EFFECT OF DRAWING ANGLE SIZE OF A DIE ON WIRE DRAWING AND BUNCHING PROCESS

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Abstract
This paper focuses on the effect of drawing angle size of a die on the wire processing into a ropery at the bunching of steel cords. Experiments were carried out with usage of standard dies with drawing angle size \( 2\alpha = 11^\circ \) and \( 2\alpha = 13^\circ \). Results of the experiments were statistically evaluated and they proved that dies with \( 2\alpha = 11^\circ \) had beneficial effect. Drawn wires on dies with \( 2\alpha = 11^\circ \) were with lower level of hardening and so the drawing process was better. This beneficial effect of \( 2\alpha \) decrease was also demonstrated by the reduction of wire fractures and lower wire scrap quantity during steel cords bunching.

Key words: wire hardening, bunching, die, drawing angle, steel cord

1. INTRODUCTION
The basic design solution of die is realized so that by drawn wire it covers the required precision of the dimension and the quality of surface. Unthinkable part of the die construction is its geometry [1, 2]. By steel wire drawing the process of plastic deformation is generated and this is in consequence of the present force effect (Fig. 1) and drawing force. Drawn steel wire and die are heated gradually. Creation of thermal energy is caused in the result of transformation of strain work and the next reason, which causes the creation of thermal energy, is friction between the wire surface and the die [3, 4]. The heating of surface layers of the wire is affected by drawing speed, because it affects directly the contact time of the wire with the die.

![Fig. 1 Pressure between the die and wire](image-url)

where: \( F \) – drawing force, \( q_m \) – pressure between die and wire, \( \mu \) – coefficient of friction
The biggest plastic deformation by the process of wire drawing ranges in the interval of elected angle of drawing cone of die $2\alpha$. By great angle of drawing cone the work for repression of secondary internal materials movement is increasing. Magnitude of the drawing force by constant friction coefficient is then stated by die geometry and reduction. In connection with the steel wire drawing there is a risk of drawing wire breaking creation. The risk of wire breaking influences then workability of wire in the process of steel cords bunching. On the basis of this fact it was realized multiple experiments with the aim of monitoring of the dependence between the die geometry and workability of wire in the bunching process. [1, 5, 6]

Steel cords are one of the basic structural components of tires and they are compound of wires, which are used for tire body or tire buffers at the production of tires. Technological process of steel wires production /wire drawing/ is a difficult process that is influenced by a wide variety of factors. The basic production tool which is used in the process of steel wire drawing is die (Fig. 1).

2. EXPERIMENT DESCRIPTION

The experiment was in progress during 41 days of continual production and 650 t of wires of suitable quality were made. Chemical composition, mechanical properties and metallographic parameters of used heats of wire rod were very similar, without significant differences. In all machines it was used the same lubricating emulsion which was balanced by technological standard. During the experiment it was judged mechanical properties of wires, breakages and next wires processing, too.

Our experiment was implemented in drawing shop and ropery of steel cords. On fine drawing (by wet wire drawing) it is produced the steel wire about diameter $0.300 \text{ mm}$ in the long term. Steel wire about diameter $0.30 \text{ mm}$ was produced from patented semiproduct about diameter $1.65 \text{ mm}$. This wire is using as a semiproduct for steel cord $2\times0.30 \text{ mm}$ bunching. This construction of steel cord is at the present time very expanded and it is using to the tire body at the production of tires for personal motor cars. The test was implemented by using of die set with twenty dies. On fine drawing it was used dies from supplier A. Dies from supplier A were standard supplied by die geometry with drawing angle $2\alpha = 13^\circ$ (A 13). These dies from company A were compared with dies from supplier B that prepared dies with drawing angle $2\alpha = 13^\circ$ (B 13) and $2\alpha = 11^\circ$ (B 11). During the experiment realization the conditions of drawing were stable. The same lubricating emulsion was used in every machine, which was defined by technologic process. The drawn speed was $v = 18 \text{ m.s}^{-1}$. Besides within the frame of experiment it was performed the following of wire workability in dependence on the change of drawing angle $2\alpha$ from original $13^\circ$ to $11^\circ$.

Wire, which is produced on fine drawing, was subsequently processed on double-twisted machines. Wire processing was in progress by particular sorts with exclusion of mutual immixture among particular groups. In the bunching process it was recorded amounts of produced steel cord, number of breakages, quality of steel cord, straightness and overall curves bounce by steel cord. Besides, it was registered a scrap, this is a wire, which was unworkable because of very high frequency of breakages. During the bunching it was from time to time obtained sample for tests. In the process of bunching every groups of wires were processed on the same double-twisted machines concurrently and on equal terms of double-twisted machines setting.

We can characterize the wire workability as a number of wire fractures which originates during the process of bunching. If the number of wire breakages is lower, so its workability is higher and by that a number of tense wire grows lower, which is disabled to the technological waste. From the view of other processing the number of breakages per ton of produced cord is a very important index. This index talks about a quality of produced wire. [7]

3. EFFECT OF DIE GEOMETRY ON WIRE WORKABILITY

The consumption of dies (Fig. 2) and assessment of mechanical properties of wires were the next parameters which were verified within of this experiment.
At the design of experiment it was appear from the assumption that lower drawing angle $2\alpha$, lower $\Delta$-parameter value (and lower relative pressure die) can positive influence dies consumption, mechanical properties of wire and also entire drawing process (Fig. 3). It was also partially confirmed in our case.

\[ \Delta = \frac{d_d}{l} = \frac{d_0 + d}{d_0 - d} \cdot \sin \alpha \]  

(1)

where: $\alpha$ – $\frac{1}{2}$ drawing angle [°], $d_0$ – diameter of wire before drawing [mm],

\[ \Delta = \frac{1}{\varepsilon_d}(1 + \sqrt{1-\varepsilon_d})^2 \cdot \sin \alpha \]  

(2)

where: $\varepsilon_d$ – calculated reduction [-]

\[ \frac{q_m}{\sigma_m} = \left[ 1 - \ln(1-\varepsilon_d) \cdot (1 + \frac{\mu}{\alpha}) + \frac{2\alpha}{3} \right] \frac{1-\varepsilon_d}{\varepsilon_d \cdot (1 + \frac{\mu}{\tan \alpha})} \]  

(3)

where: $q_m$ – pressure between wire and die [MPa]

$\sigma_m$ – flow stress, which is approximately equal to the mean value of the yield strength $S_{0.2}$ [MPa] [10]

It appears from this that in general the consumption of dies B11 was lower as the both others compared die groups. A backset occurs at the finished dies when the value of $\Delta$-parameter begins to increase and also a pressure into the die. The value is more favourable (lower) for B11 dies (for a last die $\Delta = 3.29$) against dies.
with the approach angle 13° (B13 for a last die Δ = 3.89). In general the dies with lower Δ-value require the better lubricant properties with a lower friction coefficient with good resistance against the dissociation. The properties of our lubricant did not probably satisfy in full extent to these criterions and therefore the wires hardening, which were drawn with the dies B11, were slightly more against the wires processed with dies B13. A confirmation of this idea is slightly higher breaking force and also tensile strength against dies of group B13. A comparison of relative die pressure and the Δ-parameter for each diameter in the die series are listed in the table 1.

Tab. 1 Comparison of relative die pressure and Δ-parameter for each diameter in the die series

<table>
<thead>
<tr>
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<td>2.23</td>
<td>1.89</td>
<td>0.62</td>
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<td>2.31</td>
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<td>0.57</td>
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<td>2.25</td>
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<td>2.66</td>
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<td>1.46</td>
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<td>0.37</td>
<td>1.59</td>
<td>1.59</td>
<td>1.47</td>
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<td>1.59</td>
<td>1.47</td>
<td>2.67</td>
<td>2.67</td>
<td>2.26</td>
<td>0.30</td>
<td>1.95</td>
<td>1.95</td>
<td>1.77</td>
</tr>
</tbody>
</table>

Within the experiment the total dies consumption from company B was lower more as twice against dies from company A. The lower dies consumption B13 was probably influenced by the better quality of the die treatment and accuracy of geometry keeping. At the dies B11 the Δ-parameter and so more favourable relative die pressure played a significant role, which was lower than dies with the drawing angle 13°. The comparison of total dies consumption is in a table 2.

Tab. 2 Comparison of total dies consumption

<table>
<thead>
<tr>
<th>Dies group</th>
<th>A13</th>
<th>B13</th>
<th>B11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dies consumption [pieces/tonnage of production]</td>
<td>15.29</td>
<td>6.26</td>
<td>6.56</td>
</tr>
</tbody>
</table>

When we analyzed and found the dependencies between dies consumption and relative die pressure the Wistreich’s theory was confirmed that dies consumption would increase if the relative pressure between wire and die increased. Table 2 follows that the lower relative die pressure is the lower dies consumption is and also a longer lifetime is. The lowest dies consumption was reached at the die dimensions, which were calculated with the lowest relative pressure (Fig. 2).

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

The following of mechanical parameters were carried out continuously before starting of bunching. The each of tested wires fulfilled the specific request of breaking force, request in tolerance limits from 180 to 230N and wires were statistical evaluated.
Fig. 4 Breaking force histograms of drawn wire (Ø 0.300 mm)

Tab. 3 Tensile strength of drawn wire Ø 0.300 mm

<table>
<thead>
<tr>
<th>Dies group</th>
<th>A13</th>
<th>B13</th>
<th>B11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength of drawn wire Ø 0.300 mm [MPa]</td>
<td>2963.2</td>
<td>2898.7</td>
<td>2947.3</td>
</tr>
</tbody>
</table>

The overview of wire workability in the ropery can be seen in next table 4.

Tab. 4 Overview of wire workability in the ropery (SC production, fractures and scrap) [7]

<table>
<thead>
<tr>
<th>Standard production (A13)</th>
<th>Production (B13)</th>
<th>Production (B11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>Scrap</td>
<td>Fractures</td>
</tr>
<tr>
<td>[kg]</td>
<td>[%]</td>
<td>[n/t]</td>
</tr>
<tr>
<td>362313</td>
<td>3.614</td>
<td>7.558</td>
</tr>
<tr>
<td>[kg/day]</td>
<td>8234</td>
<td>[kg/day]</td>
</tr>
</tbody>
</table>

From presented results of the experiment it is visible the quality fluctuation and workability of wires in the ropery. One of the reasons of this fact is that till 5% of dies had in the first phase damaged core and from this reason the surface of drawing wire was grooved on the surface.

This damage of wire influences the load capacity of steel wire only in minimal measure, but its negative influence shows by wire loading with torsion moment. From reason that this type of loading is by the production of wires on double-twist machines, in some phases of production it was excessive high increase of the number of wires breakages and by that it comes to the increased deletion of material. On the basis of this it is possible to state the assumption that the surface damage of wire supports directly the creation of breakages by the bunching process. This statement relates to double-twist machines above all.
It can be seen from the table 4 that the best results in the bunching process were achieved at the wire processing which was drawn with dies of B11 group. The number of fractures per tons of production was calculated only 4.70 at the processing evaluation of this wire. Maximum level was defined on 5.50 of fractures per production tons. Workability of wires from the groups A13 and B13, i.e. drawn with dies which had drawing angle \(2\alpha = 13^\circ\), was essentially worse as from wires of B11 group. Expressive scrap elimination from 3.6\% at A13 against 0.92\% at B11 was achieved by the reduction of fractures number and by the drawing process enhancement.

4. CONCLUSION

It was demonstrated and confirmed by the experiment the influence of dies geometry and dies consumption. The influence on the mechanical properties (in our case on the breaking force) was not entirely confirmed. At the same drawing conditions if we change die geometry we can reach more than twice lower dies consumption what we can see in the table 2. From experiment it is followed that the dies consumption can also be influenced by the quality and accuracy of dies geometry making up. It was also demonstrated if we change dies geometry we can achieve better workability in the ropery.

Based on mentioned in this experiment can be globally evaluated as experiment with an enormous benefit because it demonstrated a way for the next routing at the steel cord wires production. The main direction should be focused on the drawing angle decreasing, accuracy of die geometry making up and correction of calculated reductions for new die geometry.

ACKNOWLEDGEMENTS

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LITERATURE


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