THE EFFECT OF DRAWING SPEED ON FORCE PARAMETERS IN MULTIPASS DRAWING PROCESS OF STEEL WIRES

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Abstract

In this work the theoretical-experimental analysis of the effect of the drawing speed on force parameters in multipass drawing process of high carbon steel wires has been assessed. Theoretical analysis of the heating of the wire in the high speed multistage drawing process was carried out on software Drawing 2D, in which the longitudinal stresses, drawing forces and drawing stresses has been estimated. Whereas experimental studies consisted in measurement of force parameters in a real multipass drawing process of steel wires.The drawing process of ϕ 5.5 mm wire rod to the final wire of ϕ 1.7 mm was conducted in 12 passes, in industrial conditions, by means of a modern Koch multi-die drawing machine. The drawing speeds in the last passes were: 5, 10, 15, 20 and 25 m / s.

The drawing power measurements carried out in industrial conditions during high speed multipass drawing process creates a unique possibility to verify the theoretical research based on the finite element method. The study showed a significant effect of the drawing speed on force parameters in drawing process. Depending on the actual conditions of the drawing, ie. temperature, friction and lubrication, increasing the drawing speed (in range of 5 to 25 m / s) can result in both an increase and a decrease in stress drawing.

Keywords: Wire, high carbon steel, drawing speed, FEM, drawing power

1. INTRODUCTION

The multi-stage drawing technology plays a major role in the formation of the properties of drawn wires [1-4]. The group of drawing parameters with a significant effect on the properties of wire includes the drawing speed [5-8]. Recent studies have shown that high drawing speed may contribute to a worsening of the drawing conditions and steel wire properties [9-12]. In view of the above, it is essential to understand the effect of high drawing speeds on the force parameters in the steel wire drawing process.

For the calculation of the energy-force parameters in plastic working processes, empirical formulae and FEM-based computer programs, known in the literature, can be used [13-14]. The accuracy of calculation results obtained using those methods is closely dependent on the adopted boundary conditions, and particularly, on the magnitude of the preset friction coefficient [4]. In the multi-stage drawing process at high speeds, the friction coefficient depends chiefly on the lubrication conditions. These conditions change in individual draws and depend on the maximum drawing speed at the last drawing stage. Therefore, it seems essential to determine, under industrial conditions, parameters, such as power, force, drawing tension and wire temperature.

2. MATERIAL USED FOR TESTING AND DRAWING TECHNOLOGIES APPLIED

Testing of the multi-stage drawing process was carried out for wires of low-carbon steel in grade C78D (0.79 %C). The starting material for the drawing process was 5.5 mm-diameter wire rod that was subjected to the process of patenting, etching and phosphatizing.

Drawing was carried out under industrial conditions in the ŻDB Dratovna a.s. works (Czech Republic) in twelve draws on a Koch KGT 25/12 multi-stage drawing machine, using conventional dies with a drawing angle of $2\alpha = 12°$. The drawing speed in the last draw, depending on the drawing variant, was, respectively: 5, 10, 15, 20 and 25 m / s. The distribution of single reductions, the total reduction and drawing speed is given in **Table 1**.

Table 1 Distribution of single reductions G_p, the total reduction G_c and drawing speed v in individual draws

Draft	ϕ, mm	G_p, %	G_c, %	*v*, m / s				
				A	B	C	D	E
0	5.50	-	-	-	-	-	-	-
1	5.00	17.4	17.4	0.58	1.16	1.73	2.31	2.89
2	4.48	19.7	33.7	0.72	1.44	2.16	2.88	3.60
3	4.00	20.3	47.1	0.90	1.81	2.71	3.61	4.52
4	3.60	19.0	57.2	1.12	2.23	3.35	4.46	5.58
5	3.24	19.0	65.3	1.38	2.75	4.13	5.51	6.88
6	2.92	18.8	71.8	1.70	3.39	5.08	6.78	8.47
7	2.64	18.3	77.0	2.07	4.15	6.22	8.29	10.37
8	2.40	17.4	81.0	2.51	5.02	7.53	10.04	12.54
9	2.19	16.7	84.2	3.01	6.03	9.04	12.05	15.06
10	2.01	15.8	86.6	3.58	7.15	10.73	14.31	17.88
11	1.85	15.3	88.7	4.22	8.44	12.67	16.89	21.11
12	1.70	15.6	90.5	5	10	15	20	25

3. NUMERICAL ANALYSIS OF THE DRAWING PROCESS

The theoretical analysis of the multi-stage drawing process at high speeds was made based on the Drawing 2D program [11], in which the drawing stress was determined. Simulation of the multi-stage drawing process was performed for wire with the plastic properties of steel C75, as taken from the Drawing 2D program's database.

The wire drawing process was assumed to proceed in conventional dies with an angle of $2\alpha = 12°$ with reduction and at drawing speeds, as given in **Table 1**. The initial temperature of wire prior to entry to the first and subsequent dies was 20 °C. Preliminary tests carried out by the author of [14] have shown that, in the process of multi-stage drawing in the drawing speed range of $v = 2.5$-20 m / s, the value of the friction coefficient for conventional drawing ranges from 0.065 to 0.09. Hence, for simplification, the average friction coefficient identical in all draws was assumed in the modelling.

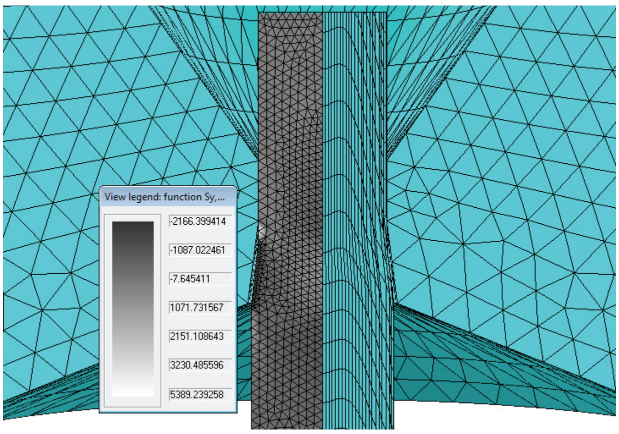

Figure 1 A sample distribution of stress σ_y in final ϕ1.70 mm wire drawn at a drawing speed of 25 m / s

The drawing stress in the process of wire drawing at high speeds was determined by analyzing the distribution of stress σ_y (longitudinal stress consistent with the drawing direction), obtained in the drawing process simulation. **Figure 1** shows an example of the distribution of stress σ_y in ϕ1.7 mm wire drawn at a drawing speed of $v = 25$ m / s.

In the drawn material upon exist from the drawing die, the longitudinal stress σ_y is the sum of the drawing stress σ_c and the distribution of residual stresses of the 1st kind σ_w, namely:

$$\sigma_y = \sigma_c + \sigma_w \quad (1)$$

The analysis of the longitudinal stress was made in the following way: from the grid nodes located at the material exit from the die's sizing portion, stress values were red out along the line consistent with the wire radius. Then, the longitudinal stress σ_y, as defined as a function of the wire radius *R*, was approximated with a parabolic function of the second degree in the following form:

$$\sigma_y = A \cdot R^2 + C \quad (2)$$

Studies [4, 15] suggest that for the determination of the drawing stress magnitude, the following relationship can be used:

$$\sigma_c = 1/3 A \cdot R^2 + C \quad (3)$$

The functions approximating the distribution of the longitudinal stress σ_y as a function of the wire radius *R*, and the calculated values of the drawing stress σ_c are given in **Table 2**. **Figure 2**, on the other hand, represents the distribution of the longitudinal stress as a function of radius *R* for the final 1.7 mm-gauge wires drawn at a speed of 25 m / s.

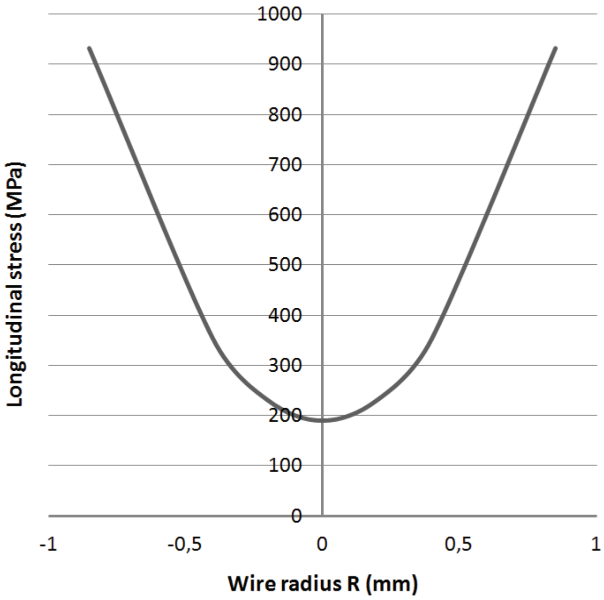

Figure 2 The distribution of the longitudinal stress as a function of radius R for the final ϕ1.7 mm wire drawn at a speed of 25 m / s

Table 2 The functions approximating the distribution of the longitudinal stress σ_y and the values of the drawing stress σ_c for the final ϕ1.70 mm wire

Drawing speed, m/s	$\sigma_y = f(R)$	σ_c, MPa
5	σ_y=926.3R^2+172.7	395.8
10	σ_y=948.7R^2+177.6	406.1
15	σ_y=982.1R^2+179.4	415.9
20	σ_y=1011.9R^2+181.9	425.6
25	σ_y=1026.8R^2+190.2	437.4

On the basis of the obtained numerical study results it can stated that the drawing speed significantly influences the drawing stress. It has been demonstrated that using high drawing speeds in the multi-stage drawing process contributes to an increase in drawing stress. Increasing the drawing speed from 5 to 25 m / s resulted in an increase in drawing stress in the last draw by approx. 10.5 %. The higher drawing stress magnitudes in wires drawn at high speeds are indicative of a greater material effort, which may lead to a rupture of the wire in the drawing process. The increase of drawing stress in wire drawn at high speeds can be explained by the higher magnitudes of redundant strains, which increase material hardening, thus contributing to an increase in the yield stress of the steel [4].

4. EXPERIMENTAL MEASUREMENT OF FORCE PARAMETERS IN THE STEEL WIRE DRAWING PROCESS

The experimental measurement of drawing power in the multi-stage steel wire drawing process was taken under industrial conditions on a Koch KGT 12/25 multi-stage drawing machine. The modern software of multi-stage drawing machines enables the direct readout of many parameters during the drawing process, including drawing power.

Owing to this, the paper presents the measured values of actual drawing power in individual draws for wires drawn at an end speed of v = 5 ÷ 25 m / s. **Figure 3** shows the surface defining the relationship between the drawing power and the total reduction and the drawing speed.

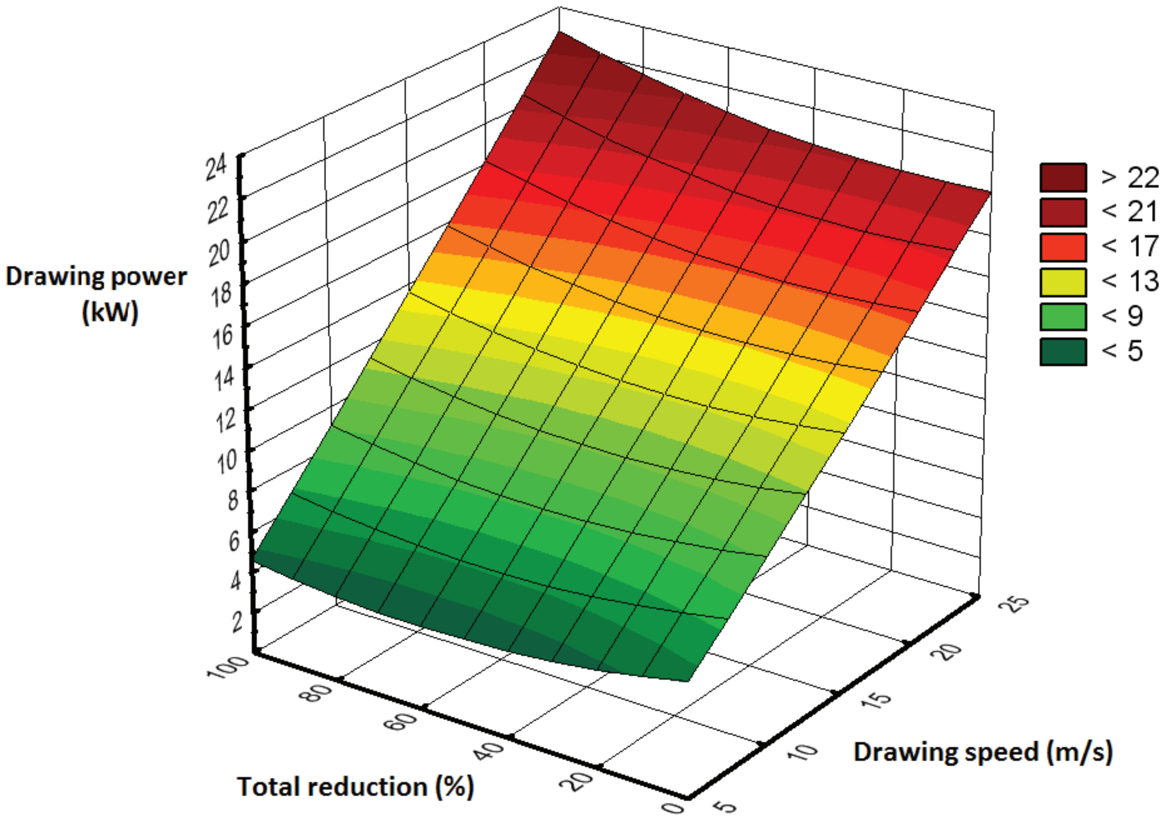

Figure 3 The surface defining the relationship between drawing power N and the total reduction G_c and drawing speed v for wires draw according to respective variants

The test results represented in **Figure 3** show that the drawing power in the multi-stage wire drawing process is proportional to the drawing speed; specifically, the fivefold increase in drawing speed caused an approximately fivefold increase in drawing power. The performed tests have also shown that the drawing power varies only slightly in individual draws, because in the multi-stage drawing process the quantity of drawn wire on each drum is constant, and the obtained relatively small differences in power values between individual drawing stages can be associated, e.g., with the variable conditions of lubrication and friction at the wire-die contact.

Literature shows a close relationship to exist between the drawing power and the drawing force. Based on formula (4) taken from study [4], the drawing force in individual draws has been calculated as follows:

$$F = \frac{N \cdot 1000}{v} \quad (4)$$

where:
F - drawing force, N;
N - drawing power, kW;
v - drawing speed, m / s.

Knowing the drawing force value, the drawing stress can also be determined. **Figure 4** shows the surface defining the relationship between drawing stress and the total reduction and drawing speed.

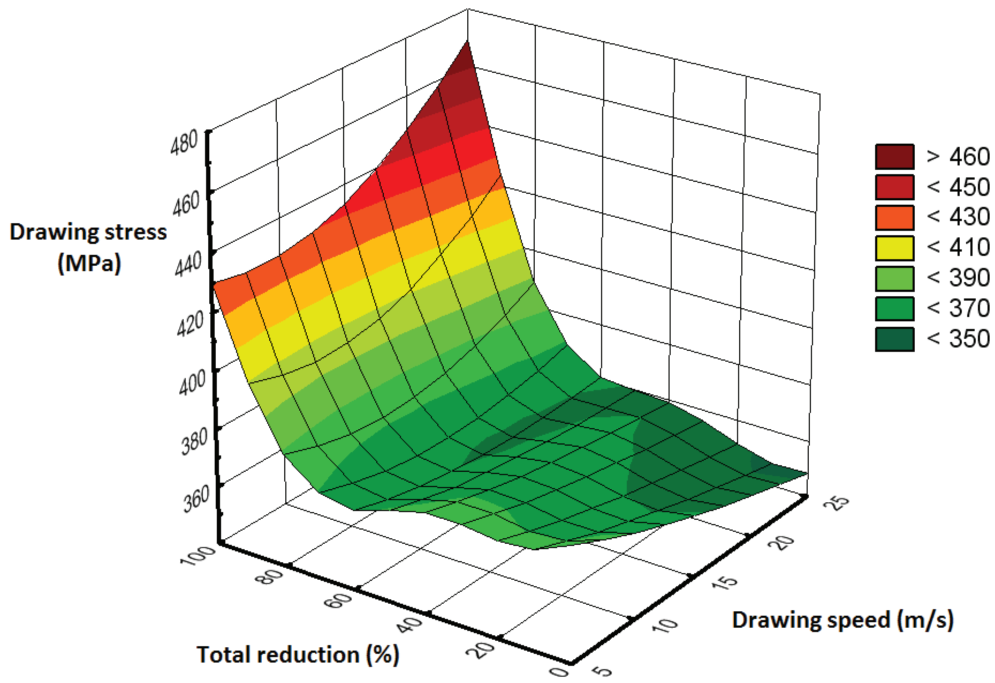

Figure 4 The surface defining the relationship between the drawing stress σ_c and the total reduction G_c and the drawing speed v for wires draw according to respective variants

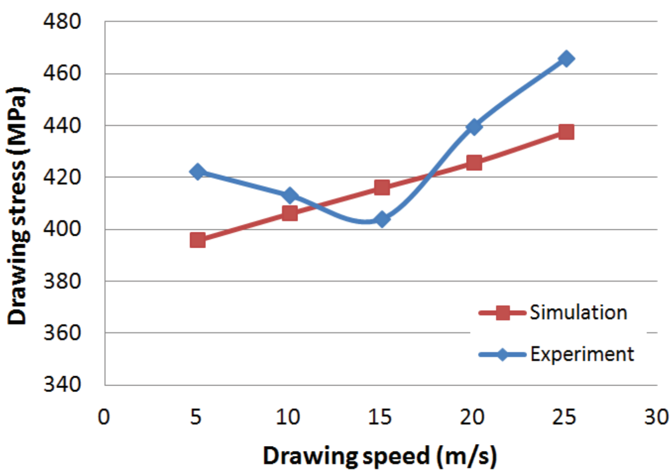

Figure 5 The effect of drawing speed on the drawing stress

From the obtained results it can be found that, at a given total reduction, depending on adopted drawing parameters, increasing drawing speed may result either in an increase or a decrease of drawing force and drawing stress (**Figure 4**). This is indicative of variable lubrication and friction conditions. In the drawing process, a factor significantly influencing these parameters is the wire temperature and the rheological properties of the lubricant. The lower values of drawing forces and stresses in the drawing speed range of 5÷15 m / s indicate that with the properly chosen drawing technology, i.e. lubricants, carrier coatings and drawing dies, the increase in drawing speed does not always have to adversely affect the drawing conditions. At higher drawing speeds (*v* = 25 m / s), as a result of intensive heating of the top wire surface, a worsening of the lubrication conditions occurs, which leads to an increase in friction and drawing stress.

Figure 5 compares the drawing stresses obtained from modelling with those obtained based on the measured actual drawing powers.

From the obtained results it can be found that, at a given total reduction, depending on adopted drawing parameters, such as lubricants or drawing methods, increasing the drawing speed may result either in an increase or a decrease of drawing stress (**Figure 4**). An adverse effect of high drawing speeds is only visible at drawing speeds exceeding 15 m / s. The data represented in **Figure 5** shows that the mathematical models adopted in the program adequately simulate the distribution of longitudinal stress and drawing stress, since at the assumed friction coefficients of μ = 0.08, the maximum difference between the stresses determined from simulation and calculated based on the measured drawing powers do not exceed 25 %. In modelling, a constant value of friction coefficient was assumed, whereas in the actual drawing process, the friction coefficient value depends on the lubricant rheology and drawing technology, and especially on the drawing speed.

5. CONCLUSIONS

Based on the theoretical studies and experimental tests carried out within this work, the following conclusions can be drawn:

1) The measurements of drawing power under industrial conditions in multi-stage drawing processes at drawing speeds from 5 to 25 m / s, reported in this paper, create unique capabilities to verify the influence of lubrication conditions on the force parameters of the drawing process.
2) The experimental measurement of drawing power carried out under industrial conditions has shown that the drawing power in the multi-stage drawing process is proportional to the drawing speed, namely, the fivefold increase in drawing speed at a given wire diameter has caused an approximately fivefold increase in drawing power.
3) It has been shown that the drawing power varies only slightly in individual draws, because in the multi-stage drawing process the quantity of drawn wire on each drum is constant, and the obtained relatively small differences in power values between individual drawing stages can be associated, e.g., with the variable conditions of lubrication and friction at the wire-die contact.
4) Based on the obtained results it can be stated that, at a given total reduction, depending on the adopted drawing technology, i.e. lubricants or a drawing method, increasing the drawing speed may result either in an increase or a decrease of drawing stress.
5) The results of the theoretical studies and experimental tests obtained in this work can be used in the design of technologies for drawing carbon steel wires at high drawing speeds, and can improve the quality of manufactured wires and intensify the wire production processes.

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