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Control of mechanical properties of fine steel carbon wire while drawing

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Abstract
Wire gets hardness owing to cold deformation, and forms a complex of mechanical properties. Mechanical properties affects manufacturability of fine wire and cord produced from this wire.
Deformation and temperature have an impact on wire while the whole drawing. Drawing velocity takes part in forming of hardness and plasticity of wire. With increasing in drawing velocity, the rate of temperature effect is increased due to more intense friction in deformation zone. In narrow range, mechanical properties can be regulated by change of die drawing velocity. It is suggested to use energy criteria W in standard units in order to control mechanical properties; it characterizes quantitatively the energy accumulated due to plastic forming process.
Key words: WIRE, STEEL WIRE CORD, DRAWING, MECHANICAL PROPERTIES, DRAWING VELOCITY

While drawing, not only wire stock deformation, but also a complex of mechanical properties formation of obtained wire take place. The chemical composition of metal and the modes of wire cold deformation contribute to wire mechanical properties formation. The wire mechanical properties influence its consumer appeal and manufacturability of its further processing.

In modern wire production, forecasting of mechanical properties of final products is mainly focused on empirical experience. The problem consists in absence of the dependences joining mechanical properties of wire with the modes of its drawing.

The evaluation of influence importance of the wire drawing modes on its mechanical properties after drawing is of significant practical value. It consists in capability to predict change of wire mechanical properties by means of use of the necessary modes of this wire drawing [1].

The work objective is studying of mechanical properties formation, control of mechanical properties of fine wire by high-velocity modes of drawing process.

These researches are conducted in the field of production of high-carbon steel brass wire used for further production of cord from it. The steel wire cord is widely used in tire branch as the reinforcing element. Process of steel wire cord production includes the main technological stages: fine wire drawing and steel wire cord twist.

Non-uniformity of stress on wire section caused by action of contact friction forces takes place because of peculiarities of drawing process. Non-uniformity of stress leads to unhomogeneity of deformation, and consequently, irregularity in hardening and distribution of mechanical properties on wire section. This phenomenon causes decrease in quality of a wire, marked by increase in breakage during further twist of steel wire cord. It is possible to reduce negative effect of unhomogeneity of deformation by additional elongation of a wire at the output from the last drawing die on stream of drawing mill [2, 3].

As a result of the conducted researches [4], we have obtained the dependences of plastic characteristics of a fine brass high-carbon wire on the modes of fine drawing. The fact that there is no analyses of values of tensile and yield strength depending on the drawing modes and research of only one steel grade 80 are the limitation of this research.

A complex of experimental and theoretical researches was conducted in order to enlarge the field of research of the drawing modes on mechanical properties of a thin wire.

The samples of wire stock, fine wire and steel wire cord, which went through the test for axial extension for the purpose of mechanical properties determination were taken in current production technologies of steel wire cord (Table 1).

Table 1. Results of mechanical tests

Mechanical characteristics	3+8x0,35HT			2+2x0,30SHT			2x0,30HT			4+3x0,35UT		
	Stock material d=1,89 mm Steel 80	Fine wire	Aggregate breakage	Stock material d=1,98 mm Steel 80	Fine wire	Aggregate breakage	Stock material d=1,77 mm Steel 80	Fine wire	Aggregate breakage	Stock material d=2,15 mm Steel 95	Fine wire	Aggregate breakage
Elastic modulus, (E) HPa	185,33	203,93	179,96	176,67	202,16	183,34	176,09	205,7	198,47	180,65	197,03	182
Conventional yield strength, (σ_y), MPa	879,47	2853,64	2663,29	889,16	3132,81	3012,5	886,02	3077,14	2894,29	994	3095	2126
Tensile strength, (σ_t) MPa	1274,54	3056,33	2825,32	1284,30	3376,13	3181,24	1271,80	3235,57	3073,46	1420	3600	2352
Maximum tensile elongation, (A_t) %	7,90	2,42	2,39	8,30	2,64	2,37	7,95	2,27	2,39	-	2,66	-

According to results of mechanical tests for axial extension (Table 1), diagrams of change of determined mechanical characteristics presented in Figures 1, 2 were constructed.

From diagram 1, it is seen that value of elasticity modulus of fine wire increases in comparison with wire stock. That is, fine drawing influences the change of elasticity modulus significantly. The value of elasticity modulus of twisted steel wire cord is lower than elasticity modulus value of separate wires.

In Fig. 2, diagrams of change of conventional yield strength σ_y and tensile strength σ_t are presented. The ratio of yield strength to tensile strength σ_y/σ_t in wire stock is 0.69 in average.

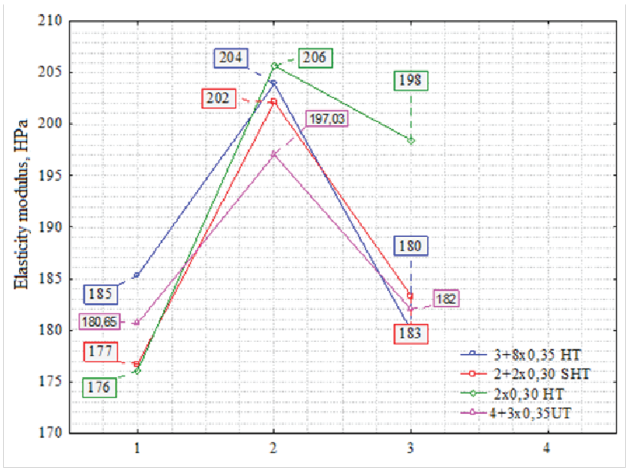

Figure 1. Determination of elasticity modulus of: 1. wire stock, 2. fine wire after drawing, 3. whole steel wire cord

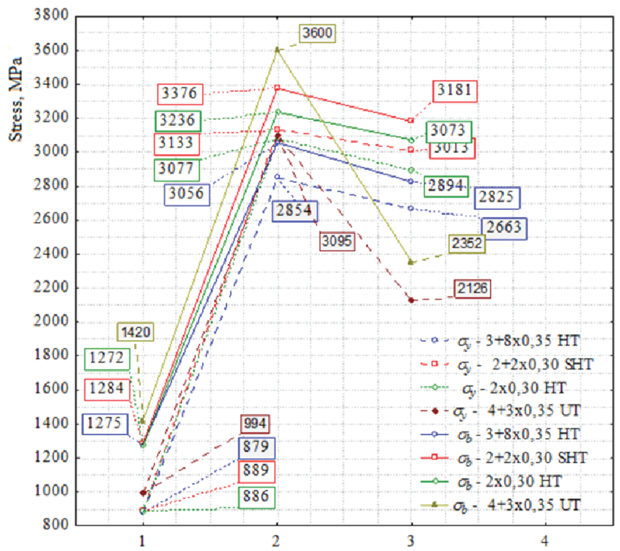

Figure 2. Change of conventional yield strength and tensile strength of: 1. wire stock, 2. fine wire after drawing, 3. whole steel wire cord

Due to the large deformation of wire stock during fine drawing, values of tensile and yield strength increase in fine wire by on average 2000 MPa in comparison with wire stock.

From the analysis of Fig. 1 and Fig. 2, we can suppose that change of drawing deformation modes can affect significantly the nature of hardening and mechanical properties of a wire. The wire properties are influenced by the main deformation modes: total deformation, drawing velocity, wire temperature while drawing. Total deformation determines the degree of deformation hardening of metal. Drawing velocity affects the wire temperature while drawing. While drawing, the wire temperature depends not only on drawing velocity, but also on surface condition between wire and drawing die. While drawing, the increased temperature of high-carbon wire causes additional hardening due to strain aging and martensite evolution on a wire surface. The pattern of hardening affects a ratio of strength and plastic properties of wire.

The research of steel wire cord 4+3x0,35UT, which is distinct in ultrastrong strength class, applied for truck tire is of great interest. The increased strength of steel wire cord provides the high efficiency of tires operation. Low productivity of fine drawing or low drawing velocity is the basic technology factor limiting of output of this steel wire cord. Therefore, further researches are connected with influence of drawing velocity on the main mechanical properties of fine wire.

The experimental researches consisted in drawing of wire 0,35UT at different velocities with the use of the following values of total deformations: for wire stock *d=2.15 mm,* the total deformation is

$$\ln\left(\frac{2{,}15^2}{0{,}35^2}\right) = 3{,}63$$

; for wire stock *d=1.9 mm,* the total deformation is 3.38; for wire stock *d=1.7 mm,* it is *3.16.*

Dependence of mechanical properties of fine wire 0,35UT (wire stock d=2.15 mm) in the current drawing technology on drawing velocity on the basis of empirical data is presented in Fig. 3.

With increase in drawing velocity, the growth of wire strength and relative elongation is observed; this testifies to simultaneous increase in strength and plasticity. The yield strength is reduced with increase in drawing velocity.

Similar tests were carried out for fine wire 0,35UT (stock d=1.9 mm) and for fine wire 0,35UT (stock d=1.7 mm). The obtained results are represented in Fig. 4, 5.

For wire 0,35UT with wire stock d=1.9 mm, the insignificant growth of tensile and yield strength with increase in velocity of drawing and decrease in relative elongation is observed. It leads to loss of plasticity and increase in metal brittleness.

For a wire 0,35UT with wire stock d=1.7 mm, the insignificant growth of tensile and yield strength with increase in velocity of drawing is observed. Relative elongation increases with growth of drawing velocity. The difference in results for different wire stocks increases because of different technological modes of drawing.

It is possible to make the conclusion that within specific ranges, mechanical properties of a wire can be controlled by means of drawing velocity change.

For mechanical properties control, it is suggested

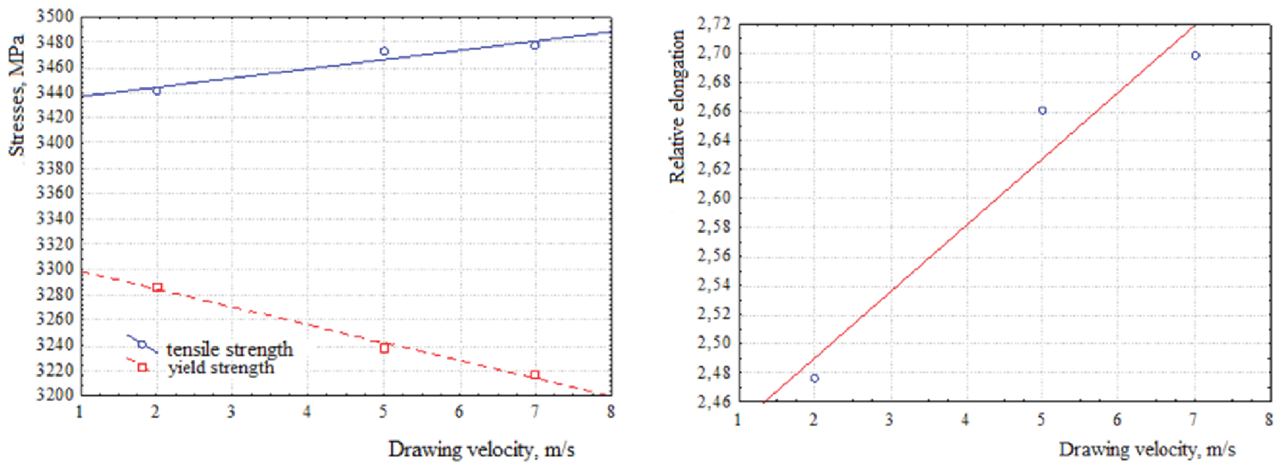

Figure 3. Dependence of wire mechanical properties on drawing velocity for a wire 0,35UT with wire stock of d=2.15 mm

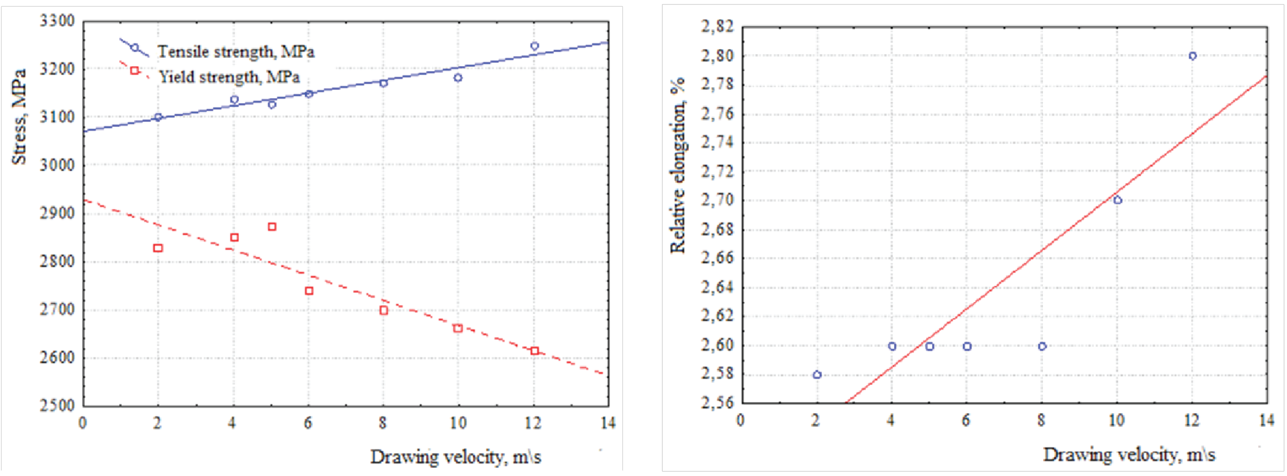

Figure 4. Dependence of wire mechanical properties on drawing velocity for wire 0,35UT with wire stock d=1.9 mm

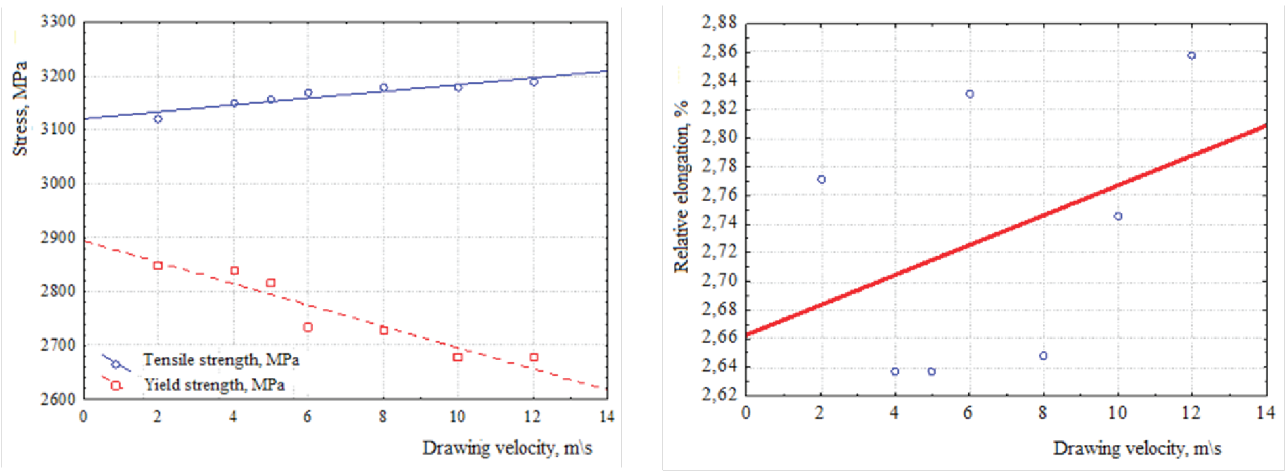

Figure 5. Dependence of wire mechanical properties on drawing velocity for wire 0,35UT with wire stock d=1.7 mm

to use the energy criterion W measured in standard units. The criterion W determines the amount of the energy, which is accumulated in a wire during plastic deformation by drawing.

The diagrams obtained during elongation of models of wire stock and fine wire can be changed from coordinates system $\sigma(\delta)$ into coordinates system $F(\Delta l)$. In this case, σ – tension, MPa; %; Δl – elongation of a sample. The area under a curve of elongation diagram in coordinates system of $F(\Delta l)$ is numerical expression of energy W.

The change from coordinates system σ (δ) to F (Δl) is shown in expression (1).

$$W = F(l_f - l_0) = \sigma \cdot \frac{(l_f - l_0)}{l_0} \cdot (\frac{\pi}{4} \cdot d^2 \cdot l_0) = \sigma \cdot \delta \cdot (\frac{\pi}{4} \cdot d^2 \cdot l_0) \quad (1)$$

$$\Delta W = \frac{W^f - W^s}{W^s} \cdot 100\% \quad (2)$$

where l_f – final length of a sample, mm;
l_0 – initial length of a sample, mm;
d – diameter of a sample, mm;
F – breaking force while tensile test, H;
δ – relative elongation of a sample, mm;
W^f – energy of fine wire after drawing;
W^s – energy of a wire stock;
ΔW – relative change of energy criterion.

The peculiar value of W^s corresponds to each complex of mechanical properties of wire stock. The peculiar value of W^f corresponds to each complex of mechanical properties of fine wire. It is suggested that for quality preservation of products, the condition $\Delta W=const$ must be observed. The constant condition ΔW provides the uniform amount of energy consumed for wire hardening. Therefore, if drawing modes are changed with observance of condition $\Delta W=const$, mechanical properties of fine wire will not be changed. If the task of increase in velocity drawing under the condition of wire mechanical properties maintaining, it is necessary to maintain the invariableness of value ΔW. On the basis of this condition, it is suggested to use the color diagram presented in Fig. 6, 7.

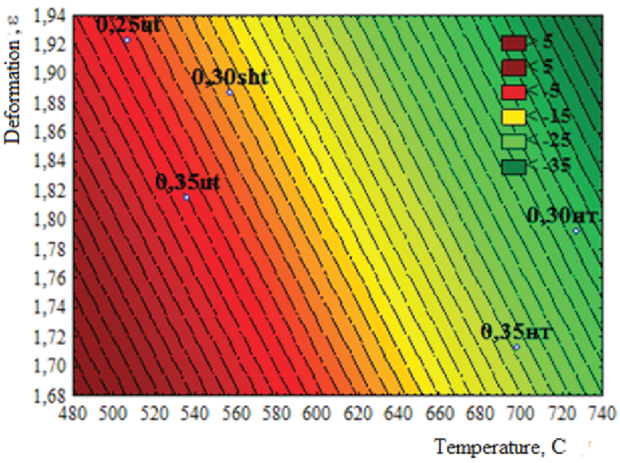

Figure 6. Color diagram of deformation and temperature of a wire at a stage of fine drawing

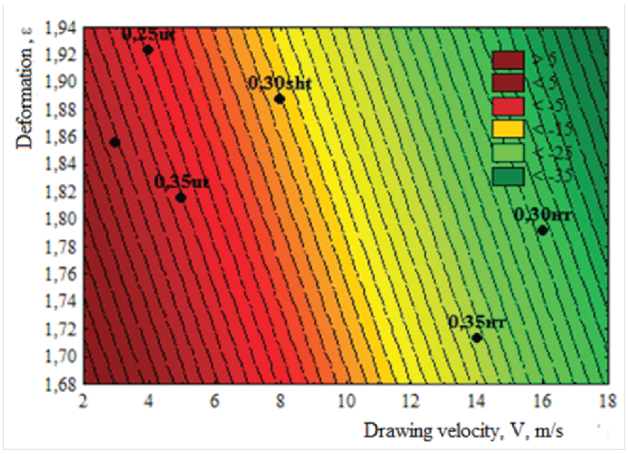

Figure 7. Color diagram of deformation and velocity of a wire at a stage of fine drawing

The different types of fine wire are shown in diagrams (Fig. 6, 7) with a help of points. The areas of identical change of energy criterion ΔW are marked by color and skew lines in the diagram. In order to maintain the mechanical properties, it is necessary that each type of wire to be in its color area while the drawing modes changing. For example, for increase in velocity, it is possible to reduce the total deformation.

Conclusion

As a result of researches, the analysis of change of value of the basic mechanical parameters of fine wire depending on the drawing modes was conducted. The new principle of control of fine wire mechanical properties based on the energy criterion was developed; it allows maintaining of the mechanical properties of a wire while drawing modes changing.

It is possible to control the formation of complex of mechanical properties of fine wire at a drawing stage by means of energy criterion. In order to obtain the specified mechanical properties of fine wire, it is necessary to maintain the change of energy criterion value.

Ways of drawing velocity increase when wire mechanical properties maintaining within the regulated limits were determined.

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