DEVELOPMENT AND EFFICIENCY ESTIMATION OF THE METHOD OF CONTINUOUS DEFORMATION NANOSTRUCTURING OF HIGH-CARBON STEEL WIRE

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Abstract.
A method of continuous deformation nanostructuring wire is developed on the basis of simultaneous overlay on continuously moving wire of deformation by drawing strain stretching, bending by pulling through a system of rollers and deformation by torsion. Devices and tools applied in various metalwire production operations are used for redistribution of this method, which greatly simplifies the installation and implementation on an existing industrial equipment. Wire after treatment by this method has a homogeneous structure in the cross section without internal discontinuities, what suggests about possibility of combining different deformation schemes for obtaining ultrafine structure of the high carbon wire. The invention of the Russian Federation has been sought on developed method, Priority Review is received. The developed system of criteria allows to estimate the possibility of the formation of ultrafine structure in high carbon wire, theoretically justifying for such technological regimes of the developed method of continuous deformation nanostructuring, which are needed to achieve the required level of strength and plastic properties of the finished wire depending on the structure and properties of the original piece.

Keywords: Method of continuous deformation nanostructuring, high carbon steel wire, process effectiveness, system of criteria

1. INTRODUCTION
Implementation of current methods of nanostructuring to existing technological processes of metallurgical and steel wire production involves a number of limitations connected with the size of processed workpieces. So developing a method of continuous deformation nanostructuring which according to its technical and technological characteristics would be compatible with existing technological processes of metalware manufacture using the existing industrial equipment is an urgent task. The method of continuous deformation wire nanostructuring was developed on the basis of simultaneous applying of tension deformation by drawing, bending deformation when going through the system of rolls and torsional deformation on a continuously moving wire. Various hardware devices and tools already applied for steel wire production can be used to implement this method thus simplifying its introduction to the current industrial equipment. The authors sent an application for an invention to the Russian Federation patent office and got a certificate of acceptance. They also carried out a number of metallographic studies which confirmed that after this treatment the wire obtained an ultra-fine grain structure. As a result of mechanical tests it was also found that simultaneous impact of tensile and torsional deformations results in improving the strength and plastic properties of wire. The wire processed by this method has a uniform structure across the cross-section without internal discontinuities that indicates the possibility of combining different deformation schemes for achieving the ultra-fine grain structure in wire [1-3].

2. METHODOLOGICAL BASICS
It is well known that ultra-fine grain structure in metals and alloys is formed as a result of gradual deformation effect on the processed material. The degree of fineness of the structural components depends on the number of nanostructuring deformation cycles (for example, the number of passes in equal channel angular pressing, the number of revolutions during intensive plastic torsional deformation, etc.). One of the theoretical approaches that makes it possible to formalize the character of structural changes as well as
changes of mechanical properties of metals and alloys in the process of deformation nanostructuring using some mathematical operator, is the application of inheritance factor quantifying the direction of variation and the degree of transfer of mechanical properties of nanostructured steel from the previous processing cycle to the next one and the susceptibility of the indicator to the technological impact [4].

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\beta_{ij} = \frac{k_{ij}}{k_{i(j-1)}} - 1, \tag{1}
\]

where \( k_{ij} \) are the values of the tested mechanical characteristics after various types of deformation processing;

\( k_{i(j-1)} \) are the values of the tested mechanical characteristics before the deformation processing.

3. EXPERIMENTAL PART

The efficiency estimation of the developed continuous method of deformation nanostructuring was carried out using annealed wire made of high-carbon steel containing 0.75 % of C. Its microstructure consisted of ferrite and carbide compound and free ferrite located on the border of irregular-sized perlite colonies. The grains were stretched in the drawing direction. The structure had no visible internal defects. Cementite plates were not destroyed.

In the continuous method of deformation nanostructuring the total reduction rate in both draw plates was 19.88%. Torsional speed changed to the wire break after the second draw plate. This value of torsion turns was taken as 100%. After the continuous method of deformation nanostructuring the following mechanical properties of the wire were examined: tensile strength as an indicator of strength and contraction ratio as an indicator of plasticity. In order to obtain the values of wire mechanical properties the coefficients of technological inheritance were calculated according to the formula (1).

4. RESULTS AND DISCUSSION

Fig. 1 represents a graphical interpretation of the results of the technological inheritance coefficients calculation for mechanical properties of high-carbon wire after the continuous method of deformation nanostructuring. When the torsional deformation degree is less than 50%, \( \beta_{ij} < 0 \). Therefore continuous deformation nanostructuring of high-carbon wire under such conditions is inefficient in terms of improving the complex of mechanical properties. The contraction at fracture is more sensitive to the changes in the processing mode (torsional deformation degree) than tensile strength. The change of technological inheritance coefficient of contraction ratio takes place more intensively and in a greater degree. Thus, the appropriate processing modes of high-carbon steel wire are the torsional deformation degree from 50% to 100% where the technological inheritance coefficient is positive in value \( \beta_{ij} > 0 \). The most effective processing mode is torsional deformation when the deformation degree is 85%.

The main efficiency measure of the developed method of deformation nanostructuring of wire is the fineness degree of its microstructure. Interlamellar distance \( h_s \), thickness of cementite plates \( h_u \) and thickness of ferritic plates \( h_f \) were chosen as control microstructure parameters. These parameters were measured according to the wire diameter (Fig. 2).

In order to assess the effectiveness of continuous method of deformation nanostructuring of wire the authors calculated coefficients of technological inheritance for cementite plate thickness \( \beta_u \), ferritic plate thickness \( \beta_f \) and interlamellar distance \( \beta_s \) in the centre and on the surface of high-carbon wire (Fig. 3 and Fig. 4).
Fig. 1. Coefficient values of technological inheritance of wire mechanical properties after continuous method of deformation nanostructuring: $\beta_\sigma$ - coefficient of technological inheritance for values of tensile strength; $\beta_\psi$ - coefficient of technological inheritance for values of contraction ratio.

Fig. 2. Dependence of microstructure parameters on torsional deformation in the central area (a) and on the wire surface (b) after continuous method of deformation nanostructuring.
Fig. 3. Values of coefficients of technological inheritance in the central area of the wire after continuous nanostructuring deformation process with varying degree of torsional deformation: $\beta_\text{ц}$ for cementite plate thickness; $\beta_\text{ф}$ for ferritic plate thickness; $\beta_\text{s}$ for interlamellar distance.

Fig. 4. Values of coefficients of technological inheritance on the wire surface after continuous nanostructuring deformation process with varying degree of torsional deformation: $\beta_\text{ц}$ for cementite plate thickness; $\beta_\text{ф}$ for ferritic plate thickness; $\beta_\text{s}$ for interlamellar distance.

Figs 3 and 4 show that microstructure parameters change significantly when the degree of torsional deformation changes. When the degree of torsional deformation increases, the coefficient values of technological inheritance for all microstructure parameters decrease monotonically. To obtain ultrafine grain structure it is necessary to use modes with maximum degree of torsional deformation with the defined total drawing deformation degree. It proves that torsional deformation contributes to microstructure refining in a greater degree than bending or drawing deformations.

The next stage of the research work was the study of the influence of technical parameters of the developed method of continuous deformation wire nanostructuring on the size of pearlite colonies. Fig. 5 shows the
graphical interpretation of the calculation results of the coefficient of technological inheritance for the size of pearlite colonies in the central area and on the surface of high-carbon wire.

![Graph showing values of coefficients of technological inheritance for pearlite colonies size after continuous method of deformation nanostructuring along the cross section of the wire with varying torsional and drawing deformations.](image)

**Fig. 5.** Values of coefficients of technological inheritance for pearlite colonies size after continuous method of deformation nanostructuring along the cross section of the wire with varying torsional and drawing deformations

In **Fig. 5** one can see that refining of pearlite colonies occurs more rapidly when the wire diameter decreases. Besides the less the value of the total drawing deformation is, the less influence is exerted by torsional deformation. On the other hand, torsional deformation does not influence the change of pearlite colonies size at the maximum value of the total drawing deformation.

### 5. CONCLUSION

The developed continuous method of deformation wire nanostructuring makes it possible to improve its mechanical properties. The measures of the process efficiency (hardening, the increase of contraction ratio, microstructure refining) are sensitive to a single reduction in the drawing plates and torsional deformation. The developed set of criteria makes it possible to estimate the possibility of ultra-fine grain structure forming in high-carbon wire and offers theoretical justification of the process modes which are necessary for achieving the required level of mechanical and plastic properties of finished wire depending on the structure and properties of the semi-finished product.

The proposed concept of “technological inheritance” in relation to the technology of deformation nanostructuring of steels allows the authors to formulate the basics of the assessment strategy of various multistage processes of material processing in terms of achieving the required set of properties. Application of the above inheritance mechanisms and variability of the object properties in multistage processes of deformation nanostructuring by means of the coefficient of technological inheritance contributes to the development of efficient solutions aimed at the technological influence on material to form the required level of properties in the material.
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LITERATURE


