# Cold Drawing Process –A Review

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## ABSTRACT

Cold drawing is widely used metal forming process with inherent advantages like closer dimensional tolerances, better surface finish and improved mechanical properties as compared to hot forming processes. Due to the ever increasing competition with the advent of globalization it has become highly important to keep on improving the process efficiency in terms of product quality and optimized use of resources. In view of this different models have been proposed and validated using experimental results over a long period of time. The demands in the automobile sector, energy sector and mining sector have led to several modifications in the drawing process. In this paper, process details of cold drawing, major analytical, experimental and numerical studies reported in literature have been reviewed. The review focuses on highlighting the developments associated with the drawing technology that includes improvement in tool design, modification in product geometry, process optimization etc. with the use of Finite element method to achieve the process related objectives.

**Keywords-**Cold drawing, Finite element method, Process optimization, Product geometry, Tool design.

## I. INTRODUCTION

Good quality and high precision products can be produced by several metal forming methods such as extrusion, drawing, rolling etc. Metal forming is the large group of manufacturing processes in which plastic deformation is used to change the shape of metal workpieces [1].The factors that determine the choice of the forming or for that matter any other process are maximum utilization of resources with high quality output. Both extrusion and drawing are net shape metal forming processes which have high material utilization and produces parts with superior metallurgical and material properties. This paper is a review on cold drawing process with a focus on the developments associated with the drawing process that includes improvement in tool design, modification in product geometry, process optimization etc. with the use of modern techniques like Finite element method to achieve the process related objectives.

## II. 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.

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.
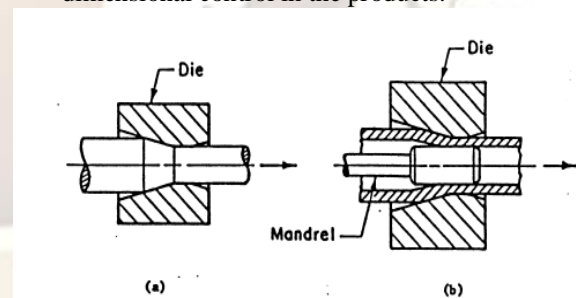


Fig.1 Types of Cold drawing (a) wire and bar drawing and (b) Tube drawing

Earlier different analytical methods like Slab method, Upper bound method or slip line theory were used for material flow and behaviour 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 [2] 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.

## III. LUBRICATION AND COEFFICIENT OF FRICTION

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 [3]. 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 [4]. In the context of the same, Chuiko et al. [5] described the development in new forms of production lubricants and methods of oxalate application over Stainless Steel Tube. Lubricity criteria of fatty-based oils (palm, groundnut and shea butter oils), an important aspect of oil selection, were qualitatively assessed by Obi and Oyinlola [6] for friction evaluation for processes like wire drawing and extrusion through open dies. Neves et al. [7] carried out experimental tests with a laboratory drawing bench with three different lubricants and two different lubrication conditions in order to study their effect on drawing loads and residual stresses. Similarly Byon et al. [8] performed Wire drawing test for four different coating materials and two different lubricants as the reduction ratio increased from 10% to 30%.Results showed that the behaviour of drawing force varies with the lubricant-type at the initial stage of drawing.

## 1V. IMPROVEMENT IN TOOL DESIGN

The profile design of die and mandrel is the most important factor related to forming energy and deformation behaviour of tubular material [9]. Gunasekera and Hoshino [10] 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. [9] 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. Wang and Argyropoulos [11] designed, modified and analyzed a plum-blossom-shape die for the direct cold drawing of hexagon/square-section rods in order to replace a series of converging dies in the traditional section drawing method. It dramatically increased the manufacturing productivity, improved the product quality, and reduced the manufacturing time and cost.

A newly developed plug featuring a tiny boss club structure in the sizing zone was proposed by Xu et al. [12]. It was found that when the plug with a tiny boss club structure is adopted, the contact quality is better and the larger plastic strain exists on the inner surface of the tube, which is very crucial in improving the surface finish of the formed part. The evaluation of effect of tools' geometries on the maximum possible tube deformation was studied by Bihamta et al. [13] on variable thickness tube drawing process with a newly developed procedure. Based on the optimum design developed by Béland et al. [14] through a finite element model, a new tool was built which minimised the maximum stress level to draw tubes in one pass.

## V. TOOL GEOMETRY MODIFICATION

Modification in conventional tube geometry like development of the Rifled Tubes etc., as per the application requirement has also been a part of several researches. Rifled Tubes have high heat-transfer efficiency and therefore are used for the furnace wall tube in the large power plant boilers. Assurance of high dimensional accuracy in the rifle tubes was given by Yoshizawa et al. [15] with the help of a manufacturing technique developed through experiments. Bayoumi [16] 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 [17] both analytically and numerically by applying finite element simulation. Parshin [18] utilized the obtained equations in the standard finite-element program to analyse the variation in the shape of the eight-beam star like tubes in the course of multipass drawing.Xu et al. [12] developed an aluminium tube with rectangular cross-section with high dimensional accuracy and surface finish. High quality micro copper tube with straight grooves (MCTSG) with an outer diameter of 6 mm was obtained by Yong et al. [19].The influence of drawing parameters on the forming of micro straight grooves was investigated based on the forming mechanism. Bihamta et al. [20] modified the classical tube drawing process. The sinking and fixed-mandrel tube drawing methods were mixed together to produce tubes with variable thickness in the axial direction.

## VI. EFFECT OF RESIDUAL STRESSES

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. [21]. Elices [22] showed that how stress-relaxation losses, environmental assisted cracking and fatigue life of cold-drawn pearlitic wires are influenced by residual stresses. Elices [22] 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. [23] to study the residual macro stress state generated by drawing. Phelippeau [24] 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. [25] 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. In the similar context, Ripoll et al. [26] proposed two methods for reducing the residual stresses during wire drawing, namely applying an advanced die geometry and performing an inexpensive post-drawing treatment based on targeted bending operations. Kuboki et al. ([27] examined the effect of a plug on residual stress in tube drawing by both numerical analysis and laboratory experiment. The typical variation in residual stresses from tensile to compressive was seen across the drawn gold wire cross section in the experiment carried out by Narayanan et al. [28]. Results of residual stress measurements and simulation were also presented by Pirling et al. [29] .A three dimensional finite element model was developed to calculate the change in wall thickness, eccentricity, ovality and residual macro-stress (RS) state for cold drawn tubes. A prediction model for the maximum axial residual stress was proposed by Béland et al. [14] through a finite element method that considers the inhomogeneous deformation and heat generation in a high-carbon (0.82-wt% C) drawn wire .

## VII. DEFECTS IN DRAWING

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 [30]. 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 [31]. Same is true for drawn tubes. In this context considerable amount of research has been carried out, some of which is reviewed below.Rajan and Narasimhan [32] presented experimental

observations of defects developed during flow forming of high strength SAE 4130 steel tubes. The major defects observed were fish scaling, premature burst, diametral growth, micro cracks, and macro cracks. When we consider the micromechanical point of view, it is a known fact that the drawing process influences the microstructure of the material in the form of progressive trend towards a closer packing and a more oriented arrangement [33]. Anisotropic fracture behaviour is exhibited by prestressing steel wires (heavily drawn) in air and in aggressive environments promoting stress corrosion cracking in several forms as was reported by Toribio et al. [33] .

Camacho et al. [34] used the Finite Element Method to study the effect of drawing variables on defects. Shinohara and Yoshida [35] carried out a three-dimensional finite element analysis (FEA) that investigated the growth of surface defects due to wire drawing. They stated that superior wires without flaws could be obtained by removing the flaws before drawing and by multi-pass drawing.Weygand et al. [36] analysed the drawing process with a finite element model to determine the factors that are responsible for defects called splits. The effect of residual stresses due to the cold-drawing process on the fatigue crack propagation in a metallic cracked round bar with a V-shaped circumferential notch was examined by Carpinteri et al. [37]. The crack propagation under cyclic tension combined with the residual stresses was analysed by taking into account the SIF values and the actual stress ratio. Toribio et al. [38] numerically analysed the role of drawing-induced residual stresses and strains in the performance of cold drawn prestressing steel wires under conditions of hydrogen embrittlement (HE). The results of the study carried out by Tang et al. [39] illustrated the damage evolution of the drawn wire in each of the eight passes and the damage distribution along axial and circular directions. Wire breakage is expected to occur in those areas of the drawn wire where fractures most possibly initiate [39]. Furthermore, the numerical analyses contributed a new approach for the optimization of the drawing parameters.

## VIII.INFLUENCE OF THE OPERATING PARAMETERS

De Castro et al. [41] 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. [42]. The calculations were done for various process parameters, including different profiles of the working part of the die. Chen and Huang [43] 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. [44] 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. [45] 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. [46] analysed distortion for a typical manufacturing process of pre-straightened, cold drawn and induction hardened AISI 1045 cylindrical steel bars using DoE (Design of Experiments). Celentano et al. [47] assessed the influence of specific operating conditions, such as the decrease of the number of wire reductions and the presence of back tension, on the material response during the whole process numerically. During the same period, Bourget et al. [48] studied the effects of time, temperature, and furnace heating rate in order to identify an optimized heat treatment for tubes with different cold work levels.

The variable thickness tube drawing was parameterized by Bihamta et al. [49]. Haddi et al. [50] studied the influence of drawing conditions on temperature rise and drawing stress in cold drawn copper wires. From the experimental results, a relationship between temperature rise, drawing stress and friction coefficient was built. Bui et al. [51] carried out a study in which experiments were conducted to evaluate the effect of cross section reduction. Nagarkar et al. [52] simulated drawing of round tubes while passing through the sink pass, using ANSYS software to study the effect of various parameters like die angle on the product quality. Cetinarslan [53] determined the effects of some drawing parameters like deformation ratio and drawing speed on wire drawing. It was observed that these variables significantly affect the tensile and torsion strength of the ferrous wires.

An investigation was carried out by Raji and Oluwole [54] on 0.12%w C steel wire cold drawn progressively by 20%, 25%, 40% and 50% to study the influence of the degree of cold drawing on the mechanical properties of the carbon steel material.

## IX. USE OF ANALYTICAL MODELS.

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 [55]. 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. [56] 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 analysed by Rubio et al. [57]using the upper bound method. Analytical formulations were extensively used by Gur'yanov [58]. 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.

Similarly tension in the drawing process was determined by Gonza´ lez et al. [59] via free body equilibrium method to solve the drawing problem for dies of axisymmetric or symmetric sections. As opposed to the classical slab method, solution of the equations obtained through this method accounted for internal material distortion.An extension of an upper bound solution developed earlier was proposed by Bui et al. [60] to predict the drawing stress field. Rubio [61] analysed tube drawing using analytical methods, i.e. Slab Method (SM), with and without friction effects and the Upper Bound Method (UBM).

## X. CONCLUSIONS

To keep up with the ever demanding customer needs the industries have to keep on improving in terms of product quality, minimum product development cycle time, optimized usage of resources and incorporation of modern methods, technologies to achieve the aforementioned goals.

This paper is a review on literature published in the context of cold drawing process; which is used for manufacturing high quality products that have wide variety of applications in different sectors of engineering. It helped in understanding the developments and research carried out over a period of time for different problems associated with cold drawing and different approaches involved in problem solving ranging from analytical methods to Finite Element Method.

## REFERENCES

[1] Groover, M. P. *Fundamentals of Modern Manufacturing*. John Wiley & Sons, Inc. 4/e 2010.

[2] Kopp, R. Some Current Development Trends in Metal-Forming Technology (1996). *Journal of Materials Processing Technology, 60,* 1-9.

[3] Rosochowska, Malgorzata, Andrzej Rosochowski and Lech Olejnik (2009). Finite Element Analysis of Cold Forward Extrusion of 1010 Steel. *The Annals of "Dunărea De Jos" University Of Galaţi Fascicle V, Technologies in Machine Building, ISSN 1221- 4566,* 101-106.

[4] Jurkovic, M., Z. Jurkovic and S. Buljan (2006). The Tribological State Test in Metal Forming Processes using Experiment and Modelling. *Journal of Achievements in*

*Materials and Manufacturing Engineering, Vol. 18,* Issue 1-2.

[5]  Chuiko, V. N., Savin G. and A. Kalashnikov(1973).Cold Drawing of Stainless Steel Tubes on Short Mandrel. *Metallurg, No. 3,* 32-33.

[6]  Obi, A. I. and A.K. Oyinlola (1996). Frictional Characteristics of Fatty-Based Oils in Wire Drawing. *Wear, 194,* 30-37.

[7]  Neves, F. O, 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]  Byon, S. M., S. J. Lee, D. W. Lee, Y. H. Lee and Y. Lee (2011). Effect of Coating Material and Lubricant on Forming Force and Surface Defects in Wire Drawing Process. *Trans. Nonferrous Met. Soc. China, 21,* S104−S110.

[9]  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.

[10]  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.

[11]  Wang, Karen L. and Vasilis Argyropoulos (2005). Design and Analysis of Direct Cold Drawing of Section Rods through a Single Die. *Journal of Materials Processing Technology, 166,* 345–358.

[12]  Xu, Wujiao, Kaiqing Wang, Pengcheng Wang and Jie Zhou (2011). A Newly Developed Plug in the Drawing Process for Achieving the High Accuracy of Aluminium Rectangular Tube. *Int J Adv. Manuf Technol, 57,* 1–9.

[13]  Bihamta, R., Q.H. Bui, M. Guillot, G. D'Amours, A. Rahem and M. Fafard (2011). Application of a New Procedure for the Optimization of Variable Thickness Drawing of Aluminium Tubes. *Journal of Materials Processing Technology, 211,* 578–589.

[14]  Béland, J. F., M. Fafard, A. Rahem, G. D'Amours and T.Côté (2011).Optimization on the Cold Drawing Process of 6063 Aluminium Tubes. *Applied Mathematical Modelling, 35,* 5302–5313.

[15]  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.

[16]  Bayoumi, Laila. S. (2001). Cold drawing of Regular Polygonal Tubular Sections from Round Tubes. *International Journal of Mechanical Sciences, 43,* 2541–2553.

[17]  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.

[18]  Parshin, S. V. (2009). Multipass Drawing of Finned Tubes", *Russian Journal of Non-Ferrous Metals. Vol. 50, No. 2,*128–132.

[19]  Yong, Tang, Ou Dong-Sheng, Wan Zhen-Ping, Lu Long-Sheng and Lian Bin (2011). Influence of Drawing Process Parameters on Forming of Micro Copper Tube with Straight Grooves. *Trans. Nonferrous Met. Soc. China, 21,* 2264−2269.

[20]  Bihamta, R., Q.H. Bui, M. Guillot, G. D'Amours, A. Rahem and M. Fafard (2011). A New Method for Production of Variable Thickness Aluminium Tubes: Numerical and Experimental studies. *Journal of Materials Processing Technology, 211,* 578–589.

[21]  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.

[22]  Elices, M. (2004).Influence of Residual Stresses in the Performance of Cold-drawn Pearlitic Wires. *Journal of Materials Science, 39,* 3889–3899.

[23]  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 Materialia, 52,* 305–309.

[24]  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.

*[25]*  Nakashima, Takashi, Kouichi Koruda and Kenichi Beppu (2008).Cold Finished Seamless Steel Tubes. *United States Patent, US 7371293B2.*

[26]  Ripoll, Manel Rodriguez, Sabine M. Weygand and Hermann Riedela (2010). Reduction of Tensile Residual Stresses during the Drawing Process of Tungsten Wires.*Materials Science and Engineering. A 527,* 3064–3072.

[27]  Kuboki, Takashi, Keigo Nishida,Tomohiro Sakaki and Makoto Murata (2008).Effect of Plug on Levelling of Residual Stress in

Tube Drawing. *Journal of materials processing Technology, 204,* 162–168.

[28] Narayanan, Karthic R., Sridhar Idapalapati and Sathyan Subbiah (2010). Effect of Cold Work on the Mechanical Response of Drawn Ultra-Fine Gold Wire.*Computational Materials Science, 12*.038.

[29] Pirling, T., A. Carradò and H. Palkowski (2011) . Residual Stress Distribution in Seamless Tubes Determined Experimentally and by FEM. *Procedia Engineering,10 ,*3080–3085.

[30] Shinohara, T. and K. Yoshida (2005). Deformation Analysis of Surface Flaws in Stainless Steel Wire Drawing. *Journal of Materials Processing Technology, 162–163,* 579–584.

[31] Savenok, A. N., T. P. Kurenkova, and A. A. Sakharnaya (2012).Influence of Surface Defects Inherited by Wire Rod on the Quality of Cold Drawn Wire. *Steel in Translation, Vol. 42, No. 5,* 452–455.

[32] Rajan, K.M. and K. Narasimhan (2001). An Investigation of the Development of Defects During Flow Forming of High Strength Thin Wall Steel Tubes. *Practical Failure Analysis, Volume 1(5),* 69-76.

[33] Toribio, J. and F. J. Ayaso (2003). Anisotropic Fracture Behaviour of Cold Drawn Steel: a Materials Science Approach. *Materials Science and Engineering, A 343,* 265-272.

[34] Camacho, A.M., C. Gonz´alez, E.M. Rubio and M.A. Sebastian (2006). Influence of Geometrical Conditions on Central Burst Appearance in Axisymmetrical Drawing Processes, *Journal of Materials Processing Technology, 177,* 304–306.

[35] Shinohara, T. and K. Yoshida (2005). Deformation Analysis of Surface Flaws in Stainless Steel Wire Drawing. *Journal of Materials Processing Technology, 162–163,* 579–584.

[36] Weygand, S.M., H. Riedel, B. Eberhard and G. Wouters (2006). Numerical simulation of the Drawing Process of Tungsten Wires. International *Journal of Refractory Metals & Hard Materials, 24,* 338–342.

[37] Carpinteri, Andrea, Roberto Brighenti and Sabrina Vantadori (2010). Influence of the Cold-Drawing Process on Fatigue Crack Growth of a V-notched Round Bar. *International Journal of Fatigue, 32,* 1136–1145.

[38] Toribio, J., V. Kharin, M. Lorenzo and D. Vergara (2011). Role of Drawing-Induced Residual Stresses and Strains in the Hydrogen Embrittlement Susceptibility of Prestressing Steels. *Corrosion Science, 53,* 3346–3355.

[39] Tang, K.K., Z.X. Li and J. Wang (2011).Numerical Simulation of Damage Evolution in Multi-Pass Wire Drawing Process and its Applications. *Materials and Design, 32,* 3299–3311.

[40] Li, Feng, Li Li, Xiang Wang and Xu Liang Ma(2010).Optimising the Seamless Tube Extrusion Process using the Finite Element Method. *JOM, Vol.62 ,No.3,*71-74.

[41] 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 Materials Processing Technology, 60,* 179-182.

[42] 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.

[43] Chen, D. C. and J. Y. Huang (2007). Design of Brass Alloy Drawing Process using Taguchi Method. *Mater. Sci. Eng., 464,* 135–140.

[44] 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.

[45] 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,* Nos. 3–4.

[46] Rocha, Alexandre da Silva, Rafael Menezes 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.

[47] Celentano, Diego J., Mauricio A.Palacios, Ennio L. Rojas, Marcela A.Cruchag, Alfredo A. Artigas and Alberto E.Monsalve (2009). Simulation and Experimental Validation of Multiple-Step Wire Drawing Processes. *Finite Elements in Analysis and Design, 45,* 163 – 180.

[48] Bourget, J.P., M. Fafard, H.R. Shakeri and T. Côté (2009). Optimization of Heat Treatment in Cold- Drawn 6063 Aluminium Tubes. *Journal of Materials Processing Technology, 209,* 5035– 5041.

[49] Bihamta, Reza, Guillaume D'amours, Quang-Hien Bui, Ahmed Rahem, Michel Guillot and Mario Fafard (2010). Optimization on the Production of Variable Thickness Aluminium Tubes. *Proceedings of the ASME 2010, International*

*Manufacturing Science and Engineering Conference, MSEC 2010,* Erie, Pennsylvania, USA.

[50] Haddi, A., A. Imad and G. Vega (2011). Analysis of Temperature and Speed Effects on the Drawing Stress for Improving the Wire Drawing Process" *Materials and Design, 32,* 4310–4315.

[51] Bui, Q. H., R. Bihamta, M. Guillot, A. Rahem and M.Fafard (2011). Effect of Cross Section Reduction on the Mechanical Properties of Aluminium Tubes Drawn with Variable Wall Thickness. *Journal of Manufacturing Science and Engineering, Vol. 133 /061004,* 1-10.

[52] Nagarkar, M.P., R.N. Zaware and S.G. Ghalme (2012). Finite Element Simulation of Sink Pass Round Tubes using ANSYS. *APTEFF, 43,* 179-188.

[53] Cetinarslan, Cem S. (2012). A Study on Influences of some Process Parameters on Cold Drawing of Ferrous Wires. Indian Journal of Engineering and Materials Sciences, Vol.19, 221-228.

[54] Raji, Nurudeen A. and Oluleke O. Oluwole (2011). Influence of Degree of Cold-Drawing on the Mechanical Properties of Low Carbon Steel. Materials Sciences and Applications, 2, 1556-1563.

[55] Pospiech, J. (1998).Description of a Mathematical Model of Deformability for the Process of Drawing Tubes on a Fixed Mandrel. Journal of Materials Engineering and Performance, Volume 7(1), 71-78.

[56] 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.

[57] Rubio, E. M., C. Gonz´alez, 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.

[58] Gur'yanov, G. N. (2009). Limiting Extension in Cold Drawing of Round Profile. *Steel in Translation, Vol. 39, No. 9,* 811–813.

[59] Rojas, Herna´n A. Gonza´ lez, Joan Vivancos Calvet and V. I. Bubnovich (2008). A New Analytical Solution for Prediction of Forward Tension in the Drawing Process. *Journal of Materials Processing Technology. 198,* 93–98.

[60] Bui, Q.H., R. Bihamta, M. Guillot, G. D'Amours, A. Rahem and M. Fafarda. Investigation of the Formability Limit of Aluminium Tubes Drawn with Variable Wall Thickness. *Journal of Materials Processing Technology, 211,* 402–414.

[61] Rubio, E.M (2006).Analytical methods application to the study of tube drawing processes with fixed conical inner plug: Slab and Upper Bound Methods. *Journal of Achievements in Materials and Manufacturing Engineering, Volume 14, ISSUE 1-2,*383-386.