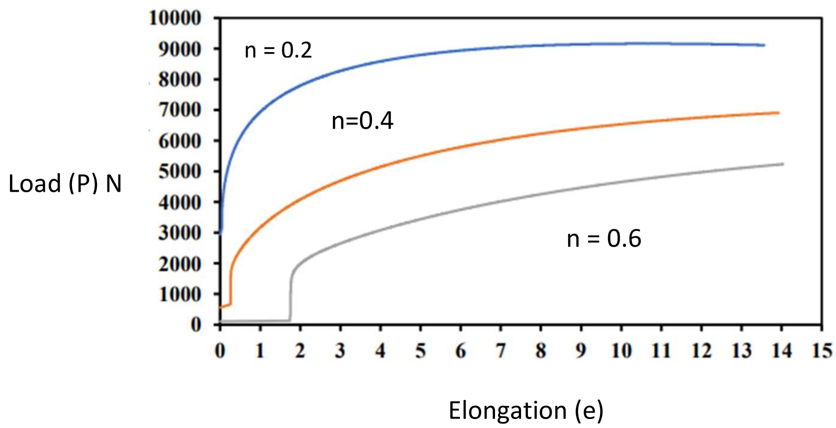


Figure 3. Load (P) Vs Elongation (e) plot with various n values.

3. RESULT: Similarly in the previous case, the Load (P) Vs Elongation (e) curve will shift down as the values of **n increase.**

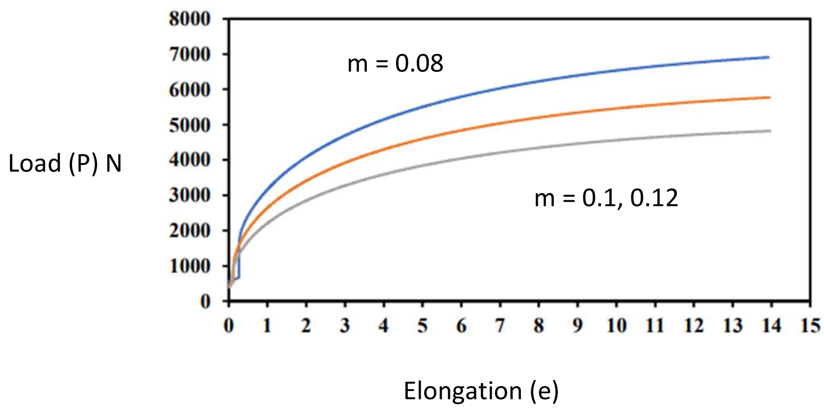


Figure 4. Load (P) Vs Elongation (e) plot with various m values.

4. RESULT: Here in the case of strain-rate sensitivity there is a similar effect observed as in the case of previous results. That is, if we increase the value of strain-rate sensitivity value (m), we can observe the lowering in the Load (P) vs Elongation curve.

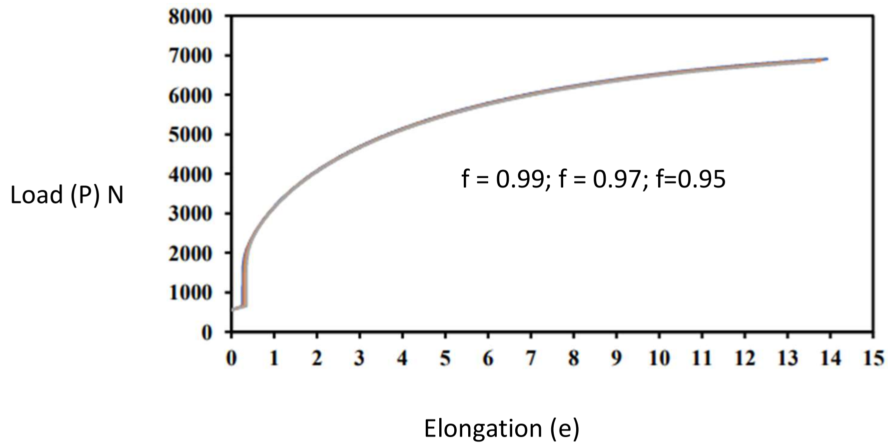


Figure 5. Load (P) Vs Elongation (e) plot with various weakness (f) factors.

4. RESULT: As the values of weakness factor (f) increase or decrease there will be no change in the behaviour of the curve. i.e., no change in the values of Load Vs Elongation.

6. SUMMARY

The one-Dimensional uniaxial-tensile testing simulation had been done using C++ programming language. The entire model is written with a C++ script. Also, the study of Load (P) Vs Elongation (e) behaviour upon various parameters like strain hardening exponent (n), strain-rate sensitivity (m) and weakness factors (f). while analysing these results, form close observation in both strain hardening exponent and strain-rate sensitivity dependency Load (P) Vs Elongation (e) get shifted down. Similarly, as the weakness factor decrease, there is no significant change in the Load (P) Vs Elongation (e) curve in the case of strain hardening exponent (n) dependency, but there is a slight shift in the curve in the case of strain-rate sensitivity (m) dependency Load (P) Vs Elongation (e) curve.

7. REFERENCES

[1] Class-Lectures (MM-668) of Prof: K. Narasimhan, Material Science and Metallurgical Engineering, Indian Institute of Technology, Bombay.