Journal for Technology of Plasticity, Vol. 28 (2003), Number 1-2

FE ANALYSIS OF THE STRESS-STRAIN CONDITION FOR THE PROCESS OF WIRE DRAWING

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ABSTRACT

This paper presents the determination of the stress-strain condition of the wire drawing process by using analytical methods and Finite Element Analysis. Since, the wire drawing process is a complex process influenced by several parameters, the point of investigation was the definition of the optimal angle of the matrix for wire drawing. The optimum angle of the die insures minimum stresses during the operation. The paper presents some of the results, which have been gotten by using Finite Element Method, and software ALGOR compared with the analytical results.
***Key words: Wire** drawing, Finite element Analysis, stress-strain condition, optimal matrixes angle*

1. INTRODUCTION

Cold drawing is the term applied to a range of cold working finishing involving either thin rod, wire, extruded tube or sheet metal.

Cold drawing of rod, wire and tube may be considered to be the opposite of direct extrusion in the material stock is pulled through a die rather than pushed trough it. As with all cold working processes, work hardening occurs and the grain flow in the finished product runs in the direction of working.

Namely, wire drawing is a process where the circular wire is produced by cold drawing and involves pulling material through a tapered die to reduce the diameter from D_1 to D_2 (Fig. 1).

During the wire drawing process three characteristic sectors are formed in the material. Sector I is the entrance of the material with the initial diameter d_0. In the case where the process is running without oposite forces, the stresses are not appeared in the material. Sector II is the main sector of plastic deformation process where the material-wire changes the cross section area and 3D stress condition appears. Sector III is the part where the material is in front of the die exit and linear stress condition is present. The material is under the elastic deformation stress condition.

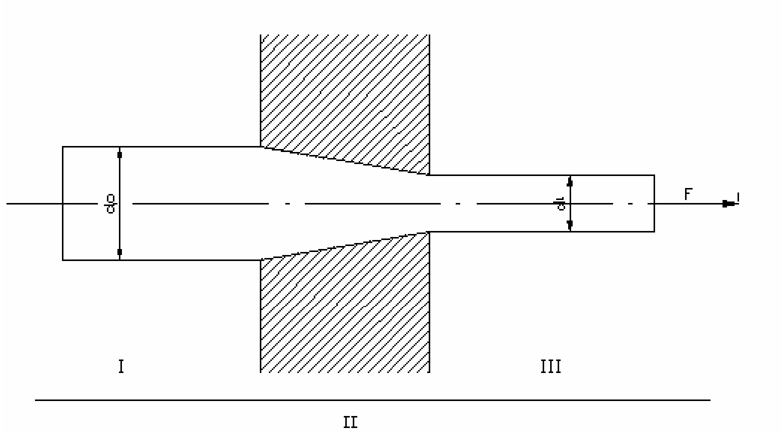


Figure 1 Sectors in wire drawing process

2. WIRE DRAWING DIE'S OPTIMAL ANGLES

The angle's value influences the stress condition during the wire drawing process:

The angle increase influence the slip line rotation and additional shearing stress and material hardening, increase of stresses on the contact surface and pulling force. Also, the increase of the angle causes the decrease of the contact surface and lower pressure of the material to the drawing die, from one side and from the other side the deformation velocity increases, and all actual stresses respectively. Because of the increase of the stresses on the contact surface $(\tau_r ; \tau_k)$, the friction coefficient increase.

The decrease of the die angle lead to: increase of contact surface and pulling force from one side and from the other side, decrease of the stresses on the contact surface, increase of the hydro-dynamical effects of the lubrication and decrease of the total deformation resistance. The determination of the optimal angle of the die is one according the Zibell equation

$$\alpha_{opt} = \sqrt{\frac{\mu \ln\left(A_2 / A_1\right)}{C}}$$

Where C depends on material type:

- for steel wire C=0,67
- for aluminum C=0,78

Because of the symetrical shape of the die, the stress-strain condition of the material will be symetrical therefor

$$\varphi_r = \varphi_\theta = \ln\frac{r}{R} ;$$

and longitudinal deformation will be determined as:

$$\varphi_z = -\left(\varphi_r + \varphi_\theta\right) = 2\ln\frac{R}{r}$$

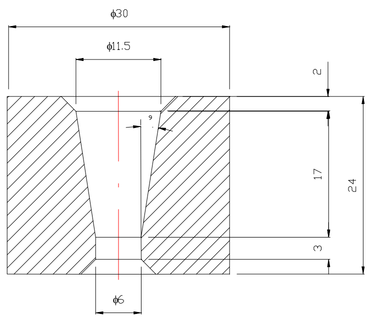
Because of the slip line rotation the shearing strains which appear are defined as $\gamma \approx \frac{r}{Z}$ and they decrease from max value on the contact surface $\gamma_{max} = \alpha$ to zero on the base line.

Therefor the effective strain could be calculated as

$$\varphi_e = \sqrt{\frac{2}{3}\left[\varphi_\theta^2 + \varphi_r^2 + \varphi_z^2 + \gamma^2\right]} \approx \varphi_z = 2\ln\frac{R}{r}$$

The analyzed wire drawing process is going from the wire with diameter of 6.5 mm to final diameter of 3.4 mm (Table 1)., through five dies for steel wire C 0148

Table 1



Wire drawing die

Phase	$\varphi_1 = \ln\frac{A_1}{A_2}$	*Angle of the workine cone*
1	16%	9^0
2	38%	17^0
3	23%	13^0
4	28%	13^0
5	22%	11^0

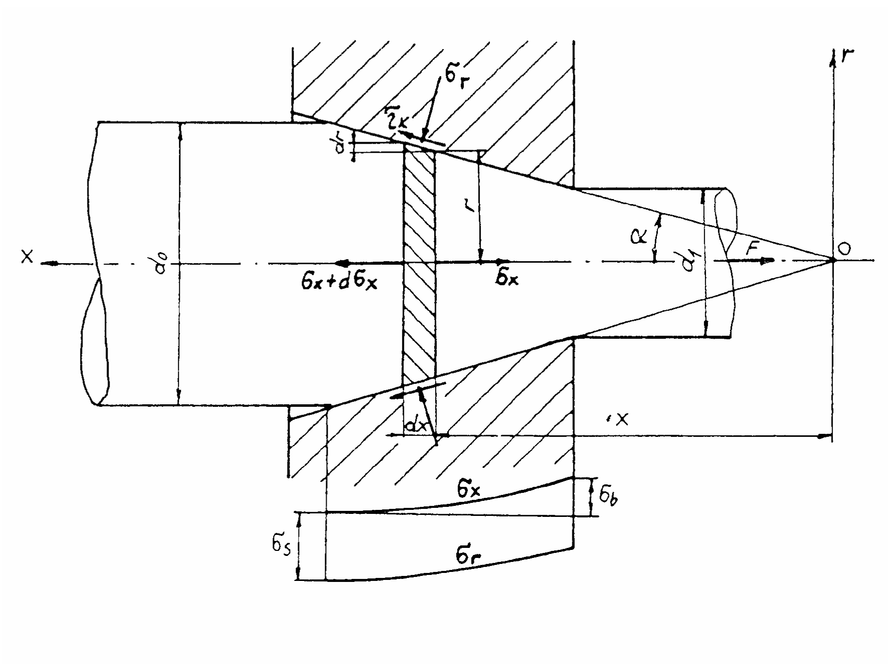


Figure 2. Stress distribution in the wire drawing die

3. ANALYTICAL CALCULATION OF THE STRESS-STRAIN CONDITION IN WIRE DRAWING'S DIE

For each pass of wire through the die, the stresses and strains have been determined in the conical part of the die (fig. 2).

For that purpose, for all five dies, analytical equations have been used to determine the stresses and strains according the postulates of the theory of plastic deformation. The Table 2 shows the determination of the stresses and strains for the first die, where the reduction of the cross section is from the diameter of 6.5 mm to 6 mm.

Table 2

σ_M	ψ_m	d	d_o	ψ	ψ %	σ_s	σ_x	σ_r	τ_k
450	0.2	6.5	6.5	0.00	0.00	0.00	0.00	0.00	0.00
450	0.2	6.4	6.5	0.03	3.05	351.61	17.41	334.20	33.42
450	0.2	6.3	6.5	0.06	6.06	417.32	41.24	376.08	37.61
450	0.2	6.2	6.5	0.09	9.02	460.93	68.20	392.73	39.27
450	0.2	6.1	6.5	0.12	11.93	494.33	97.34	396.99	39.70
450	0.2	6	6.5	0.15	14.79	521.65	128.15	393.50	39.35

Where:

σ_M - Ultimate strength (N/mm^2) for steel C 0148

ψ_m - max deformation (N/mm^2) for steel C 0148

d- material diameter in the conical part of the die (mm)

d_o - initial material diameter at die entrance (mm)

ψ - area cross section contraction in the conical part of the die

σ_s - real stress (N/mm^2)

σ_x - longitudinal stress, along the material axis (N/mm^2)

σ_R - radial stress – normal direction on the conical part of the die (N/mm^2)

τ_k - shearing stress in the conical part of the die (N/mm^2)

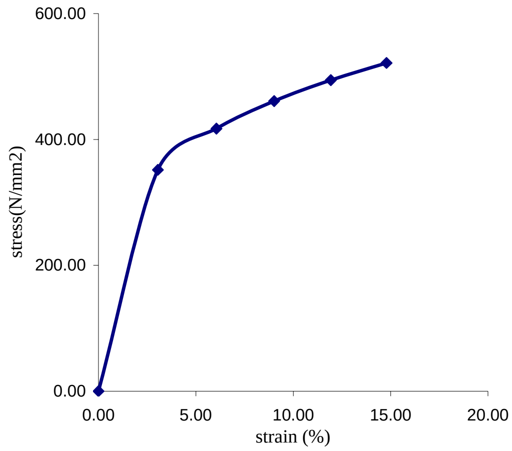


Figure 3. Stress vs. strain

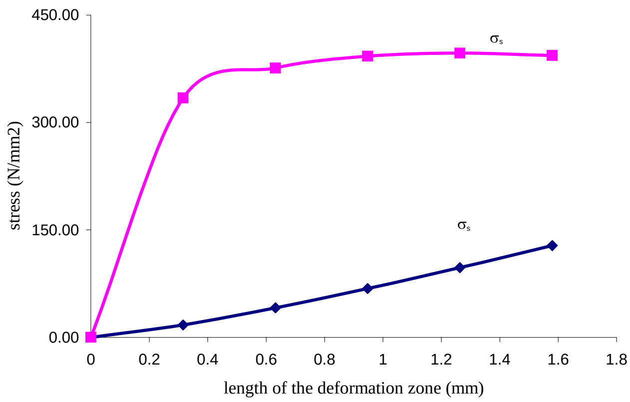


Figure 4. Stress distribution along the deformation zone

4. ANALYSIS OF THE RESULTS GOTTEN BY USING ALGOR-FEA

The die model has been generated by using the graphical pre-processor Super Draw a part of the ALGOR software. The finite element which has been used is element: “Brick” with 8 nodes. The model discretization is done with 1800 elements. The total number of nodes is 14400. The die model is shown on fig. 5. The node’s coordinates are defined according the global coordinate system. The boundary conditions are defined according the real conditions for wire drawing process. For all five different dies the boundary conditions are defined as absolute rigid supported die on the exit surface of the die. The loading is according the value of the pulling force for each level of cross section area reduction, respectivly. The force is distribuited on the nodes in the conical part of the die, which is the contact surface between the material and the die.

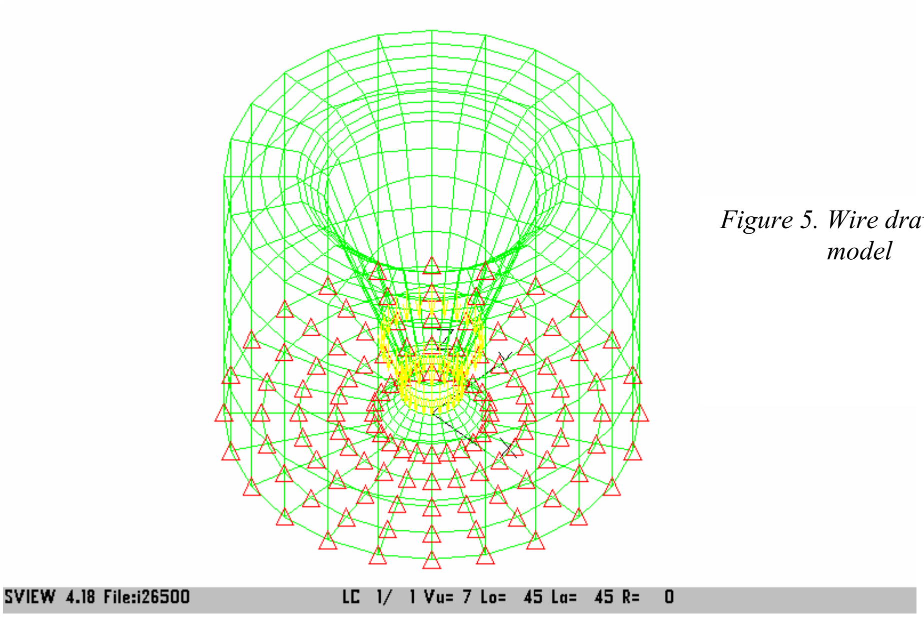


Figure 5. Wire drawing’s die model

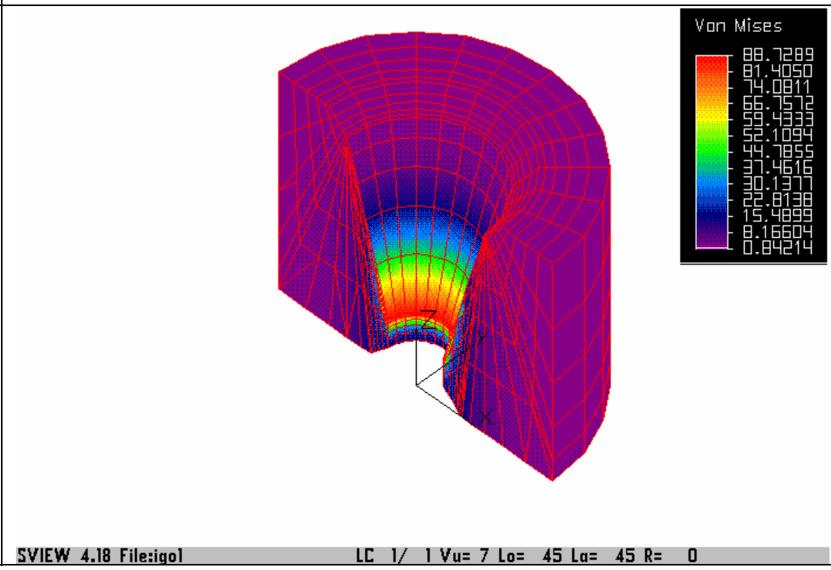
Phase	Stress distribution in the drawing die
ϕ 6.5 to ϕ 6.0 $\alpha= 9^0$ F_1=3621 N	

Figure 6 Stress distribution in the wire drawing die

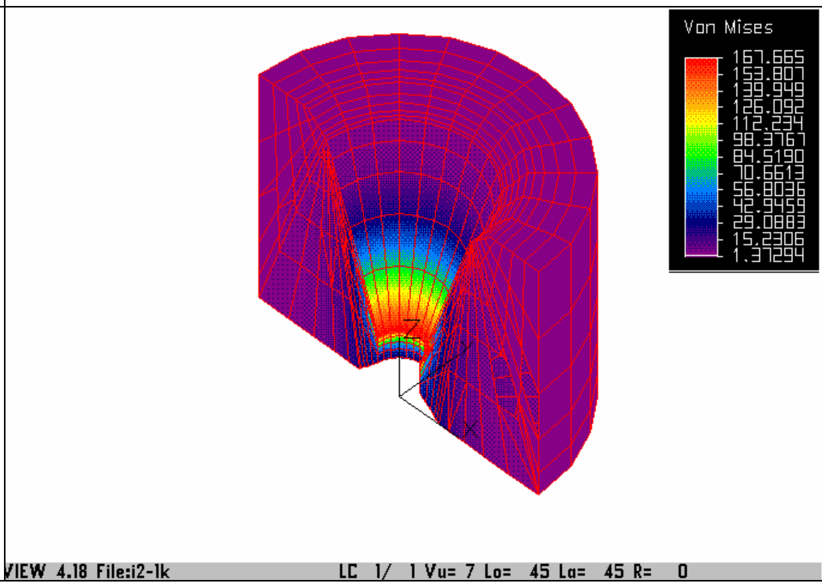
Die's angle	Stress distribution in the die
15^0	

Figure 7. Stress distribution in the wire drawing die for die's angle of 15^0

On the base of numerical investigations, the loadest die is the second wire drawing die with reduction of 6.0 mm to 4.9 mm, where the effective stresses according the Von-Mises are 155.04 Mpa (fig. 6).

The analysis for the determination of the angle influence, several models have been investigated with angle value around the optimal angle value. Namely, there is analyzed model of the die with angle of 15°, 16°, 18° and 19° (fig.7). The analysis shows that after the minimum value of the angle, there is obvious increase of the effective stresses. Also, the increase of the angle causes slow but evident increase of the effective stresses(fig. 8).

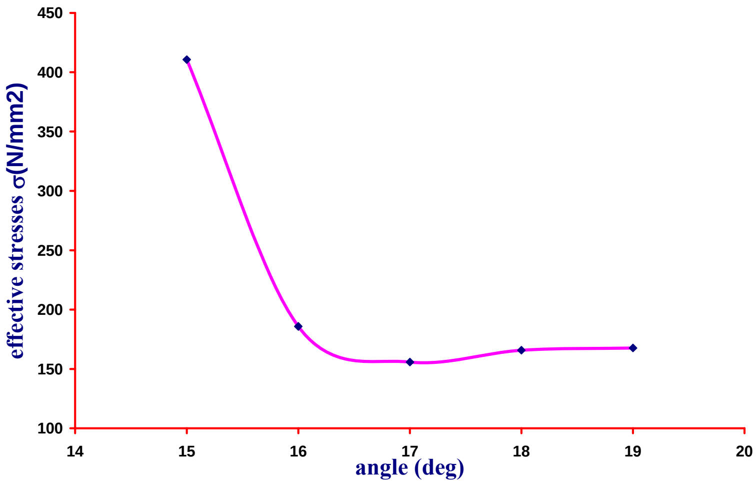


Figure 8 Effective stresses vs. die angle

5. CONCLUSIONS

On the base of analytical and numerical analysis the following conclusions could be established:

- The used software ALGOR FEA could satisfied the conditions for analysis of the stress-strain condition for wire drawing's die, with the main aim: definition of the wire drawing's die geometry
- The defined stress-strain condition insures the calculation of the optimal value of the wire drawing's die angle
- The analysis show that the value of the stress-strain conditions are in the frame of the allowable values
- Special attention should be paid on the work hardening, which occurs during the wire drawing process, especially for steel materials. As a result of the decrease of the material plasticity. Because of the work hardening, intermediate annealing between passes may be necessary to maintain sufficient ductility during cold drawing. For example, the drawn copper and brass wires are designated by their temper, such as ¼ hard, ½ hard etc. High carbon steel wires are made by heat treating, or patenting the drawn wire, whereby the microstructure obtained is fine pearlite. These wires have ultimate tensile strengths as high as 5 GPa and tensile reduction of area of about 20 percent.

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FE ANALIZA NAPONSKO-DEFORMACIONIH ODNOSA U PROCESU VUČENJA ŽICE

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REZIME

Vučenje žice je kompleksan proces u kome se pojavljuje više uticajnih parametara. U radu je istraženo naponsko-deformaciono stanje u procesu vučenja žice i to koristeći analitičku metodu i FE analizu. Fokus rada je bio na određivanju optimalnog ugla matrice. Taj ugao daje najmanje vrednosti napona u obratku. Rad je struktuiran u sledeća poglavlja:

1. *Uvod*
2. *Optimalni ugao kod vučenja žice*
3. *Analitički pristup kod determinisanja naponsko-deformacionih uslova pri vučenju žice*
4. *Analiza rezultata dobijenih korišćenjem ALGOR – FEA*
5. *Zaključak*

Ugao matrice veoma značajno utiče na naponsko stanje u obratku. Povećanje ugla matrice utiče na povećanje tangencijalnih napona, ojačavanje materijala, povećanje kontaktnih napona i potrebne vučne sile. Smanjenje ugla matrice vodi ka povećanju kontaktne površine ali i smanjenju kontaktnih napona. Prema Siebelu, optimalni ugao matrice iznosi:

$$\alpha_{opt} = \sqrt{\frac{\mu \ln\left(A_2 / A_1\right)}{C}}$$

gde parametar "C" zavisi od vrste materijala:

- *čelik C = 0,67*
- *aluminijum C = 0,78*

Na osnovu analitičke analize i FE modeliranja autori donose sledeće zaključke:

- *software ALGOR – FEA je pogodan za analizu procesa vučenja žice i za određivanje naponsko-deformacionog stanja a sa ciljem određivanja optimalne geometrije alata (matrice)*
- *definisani naponsko-deformacioni odnosi i uslovi omogućuju izračunavanje optimalnih vrednosti geometrije alata*
- *analiza je pokazala da su naponsko-deformacioni odnosi u granicama dozvoljenih vrednosti*
- *specijalna pažnja treba da se posveti hladnom ojačavanju materijala koje nastaje u procesu vučenja, posebno ako su u pitanju čelični materijali. Zbog toga je ponekad potrebno izvršiti međužarenje između pojedinih prolaza vučenja.*