FEA Based comparative analysis of Tube Drawing Process

Prof. J.Y. Acharya
Department of Mechanical, Mumbai University / RSCOE, Chiplun, India
jitu.ach@gmail.com
Prof. S. Magbul Hussein
HOD, Department of Mechanical, JNTUH University / HMIT, Hyderabad, India.

Abstract

Finite element analysis (FEA) simulations are extensively used in tube manipulation processes such as tube drawing, sinking and extrusion.FEA is one of the most important methods to simulate metal forming. This work aims to find the best geometry of die and plug to reduce the drawing force, and also find the residual stresses in the tube using FEA. Die has been designed with different semi-die angle and plug configurations which are all analyzed through FEA. Geometric, contact to contact surface and material nonlinearity are involved in this problem. The material of pipe used is steel, die and plug material used is tungsten carbide. In tube drawing, the optimum semi-die angles are identified using FEA. In this work, the cold drawing of tubes with fixed plug was simulated by using the commercial software Altair Hyper mesh for pre-processing and Simuilia Abacus for solving and post processing of this study. The project intends to determine the drawing force and stress, and also helps in reducing lead time and try outs and providing products free of defects and with controlled mechanical properties.

Keywords: *Cold tube drawing, finite element analysis, die design, upper bound solution*

Introduction

Superior quality products with precise dimensions, good surface finish and specified mechanical properties can be obtained with drawing processes. The material of pipe is steel and the material of die and the plug is tungsten carbide. The friction between the outer surface of the tube and the die and between the inner surface of the tube and the plug has been modelled by Coulomb friction. Besides, the change in the diameter of the tube has been considered negligible during the process, then, the forming process can be assumed that it is made under a state of plane strain condition. After the analysis we are able to know the force required to draw a tube, the stress distribution

In this study, we present a tool device specially designed to reduce drawn force, formed by two dies assembled within a recipient which can be sealed, generating a pressurized lubrication during the process. Die and plug geometry are obtained from the numerical simulation. Experimental tests with this tooling in a laboratory drawing bench were performed, using three different lubricants and pressurized and unpressurized lubrication. The experimental results were compared to numerical results and the performance of the process was analyzed with a statistical model.

Nomenclature

Ri = external inlet radius of the tube
Rii = internal inlet radius of the tube
Rf = external outlet radius of the tube
Rf = internal outlet radius of the tube
L = bearing length
Wh = Homogeneous work
Wr = redundant work

Wa = friction work

Greek Symbols

a = die semi-angle
ap = plug semi-angle
dp = nib diameter
b = semi-angle of the internal cone of the tube after drawing without plug
e = true strain
m1 = Coulomb friction between tube and die
m2 = Coulomb friction between plug and tube
s = stress
stref =drawing stress
s0 = average yield stress
t1 = Velocity surface discontinuity on inner die
t2 = Velocity surface discontinuity on outer die
t3 = Contact surface in the work zone at die/work piece interface
t4 = Contact surface in the die bearing/work piece interface
t5 = Contact surface in the plug bearing/work piece interface
t6 = contact surface in the work at zone plug/work piece interface

Plug Geometry

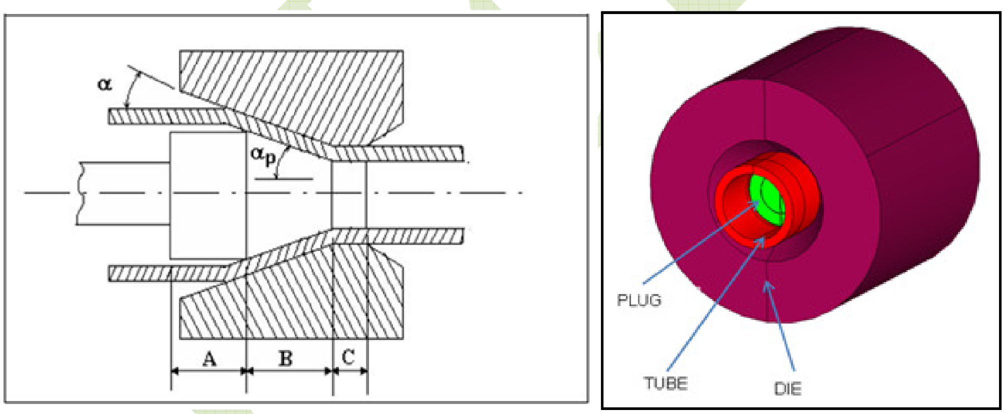


Fig. 1 Plug geometry and CAD model

Plug geometry is shown in Fig. 1. The region A is a cylindrical portion to position the plug inside the die. Its diameter is slightly smaller than the tube inner diameter. The plug semi-angle (ap) in the work zone B is smaller than die semi-angle (a). It is defined to be 2 degrees or smaller than die semi-angle. Region C, called 'nib', is cylindrical and controls the inner diameter of the tube. In the present study the wall thickness of the tube was reduced by 0.1 mm. The length of the nib was fixed in 2 mm for all tests. [1]

Finite Element Model

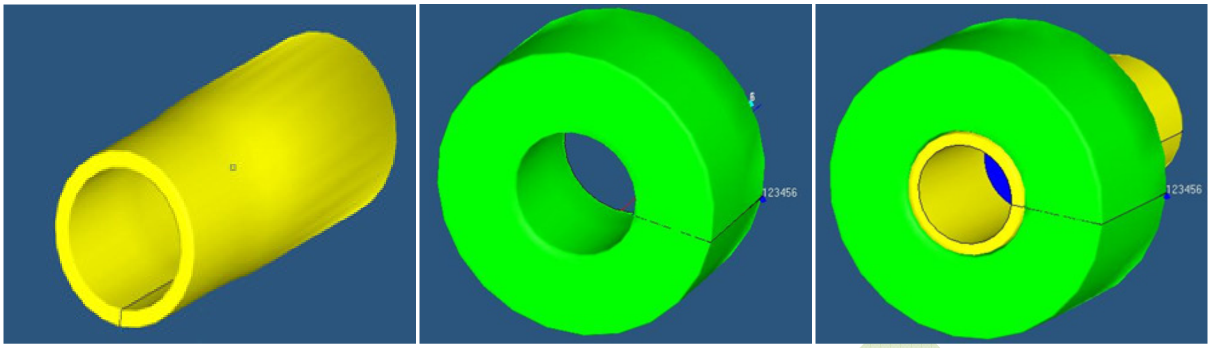


Fig 2. The geometry of the plug.

The outer diameter of the plug is 210mm. The plug is cylindrical in shape. The material of the plug used is tungsten carbide. The figure 2 shows the geometry of the tube. The initial outer diameter & inner diameter of tube are 273 mm & 223 respectively. After the tube is been processed the final dimensions of the tube will be outer diameter = 260mm, and inner diameter = 210mm and the length is 700mm.The material of the tube used is steel. The figure 2 shows the geometry of the die. The die material used is tungsten carbide. The outer diameter of the die is 360mm, inner diameter is mm. The die consists of a semi die angle (6, 7, and 8). The figures 2 show the assembly of the plug, tube and the die as in the process. The figure 2 shows the section of the assembly which makes it convenient to carry out the analysis. An elasto-plastic model was used for the material of the tube. Tensile tests of stainless A304 steel tubes were carried out to obtain the stress-strain curve (s x e) to be used in the simulation. This stress-strain curve was approached by Holloman's equation as shown in Eq. (1).

s = 1137 e0,52 [MPa] (1)

Young modulus of 210 GPa and a Poisson ratio of 0.3 were defined to the tube material, which was assumed to be isotropic and insensitive to strain rate. During experimental drawing it was noticed that the temperature at the tube was not higher than 100 ºC, thus allowing the tube material to be modeled independent on the temperature.

Experimental Design

To evaluate the drawing force, a random factorial analysis was designed with the following variables:

- Lubricants: commercial mineral oil, semi-synthetic oil, and mineral oil with extreme pressure additives;
- Drawing speed: 1 m/min; 2 m/min and 5 m/min;
- Lubrication: Pressurized and not-pressurized.

FEM Analysis

PROCESS PARAMETERS

The process variables are:

1. Initial Dimensions of the pipe
    - Outer diameter: 273 mm
    - Inner diameter: 223 mm
    - Length of pipe: 700 mm.
    - Thickness: 13 mm
2. Final dimensions of pipe
    - Outer diameter: 260 mm

- Inner diameter: 210 mm
- Thickness: 13 mm

3. Dimensions of die.
   - Semi die angle: 6, 7, 8
   - Outer diameter: 360 mm
   - Inner diameter: 260 mm
4. Dimensions of plug.
   - Outer diameter: 210 mm
5. Co efficient of friction.
   - 0.
   - 0.05.
   - 0.1.
   - 0.15.
   - 0.2.

MATERIALS SPECIFICATION

Sl. No:	Material Name	Density (Tonne/mm^3)	Young's Modulus (N/mm^2)	Poisson's Ratio
1	**Steel - 4340**	**7.85e-9**	**210e3**	**0.3**
2	**Tungsten**	**15.0e-9**	**700e3**	**0.2**

Table no.1: Materials properties

Units Used

Geometry— in mm
Density——Ton/mm^3
Stress —— MPa
Force —— N

Mechanical Properties

Tensile Strength, Ultimate: 745 MPa
Tensile Strength, Yield : 470 MPa
Modulus of Elasticity : 210000 MPa
Bulk Modulus : 140000 MPa
Poisson's Ratio : 0.30
All Dimensions in mm

After completion of preparation of Finite Element model i.e., preparation of CAD model, meshing & applying boundary condition a solvers' work begins. The finite element model from the Hyper Mesh (.INP file) is exported to the Simulia Abaqus software as an input file to run the analysis. Abaqus viewer software is used to view the results. The analysis is carried out for a combination die semi angle 6, 7, 8 at various frictions (0, 0.05, 0.1, 0.15, 0.2), and then the stress and drawing force obtained from the analysis for die semi angle 6, 7, 8 are compared and the optimized values of them are chosen for best geometry which reduces lead time and try outs and providing products free of defects and with controlled mechanical properties.

CASE 1: Die semi angle 6 Degree and Friction (0, 0.05, 0.1, 0.15, 0.2)

1. **Friction 0**

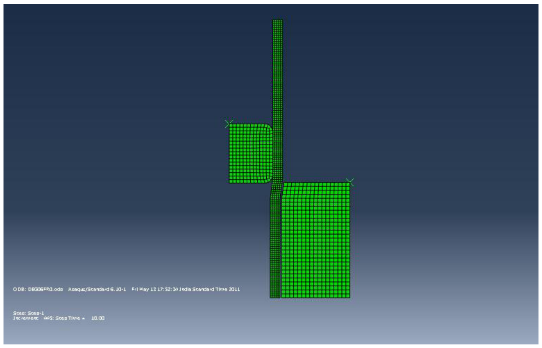


Figure 3.1: Initial step at 6 degree and friction 0

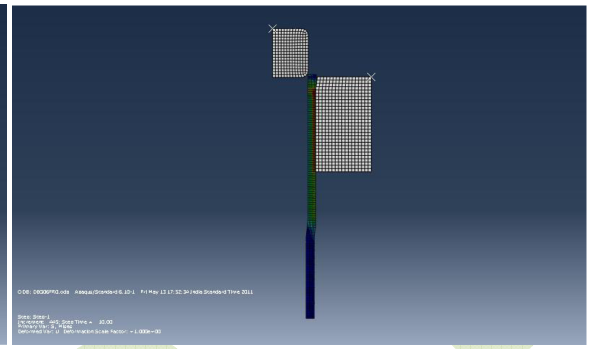


Figure 3.2: Final step at 6 degree and friction 0

2. **Friction 0.05**

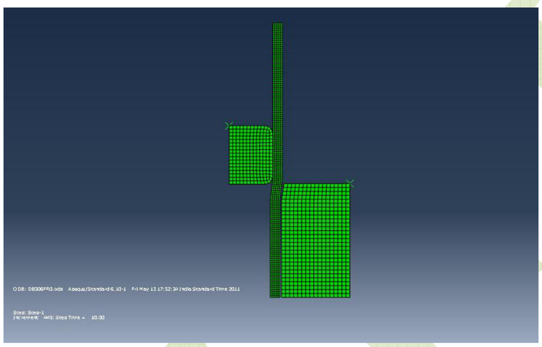


Figure 3.3: Initial step at 6 degree and friction 0.05

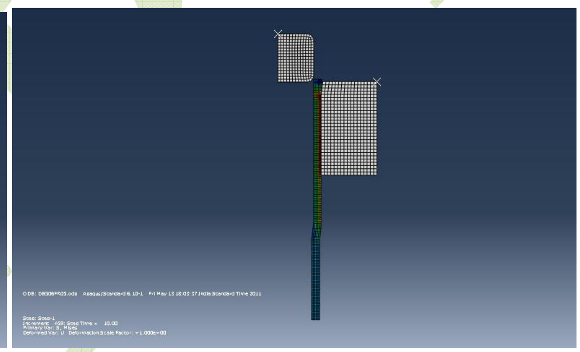


Figure 3.4: Final step at 6 degree and friction 0.05

3. **Friction 0.1**

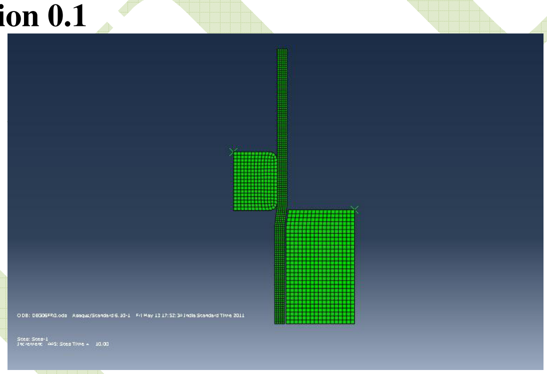


Figure35: Initial step at 6 degree and friction 0.1

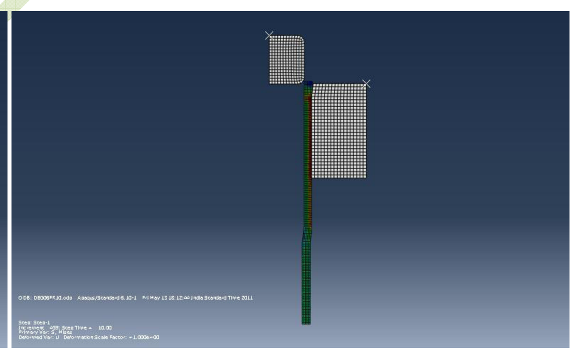


Figure 3.6: Final step at 6 degree and friction 0.1

4. **Friction 0.15**

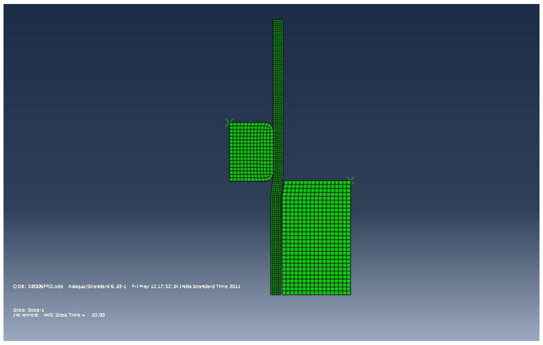
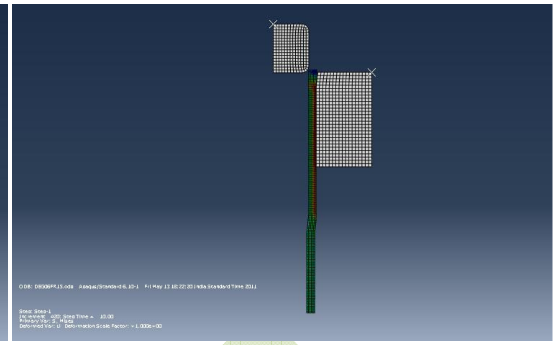



Figure 3.7: Initial step at 6 degree and friction 0.15Figure3.8: Final step at 6 degree and friction 0.15

5. **Friction 0.2**

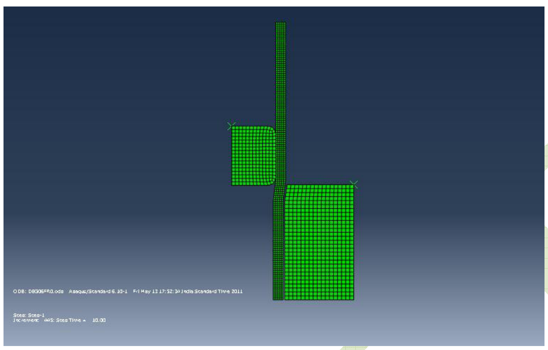
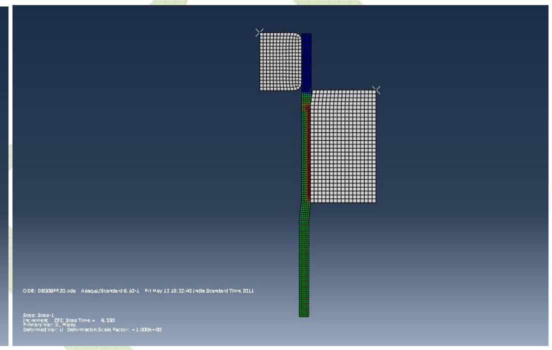
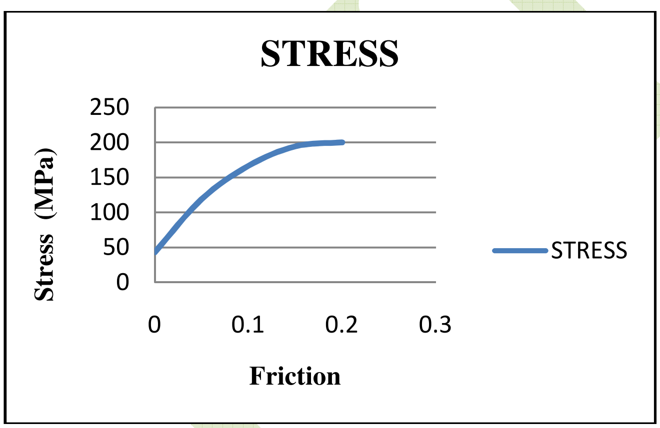



Figure 3.9: Initial step at 6 degree and friction 0.2Figure 3.10: Final step at 6 degree and friction 0.2

RESULT OF CASE 1:

The below graph of stress and drawing force are obtained from the above analysis of model at die semi angle of 6 degrees and friction (0, 0.05, 0.1, 0.15, 0.2).



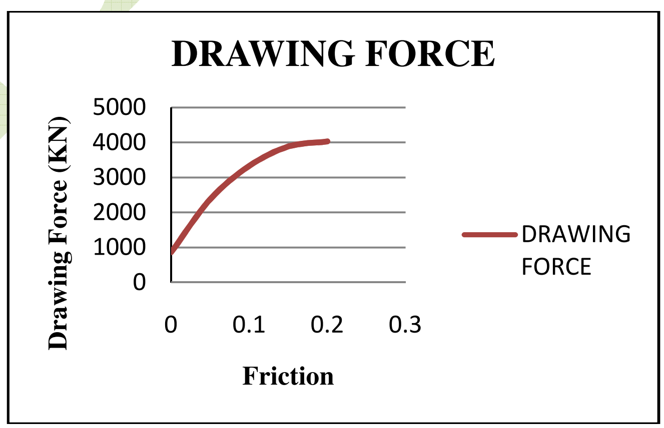


Figure 3.11: Stress graph for case 1 Figure 3.12: Drawing Force graph for case 1

CASE 2: Die semi angle 7 Degree and Friction (0, 0.05, 0.1, 0.15, 0.2)

1. **Friction 0**

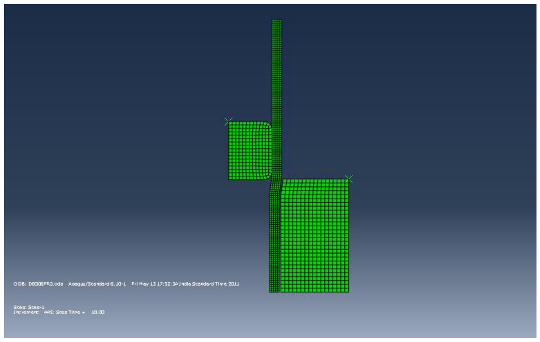
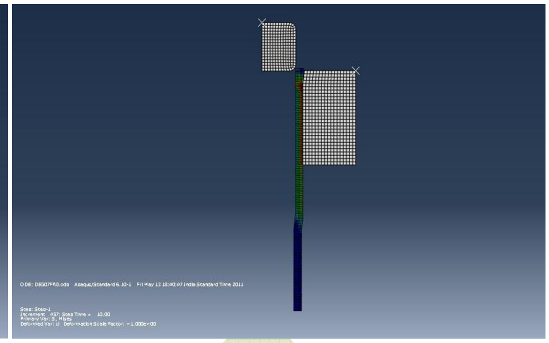



Figure 3.13: Initial step at 7 degree and friction 0Figure3.14: Final step at 7 degree and friction 0

2. Friction 0.05

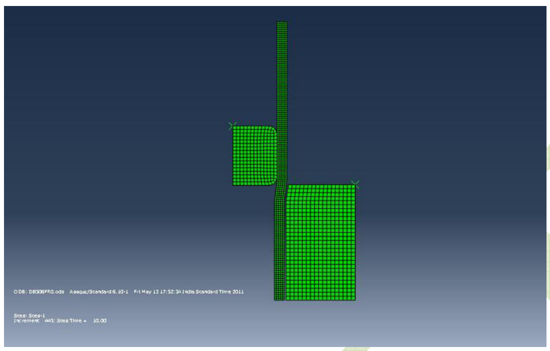
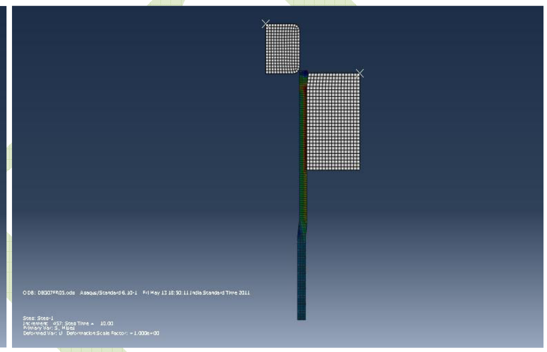



Figure 3.15: Initial step at 7 degree and friction 0.05Figure 3.16: Final step at 7 degree and friction 0.05

3. Friction 0.1

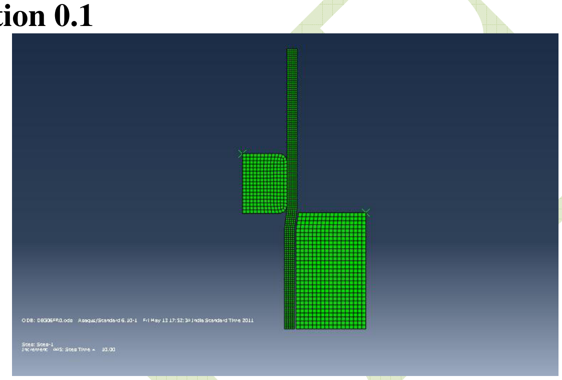
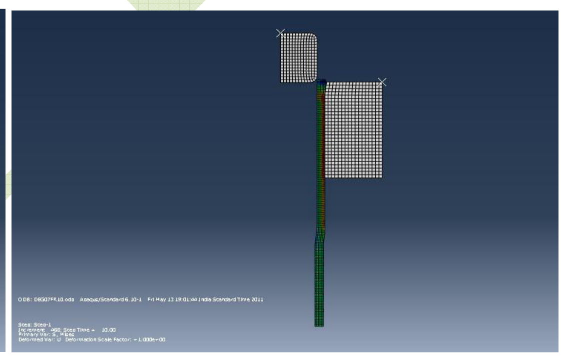
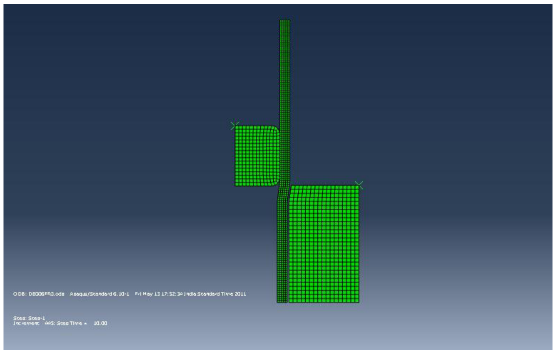



Figure 3.17: Initial step at 7 degree and friction 0.1Figure 3.18: Final step at 7 degree and friction 0.1

4. Friction 0.15



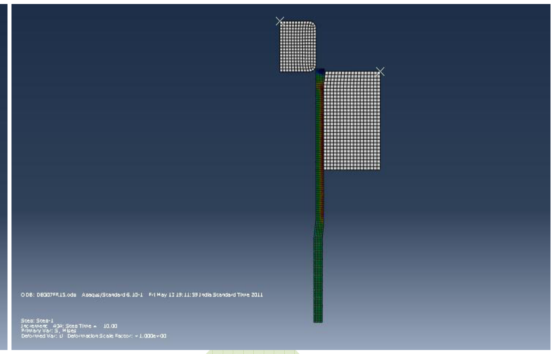
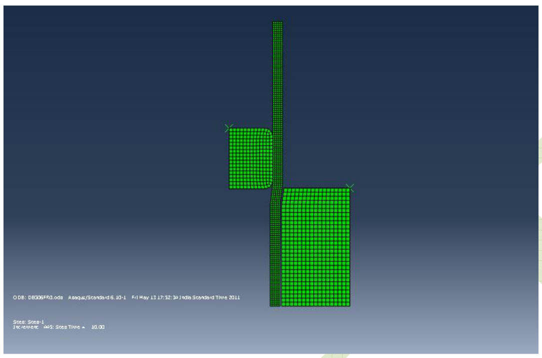


Figure 3.19: Initial step at 7 degree and friction 0.15Figure 3.20: Final step at 7 degree and friction 0.15

5. **Friction 0.2**



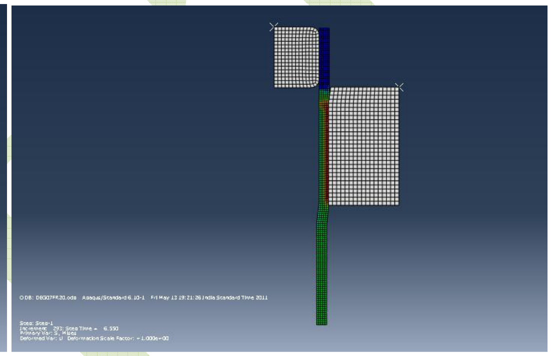
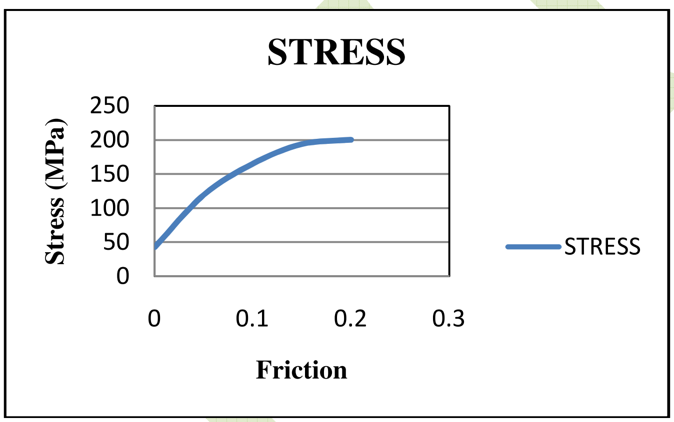


Figure 3.21: Initial step at 7 degree and friction 0.2Figure 3.22: Final step at 7 degree and friction 0.2

RESULT OF CASE 2:

The below graph of stress and drawing force are obtained from the above analysis of model at die semi angle of 7 degrees and friction (0, 0.05, 0.1, 0.15, 0.2).



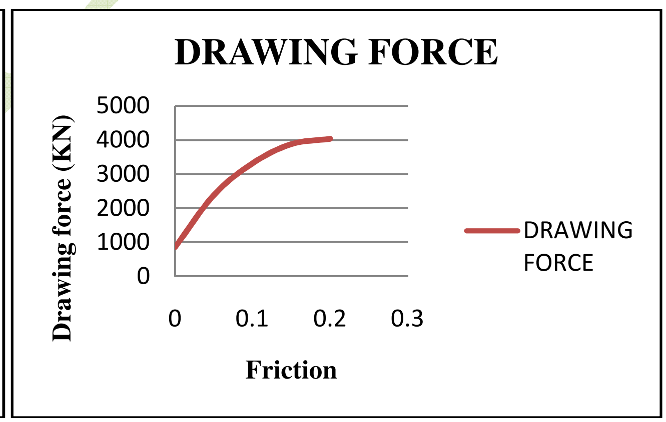


Figure 3.23: Stress graph for case 2 Figure 3.24: Drawing Force graph for case 2

CASE 3: Die semi angle 8 Degree and Friction (0, 0.05, 0.1, 0.15, 0.2)

1. **Friction 0**

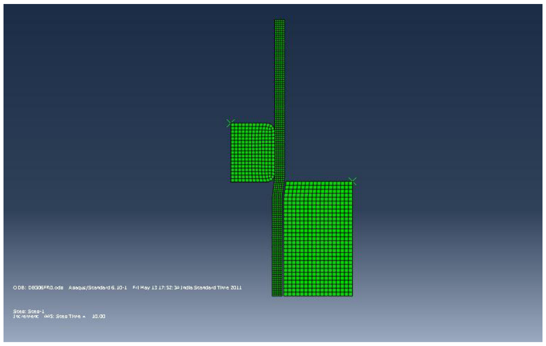
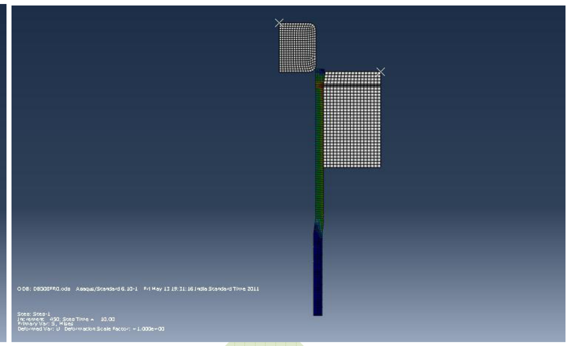



Figure 3.25: Initial step at 8 degree and friction 0 Figure 3.26: Final step at 8 degree and friction 0

2. **Friction 0.05**

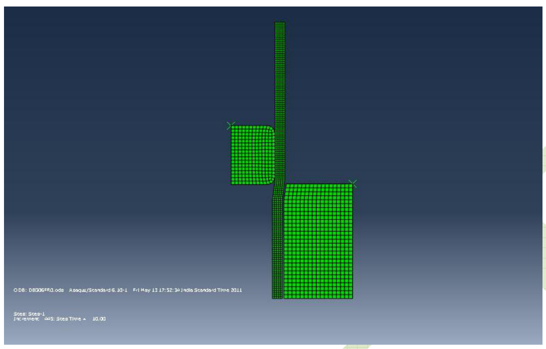
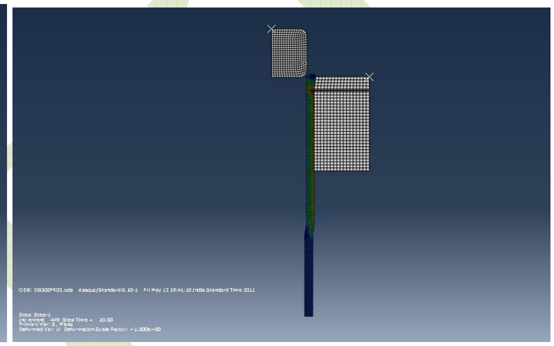



Figure 3.27: Initial step at 8 degree and friction 0.05Figure 7.28: Final step at 8 degree and friction 0.05

3. **Friction 0.1**

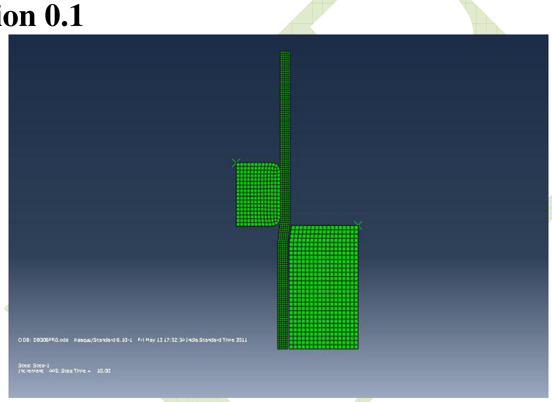
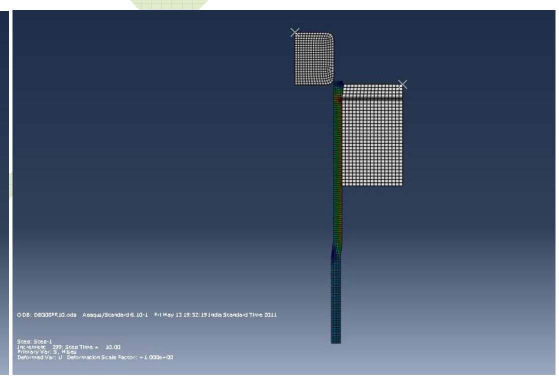



Figure 7.29: Initial step at 8 degree and friction 0.1Figure 7.30: Final step at 8 degree and friction 0.1

4. **Friction 0.15**

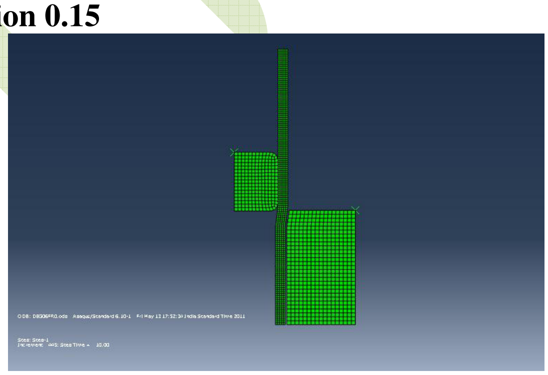
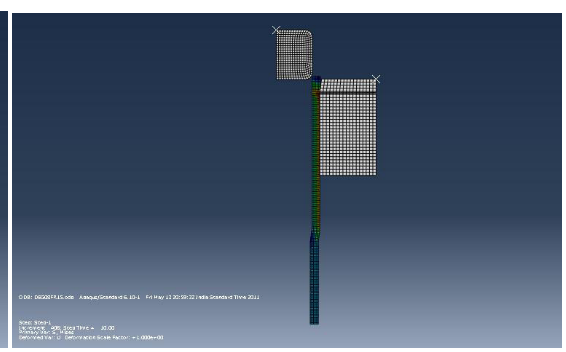



Figure 7.31: Initial step at 8 degree and friction 0.15Figure 7.32: Final step at 8 degree and friction 0.15

5. Friction 0.2

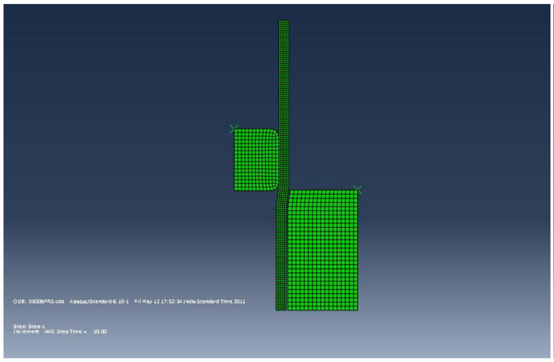
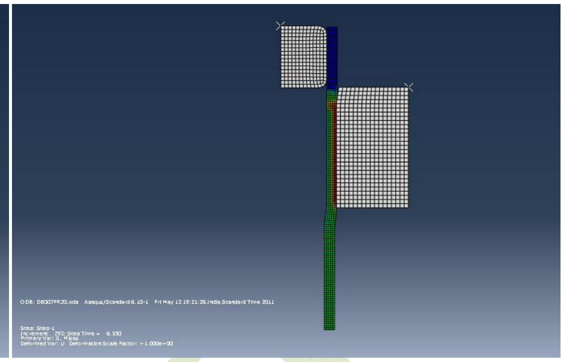
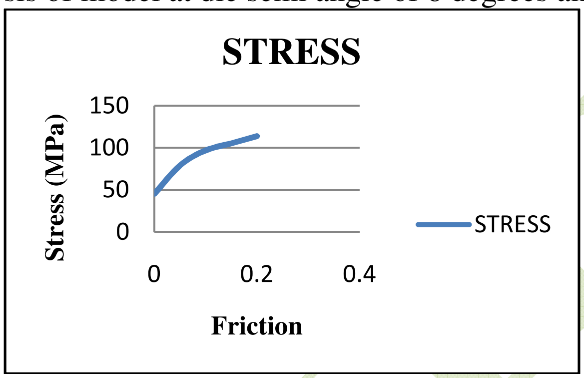



Figure 7.33: Initial step at 8 degree and friction 0.2Figure 7.34: Final step at 8 degree and friction 0.2

RESULT OF CASE 3: The below graph of stress and drawing force are obtained from the above analysis of model at die semi angle of 8 degrees and friction (0, 0.05, 0.1, 0.15, 0.2).



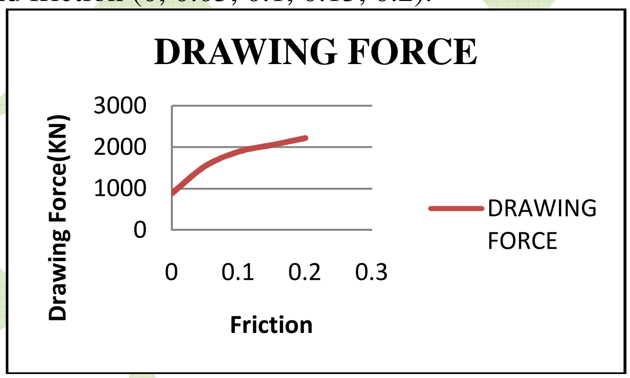


Figure 3.35: Stress graph for case 3 Figure 3.36: Drawing Force graph for case 3

Conclusions

The main objective of the project work is to determine the optimum drawing force and stress for the tube drawing process. After completing the analysis for combination of friction and different die geometry, the results obtained are compared to find out the optimum drawing force and stress to produce a tube with a best geometry. After comparing all the 3 cases in graphs shown below, it is found that the case 3 with die geometry i.e. semi die angle 8 is found optimum for drawing a tube of outer diameter 260mm and inner diameter of 210mm. The optimum drawing force and the stress found for die geometry of semi die angle are respectively 2218.5 KN and 113.87 MPa.

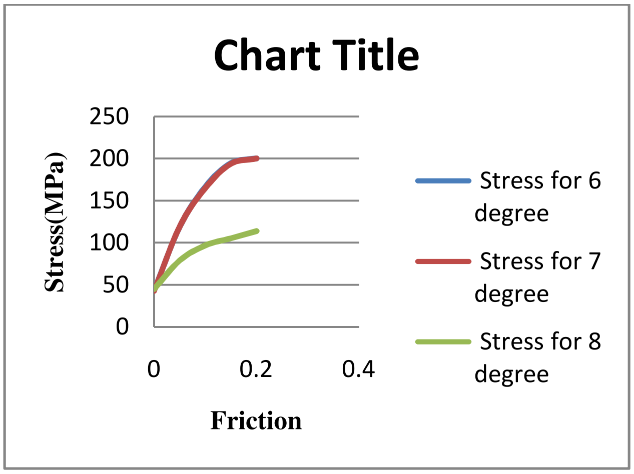


Figure 4.1 Comparison of stress.

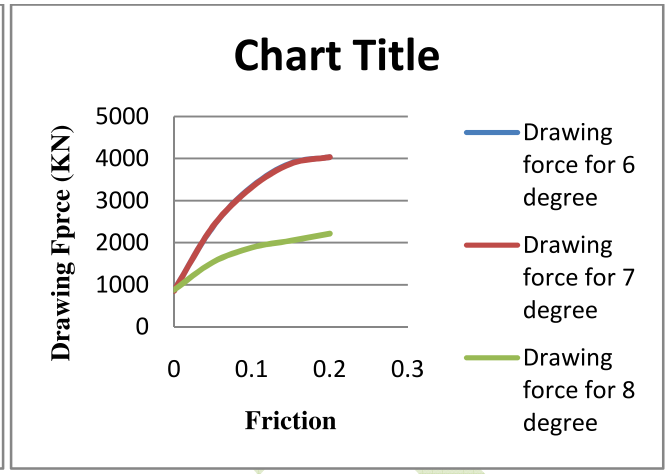


Figure 4.2: Comparison of the drawing force.

References

[1]S.T.Button, C.Caminaga and F.C.Gentile, Numerical and Experimental and analysis of tube drawing with fixed plug.

[2]E.M.Rubio, Analytical methods application to the study of tube drawing process with fixed conical inner plug.

[3]C.S.Wang and Y.C.Wang, The theoretical and experimental of tube drawing with floating plug for micro heat-pipes, R.O.C.

[4]George.E.Dieter, Mechanical Metallurgy, McGraw-HILL Book Company. Chapter 15 pg no 518, Chapter 19 pg no 650.

[5]Heinz Tschaetsch, Metal Forming Practise Springer, Chapter 11 pg no 105.

[6]Nitin.S.Gokhale, Sanjay.S.Deshpande, Sanjeev.V.Bedekar, Anand.N.Thite.Practical Finite Element Analysis.