©2016 Published in 4th International Symposium on Innovative Technologies in Engineering and Science 3-5 November 2016 (ISITES2016 Alanya/Antalya - Turkey)

Effects of the semi die/plug angles on cold tube drawing with a fixed plug by FEM for AISI 1010 steel tube

Jabbar Gattmah[1,2*], Fahrettin Ozturk[3],Sadettin Orhan[1]
[1]Department of Mechanical Engineering, Yildirim Beyazit University, Ankara, Turkey
[2]Department of Mechanical Engineering, Diyala University, Diyala, Iraq
[3]Department of Mechanical Engineering, The Petroleum Institute, Abu Dhabi, UAE

Abstract

In this present paper, finite element method (FEM) is used to simulate cold tube drawing process with a fixed plug for AISI 1010 steel tube. The effects of semi die/plug angles on drawing stress for different friction coefficients at 23%reduction of area are studied. The finite element model is successfully validated with the experimental data. Results indicate that a good agreement between the experimental and the finite element method is found. Consequently, the effect of semi die angle on plastic deformation is larger than the semi plug angle because of the bigger size of the semi die angle. Semi die angle of 12° gives minimum drawing stress for all coefficient of frictions. A semi plug angle between 2° and 4° should be used in tube drawing process with a conical fixed plug when semi die angle is equal to 7°.

Keywords: Tube cold drawings; semi die angle; semi plug angle; drawing stress; finite element method.

1. Introduction

Tube drawing is one of the technologically important metalworking processes to reduce tube thickness where outside is formed by a drawing die and the inside by a plug or a rod. There is a significant increase in the use of tube products in several of mechanical applications. However, the quality of tube products and a good surface finish of inner and outer diameters have been concerned. High quality and good surface finish tube products are big challenges in cold tube drawing processes. Basically, four types of tube drawing processes can be considered to reduce outer and inner diameter of the tube. For all of the types, die diameter is used to calibrate the outer diameter, while there are also various other techniques are developed to calibrate inner diameter of the cold drawn tube. These four processes are follow: drawing without a mandrel (tube sinking), drawing over a stationary mandrel (plug), drawing over a floating, plug and drawing over a moving mandrel [1]. In this study, the drawing over a stationary mandrel (plug) as shown in Fig.1 was considered. It has been known that finite element analysis (FEA) has been widely used to solve complex metals forming problems. Besides, the rapid technological development in computers field has reduced hum an effort and cycle time. Although tube drawing process have been taken into consideration by many researchers analytically and numerically, only few researchers have studied cold tube-drawing process experimentally. Because, it is expensive, complex, and requires advanced control during the drawing process.

*Corresponding authors, Address: Department of Mechanical Engineering, Yildirim Beyazit University, Ankara, Turkey. Email: msc_jgj_katma7@yahoo.com, Phone:+90 531 7324476

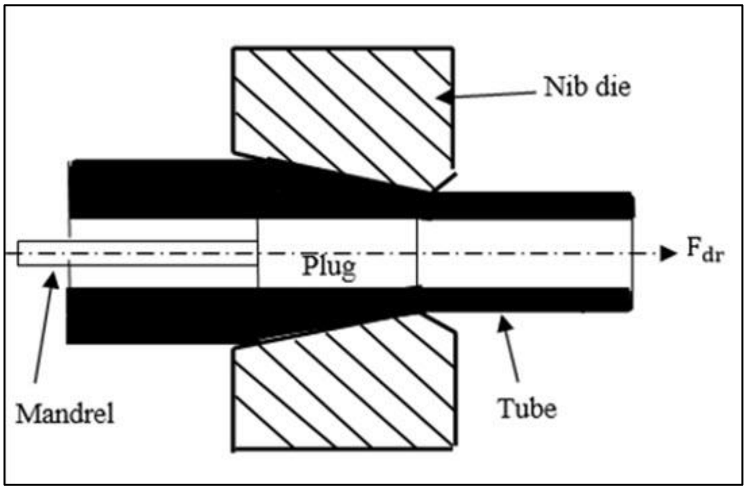

Fig.1 Tube drawing over a stationary mandrel (drawing with a fixed plug)

Tube drawing with a floating plug was studied by Joachim and Endelt [2] using finite element software LS-DYNA with implicit time integration. The study showed that both the length and shape of bearing channel depend on the drawing force with conventional tooling [2].In another study, Beland et al. [3] used LS-DYNA to determine optimization of tool geometry for reducing stress level for 6063 T4 by a sinker die, a drawing die, and cylindrical plug. The study reveals that three tubes can be drawn at the same time up to maximum length of 12 m at different tube diameters and wall thicknesses. Bihamta et. al [4] studied the effects of die angle, mandrel angle, and fillet radius on the max tube deformation using D-optimal method experimentally and finite element method. AL 6063-0 tube was produced at variable thicknesses. The study proved that the finite element method is active tool to determine optimum geometry. Tube cold drawing with and without plug was studied by finite element method to improve the quality of finish surface for Cobalt-Chromium alloy tubes [5].Physical parameters experimentally have been analyzed to identify the constitutive equation, the inelastic heat friction, and the convection of heat transfer. The outcome of the study is that the temperature variation and interface properties affect the local behavior of material significantly. Several mandrel and different diameters have been examined to estimate tube drawing limit and to evaluate ductile failure criteria in a series of drawing test by applying experimental method. SEM images were determined and evaluated. Linardon et. al [6] simulated local stress and strain data that represent a tool of the process optimization. Optimum die profile according to the arc and Bezier curves was designed by Ref [7] to estimate maximum drawing force and the mean effective strain deviation along the tube thickness. The results showed that the method of die design can give better results of the drawn tubes. Trana et. al [8] developed numerical and experimental approach to determine the drawing efficiency of 6082-0 temper aluminum alloy for cartridge tubes manufacturing. Tensile, compression, and shear tests for the various samples were conducted. The plastic strain and graph of material envelope for zero Lode parameters were determined. Finite element model using 3D LS-DYNA was also improved using a solid element type. The study verified that the drawing degree can be safely determined while processing cartridge thin tube subjected to inner pressure.

In this research, the effects of semi die and semi plug angles on drawing stress were studied by reducing tube dimensions (outer diameter, inner diameter, and thickness). Cold tube drawing with a straight plug was done experimentally by a chain assisted machine. The process was performed under lubrication. Finally, the process was modeled by FEA and was validated with the experimental data. The finite element model was used to simulate different semi die and semi plug angles at 23 %reduction of area. Several coefficients of friction; 0.1, 0.125, and 0.15with constant of velocity were tested. In all our simulations, a commercially available finite element software ABAQUS^{TM} was used.

2. Die and Plug Geometries

The die geometries consist of semi die angle, bearing length, and entry radius as displayed in Fig.2. Semi die angle is defined as the slant of die wall toward to the drawing direction [9]. In this study, different semi die angles, fix bearing length of 7 mm and die entry radius of 7 mm were selected for outer diameter reduction analysis.

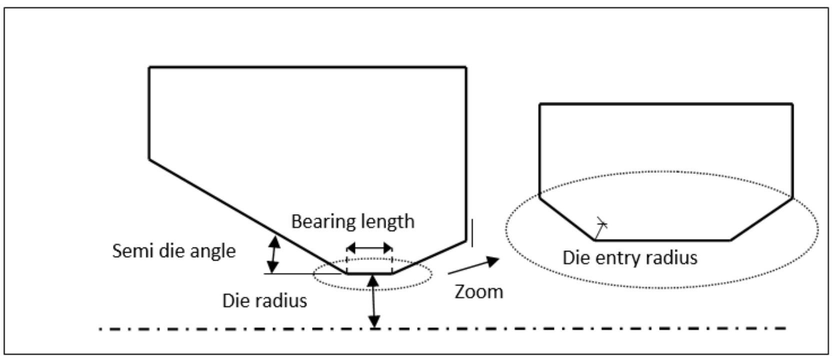

Fig. 2 Die geometries

Straight and conical plug geometries were used for deformation of inner diameter. The conical plug includes semi plug angle and nib as shown in Fig. 3. Semi plug angle is the slant of plug wall at drawing direction. It has a major role to obtain a good surface finish of inner diameter of drawn pipe.

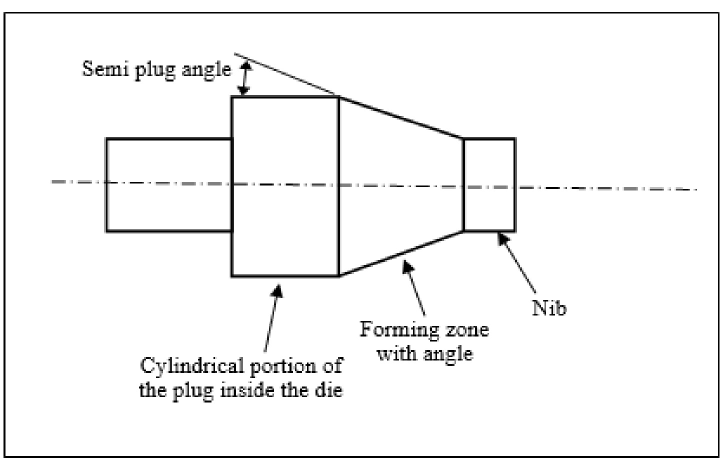

Fig.3 Conical plug geometries

In tube drawing process with a fixed plug, the nib die and plug are very important because of the contact between the internal surface of the die and external surface of tube and the contact between external surface of plug and the internal surface of tube during the drawing process. Nib die and plug are made of tungsten carbide, which has strong corrosion resistance. The mechanical properties of tungsten carbide are density of 15500$\mathrm{kg/m^3}$, Poisson's ratio of 0.2, and Young's modulus of 650 GPa.

3. Experimental Work

AISI 1010 tube was drawn with lubrication at room temperature (RT) with velocity of 4.25 m/min. The drawing was conducted by a chain-assisted custom made drawing machine. The initial outer and inner diameters of the tube are 78 mm and 71 mm, respectively. The tube has a thickness of 3.5 mm. The tube was reduced to outer diameter of 70 mm, inner diameter of 64 mm, and thickness of 3 mm. The initial length of tube was 4.1 m. After drawing the final length of the tube became 5.47 m. Drawing force was not measured during the test due to unavailability of load cell on the drawing die. Drawing force was determined by a compressive test under the same condition of machine using the lubricant.

4. Finite Element Model

Tube drawing with a fixed plug was modeled by finite element method (FEM) using ABAQUS^{TM}6.14-2 software. The geometry was modeled as an axisymmetric model. Several semi die angles of 5°, 7°, 10°, 12°, and 15° were studied by FEM. Semi plug angles were selected as 0°, 1°, 2°, 3°, and 4°. The coefficients of the friction were 0.1, 0.125, and 0.15.The mechanical properties and true stress with true plastic strain values of AISI 1010 steel are presented in Table 1 and Table 2, respectively.

Table 1 Mechanical properties of AISI 1010 steel

Density ($\mathrm{kg/m^3}$)	7722	Total Elongation (%)	28.453
Young's Modulus (GPa)	200	Yield Strength (MPa)	305
Poisson's ratio	0.285	Tensile Strength (MPa)	395
Reduction of area %	40	Tensile/Yield	1.3
Bulk Modulus (GPa)	135	Uniform Elongation (%)	18.973

Table 2True stress and true plastic strain of AISI 1010 steel

True stress (MPa)	True plastic strain (mm/mm)
305	0
306.6822729	0.078823805
311.3144875	0.079580754
332.8049375	0.083154783
354.445	0.086728003
368.998875	0.089228084
383.85655	0.09233576
392.4691	0.0954888
395.9799641	0.098631929

In the finite element simulation, a step was defined with proper time increment therefore, solution was easily converged. Dynamic/Explicit solution was used due to the model has complex contact interaction. Arbitrary Lagrangian Eulerian ALE meshing combines the features of pure Lagrangian analysis and pure Eulerian analysis. So, it can be used with *explicit, dynamic* that allows to maintain a high-quality mesh throughout dynamic analysis and makes the mesh move independently of the material when occurring large deformation or losses of material with the mesh topology remains unchanged. The frictional constraints were defined with the interaction option. In procedure of Explicit/Dynamic, surface-to-surface (explicit) was developed to create an interaction. Finite sliding with a penalty contact method was selected for all contacts to resolve tangential behavior of a mechanical contact. In this method, the compressive force is proportional to the penetration of the material, using the basic concept of the Coulomb friction model. Contact interaction property was selected to define normal behavior (hard contact) and tangential behavior with friction coefficients of0.1, 0.125, and 0.15. Boundary conditions were applied to move material between the die and the fixed plug. First, for initial condition the die and the fixed plug were fixed at all direction (U_1=0, U_2=0, UR_3=0). In the second step, velocity 4.25 m/min was applied. It is known fact that the accuracy of simulation results strongly depend on selected element type and mesh size. In this study, a 4-node bilinear axisymmetric quadrilateral, reduced integration, hourglass control element was used as seen in Fig.4.

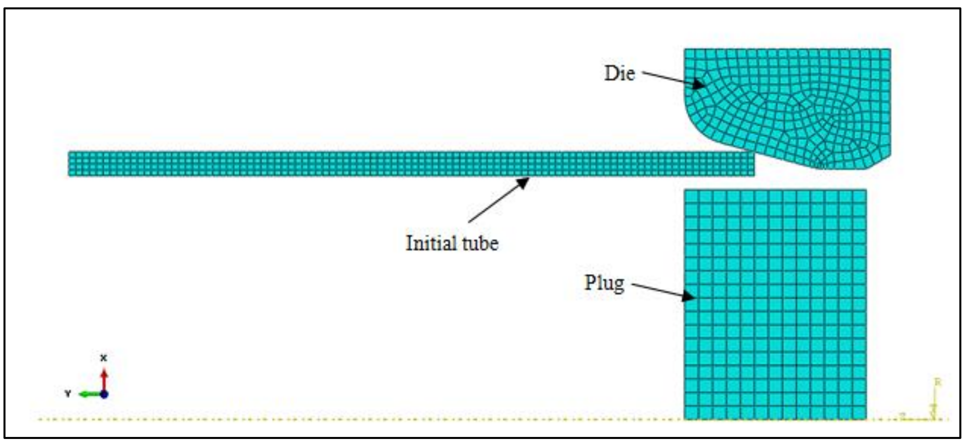

Fig.4 Mesh of axisymmetric tube drawing process with a fixed plug

5. Results and Discussion

5.1 Model Validation

First, the proposed model was validated. It was explained earlier that experimental data was measured in order to validate the proposed model. For this reason, drawing forces were compared as shown in Fig.5. The figure displays a comparison between the experiment and the finite element results for the case of 23%reduction of area; semi die angle; 15°, semi plug angle; 0°, and the coefficient of friction was 0.1. Based on the comparison, it is clear that a similar drawing force vs. displacement diagram was determined. The results show that the experimentally and numerically determined drawing forces were 137 and 142 kN, respectively corresponding displacements of 27.9 and 27.7 mm. This outcome clearly proves the validation of the model. The difference between two forces was quite small.

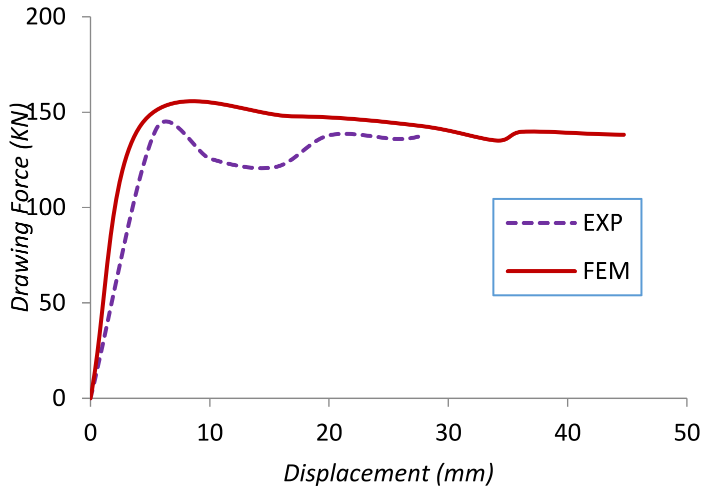

Fig. 5 Comparison between experimental and FEM

5.2 Finite Element Results

5.2.1Effect Semi Die/Plug Angles on Plastic Deformations

Fig 6a and b show equivalent plastic strain (PEEQ) distribution. In Fig. 6a, semi die angle is 12°, semi plug angle is 0°, and coefficient of friction is 0.1 while in Fig. 6b, semi die angle is 7°, semi plug angle is 4°, and coefficient of friction is 0.1.

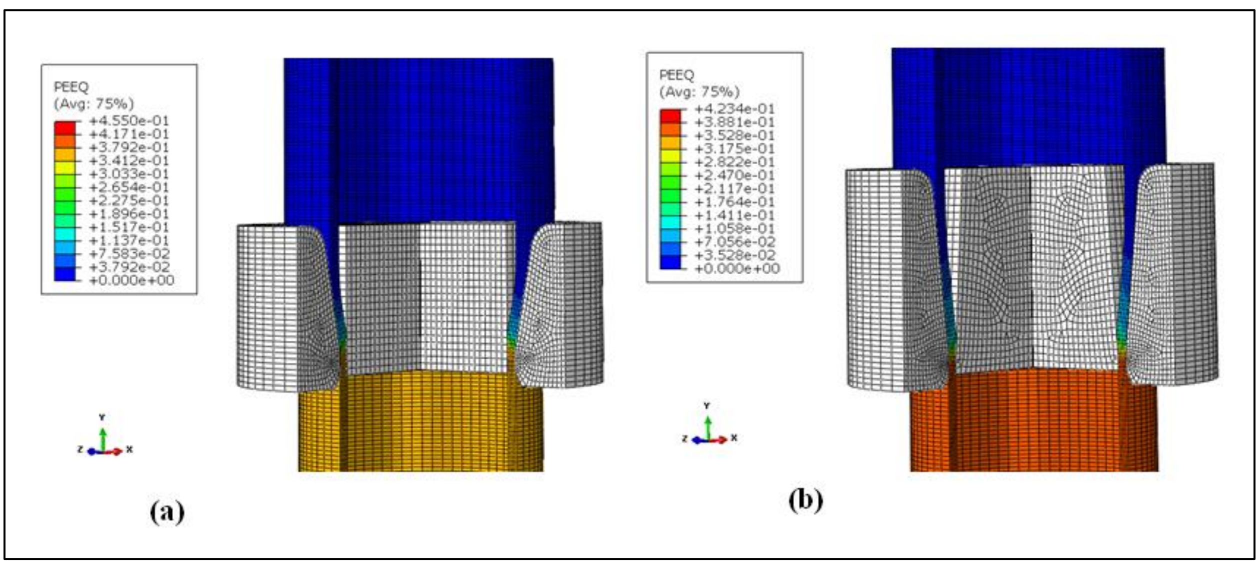

Fig. 6 PEEQ axisymmetric finite element models (a) semi die angle of 12° and semi plug angle of 0° (b) semi die angle of 7° and semi plug angle of 4°

In Fig. 6, it is quite obvious that there is a clear difference in plastic deformation for (a) and (b) due to the change in semi die/plug angles. The plastic deformation occurs as a result of dislocation motions that represent a linear defect in the crystal structures. A preferred orientation is produced since the crystallographic directions gradually rotate toward more stable orientations that represent drawing direction and this lead to isotropic material transforms to anisotropic [10]. The effect of semi die angle is larger than the effect of semi plug angle on plastic deformations due to the increase in plasticity (higher dislocation density) that take place in contact region.

5.2.2 Effect Semi Die Angle on Drawing Force

Drawing force vs. displacement at different semi die angles were plotted in Fig. 7. The figure shows the effect of semi die angle on drawing force vs. displacement plot for the case of semi plug angle of 0° and coefficient of friction of 0.1. The behaviors of all semi die angles were similar. The drawing force when the semi die angle is equal to10° was recorded less than semi die angles of 5° and 7°because of the decreasing in plastic deformation in contact areas. It can be clearly seen that the drawing force sharply raise due to plastic deformation. Then the drawing force is almost constant because of steady forming state is reached that keeps constant force. Finally, the drawing force is sort of decreased when the tube exits the die.

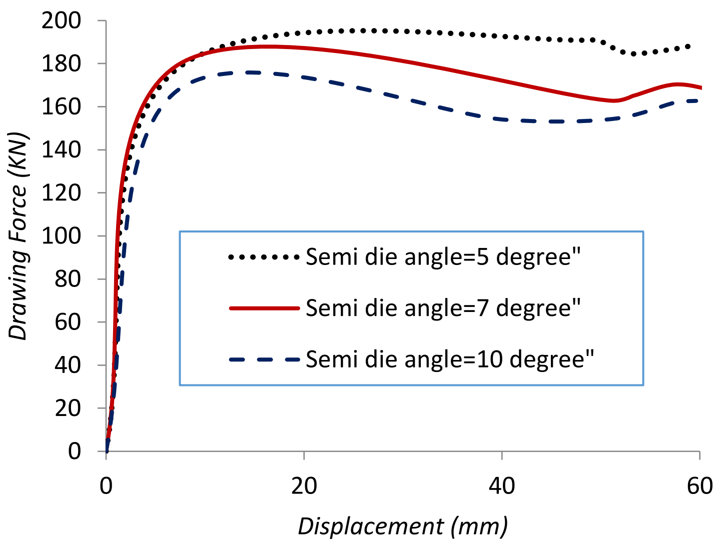

Fig. 7 Relationship between drawing force and displacement at different semi die angles

5.2.3 Effects Semi Die/Plug Angles on Drawing Stress at Different Coefficients of Friction

The effect of semi die angle on drawing stress with a constant semi plug angle of 0°at different friction coefficients were plotted in Fig. 8. The figure indicates that the drawing stress corresponding to the semi die angle of 5° recorded larger than other semi die angles because of the increase in dislocation density. Semi die angle produces differences of the friction work, as well as it has the effect of the redundant plastic work of deformation [11]. The redundant deformation represents both of friction and shear deformation and it is a radial strain. Therefore, it can be said that, the semi die angle strongly has a strong effects on drawing stress. The minimum drawing stresses171, 186, and 215 MPa were determined at semi die angle of 12°for friction coefficients of 0.1, 0.125, and 0.15 correspondingly.

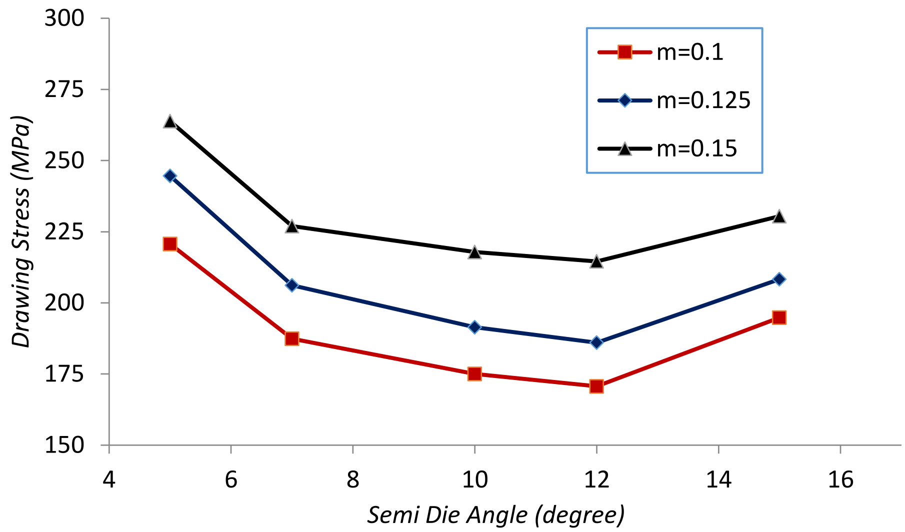

Fig. 8 Relationship between drawing stress and semi die angle at different of friction coefficients

Fig.9 indicates the relationship between semi plug angle and drawing stress at constant semi die angle of 7°at different friction coefficients. The minimum drawing stress was founded with semi plug angle of 0° and the maximum drawing stress was estimated with semi plug angle 1° because of the increase in plastic deformation at inlet and outlet of the dies. There is a possibility to use semi plug angle between 2° to 4° which is less than the semi die angle that can give very good surface finish for the internal of tube [12].

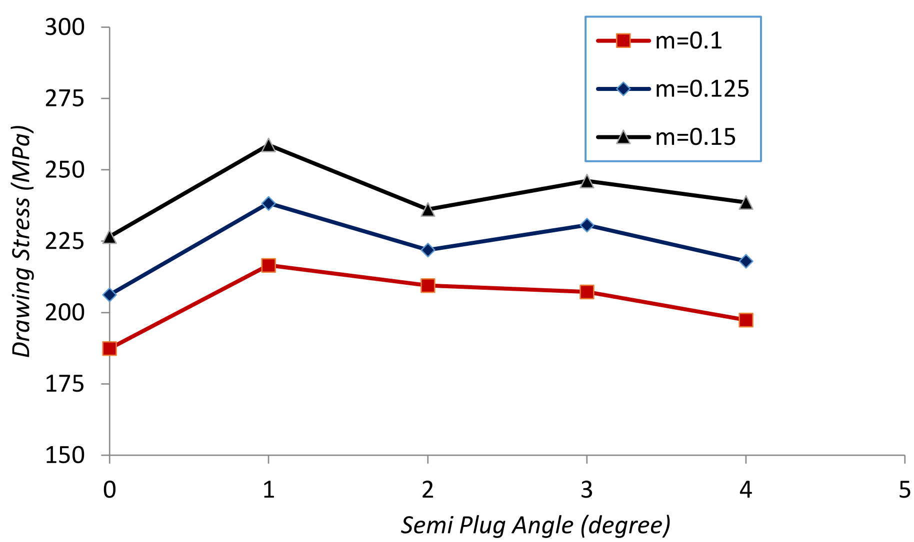

Fig. 9 Relationship between drawing stress and semi plug angle at different of friction coefficients

5. Conclusion

In this work, the FEM was successfully applied for modeling of tube drawing process with a fixed plug. Different semi die/plug angles at different coefficients of friction were studied in order to determine drawing force and stress. Following conclusions were drawn:

1. An axisymmetric model was successfully validated by experimental data.
2. The effect of semi die angle on plastic deformation was larger than semi plug angle because of the bigger size of semi die angle.
3. Semi die angle of 12° gives minimum drawing stress for all coefficient of frictions.
4. A semi plug angle between 2° and 4° should be used in tube drawing process with a conical fixed plug when semi die angle is equal to 7^o.
5. Drawing stress increases with increasing coefficients of friction for all semi die/plug angles.

Acknowledgements

The authors would like to thank Graduate School of Natural Sciences at Yildrim Beyazit University. Experimental part of the research presented in this paper was funded by Yildrim Beyazit University. BAP project # 2641. Support of project unit at Yildirim Beyazıt University is greatly acknowledged.

References

[1] Teschaetsch, H. Metal forming practice. Published by Vieweg Verlag, Process-Machine-Tools, Dresden, Germany, p. 105-108. 2006.

[2] Dankert Joachim, T., Endelt, E. LS-DYNA used to analyze the drawing precision tubes. 7th European LS-DAYNA Conf. 2009.

[3] Beland J, Fafard M, Rahem A, Amours G, Cote T. Optimization on the cold drawing process of 6063 aluminum tubes. J Applied Mathematical Modelling 2011; 35: 5302-5313.

[4] Bihamta R, Bui QH, Guillot M, Amours G, Rahem A, Fafard M. Application of a new procedure for the optimization of variable thickness drawing of aluminum tubes. CIRP J of Manf. Sci. and Technol. 2012; 5: 142-150.

[5] Palcngat M, Chagnon G, Favier D, Louche H, Linardon C, Plaideau C. Cold drawing of 316L stainless steel thin-walled tubes: Experiments and finite element analysis. Int. J. of Mech. Sci. 2013; 70: 69-78.

[6] Linardon C, Favier D, Chagnon G, Gruez B. A conical mandrel tube drawing test designed to assess failure criteria. J. of Mat. Process. Technol. 2014; 214: 347-357.

[7] Shea Jong J, Yi Lin S, Hsien Yu C. Optimum die design for single pass steel tube drawing with large deformation. J. of Procedia Eng. 2014; 81: 688-693.

[8] Trana E., Rotariu A., Lixandru P., Matache L., Enache C., Zecheru T Experimental and numerical investigation on 6082 0 temper aluminum alloy cartridge tube drawing. J. of Mat. Process. Technol. 2015; 216: 59-70.

[9] Kasim J. Calculation of relative extrusion pressure for circular section by local coordinate system by using finite element method FEM. Diyala J. of Eng. Sci. 2010; 03: 80-96.

[10] Chakrabarty J. Theory of plasticity. 3rd ed. Texas: Butterworth-Heinemann, 2006

[11] Aguilar M, Correa E, Silva R, Cetlin p. The evaluation of redundant deformation factors in axi-symmetric bar of austenitic stainless steel. J. of Mat. Process Technol. 2002; 125-123: 323-325.
[12] Dieter G.E, Kuhn H.A, Semiatin S.l. Handbook of workability and process design. ASM International 2003, Chapter 19: p. 278-290.