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# STUDY OF TEXTURE AND MICROSTRUCTURE FORMATION IN MEDIUM CARBON STEEL WIRE SUBMITTED TO COMBINED DEFORMATION BY DRAWING WITH BENDING AND TWISTING

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**Abstract.** Deformation scheme plays the significant role in texture and microstructure formation of the processed metal ensuring the definite level mechanical properties. Medium carbon steel wire with 0.5 %C was chosen for investigation. It was deformed by combined deformational processing by drawing with bending and twisting. XRD analysis of the processed wire showed that after drawing <110> fiber texture is formed along the drawing direction. Combined deformational processing by drawing with bending and drawing with bending and twisting results in texture formation in the wire in each case in transverse direction. In microstructure of medium carbon steel wire deformation and breakdown of cementite lamellae can be noticed after all kinds of deformational processing.

**Keywords:** medium carbon steel wire; combined deformation; texture; microstructure.

## 1. Introduction

Methods of metal processing are based on principal schemes of plastic deformation such as tension, compression, bending, twisting, etc. with their special effect on microstructure and mechanical formation of the processed workpiece.

Changing of metal microstructure depends to high extent on the deformation scheme. Alternate bending is widely used in different metal processing technologies as auxiliary (winding and rewinding) and as independent (complicated sheet forging, dressing) operation of plastic deformation. In some cases alternate bending is used for special impact on metal microstructure and properties without billet shape changing. Alternate bending differs from traditional metal processing methods by total deformation degree which is not limited as well as the length of the processed workpiece. Alternate bending can be a continuous deformational processing increasing the process efficiency [1-4]. Twisting is another kind of deformation effecting metal properties. It is considered that torsion deformation is not universal in the cross section of the workpiece: it is maximum on the surface and is absent in the center [5-7]. Tension and compression are the main kinds of deformation at drawing. Drawing is the basic operation for wire production. Contralateral scheme of stress state at drawing, which is characterized by one tension and two compression main stresses, makes conditions which decreases plasticity of the stretched metal to higher extent as compared with other metal processing methods excluding tension. Such deformation scheme causes special microstructure formation in metal denoted as texture. Grains elongate towards drawing direction without changing in size [8-13].

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Drawing is characterized by rather tough stress-strain state of the processed metal resulting in decreasing its ductility especially at manufacturing of wire with thin diameters [8]. As a result for improving wire ductile properties it is necessary to use interoperational heat treatment. One of the solutions is decreasing single reduction of the drawing rate. In this case drawing force decreases, i.e. tension stress decreases with increasing compression stress. However, this fractionality of deformation increases material and energy sources consumption at drawing [14].

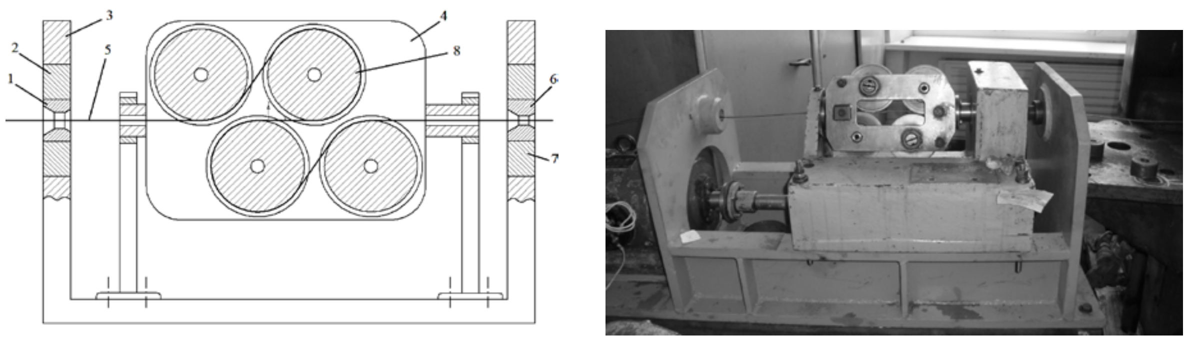
There are several solutions for increasing wire ductility. At industrial conditions lower single reduction degrees along the drawing rate are used. Essential advantages have drawing with lower additional reduction degrees by broaching through dies with the same diameter or by rotating rolls breaking-in. Good results in improving wire ductility have been achieved at alternation of deformation by drawing with bending. Another factor influencing wire ductility is application of torsion deformation on wire or die. It was proved experimentally that with increasing die rotation rate the drawing force decreases.

Correlation between microstructure and mechanical properties of steel with different carbon content is one of the important topic for investigation [15-19]. Changing deformation parameters allows to get the wire with definite properties which are necessary for wire application in accordance with customer demands. However, each kind of deformational processing, especially their combination, demand conducting experiments for investigation wire texture and microstructure peculiarities because of their high effect on wire mechanical properties.

The aim of this paper is to study texture and microstructure formation in medium carbon steel wire at continuous deformational processing by drawing with bending and twisting.

## 2. Methodology

For the experiments medium carbon steel wire with 3.45 mm in diameter was chosen. It contained 0.5 % C (0.5 %C - 0.2 %Si - till 0.6 %Mn - till 0.25 %Cu - till 0.08 %As - till 0.25 %Ni - till 0.040 %S - till 0.035 % %P - till 0.25 %Cr - in wt. %). Combined deformational processing by drawing with bending and twisting was arranged on the laboratory setup (Fig. 1).




a b

**Fig. 1.** Laboratory setup for continuous method of combined wire deformation:
a – principal scheme; b – laboratory installation.

It consists of two consequently arranged along the longitudinal symmetrical axis dies 1 and 6 with four rolls 8 joint toughly together in system 4 placed between them. Dies are put into adapters 2 and 7 and fixed inside the frame 3. Four rolls system can rotate because of connecting with independent engine. Wire 5 while moving through dies is subjected to tensile and compression strain by drawing when four rolls system enables to get bending and twisting deformation simultaneously [20]. Although in many industrial technologies of metal ware production dies and such rolls system are used the novel step was to adjust these tools together. Maintaining the processed wire rate permanency in axis direction and its rotation around of the longitudinal axis ensures the synchronization of deformational parameters at different kinds of deformational processing. The process and the setup construction are defended by patents of the Russian Federation [21, 22].

The XRD measurements were performed in DII, University of Padova. Siemens D500 X-ray diffractometer, using a Cu-Kα radiation, at 40 kV at 30 mA was used. The samples were subjected to texture analysis on a texture goniometer using a WINHRD32 software for the data acquisition and the program TEX-VIEWER for the elaboration of the results. The specimen's tilt were limited to the range of 0 to 70 deg, owing to instrumental geometrical limits.

Scanning electron-microscope analysis of the processed wire was carried out in Nano Steel Research Studies Institute of Nosov Magnitogorsk state technical university using the electron microscope JEOL JSM-6490 LV. Samples for metallographic examination were prepared from the deformed wire by polishing and etching the cross-section and observed on the surface of the sample.

The amount of total reduction degree in dies was 36.46 %, rotation rate of four rolls system reached 150 RPM (revolutions per minute).

## 3. Experimental results and discussion

In Fig. 2 XRD diffraction patterns of medium carbon steel wire after different kinds of deformational processing are presented. The sample after drawing was chosen as the reference one. Based on the obtained results the pole figures of the medium carbon steel wire after different kinds of deformational processing both in longitudinal direction and transverse section were constructed (Fig. 3). The following data show the (110) pole figure, collected at 2θ = 44.78”, according to the peak position of 110 plane in the XRD diffraction.

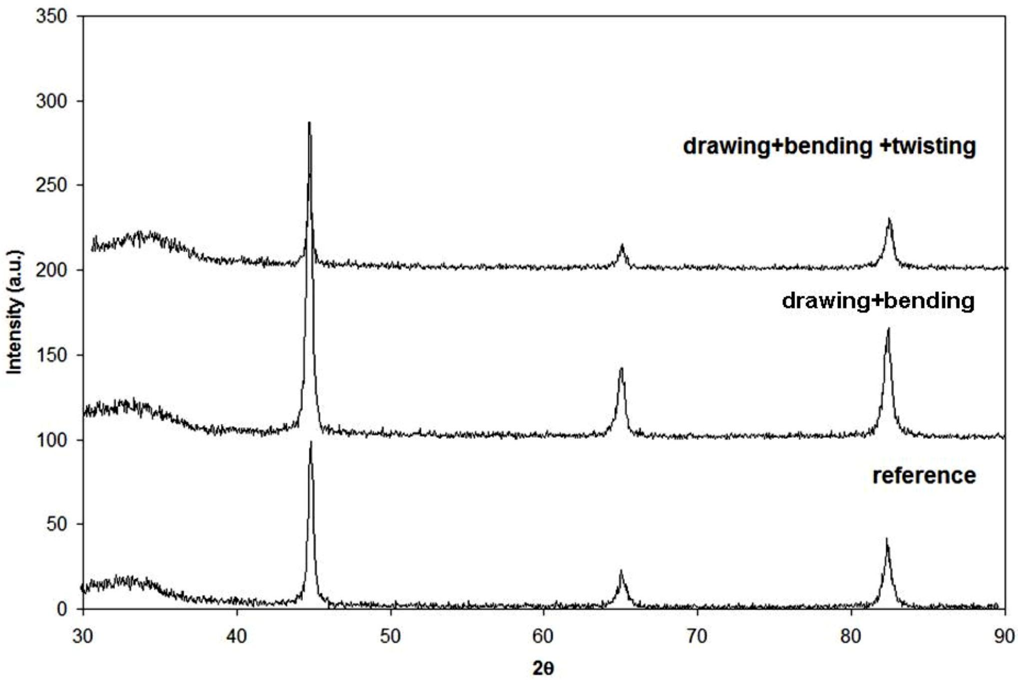



**Fig. 2.** XRD diffraction patterns of medium carbon steel wire after different kinds of deformational processing.

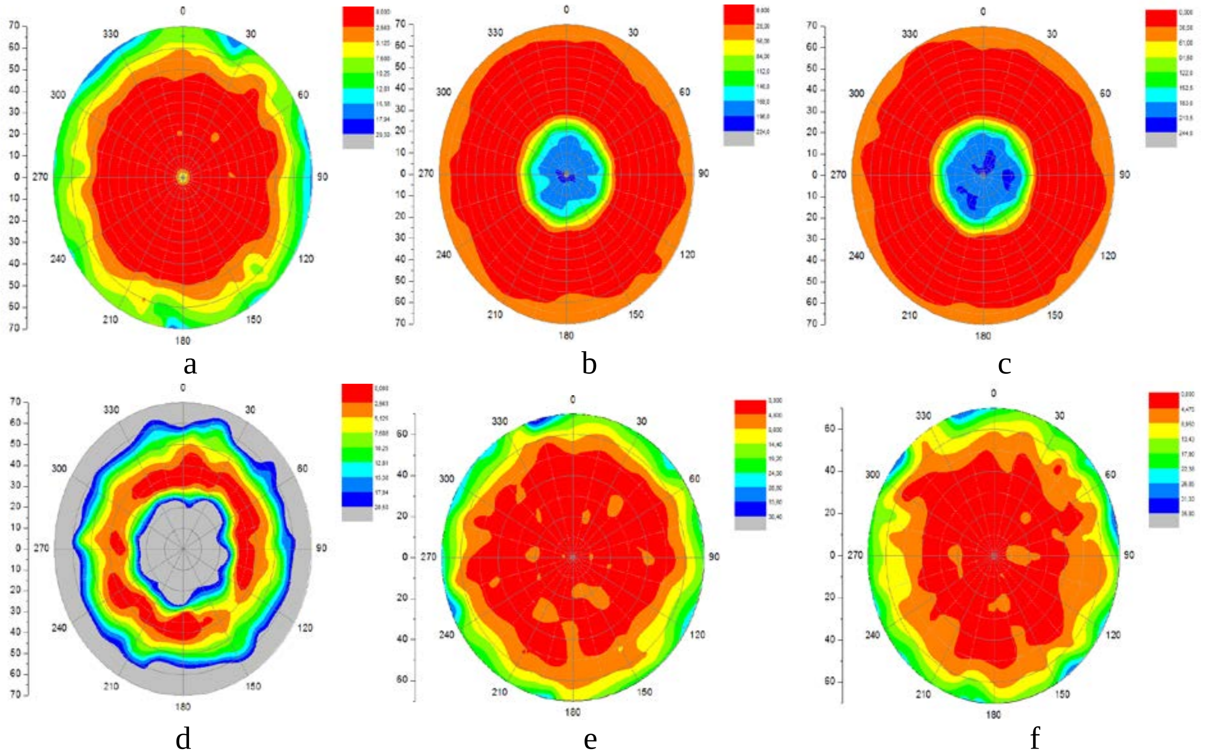



**Fig. 3.** Pole figure of (110) in longitudinal direction (a-c) and transverse section (d-f) of the medium carbon steel wire after different kinds of deformational processing: a, d – drawing with total reduction 36.46 %; b, e – drawing with total reduction 36.46 % and bending in four rolls system (rolls with 90 mm in diameter); c, f - drawing with total reduction 36.46 % with bending in four rolls system (rolls with 90 mm in diameter) and twisting at 150 RPM.

Results of XRD analysis show that after drawing <110> fiber texture is formed along the drawing direction (see Fig. 3, a). Combined deformational processing by drawing with bending (see Fig. 3, b, e) and drawing with bending and twisting (see Fig. 3, c, f) results in texture formation in the wire in transverse direction.

Medium carbon steel microstructure changing also depends on the kind of deformational processing (Fig. 4). Microstructure is typical for steel with 0.5 % C and consists of ferrite-carbide mixture and small quantity of structural free island shape ferrite located along perlite colonies boundaries.

At drawing with total reduction degree 36.46 % pearlite colonies anisotropy is observed. In central area of wire the anisotropy is higher as compared with the surface area. After supplementation of bending deformation structure becomes uniform and pearlite colonies anisotropy is observed both in the center and on the surface of the processed wire. However, in the center it is more progressive [23-25]. Combination of drawing with bending and twisting the wire microstructure changes with the same tendency. Pearlite colonies anisotropy is strongly marked. At the same time microstructure is more uniform and dispersed as compared with previous kinds of deformational processing.

In all cases one can see the pearlite colonies and structural free ferrite elongation in longitudinal direction. Deformation and breakdown of cementite lamellae can be noticed after all kinds of deformational processing. Nevertheless, at combination of drawing with bending (see Fig. 4 c, d) and with bending and twisting (see Fig. 4 e, f) this breakdown occurs to higher extent.

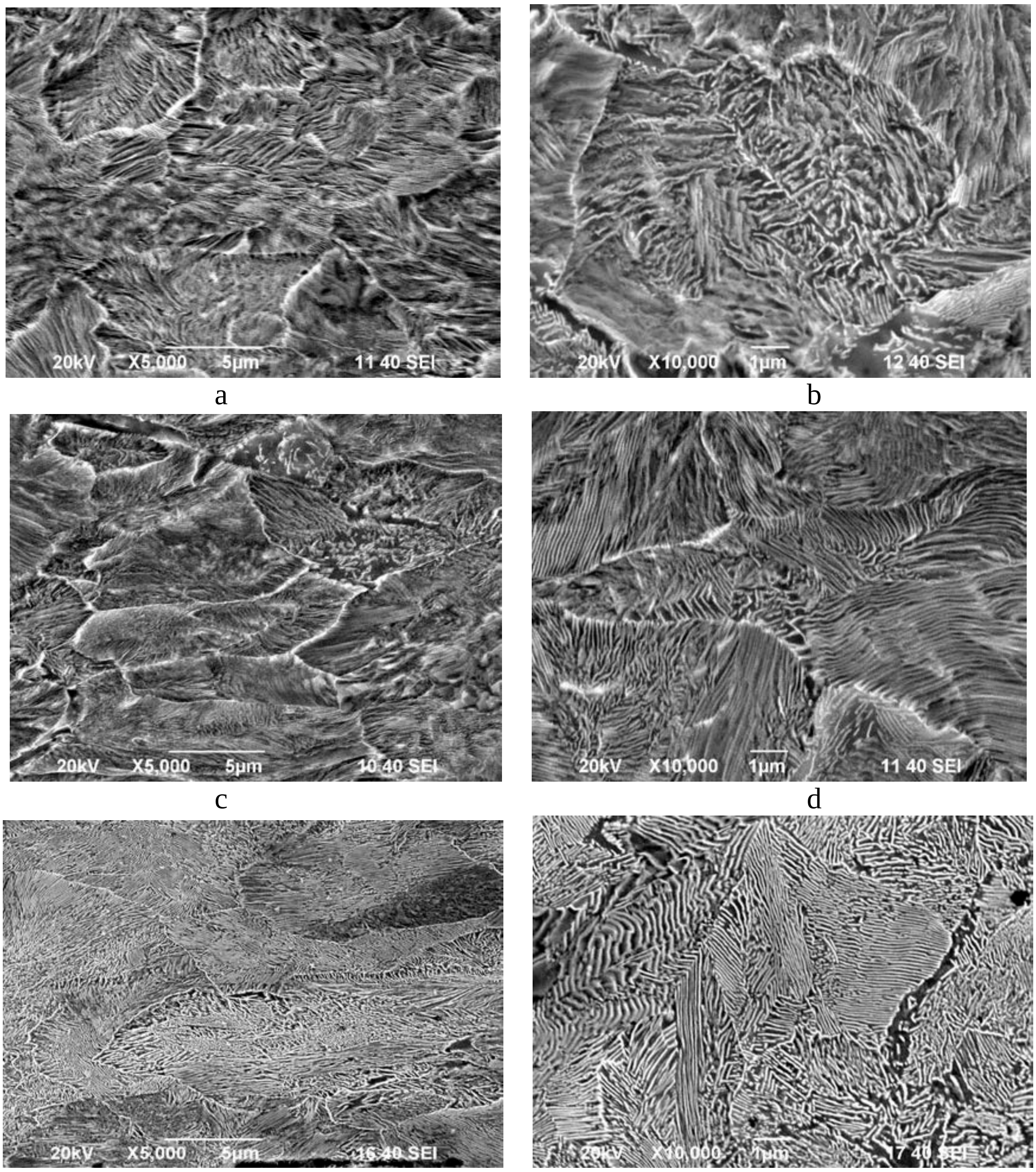



**Fig. 4.** Medium carbon steel o.5 %C microstructure after drawing (a, b), combination of drawing with bending (c, d) and combination of drawing with bending and twisting (150 RPM) in longitudinal (a, c, e) and transverse (b, d, f) directions.

All variations of medium carbon steel wire at drawing with simultaneous application of twisting are the result of obtaining complicated stress-strain state of the processed metal. Such scheme of combined deformational processing contributes to appearing shear stress near grain boundaries causing refinement processes. Additional factor for improving deformation intensity is applying bending deformation at twisting in the space between dies. It makes it possible to ensure microstructure homogeneity across the cross section of the processed medium carbon steel wire [26-29].

## 4. Conclusions

Continuous method of wire combined deformational processing by drawing with bending and twisting was used to study texture and microstructure formation of medium carbon steel wire with 0.5 %C. Pole figure of (110) in longitudinal direction and transverse section of the medium carbon steel wire after different kinds of deformational processing was constructed. It was proved that after combined deformational processing texture was formed in the processed medium carbon steel wire. These results correlate well with microstructure variations. It was found out that independently on combination of deformation the pearlite colonies and structural free ferrite elongate in longitudinal direction. Deformation and breakdown of cementite lamellae can be noticed. The obtained results can be used for designing new methods of deformational processing based on combination of different kids of deformation.

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