CHANGES IN THE PROPERTIES OF Fe37-3FN STEEL DURING ECAP-DRAWING

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Received 08 September 2022
Accepted 09 November 2022

ABSTRACT

One of ways of high-quality processing of metal billets is drawing of a lengthy wire. But at modern technology of processing total reductions during the drawing of billet into a wire are rather big (up to 99.2 %) that demands carrying out additional intermediate heat treatments. Therefore, increase in strength and plastic properties of metal without intermediate heat treatment with saving of necessary final characteristics of a wire at improvement of already existing technologies is the perspective direction of development of metal working. In this paper, the deformation of a wire made of Fe37-3FN steel by ECAP-drawing is carried out. It is shown that as a result of large deformations, the grain structure of the metal reached the UFG level, and the wire itself was highly textured, both due to a very high level of deformations, and due to the lack of intermediate annealing, the latter is dictated by energy and resource saving. It was found that after deformation by the ECAP-drawing method, the wire has an increased reserve of plasticity in comparison with the traditional drawing process, which allows its further processing with high degrees of deformation without intermediate annealing.

Keywords: severe plastic deformation, steel, microstructure, mechanical properties, ECAP-drawing.

INTRODUCTION

One of ways of high-quality processing of metal billets is drawing of a lengthy wire. Drawing is directed to receiving geometrically correct products, with a plain and clean surface, as a rule, of small section. Reduction of the diameter of a wire and increase in its length is the result of the process. It is relevant for production of a wire of a different profile and other wire products applied in all areas of human activity.

In the last twenty-five years the researches concentrated on receiving ultrafine-grained and nanocrystal materials with the increased physical-mechanical properties which are perspective structural and functional materials of new generation actively develop. At the moment there are whole schools of sciences which are actively developing science in this direction as in Kazakhstan, and abroad. Nevertheless, the problem of receiving lengthy volume nanostructural materials fully remains not solved. Therefore, development of own latest technologies and mastering of new ways of processing of metals by pressure here main directions of development of the industry in production of a wire [1 - 5].

The use of methods of severe plastic deformation (SPD), such as high-pressure torsion (HPT), equal-channel angular pressing (ECAP) [8 - 10], screw extrusion leads to the grinding of the alloy structure, but they are not applicable for obtaining long ultra-fine-grained blanks [6, 7]. The result of approximation of SPD processes to the conditions of industrial production is continuous SPD methods.

The Conform method is a type of continuous pressing that was developed in 1971 in England [11]. The Conform is based on continuous deformation of the workpiece by feeding it by active friction forces into the working channel formed by the shoe and a movable rotating wheel with a stream in the form of a groove along the periphery, while a matrix is installed at the end of the shoe, which forms a decompression chamber. It is worth noting that the traditional Conform method is characterized by high energy intensity and increased unevenness of deformation. A new direction of development of the method was its development as a method of severe plastic deformation for obtaining long products with ultra-fine-grained structure [12].

It is also worth noting the method of equal-channel angular free broaching (ECA-broaching), which leads to the formation of a UFG structure in long blanks of a round cross-section [13].

This process consists in repeatedly pulling the wire through special matrices, in the design of which two channels intersecting at an angle are provided. In [14], the influence of heat treatment and matrix design on the mechanical properties of the resulting samples is studied. It is also shown that to obtain a UFG structure, it is necessary to conduct from 4 to 10 processing cycles, which is the main drawback of this process. It is worth noting that when ECA-broaching in the processed workpieces, a non-uniform UFG structure is observed even after 8 passes.

Many of these methods are based on bending, such as multiple angular accumulative drawing (AAD), described in [15]. In contrast to ECA-broaching, the AAD method is characterized by a complex mode of changing the type of deformation - diameter compression, stretching and torsion, which affects the change in the microstructure of the final product, which, with appropriate control, leads to improved properties, which is especially important for alloys that are not characterized by a complex composition.

The authors of several works proposed the ECAP-drawing method [16 - 20]. This method of deformation, due to the combination of two methods: intensive plastic deformation in an equal-channel step matrix and the drawing process, allows you to obtain a wire of the required size and shape of the cross section, which has an ultra-fine-grained structure. At the same time, restrictions on the length of the initial blank are removed, and the length of the finished products can reach several tens of meters.

The essence of the proposed method of deformation is as follows. The pre-pointed end of the wire is set in an equal-channel step matrix, and then sequentially in the calibration drag (in essence, the process of the metal task does not differ from the task of the wire in the drag in the standard drawing process). After the end of the workpiece comes out of the portage, it is fixed with gripping tongs and wound on the drum of the drawing mill. In this case, the process of pulling the workpiece through an equal-channel step matrix and a calibration drag is realized by applying a pulling force to the end of the workpiece. An external load is applied to the metal being stretched, and contact stresses occur on the metal-tool contact surface. In contrast to other methods of processing materials by pressure, the implementation of which cannot be carried out without the presence of contact friction forces, when drawing on the metal-tool section, directed against the movement of the metal, are negative phenomena of the process, which undoubtedly implies the use of technological lubricants that reduce friction.

EXPERIMENTAL

The laboratory experiment was carried out on an industrial drawing mill B-I/550 M. For this purpose, an equal-channel step matrix with a channel diameter of 7 mm was fixed in front of the hauling machine. The matrix was located in a lubricant container. Soap shavings were used as a lubricant.

The main condition for the continuity of the ECAP-drawing process is the coordination of the wire drawing speeds in the drag and the wire pushing speed in the equal-channel-step matrix. The mill is equipped with a system for automatically adjusting the linear rotation speeds of the drum and the rollers of the pushing device. The unit drive is controlled automatically by changing the frequency of the motor current. Thus, when setting any route, the mill automatically adjusts and speeds are set so that they are synchronized. Reducing the heating of the wire during the drawing process is achieved by reducing the number of compressions. The speed of pulling and pushing the wire is consistent with such a condition that the drawing mode with anti-tension is provided.

To identify the advantages of the proposed technology in comparison with the current drawing technology, 4 experiments on wire drawing using the current technology were conducted - from a wire rod with a diameter of 7.0 mm to 6.5 mm, 6.0 mm, 5.5 mm, and 5.0 mm. Experiment was performed at room temperature and soap shavings were used as a lubricant. After each experiment, the wire diameter was measured and the templets were cut.

The main chemical element that determines the behavior of steel during drawing is carbon. An increase in the carbon content leads to an increase in the strength and ductility of the wire, while significantly reducing the resistance of the deforming tool, increasing the size and number of defects (cracks, flaws, etc.), and deteriorating product design. Therefore, carbon steel of the Fe37-3FN brand, which is widely used in cold climates, was chosen for the study.

The choice of a cheap, widespread steel grade is due to the fact that after improving the structure and improving the mechanical properties, it will be possible to replace more expensive, but similar in characteristics, alloyed steel grades.

Metallographic analysis of all examined samples in cross-sectional and longitudinal sections was performed using a JEM2100 electron transmission microscope. All samples were tested in the median plane to avoid the influence of peripheral areas. Preparation of samples for metallographic analysis was carried out on an electrolytic sample preparation unit Struers.

Mechanical uniaxial tension tests were performed at room temperature on Instron 5882 machine at a deformation rate of 1.0 mm/min. The sample deformation was measured with an Instron strain gauge. Tensile tests were carried out on flat samples cut from the ring in accordance with GOST 1497-84 recommendations. Tensile tests of mechanical properties were used to determine strength and ductility characteristics: yield strength ($\sigma_{0,2}$), tensile strength (σ_B) and maximum elongation to failure (δ).

RESULTS AND DISCUSSION

In the initial state, Fe37-3FN steel has a ferrite-perlite structure with a perlite content of about 16 %, with an average grain size of 12 microns.

After analyzing the microstructure of deformed samples, we can conclude that cold deformation during drawing using the current technology with moderate and high total compression (from 50 % to 85 %, depending on the cross-section size) leads to the formation of a pronounced textured structure. However, even as a result of significant compression received by the wire during the drawing process, not all grains are crushed and are deployed in the direction of the deformation axis. As the microstructure analysis shows, as a result of the uneven distribution of deformation across the cross section of the sample, a zone of large grains is preserved in the central part, which results in an inadequate level of plastic properties of the finished wire, in particular the relative elongation. Thus, from Fig. 1(b) it can be seen that in this case, the deformation leads to a slight grinding of the grain in the transverse direction, in the longitudinal direction (Fig. 1(a)), the grains are lengthened and somewhat thinned to form a visible axial texture [21]. It can also be noted that in the longitudinal direction of the deformed samples, the structure is pronounced and has a striped character. The appearance of the drawing texture leads to anisotropy of the material properties in the longitudinal and transverse directions, which can negatively affect the operation parameters of the finished product.

To reduce the appearance of the axial deformation texture, it is necessary to perform recrystallization annealing of the resulting wire with correctly selected heat treatment parameters.

The proposed ECAP-drawing technology eliminates the drawbacks of the drawing process. At the first stage of drawing, a cellular structure is formed before compression of 30 % - 40 % (Fig. 1(c)). As a result of turning and crushing unfavorably oriented cementite plates, the density of dislocations on the phase interface surfaces increases, and second-order distortions increase. A local increase in the internal stress field (local slope of the ferrite matrix) causes the formation of stable microcracks. Intensive disclosure of stable microdefects leads to stress relaxation, which in the process of subsequent deformation opens previously blocked Frank-Reed sources. At the same time, the cellular structure is improved, the fibrous structure is formed and the texture is formed. The grain/subgrain size after 4 passes is ~ 0.6 microns. It is impossible to achieve an ultra-fine-grained structure only due to a uniform flow of dislocations: as plastic deformation accumulates and the density of dislocations increases, there is a disproportionately rapid increase in stops and obstacles that inhibit their progress through the crystal. The dislocation flow is gradually depleted, and the level of internal stress increases. This continues until cracks begin to appear and the sample is brittle. To prevent this from happening, and the energy supplied to the sample did not accumulate in the material mainly in the form of elastic distortions, but continued to dissipate, before drawing, a deformation was applied in an equal-channel

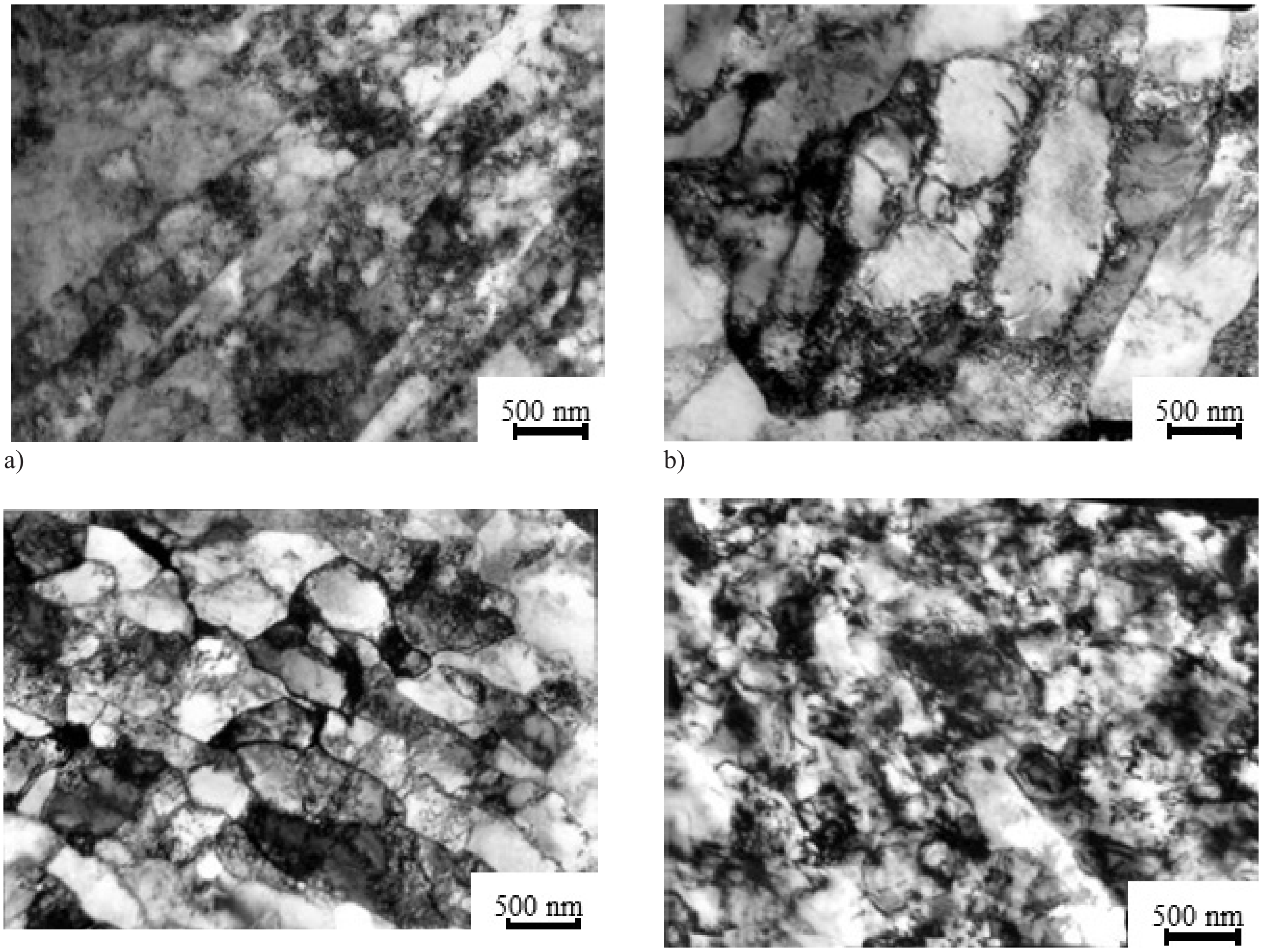


Fig. 1. Structure of a wire from Fe37-3FN steel: after the current drawing technology (a, b), after the proposed ECAP-drawing technology (c, d); (a, c - longitudinal direction; b, d - transverse direction).

step matrix, which provides shear deformations and the formation of large-angle boundaries, as a result, conditions are created for the continuation of plastic deformation at large values [16].

EBSD analysis confirmed the obtained TEM data. As Fig. 2(a) shows, only small-angle borders are formed in traditional drawing. Combined ECAP-drawing technology allows to obtain a fine-grained (~1 micron) structure with a high proportion of large-angle borders (Fig. 2(b)).

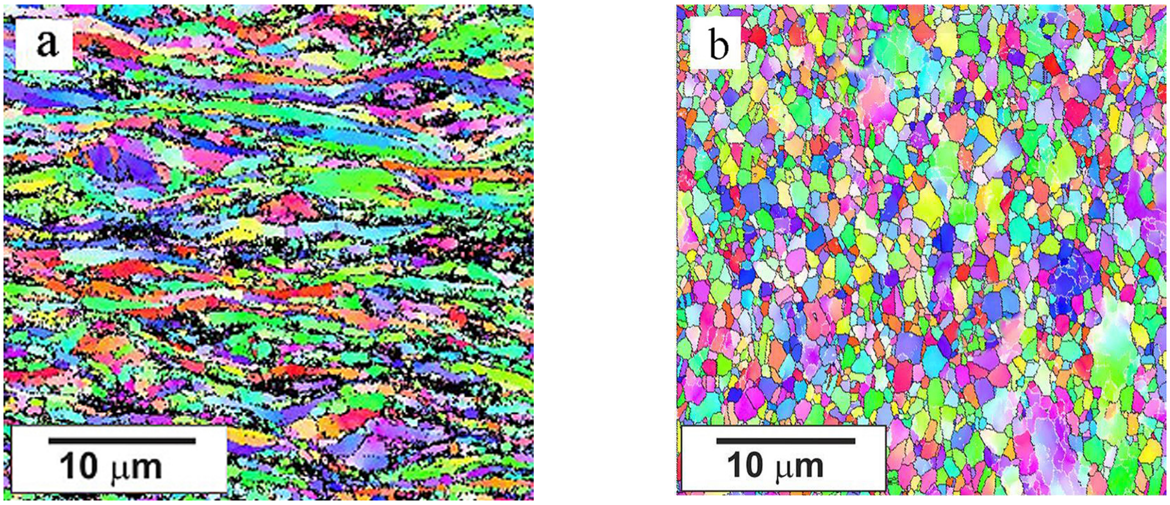
The values of tensile strength and yield strength increase in four passes from 380 MPa to 740 MPa (absolute increase is 360 MPa) and from 220 MPa to 680 MPa (absolute increase is 460 MPa), respectively.

The analysis of experimental data showed that the wire after the combined ECAP-drawing technology has a higher reserve of plasticity: the ratio of the conditional yield strength to the tensile strength is less than when drawing along a similar route. This indicates that this wire can be subjected to high degrees of deformation in subsequent technological operations of its conversion without intermediate annealing.

As it is known, the characteristic that most fully reflects the ability of the material to plastic deformation is the relative contraction in the neck area. The relative contraction in Fe37-3FN steel after deformation by the ECAP-drawing method changes from 63 % to 55 %, i.e. the drop is not as significant as in classical drawing.

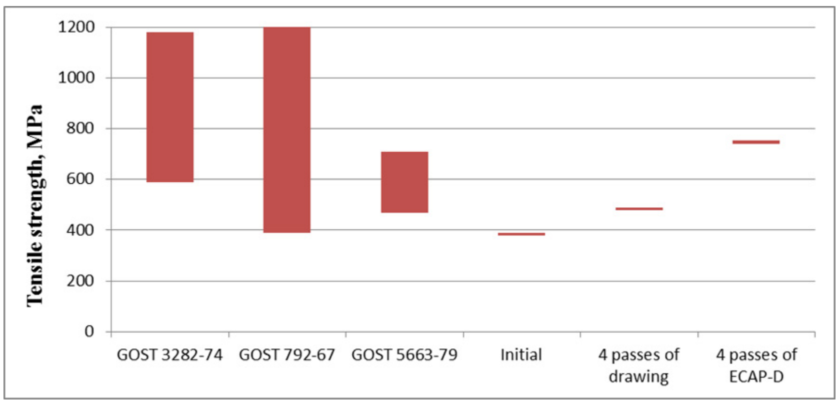
In this chapter the compliance of the mechanical properties of the wire after ECAP-drawing with the requirements of standards to assess the possibility of its further application was performed.

To compare the mechanical properties of the wire, the following wire standards were selected:

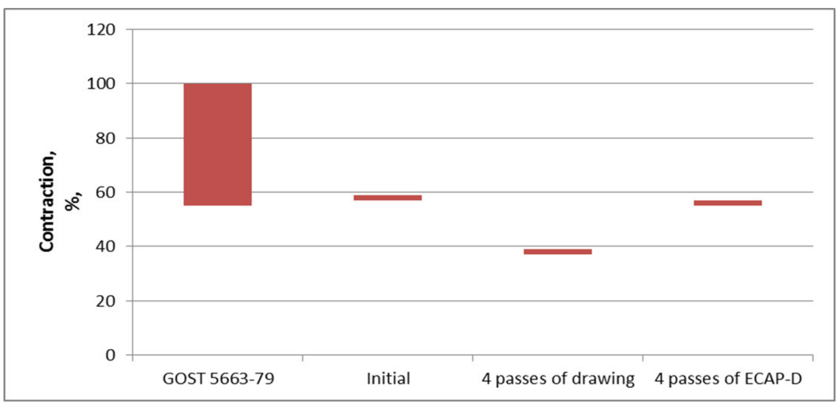


a) b)

Fig. 2. Orientation cards of a microstructure: drawing (a), ECAP-drawing (b).



a)



b)

Fig. 3. Comparison of tensile strength with the requirements of standards for Fe37-3FN steel wire (a) and Comparison of contraction with the requirements of GOST 5663-79 for Fe37-3FN steel wire (b).

- GOST 3282-74 “General purpose low-carbon steel Wire. Thermally untreated uncoated»;
- GOST 792-67 “Low-carbon quality wire»;
- GOST 5663-79 “Carbon steel wire for cold landing».

Fig. 3(a) shows the ranges of change in the time resistance to rupture, which are regulated by the standards for the Fe37-3FN wire according to the above standards. The values obtained after tensile tests after 4 passes of deformation by the traditional drawing method and ECAP-drawing are also presented.

As shown by the comparison of the level of the obtained properties of the wire obtained by the developed method, this method allows to achieve the required level of tensile strength for all the specified standards.

The relative elongation is not regulated by GOST 792-67 and GOST 5663-79, and GOST 3282-74 regulates the relative elongation of only heat-treated wire, but the resulting value of 22 % is included in the range of plastic metals.

The relative contraction is regulated only by GOST 5663-79. The comparison results obtained after tensile tests, after 4 passes of deformation by the traditional drawing method and ECAP-drawing are shown in Fig. 3(b).

CONCLUSIONS

Based on the conducted research, it can be concluded that the proposed combined method of deformation ECAP-drawing has a significant advantage in comparison with previously known methods for producing metal with an ultra-fine-grained structure. This method of deformation, due to the combination of two methods: intensive plastic deformation in an equal-channel step matrix and the drawing process, allows to obtain a wire of the required size and shape of the cross section, which has an ultra-fine-grained structure. It also removes restrictions on the length of the initial blank, and, therefore, allows to get finished products up to several tens of meters long.

It is shown that when the wire is deformed using the proposed combined ECAP-drawing technology, after four passes of deformation, the structure of Fe37-3FN steel is significantly reduced, compared to traditional drawing, not only on the surface, but also in the center of the wire. At the same time, the texture and anisotropy are significantly less pronounced, since, despite the high number of equivalent sliding systems in the HCC lattice, the character of crystallographic textures formed as a result of ECAP-drawing depends on the shear deformation that passes in the matrix channel after each pass, which allows further fragmentation of the structure.

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