ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Study of Different Parameters in Seamless Cold Drawing Process Using Finite Element Simulation

Bahadur Singh Rajput*, Richard Victor

Department of Mechanical Engineering, Sagar Institute of Research & Technology Excellence Bhopal, India

Abstracts

The application of steel tubes especially with close tolerances and good dimensional accuracy, in hydraulic cylinders for different applications makes in a point of interest for various designers. In this paper effect of different parameters like die entry angle, coefficient of friction and cross section reduction of the tube was studied with a 3D model of seamless cold drawing process using ABAQUS 6.10. Simulations were carried out with two sets of data, one comprising of different levels of die entry angle and cross section reduction and other set comprising of different levels of die entry angle and coefficient of friction. The effect of these parameter on process and material behavior was studied. Model was validated through the data obtained from the industry.

The developed models have given important contribution to the understanding of how different parameters affect the drawing process. It also helps in determining the condition of failure. These models can further b used to carry out other process improvement studies and analysis..

Keywords: Finite Element Method, Metal Forming, Tube Drawing, STR-525

Introduction

The application of finite method for the analysis of mechanical systems is very popular in the industrial and academic environments. In this paper, study of parameters like die entry angle, coefficient of friction and cross section reduction by the finite element method is presented and applied to determine the optimized values of the above parameters. Also to determine the failure condition for the tube material. The seamless cold drawing process has very important role in the production of tubes especially for transportation applications. In tube drawing process if we have to predict the behavior of material during the drawing process then we have study different parameters by built a physical setup again and again for different configurations of parameters which is very time consuming and costly. The main purpose of this study is to replace on field experiments with a 3D model of seamless cold drawing process using ABAQUS 6.10

The drawing process that is studied in this paper is a simulation of seamless cold drawing process using Finite Element Method and the model was validated through the data obtained from the industry. In first set of analysis we have study the effect different levels die entry angle and cross-section reduction for the following three theories i.e. Equivalent Plastic Strain, Von-Misses Stresses and Axial Stresses. Similarly the second set of analysis is the study of the effects of different levels of die entry angle and coefficient of friction for the same three theories.

Cold drawing process-an overview

The Cold drawing is one of the oldest metal forming operations and has major industrial significance. It is the process of reducing the cross-sectional area and/or the shape of a bar, rod, tube or wire by pulling through a die. This process allows excellent surface finishes and closely controlled dimensions to be obtained in long products that have constant cross sections. It is classified as under:

- Wire and Bar Drawing: Cross-section of a bar, rod, or wire is reduced by pulling it through a die opening (Fig. 1 a) .It is similar to extrusion except work is pulled through the die in drawing. Both tensile and compressive stress deforms the metal as it passes through the die opening.
- Tube Drawing: It is a metalworking process to size tube by shrinking a large diameter tube into a smaller one, by drawing the tube through a die (Fig. 1 b). It is so versatile that it is suitable for both large and small scale production.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

The drawing process improvement has been an area of extensive research over a long period of time due to its commercial significance as it offers excellent surface finish and closer dimensional control in the products.

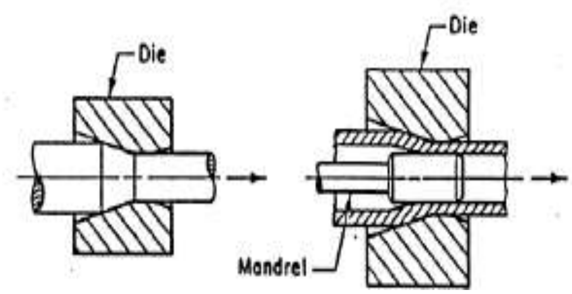


Fig.1 Types of Cold drawing (a) wire and bar drawing and (b) Tube drawing

Earlier different analytical methods like Slab method, Upper bound method or slip line theory were used for material flow and behavior analysis. In the recent years with the development in Numerical techniques and with the advancement in computers there is tremendous rise in the accuracy and pace of the solutions and information obtained in the researches. In this context, Finite Element Method is one of the most popular methods employed to resolve the metal forming problems. Kopp [1] presented a report that described ways for the shortening, flexibilization and optimization, as important tools. Numbers of studies on the analysis of drawing process carried out by researchers are discussed below under different criteria.

Establishing friction conditions is crucial in bulk metal forming because of the usually high contact pressure and the influence of friction on the material flow, tool stresses and the forming force [2]. The friction minimization by forming processes is reflected in: tool life increase, stagnation time reduce, increase of the machining process productivity, less energy consumption, less consumption of tools and less production costs [3]. In the context of the same, Chuiko et al. [4] described the development in new forms of production lubricants and methods of oxalate application over Stainless Steel Tube.

The profile design of die and mandrel is the most important factor related to forming energy and deformation behaviour of tubular material [5]. Gunasekera and Hoshino [6] described a new method for obtaining optimal die shape which produces minimal stress in the extrusion or the drawing of non-axisymmetric sections from round bar stock. In order to find the best geometry of die and plug to reduce the drawing force. , Neves et al. [7] simulated the cold drawing of tubes with fixed plug by FEM with the commercial software MSC Superform. Kim et al. [5] investigated the process parameters related with tool configuration. As a result, the advanced mandrel shape, which can effectively transmit, without generating defect, drawing force to deforming tube, was designed. Modification in conventional tube geometry like development of the Rifled Tubes etc. Assurance of high dimensional accuracy in the rifle tubes was given by Yoshizawa et al. [8] with the help of a manufacturing technique developed through experiments. Bayoumi [9] gave an analytical solution for the problem of cold drawing through flat idle rolls of regular polygonal metal tubular sections from round tube. The forming tool load in plastic shaping of a round tube into a square tubular section was determined by Bayoumi and Attia [10] both analytically and numerically by applying finite element simulation.

Residual stress and its measurement is very important aspect of cold drawing process as it has a significant impact on the material performance in the field. Minimisation of the induced tensile residual stresses was investigated by Karnezis et al. [11]. Elices [12] showed that how stress-relaxation losses, environmental assisted cracking and fatigue life of cold-drawn pearlitic wires are influenced by residual stresses. Elices [12] further discussed that residual stresses due to cold-drawing are known to be detrimental to the mechanical performance- particularly as regards to creep, fatigue and ductility. A numerical model using the code ABAQUS was developed by Atienza et al. [13] to study the residual macro stress state generated by drawing. Phelippeau [14] identified and discussed the mechanisms controlling the elongation to failure of cold drawn steel wires and examined, in particular, the role of residual stresses. Nakashima et al. [15] patented a method to produce seamless tubes in such a way that the residual stress generated during the stage of correction after cold working is limited to 30 MPa and scattering thereof is 30 MPa or less, when measured by Crampton method.

The misapplication of the manufacturing process or lack of control at any stage may introduce defects and residual stresses that can affect the performance of structure in service, making it susceptible to failure. The surface flaw of a drawn wire has a significant influence on the quality of product [14]. The defects of cold drawn wire inherited from the wire rod may be divided into two groups: those due to metallurgical processes; and those due to rolling. The first group is formed in steel smelting and casting; the second is formed in heating and deformation in the course of rolling [15].

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

De Castro et al. [16] investigated the effects of die semi-angle on the mechanical properties of round section annealed copper bars. The FEM calculations of the drawing stress and the effective strain distributions in the tube sinking process were performed by Sadok et al. [17]. The calculations were done for various process parameters, including different profiles of the working part of the die. Chen and Huang [18] employed the finite element method and the Taguchi methods to optimize the process parameters of the wire drawing process. Neural networks were used by Dwivedi et al. [19] to model relationships between controlled and uncontrolled process parameters and the yield. In most cases emphasis is given on one process parameter at a time and its individual effect is studied on the product. Dekhtyarev et al. [20] carried out a research to demonstrate the combined effect of these parameters on final properties of the product and production process as a whole. Rocha et al. [21] analyzed distortion for a typical manufacturing process of pre-straightened, cold drawn and induction hardened AISI 1045 cylindrical steel bars using DOE (Design of Experiments).

Application and development of analytical methods and Models along with the Finite Element Method is being done over the years. For instance, a generalized model, as devised by Kolmogorov, describing the deformability of metal in the process of drawing tubes on a fixed mandrel was presented by Pospiech [22]. According to this model the coefficient of utilization of reserve of plasticity decreases with the increase of the coefficient of friction (at a constant angle of the die reduction zone).Rubio et al. [23] studied the main variants of the drawing process by different methods. Thin-walled tubes drawing through conical convergent dies with fixed inner, conical or cylindrical, plug was analyzed by Rubio et al. [24] using the upper bound method. Analytical formulations were extensively used by Gur'yanov [25]. He calculated the limiting extension per drawing pass using six different formulas in order to determine the axial-stress increment in the working cone of the die.

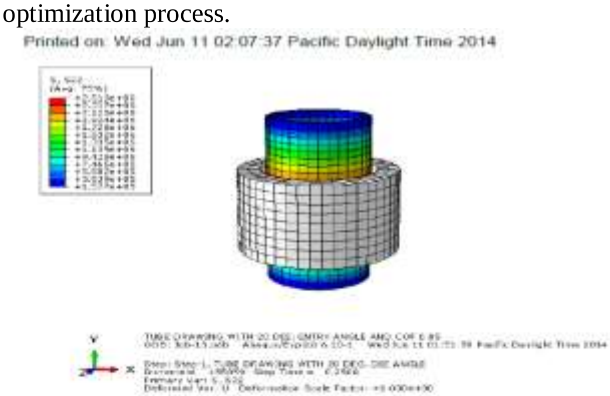
Numerical modeling

For the study of this process, it was necessary to develop an initial FE model and to include this model in an appropriate optimization loop. In the first step the model was explained and then study of different parameters were carried out.

Base FE model

The 3D model geometry and loading allows this process to be modeled by FE method. At the same time, 3D model produced almost the same result which was given by the actual tube drawing of STR-525 material in industry.

The geometry of die were defined and die, plug and pipe were meshed. During the optimization process depending on the selected values for the design variables, i.e. die entry angle, coefficient of friction and cross-section reduction ratio, the geometries are updated according to the combination required. The other necessary FE definitions, such as boundary conditions and material properties, are done once before start of optimization process.



Material properties

The material chosen was STR-525, which is an alloy steel, used specially for making hydraulic cylinders. The composition of the material is close to ST 52 which is a standard alloy steel. The density of STR 525 is 7860 Kg/m3' Poisson's ratio is 0.3 and Young's modulus is 21172 MPa as obtained through load versus elongation plot (Fig. 4.6). As far as tooling is concerned, i.e.,, die and plug, the material used was Tungsten Carbide with density 15800 Kg/m3sPoisson's ratio 0.24 and Young's Modulus around 70 GPa. Although exact values of properties were not of significant importance (Young's Modulus is on higher side) as both of them are unreformed during the process.

Experimental work

The flow behaviour of the material was determined with the help of tensile test carried out on the Universal Testing Unit at Patson Pipes and Tubes vadodra. The tensile specimen was cut from a hollow of STR 525 and machined as per standard.

The dimensions of the specimen were as follows:

Gauge Length (Initial) : 77.13 mm
Gauge Length (Final) : 99.70 mm
Initial width : 19.7 mm
Final width : 9.46 mm
Thickness : 9.46 mm

The strains obtain in material test data used to define the plastic behaviour are not likely to be the strains in the material. Instead, they will probably be the total strains in the material. We must decompose these total strain values into the elastic and plastic strain components. The plastic strain is obtained by subtracting the elastic strain, defined as the value of true stress divided by Young's modulus, from the value of total strain.

The major observations from the test are listed below:

- Peak load – 98.10 KN
- 0.2% Proof Load- 64.20 KN
- Load at breakage - 72.60 KN
- % Elongation- 29.16

This relationship between plastic strain and total strain is written as,

$$\epsilon_{pl} = \epsilon^{t} - \epsilon^{el} = \epsilon^{t} - \sigma / E$$

True stress-strain and plastic strain values are shown in Table 1.

True Stress	True Strain	Plastic Strain
345.1380762	0.0019	0.0003
364.3580955	0.0028	0.0012
374.2376063	0.0034	0.0017
382.2664655	0.0039	0.0023
389.6521892	0.0045	0.0029
397.0030874	0.0051	0.0035
404.4108247	0.0057	0.0041
465.0296239	0.0382	0.0365
528.8217261	0.0749	0.0733
568.0865205	0.1115	0.1099
606.5480318	0.1457	0.1441
628.8409554	0.1799	0.1782
643.0925671	0.2002	0.1986

Validation of model

Initial and Boundary Conditions

The tube to be drawn is cylindrical in shape. As the deformation characteristic of the cylindrical hollow is axisymmetric. The whole geometry for the process can be modeled as 3 D axisymmetric for simulation. The tools, is e,, die and plug are given fixed boundary condition, while the hollow edge was given initial velocity of 400 mm/s in the downward direction.

Validation

Model was validated by comparing the strains developed in actual drawing practice to the strains developed after drawing simulation in the finite element model.

Expressions for the strain calculation are as follows:

Radial Strain,

$$\epsilon_{Radial} = \ln (h_f / h_i) \qquad 1$$

Where,
h_f is tube wall thickness at exit,
h_i is tube wall thickness at inlet.

Circumferential Strain,

$$\epsilon_{cir.} = \ln \{(D_{of} - h_f) / (D_{oi} - h_i)\} \qquad 2$$

Where,
D_{of} is Tube outside diameter at exit,
D_{oi} is Tube outside diameter at inlet.

Axial strain,

$$\epsilon_{Axial} = - \epsilon_{radial} - \epsilon_{cir.} \qquad 3$$

The data given below gives the detail of the model used for validating the cold drawing simulation. The coefficient of friction was kept as 0.05 (Neves et al; 2005) and drawing speed as 400 mm/s.

- Hollow Dimensions : 110x 9.50
- Tube Dimensions : 103x7.25 (Experimental value)
- Tube Dimensions : 102.55x7.04 (Finite Element analysis)

Table 5.1 gives the comparison between radial strain, circumferential strain and axial strain. Expressions 5.1, 5.2 and 5.3 were used to calculate the strain values. It was observed that both the experimental and finite element results are in fair agreement with each other which validated the model and further simulations were lined out, the results for which are discussed in the following sections.

TABLE .2

Strain	**Experimental Results**	**F.E. Results**
Radial Strain (∈)	-0.270	-0.299
Circumferential Strain (∈)	-0.0484	-0.059
Axial Strain (∈)	0.3184	0.3499

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

EFFECT OF COLD DRAWING PARAMETERS

The following subsections study the response of variation in cold drawing parameters with the help of contour diagrams.

Die Entry Angle and von-Mises Stress Distribution

As can be seen in the Figures, when the initial contacts established, stresses are induced in other regions of hollow that are still not in the deformation zone. Although the maximum stress at deformation doesn't vary but a can be clearly seen, that in the drawing region, increase in the die entry angle results in an increase in the Von-Mises stress (compare Fig. 5.3.1 a, Fig, 5.3.1 b, Fig. 5..3.1 c).

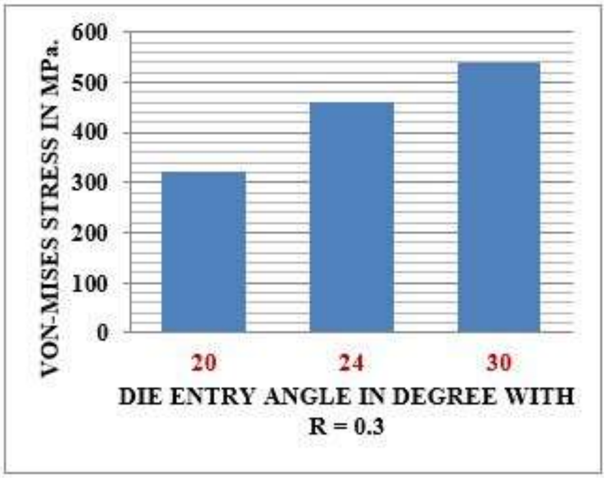


Figure 5.3.1(a)

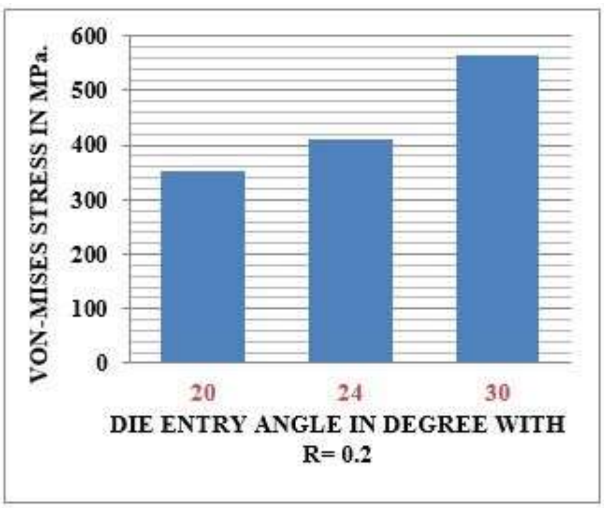


Figure 5.3.1(b)

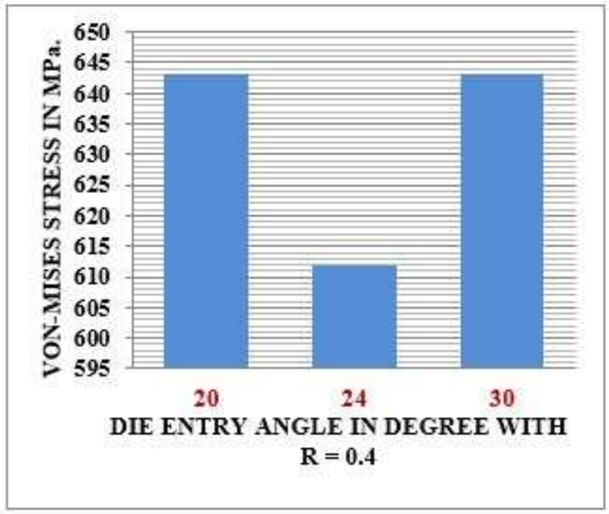


Figure 5.3.1(c)

Coefficient of Friction and von-Mises Stress Distribution

It can be seen that the 'increase in friction results in the increase of von-Mises stresses (compare Fig. 5.3.2 a, Fig. 5.3.2 b, Fig. 5.3.2 c).This can be attributed to the fact that layers of the tube surface both inside and outside not only undergo cross-section reduction but they also deform in shear due to drag forces exerted by the die surface.

Therefore, as the friction increases material has to overcome higher forces thereby leading to increase in stress values.

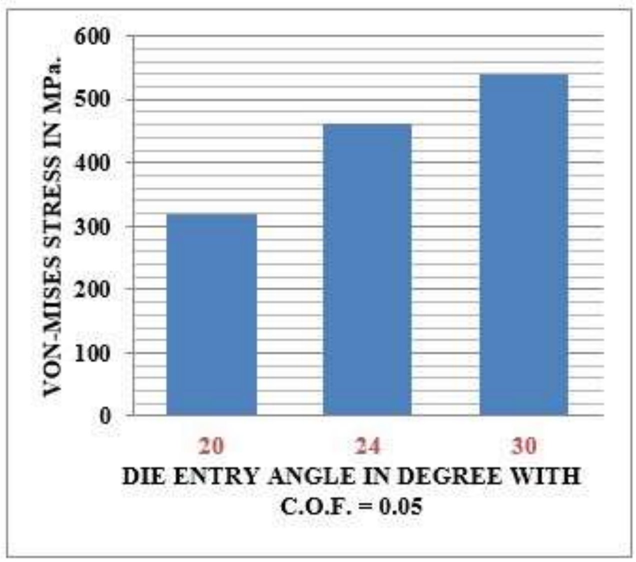


Figure 5.3.2(a)

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

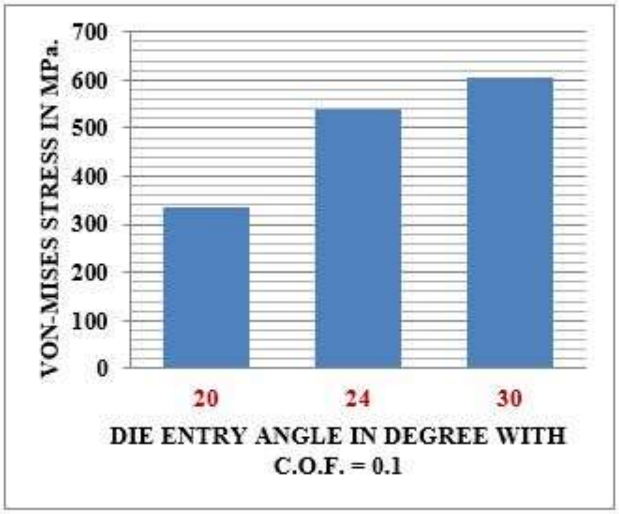


Figure 5.3.2(b)

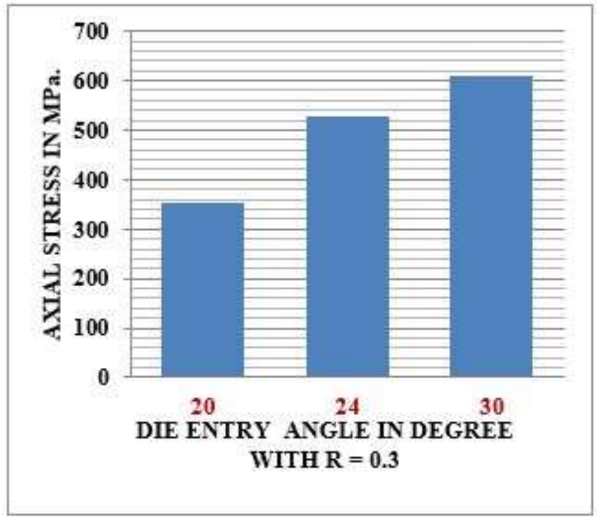


Figure 5.3.3(a)

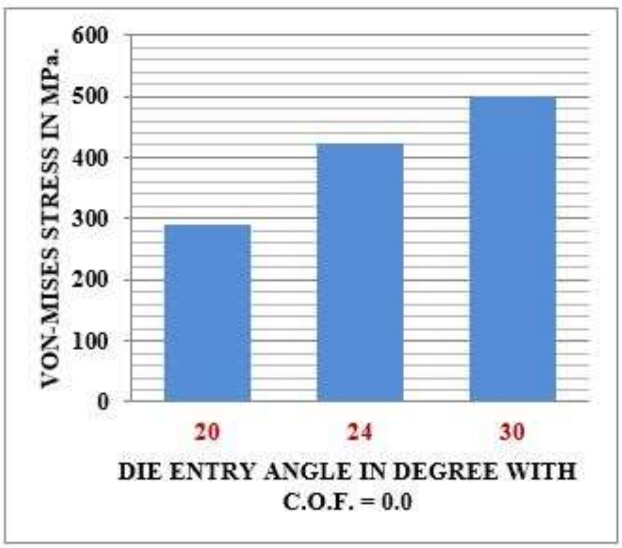


Figure 5.3.2(c)

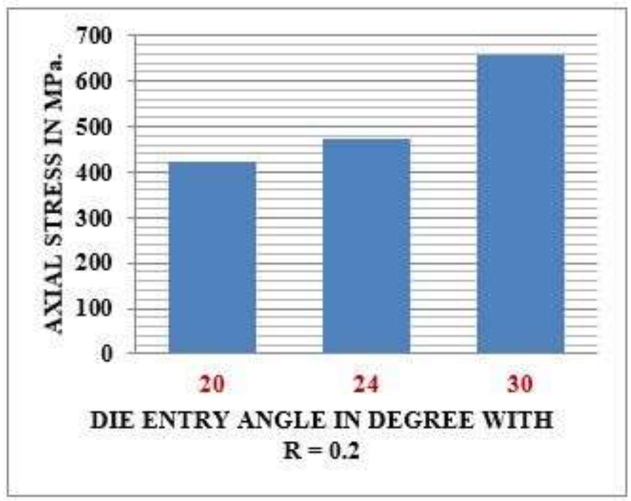


Figure 5.3.3(b)

Cross-Section Reduction and Axial Stress Distribution

Axial stress (σ_{yy}) distribution contour graphs for variation in cross-section reduction is shown in Figures below. On comparing Fig. 5.3.3 a, Fig. 5.3.3 b and Fig 5.3.3 c, It is clear that axial stress values increase with increase in cross-section reduction. This phenomenon can be attributed to the fact that as the cross-section reduction increases there is greater work to be done by the drawing mechanism on the material which results in higher reaction and drag forces resulting in increase in the axial stresses.

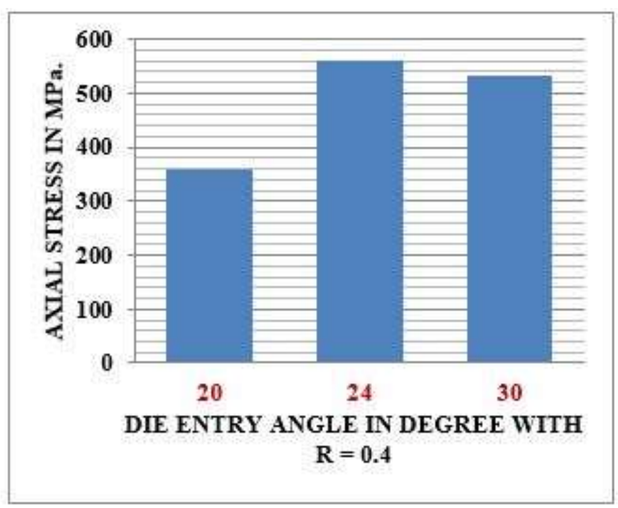


Figure 5.3.3(c)

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

Coefficient of Friction and Axial Stress Distribution

The comparative study of Fig. 5.3.4 a, Fig. 5.3.4 b and Fig. 5.3.4 c reveals that variation in coefficient of friction significantly affects the value of axial stresses. That I s, as the friction increases the axial stress follows the similar trend to that of von-Mises stress in the previous case due to same reason of increase in the drag force. Moreover stress distribution is more homogenized at higher value of coefficient of friction.

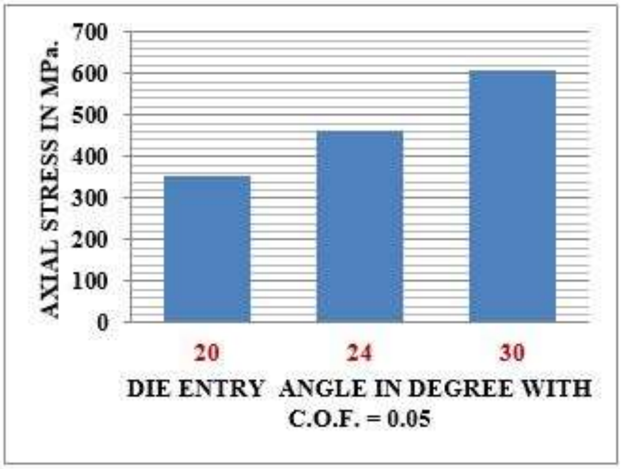


Figure 5.3.4(a)

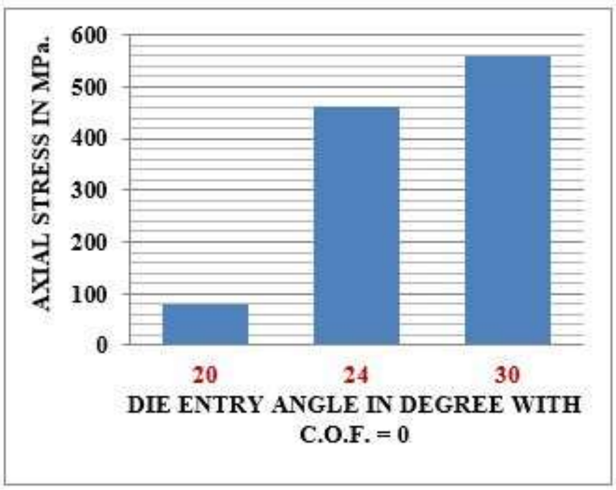


Figure 5.3.4(b)

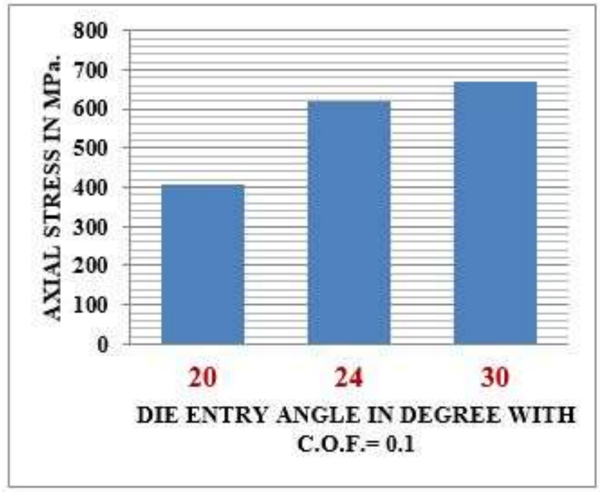


Figure 5.3.4(c)

Cross-Section Reduction and Equivalent Plastic Strain Distribution

The cross-section reduction, naturally affects the strain component in any metal forming process significantly. When we see the contour diagrams (Fig. 5.3.5 a, Fig. 5.3.5 b, Fig. 5.3.5 c) for equivalent plastic strain with varying cross-section reduction it is evident that as the reduction in cross-section is increased the strain is also increased. For cross-section reduction 0.2, under steady state conditions at step time 0.45, P.E.E.Q. is 0.3238 which rises to 0.3753 and 0.5285 for cross section reductions 0.3 and 0.4 respectively.

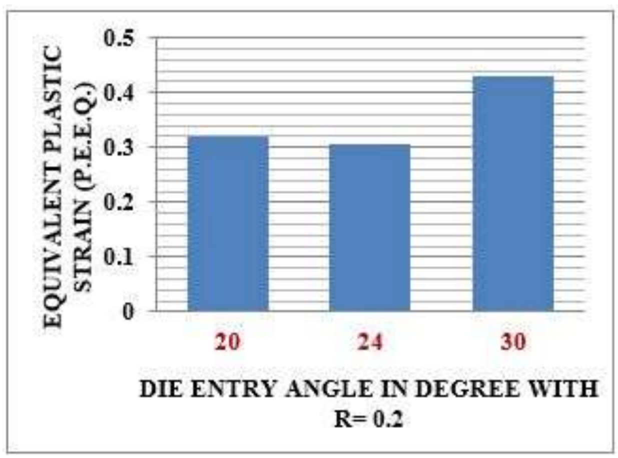


Figure 5.3.5(a)

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

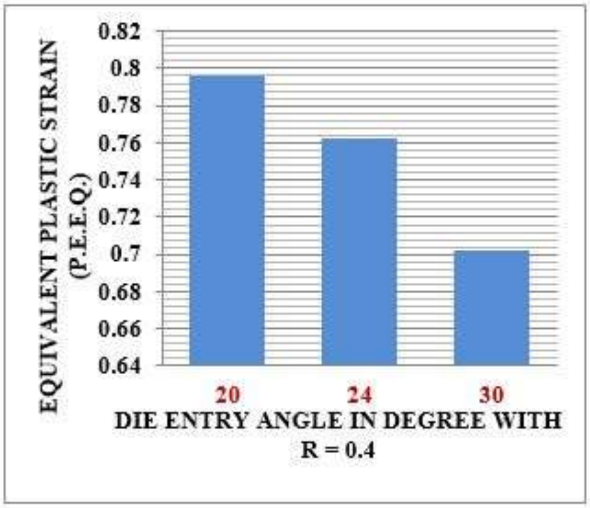


Figure 5.3.5(b)

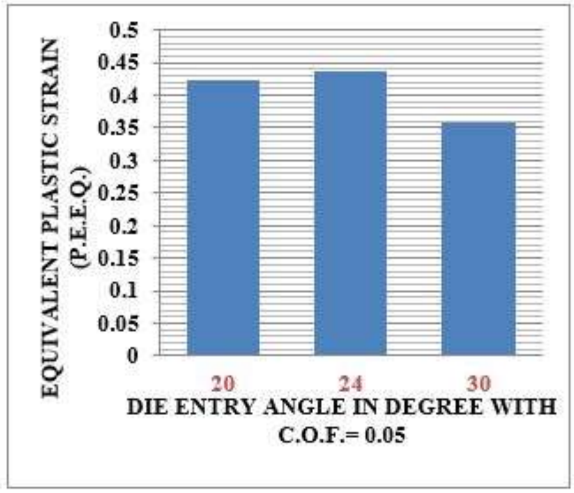


Figure 5.3.6(a)

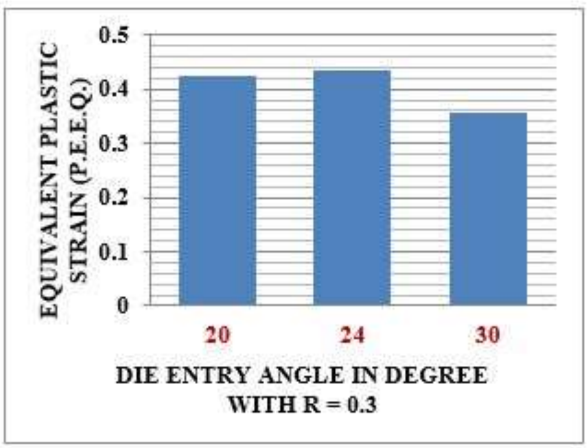


Figure 5.3.5©

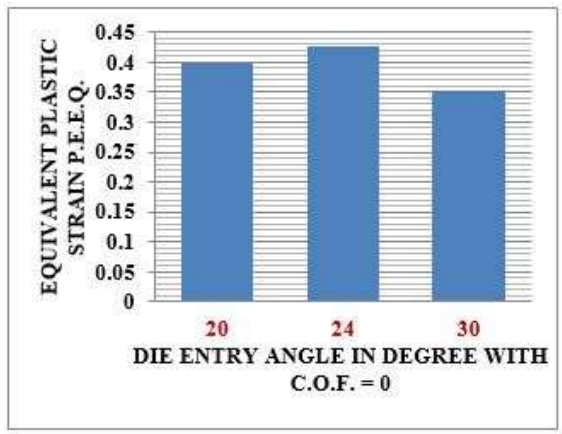


Figure 5.3.6(b)

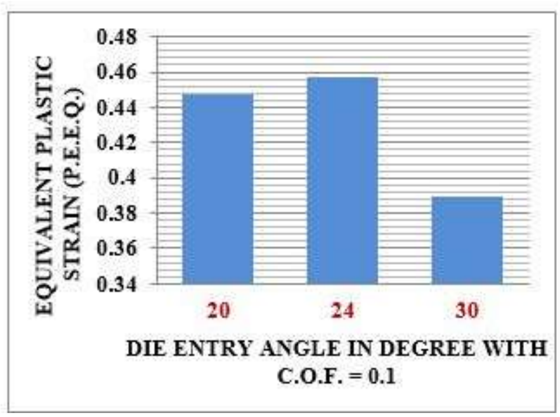


Figure 5.3.6(c)

Coefficient of Friction and Equivalent Plastic Strain Distribution

On comparing the contour diagrams (Fig. 5.3.6 a, Fig. 5.3.6 b, Fig. 5.3.6 c), it can be seen that the maximum values tend to increase with the increase in the value of coefficient of friction. But still it is evident that coefficient of friction has very little effect on the Equivalent plastic strain.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

Conclusions

Following conclusions were drawn from the research carried out in this study:

1. Seamless tube cold drawing can be successfully simulated using 3D axisymmetric model.
2. Stress distribution patterns were observed in the parts of tube even before coming in contact with the die, it suggests that elastic deformation of the tube material starts well before it enters into the deformation zone.
3. It was observed that cross-section reduction has significant effect on equivalent plastic strain, von-Mises stresses and axial stresses. They all increase with the increase in the cross-section reduction value. Cross-section reduction upto 0.3 maintains the flow stresses at lower side and hence most preferred zone of metal working.
4. Die entry angle is a crucial parameter in the drawing process. It was found that beyond 24 degrees, the value of flow stresses follow the rising pattern with the increase in the die entry angle. Consequently, the load on drawing mechanism increases.
5. As far as coefficient of friction is concerned, the flow. Stresses and consequently drawing load increase as the values go on higher side. Best range of working was found to be under 0.05. But due to limitations with the lubricants available and tool material. This value currently hovers around 0.05.

References

1. Kopp, R Some Current Development Trends in Metal-Forming Technology (1996) Journal of Materials Processing Technology, 60, 1-9.
2. Byon, S. M., S. J. Lee, D. W. Lee, Y. H. Lee and Y. Lee (2011). Effect of Coating Material ad Lubricant on Forming Force and Surface Defects in Wire Drawing Process. Trans. Nonferrous Met. Soc. China, 21, S104—S110.
3. Kim, S. W., Y. N. Kwon, Y. S. Lee and J. H. Lee (2007). Design of Mandrel in Tube Drawing Process for Automotive Steering Input Shaft. *Journal of Materials Processing Technology, 187–188,* 182–186.
4. Chuiko, V N., Savi -1 G. and A. Kalashnikov(1973).Cold Drawing of Stainless Steel Tubes on Short Mandrel. Metallurg, No 3, 32-33.
5. Kim, S W., Y. N. Kwon, Y. S. Lee and J. H. Lee (2007). Design of Mandrel in Tube Drawing Process for Automotive Steering Input Shaft. Journal of Materials Processing Technology, 187-188, 182-186
6. Gunasekera, J. S. and S. Hoshino (1982). Analysis of Extrusion or Drawing of Polygonal Sections through Straightly Converging Dies. *Journal of Engineering for Industry, Vol. 104,* 38-45.
7. Neves, F. 0, S. T. Button, C. Caminaga and F. C. Gentile (2005). Numerical and Experimental Analysis of Tube Drawing with Fixed Plug J. of the Braz. Soc. of Mech. Sci. & Eng., Vol. XXVII, No. 4/426-431.
8. Yoshizawa, Mitsuo, Daigo Sumimoto and Kakinum Kazuhiro (1984). The Forming Technique and Quality Characteristics of ERW Rifled Boiler Tube. 106th ISIJ Meeting, S1221 and S1394.
9. Bayourni, Laila. S. (2001). Cold drawing of Regular Polygonal Tubular Sections from Round Tubes. International Journal of Mechanical Sciences, 43, 2541-2553.
10. Bayoumi, Laila. S., and Ahmed. S.Attia (2009).Determination of the Forming Tool Load in Plastic Shaping of a Round Tube into a Square Tubular Section. Journal of Materials Processing Technology, 209, 1835-1842.
11. Karnezis, P and D C. J. Farrugia (1998). Study of Cold Tube Drawing by Finite-Element Modeling Journal of Materials Processing Technology, 80-81, 690-694.
12. Elices, M. (2004). Influence of Residual Stresses in the Performance of Cold-drawn Pearlitic Wires. Journal of Materials Science, 39, 3889-3899.
13. Atienza, J.M , M.L. Martinez-Perez, J. Ruiz-Hervias, F. Mompean, M. Garcia-Hernandez and M. Elices (2005). Residual Stresses in Cold Drawn Ferritic Rods, Scripta Matenalia, 52, 305-309.
14. Phelippeau, A., S.Pommier, T. Tsakalakos, M. Clavel and C. Prioul (2006), Cold Drawn Steel Wires-Processing, Residual Stresses and Ductility-Part I: Metallography and Finite Element Analyses. Fatigue Fract Engg Mater Struct, 29, 243-253.
15. Nakashima, Takashi, Kouichi Koruda and Kenichi Beppu (2008).Cold Finished Seamless Steel Tubes. United States Patent, US 7371293 B2.
16. De Castro, A L.R., H.B. Campos and P.R. Cetlin (1996). Influence of die semi-angle on mechanical properties of single and multiple pass drawn copper Journal of Nlatenals Processing Technology, 60, 179-182.

17. Sadok, L., J. Kusiak, M. Padko and M. Rumifiski (1996). State of Strain in the Tube Sinking Process. Journal of Materials Processing Technology, 60, 161-166
18. Chen, D C and J. Y. Huang (2007). Design of Brass Alloy Drawing Process using Taguchi Method. Mater. Sci. Eng., 464, 135-140.
19. Dwivedi, Saurabh, Samuel H. Huang, Jun Shi and William H. VerDuin (2008). Yield Prediction for Seamless Tubing Processes: a Computational Intelligence Approach. Int J Adv Manuf Technol, 37, 314-322.
20. Dekhtyarev, V. S., Ya. V. Frolov, A. A. Tereshchenko and A. P. Golovchenko (2009). Comprehensive Approach to Realizing New Technologies for the Production of High-Precision Cold-Worked Tubes. Metallurgist, Vol. 53, 3-4.
21. Rocha, Alexandre da Silva, Rafael IvIenezes Nunes and Thomas Hirsch (2012). Analysis by Design of Experiments of Distortion Potentials in Drawn and Induction Hardened Wire,Materials Research, 15(2), 266-276.
22. Pospiech, J. (1998).Descnption of a Mathematical Model of Deformability for the Process of Drawing Tubes on a Fixed Mandrel Journal of Maierials Engineering and Performance, Volume 7(1), 71-78
23. Rubio, E. M,, A. M. Camacho, L. Sevilla and M. A. Sebastian (2005).Calculation of the Forward Tension in Drawing Processes. Journal of Materials Processing Technology, 162-163, 551-557,
24. Rubio, E. M., C. Gonzalez, M. Marcos and M.A. Sebasti'an (2006). Energetic Analysis of Tube Drawing Processes with Fixed Plug by Upper Bound Method. Journal of Materials Processing Technology, 177, 175-178.
25. Guer’yanov, G. N. (2009). Limiting Extension in Cold Drawing of Round Profile, Steel in Translation, Vol. 39, No. 9, 811-813.