STUDIES ON MECHANICAL PROPERTIES IN GALVANIZED COATED OF DIFFERENT BEGINNING DIAMETER ON HIGH CARBON STEEL WIRE

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Abstract

The cold drawn wires are used to spring manufacturing in automotive and whiteware equipment. The most important mechanical properties of the wire used in spring production are tensile strength and minimum number of twists in the torsion test. In this study, the change of mechanical properties was examined by drawing wire with a diamater of 3.80 mm from wires with diameters of 7.00 and 8.00 mm diameter by cold wire drawing. The 3.80 mm wire was drawn from both the 7.00 mm wire at 6 steps with a diameter reduction of 70 % and from 8.00 mm wire at 7 steps with a 77 % diameter reduction. Following the production of the 3.80 mm wires, the values of tensile strength, elongation, elongation ratio, torsion, galvanizing thickness as micro, surface quality as macro were investigated by mechanical and microscobic analyzes.

Keywords: Mechanical properties, high carbon galvanising coated steel wire, microscopic analyze

1. INTRODUCTION

Wire drawing; a piece of thick cross-section is passed through the drawing die, reduction process. Generally speaking, any material that may deform under the minimum conditions necessary for wire drawing may be subjected to the drawing process [1]. Circular cross-section wire is come across in the areas of conductor wires, musical instruments and packaging industry, especially steel industry and welding industry. A rod of steel is pulled through a hole in a forming tool that has a smaller diameter than the rod [2,3]. The forming tool, which is called the wiredrawing die, is designed in such a way that the rod is not 'shaved' but is plastically deformed such that its diameter is reduced to the same diameter as the hole in the die without any metal being removed [4].

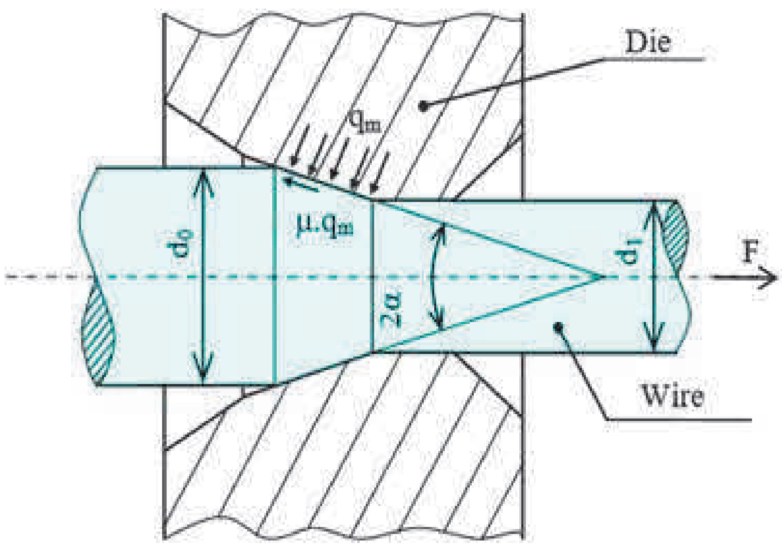

Figure 1 Schematic view of wiredrawing die [5]

Wire drawing is different from conventional cold drawing methods by diameter reduction process with more than one drawing die and this process varies according to final wire diameter and lubricant change [4,6]. During wiredrawing process, the surface and mechanical properties of the wire depend on the die angle, wire drawing speed, temperature, lubrication and reduction ratio [7]. Calculation of reduction ratios and input-output diameters is of great importance for determining the mechanical properties. Tensile and expansion properties are the most important mechanical properties that determine the identity of the material. Deformation rate and strength are parameters that are proportional to each other [8]. So that the change in inlet diameter increases the amount of deformation affecting the unit area of the material, and as a result, an increase in strength is observed. Although the maximum reduction ratio per pass is 63 %, the surface quality is lower than 45 % reduction.

2. EXPERIMENTAL DETAILS

The steel material for the experimental study was Ø 7.00 mm and Ø 8.00 mm wires from wt.% 0.83 C (**Table 1**). The wires were subjected to heat treatment in industrial conditions on the patenting production line. After passing from a patenting line the wires were subjected to a surface treatment, ie. washing in water, pickling in HCl, by rinsing in a cold water and then galvanizing. After galvanizing, Ø 7.00 mm and Ø 8.00 mm were drawn to Ø 3.80 mm.

Table 1 Steel chemical composition

C %	Mn%	Si%	P%	S%	Cu%	Cr%	Ni%	N%	V%
0.81	0.50	0.21	0.01	0.015	0.012	0.03	0.017	0.004	0.001

Ø 3.80 mm wire was drawn from both the Ø 7.00 mm wire at 6 steps with a reduction of 70 % and from Ø 8.00 mm wire at 7 steps with a 77 % reduction. The reduction values, reduction angles and diameter for each steps used for wire drawing are shown in **Table 2**. The galvanized wire samples and cold drawn wire samples were pulled with the universal tensile testing unit Zwick 5kN with test speed: 0.006 sn^{-1}, 250 mm jaw distance and 5 MPa pre-load according to TSE EN ISO 6892-1 Method B. Yield strength, tensile strength, elongation ratios were compared according to the result of tensile test. The torsion test was conducted with 300 mm sample length according to TS EN ISO 10218-1. The torsion results were compared according to the fractures occurring during torsion test which are shown in **Figure 2** (The fracture of the torsion test piece must be perpendicular to the wire axis). The galvanizing layer was examined with optical microscope and the surface quality was examined with stereo microscope.

Table 2 % Reductions, reduction angles and diameters for each step

Initial	8.00mm	Reduction Angle	Reduction%
1	7.06	10°	22.16
2	6.27	10°	21.16
3	5.60	10°	20.16
4	5.03	10°	19.16
5	4.55	10°	18.16
6	4.15	10°	17.16
7	3.80	8°	16.16

Initial	7.00mm	Reduction Angle	Reduction%
1	6.22	10°	20.92
2	5.57	10°	19.92
3	5.02	10°	18.92
4	4.54	10°	17.92
5	4.14	8°	16.92
6	3.80	8°	15.92

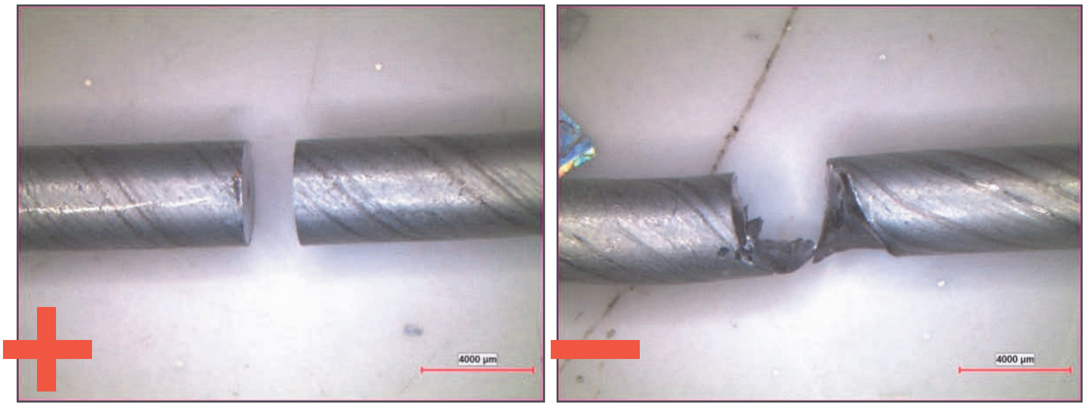

Figure 2 Evaluation of fractures occurring during torsion test

3. RESULTS AND DISCUSSION

Ø 7.00 mm and Ø 8.00 mm galvanized wires mechanical properties are shown in **Table 3**. The cold wire drawing process increases the tensile strength (σ_m) and yield strength ($\sigma_{0,2}$) because of a strengthening mechanism with decrease of the elongation(ductility). Ø 3.80 mm galvanized wires mechanical test results can be seen in the **Table 4**.

Table 3 Ø 7.00 mm and Ø 8.00 mm galvanized wires mechanical properties

d_0 (mm)	S_0 (mm²)	m_E (GPa)	$Rp_{0.2}$ (Mpa)	R_m (MPa)	A_{100} (%)
8.00	50.27	77	1041	1338	6.7
7.00	38.48	89	1071	1413	5.7

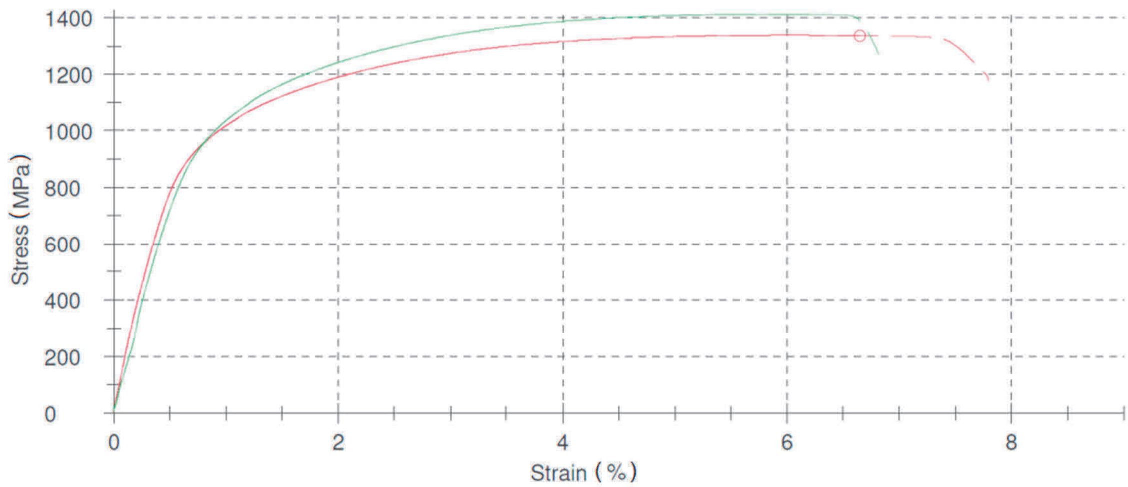

Figure 3 Strain - Stress curve of Ø 7.00 mm and Ø 8.00 mm galvanized wires

At this point, the effect of the initial diameter on the tensile and yield strength is clearly visible. After wire drawing, Ø 3.80 mm wire tensile strength was increased from 1338 MPa to 1841 MPa where initial diameter was Ø 8.00 mm. Ø 3.80 mm wire tensile strength was increased from 1413 MPa to 1814 MPa where initial diameter was Ø 7.00 mm. As seen from the results, 1.00 mm increase in initial diameter causes 1.48 % increase in tensile strength. The elasticity of initial diameters Ø 7.00 mm and Ø 8.00 mm are almost the same when strength-yield ratio are taken into consideration. It is seen that the tensile strength and the yield strength increases as the entry diameter, (total reduction) increases.

Table 4 Ø 3.80 mm (from Ø 8.00 mm) cold drawn galvanized wires mechanical properties

From Ø 8.00 mm to Ø 3.80 mm						
Series n=25	**d_0 (mm)**	**S_0 (mm²)**	**m_E (GPa)**	**$Rp_{0.2}$ (MPa)**	**R_m (MPa)**	**A_{100} (%)**
x	3.80	11.34	194	1541	1841	1.9
s	0	0	9	32	7	0.1

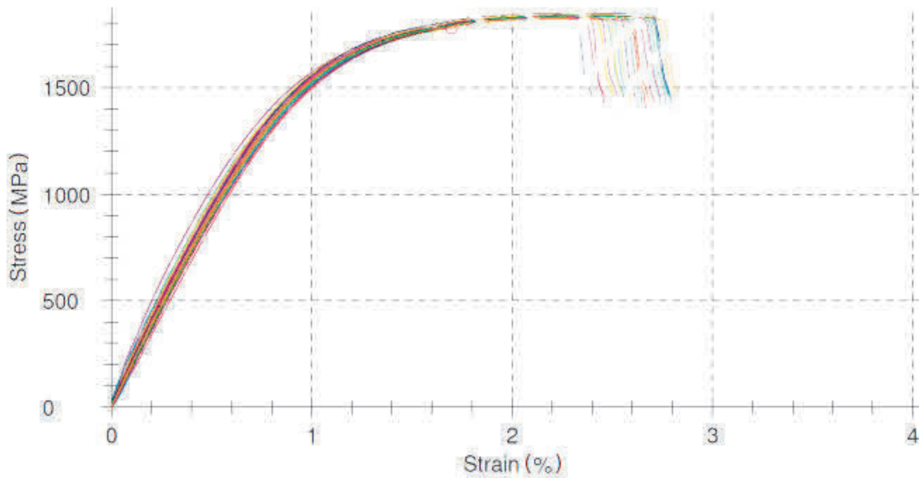

Figure 4 Strain - Stress curve of Ø 3.80 mm galvanized which was drawn from Ø 8.00 mm

Table 5 Ø 3.80 mm (from Ø 7.00 mm) cold drawn galvanized wires mechanical properties

From Ø 7.00 mm to Ø 3.80 mm						
Series n=25	**d_0 (mm)**	**S_0 (mm²)**	**m_E (GPa)**	**$Rp_{0.2}$ (MPa)**	**R_m (MPa)**	**A_{100} (%)**
x	3.80	11.34	185	1522	1814	2.0
s	0	0	7	33	5	0.1

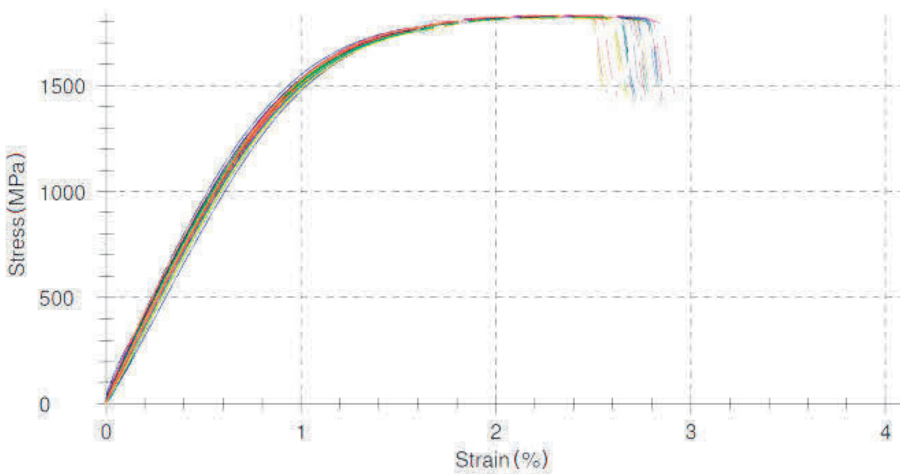

Figure 5 Strain - Stress curve of Ø 3.80 mm galvanized which was drawn from Ø 7.00 mm

Ø 3.80 mm cold drawn galvanized wires were examined for the galvanizing thickness under the optic microscope as micro with 100x zoom. Also wires were examined for the surface quality under stereo microscope as macro. Both of examining pictures can be seen in the **Figure 6**. Because of wire drawing steps, the galvanizing layer was thicker which was drawn from Ø 7.00 mm wire. (Average galvanizing thickness of wire drawn from 8.00 mm is 33.4 µm, drawn from 7.00 mm is 53.7 µm)

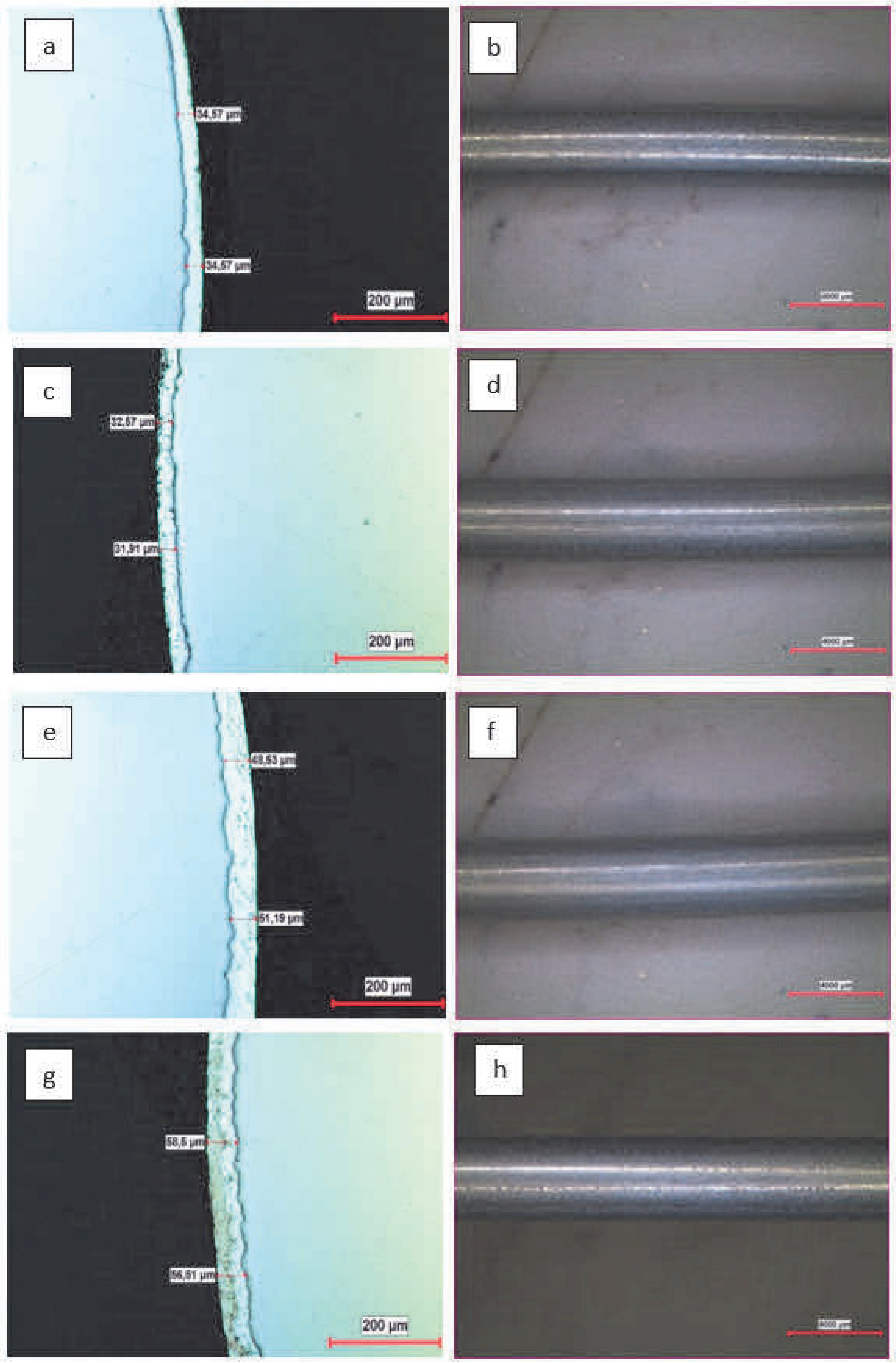

Figure 6 Galvanized tickness and surface quality **a.** Image of optical microscope drawn from Ø 8.00 mm to Ø 3.80 mm **b.** Image of stereo microscope drawn from Ø 8.00 mm to Ø 3.80 mm **c.** Image of optical microscope drawn from Ø 8.00 mm to Ø 3.80 mm **d.** Image of stereo microscope drawn from Ø 8.00 mm to Ø 3.80 mm **e.** Image of optical microscope drawn from Ø 7.00 mm to Ø 3.80 mm **f.** Image of stereo microscope drawn from Ø 7.00 mm to Ø 3.80 mm **g.** Image of optical microscope drawn from Ø 7.00 mm to Ø 3.80 mm **h.** Image of stereo microscope drawn from Ø 7.00 mm to Ø 3.80 mm

Torsion test is conducted for assessing the deformability, fracture behaviour and surface condition. Torsion test results of Ø 3.80 mm cold drawn galvanized wires can be seen in **Figure 7** and **Table 6**. Because of higher reduction ratio, number of twist in the torsion test is better which is drawn from Ø 8.00 mm.

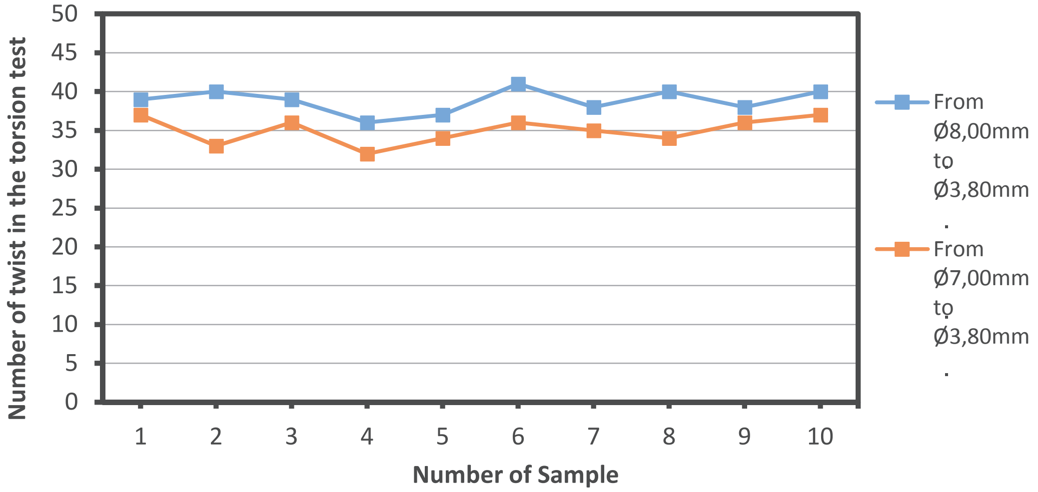

Figure 7 Number of twist in the torsion test

The fracture of the torsion test pieces was being perpendicular to the wire axis which was drawn from Ø 8.00 mm. Fracture of torsion test surface was the worst which was drawn from Ø 7.00 mm. According to minimum number of twist in torsion test results and the fracture of test pieces, initial diameter affects both of them.

Table 6 The fracture of the torsion test pieces (compared according to **Figure 2**)

Wires	The fracture of the torsion test pieces									
	1	2	3	4	5	6	7	8	9	10
From Ø 8.00 mm to Ø 3.80 mm	+	+	+	+	+	+	+	+	+	+
From Ø 7.00 mm to Ø 3.80 mm	+	-	-	+	-	+	-	-	-	+

4. CONCLUSION

The effect of the initial diameter on the mechanical properties of an important parameter of the wire drawing process was investigated. In this study, it was observed that 1.00 mm change in the initial diameter, tensile strength increases by 1.48 %. Galvanizing coated on the wire with a initial diameter of Ø 8.00 mm is less compared to Ø 7.00 mm, although the draw-through rates and elongation ratios remain almost the same. 1.00 mm change in the initial diameter, galvanizing thickness increases by 37.80 %. Because the difference between the Ø 8.00 mm wire and the Ø 7.00 mm wire reduction ratio and the number of steps also changes the state of the galvanizing coated. Torsion test results show that initial diameter affect number of twists and fracture characteristics because of reduction ratio change. It is seen that, number of twits in the torsion test are higher and also fracture of surface is beter where initial diameter was 8.00 mm comparing 7.00 mm.

REFERENCES

[1] ÜNSEREN, M., Tel çekme matrisleri üzerine bir araştırma, *Süleyman Demirel Universty*, Master tesis, 2006.

[2] CHAUDHARY, A., KUMAR, R., ANEJA, A., Rectification of Problem in Wire Drawing By Lean Way. *International journal of emerging technology and advanced engineering*. 2014. vol. 4, iss.1.

[3] RUBİO, E.M., CAMACHO, A. M., SEVILLA, L., SEBASTIAN, M. A., Calculation of the forward tension in drawing processes. *Journal of materials processing technology*. 2005. pp. 162-163.

[4] SHEMENSKI, R. M., FOSTER, M. A., WALTERS, J. “Finite Element Analysis of Die Geometry for Drawing Steel Wire,” Conference Proceedings, *74th Wire & Cable Technical Symposium*, pp. 42-55, Cleveland, Ohio, The Wire Association International, Inc., Guilford, Connecticut, 2002.

[5] TITTEL, Viktor. *Steel Wire Production by Cold Drawing*. 1st ed. Köthen: Hochschule Anhalt, 2010. p. 83.

[6] FLANDERS, N. A., ALEXANDER, E. M., “Analysis of Wire Temperature and Power Requirements on Multi-Pass Drawing Productivity,” *Wire Journal International,* Vol. 12, No. 4, pp. 60-64, The Wire Association International, Inc., Guilford, Connecticut, 1979.

[7] WRİGHT, R. N., Workability in Extrusion and Wire Drawing, in Workability Testing Techniques, ed. G. E. Dieter, p. 255, *ASM International*, Materials Park, Ohio, 1984.

[8] DIXON, R. F., “Company Works to Develop Die-Less Drawing Process,” Wire Journal International, vol. 20, no. 10, pp. 25-26 and 28, *The Wire Association International,* Inc., Guilford, Connecticut, 1987.