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A COMPARISON OF DIE GEOMETRY IN THE DRAWING PROCESS

Viktor TITTEL, Miroslav ZELENAY

Abstract

Experiments were conducted on the drawing of high tensile strength wires ($S_u \leq 3\ 000$ MPa) ϕ 0.30 mm. An influence of relative die pressure on their consumption was found. The drawing angles of dies were sought which had a size of $2\alpha = 11°$ and 13° from producers A (current) and B (new). Approximately 650 tons of wires with very good quality were produced during the experiment. The total die consumption from company B was lower by more than half as compared to company A. The lower die consumption of B13 was probably influenced by the quality of the die treatment and the keeping of geometric accuracy. For the dies B11, a more favourable Δ-parameter, and therefore the relative die pressure, played a significant role, which was lower than dies with a drawing angle of 13°. The mathematical dependencies between the relative pressure and die consumption were also found.

Key words

die, reduction, die geometry, wire, drawing process, die consumption

Introduction

A die is a basic tool which is used for the drawing process of steel wire. The process of plastic deformation of drawn wire is performed in the die. The plastic deformation is impacted by the influence of a common pressure in the die and the drawing force which is affected on the wire. The die is constructed so that it ensures the required accuracy of size and surface quality. Die geometry is an indispensible component of die construction and mainly approaches the angle size 2α [4, 5].

Both the wire and the die warm during the drawing process due to the transformation of deformation work with heat. The next source of heating is friction between the wire surface

Viktor Tittel, Assoc. Professor, PhD. - Institute of Production Technologies, Faculty of Materials Science and Technology in Trnava, Slovak university of Technology Bratislava, Slovak Republic, e-mail: viktor.tittel@stuba.sk
Miroslav Zelenay, MSc. Eng. (PhD Student) - Institute of Production Technologies, Faculty of Materials Science and Technology in Trnava, Slovak university of Technology Bratislava, Slovak Republic

and the die. The heating of surface layer wire is also influenced by the drawing speed, which is dependent on the contact time of the wire surface and the die. The greatest efficiency of deformation work on the wire is drawn through die ranges in a relatively narrow band of the chosen die angle 2α. The work will increase if we use a small approach die angle, which is because it is needed for overcoming the friction between the wire and die. The work will increase if we use a big approach die angle because it is needed for additional internal material movement. The size of the drawing angle also influences lubrication efficiency. Decreasing the drawing angle can decrease the friction factor μ from 0.05 to 0.005. One reason is that the lubrication gains more hydrodynamic character [2, 4].

The experiment

A target of the experiment was to verify a change of the die geometry directly in conditions of steel cord wire production. The die geometry change consisted of a drawing angle change of 2α from the original 13º to a verified 11º. Other goals were to make a comparison of dies in the same operational drawing conditions, an evaluation of drawn wire quality, and also an evaluation of complex die consumption.

Description

Our experiment proceeded in a wet wire drawing shop. Steel cord wire with a diameter of 0.30mm was produced in the wet wire drawing shop over a long term. This type of wire was used as a semi-product for a bunching (double twisted cabling) of steel cord 2 x 0.30.

Wire with diameter of 0.30 mm was produced from a patented semi-product and the surface of the semi-product was coated with brass. The experiment was executed by using a die series with 20 dies.

The dies from company A were preferentially used in wet wire drawing. The dies were delivered as semi-products. It was necessary to prepare and polish these at required dimensions and a specified geometry in a local die shop. The dies from "company A" were delivered with a standard die geometry with approach angle 2α = 13º (A13). The dies from the "supplier A" were compared to dies from company B which prepared dies with approach angle 2α = 13º and 2α = 11º (B13, B11).

At the beginning of the experiment three machine groups were dedicated for the location of die series from "company B" with approach angles 2α = 13º and 2α =11º (B13, B11) in a wet wire drawing shop. All other machines were used for the installation of standard die series with an approach angle of 2α = 13º (A13). The standard wire production for a comparison purposes was just produced on these machines. During the experiment the evidence form was located directly on the machines, and the operators which operated those machines registered the required data. The drawing speed was 18 $m.s^{-1}$.

The experiment took 41 days. During this time more than 650 tons of wire with very high quality was produced. During the experiment some heats of wire rod were produced. The chemical composition, mechanical properties, as well as metallographic parameters of the wire rod heat that was used were very similar, without expressive differences. The lubricant emulsion used was the same on all machines and the same conditions were kept according to the valid technological procedure. During the experiment we also evaluated die consumption, mechanical properties, wire fractures, and the following wire processing – those detailed results will be published later. Die consumption was evaluated in dependency on a Δ – parameter size and relative die pressure. In 1958 Δ – parameter was defined by J. G. Wistreich [3] as "the ratio of the arc, spanning the midpoints of the die face "d_m" to the length of contact between wire and die "l" (fig. 1).

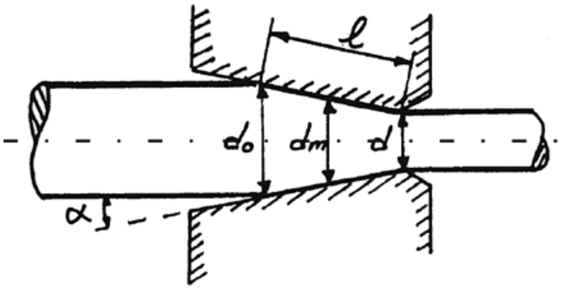

Fig. 1. *The wire in the die. Schematic [2,3]*

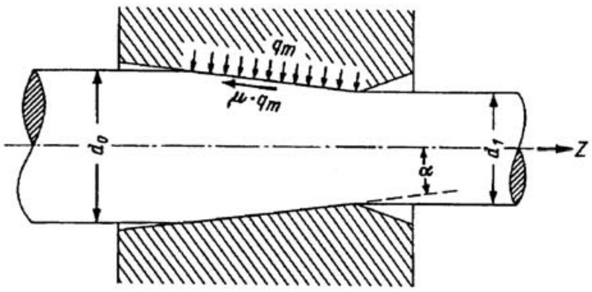

Fig. 2 *Pressure between wire and die [2,3]*

$$\Delta = \frac{d_m}{l} = \frac{d_0 + d}{d_0 - d}.\sin\alpha \ , \quad (1)$$

where α – ½ drawing angle [°], d_0 - diameter of wire before drawing [mm], d - diameter of wire after drawing [mm].

$$\Delta = \frac{1}{\varepsilon_d}(1+\sqrt{1-\varepsilon_d})^2.\sin\alpha \qquad \text{where } \varepsilon_d \text{ – calculated reduction [-] .} \quad (2)$$

Relative die pressure

$$\frac{q_m}{\sigma_m} = \left[-\ln(1-\varepsilon_d).(1+\frac{\mu}{\alpha}) + \frac{2\alpha}{3}\right].\frac{1-\varepsilon_d}{\varepsilon_d.(1+\frac{\mu}{tg\alpha})} \ , \quad (3)$$

where q_m – pressure between wire and die [MPa],

σ_m – flow stress, which is approximately equal to the mean value of the yield strength $S_{0.2}$ [MPa].

Results and discussion

All values of the drawn wires kept in the tolerance zone 180 ÷ 230 N. Exchanges of individual dies were continuously registered and the exchanges can be seen in Fig. 3.

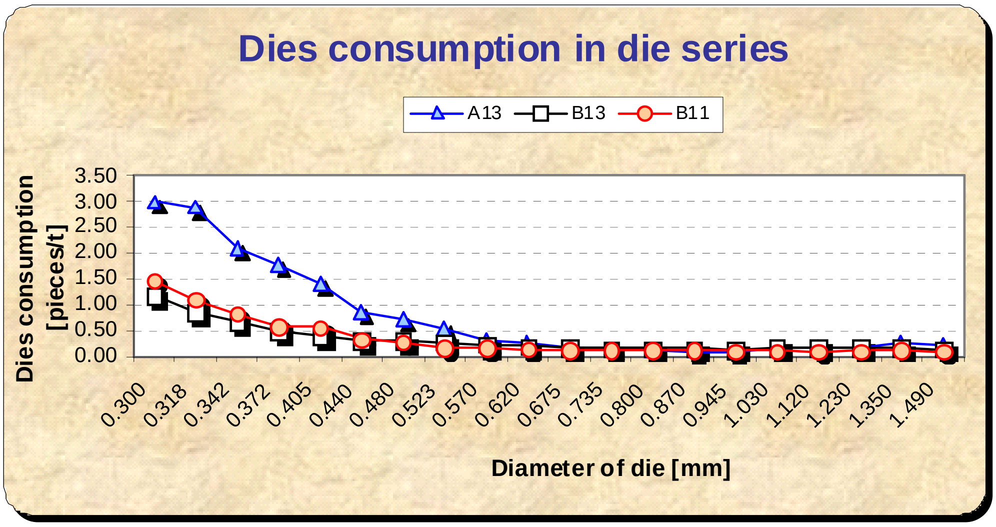

Fig. 3. *Dies consumption*

In general the consumption of B11 dies was lower compared to both other die groups. A backset occurs in the finished dies when the value of the Δ-parameter begins to increase and there is also pressure in the die. The value is more favourable (lower) for B11 dies (for the last die Δ = 3.29) against dies with the approach angle 13º (B13 for the last die Δ = 3.89). In general, dies with a lower Δ-value require better lubricant properties with a lower friction coefficient and good resistance against dissociation. The properties of our lubricant did not probably satisfy to a full extent these criteria and therefore the hardening of wires which were drawn with the die B11 were slightly more compared to wires processed with die B13. A confirmation of this idea is the slightly higher breaking force and also tensile strength compared to dies of group B13. A comparison of relative die pressure and diameters are listed in Table 1.

COMPARISON OF RELATIVE DIE PRESSURE AND Δ-PARAMETER FOR EACH DIAMETER IN THE DIE SERIES Table 1

∅ [mm]	A13	B13	B11	A13	B13	B11	Ø [mm]	A13	B13	B11	A13	B13	B11
	q_m/σ_m [-]			Δ – parameter [-]				q_m/σ_m [-]			Δ – parameter [-]		
1.49	1.45	1.45	1.35	2.23	2.23	1.89	0.62	1.59	1.59	1.47	2.68	2.68	2,26
1.35	1.48	1.48	1.37	2.31	2.31	1.95	0.57	1.60	1,60	1.48	2.70	2.70	2.29
1.23	1.46	1.46	1.36	2.25	2.25	1.90	0.52	1.58	1.58	1.46	2.64	2.64	2,24
1.12	1.59	1.59	1.48	2.66	2.66	2.25	0.48	1.58	1.58	1.46	2.65	2.65	2,24
1.03	1.60	1.60	1.46	2.71	2.71	2.30	0.44	1.57	1.57	1.45	2.61	2.61	2.21
0.95	1.58	1.58	1.49	2.64	2.64	2.23	0.41	1.61	1.61	1.49	2.74	2.74	2.32
0.87	1.61	1.61	1.48	2.75	2.75	2.33	0.37	1.59	1.59	1.47	2.68	2.68	2.26
0.8	1.60	1.60	1.47	2.71	2.71	2.29	0.34	1.60	1.60	1.48	2.70	2.70	2.29
0.74	1.59	1.59	1.47	2.68	2.68	2.27	0.32	1.73	1.73	1.58	3.12	3.12	2.64
0.68	1.59	1.59	1.47	2.67	2.67	2.26	0.30	1.95	1.95	1.77	3.90	3.89	3.29

Within the frame of the experiment the total die consumption from company B was more than twice lower than dies from company A. The lower consumption of B13 dies was probably influenced by the quality of the die treatment and the keeping of geometric accuracy. For the B11 dies the Δ-parameter, and therefore more favourable relative die pressure, played a significant role which was lower than dies with the drawing angle 13º. The comparison of total die consumption is in Table 2.

COMPARISON OF TOTAL DIE CONSUMPTION Table 2

Die group	A13	B13	B11
Die consumption [pieces/tonnage of production]	15.29	6.26	6.56

When we analyzed and found the dependencies between die consumption and relative die pressure, Wistreich´s theory was confirmed that die consumption would increase if the relative pressure between wire and die increased. Table 1 and Fig. 3 show that the lower relative die pressure affects the lower die consumption and also a longer lifetime. The relative die pressure shows that the higher it is the higher the non-homogenous deformations are [2, 3]. The lowest die consumption was reached at the die dimensions which were calculated with the lowest relative pressure (Fig. 4).

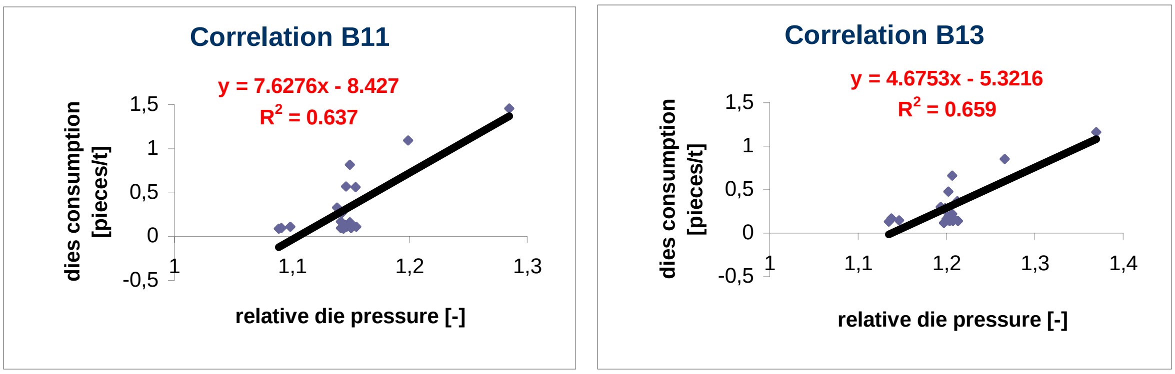

Fig. 4. *Dependency of die consumption on relative die pressure*
Note: a value of $R^2 = 0.4995$ *and correlation equation* $y = 13.813x – 15.884$ *are valid for A13 dies*

Based on the results it can be supposed that it would be suitable to use different calculated reductions for dies with a drawing angle of 11° such that we decreased the relative die pressure and so positively influence the die consumption. In the future we can also suppose a trend for the next decrease of the drawing angle 2α for the wires drawn at the allowance of Δ-parameter size and relative pressure.

Contribution to this problem

We see a contribution that we used the Δ-parameter and relative die pressure for evaluation of die consumption. The mathematical dependencies between die consumption and relative die pressure were confirmed. Wistreich´s theory was confirmed by the lengthy experiment and the direction of the drawing angle decrease with an allowance for the relative pressure and Δ-parameter size.

Conclusion

As demonstrated and confirmed by the experiment the influence of die geometry on mechanical properties and die consumption is enormous. Under the same drawing conditions if we change the die geometry we can reach a reduction of more than twice lower die consumption, as we can see in Table 2. From the experiment it follows that die consumption can also be influenced by the quality and accuracy of die geometry composing what is seen in Table 2 from the comparison of both die groups with drawing angle of 13°.

Based on the results, this experiment can be globally evaluated as an experiment with enormous benefit because it demonstrated a way for the next route in steel-cord wire production. The main direction should be focused on the drawing angle decrease, accuracy of die geometry make-up, and correction of calculated reductions for new die geometry.

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Reviewers:

Ján Boroška, Professor, PhD. - Logistics Institute of Industry and Transport Faculty of Mining, Ecology, Process Control and Geotechnology, TU Košice

Jozef Bílik, Assoc. Professor, PhD. – Institute of Production Technologies, Faculty of Materials Science and Technology in Trnava, Slovak University of Technology Bratislava