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INFLUENCE OF CRYOGENIC COOLING AFTER DRAWING ON CHANGES IN PROPERTIES OF STEEL WIRE

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ABSTRACT

One of the promising and little-studied methods for obtaining an ultrafine-grained structure and enhanced mechanical properties is the so-called cryogenic deformation - deformation at temperatures below 120K. It is assumed that low deformation temperatures suppress recovery processes, thus contributing to the accumulation of an extremely high dislocation density and increase internal stresses, as well as activate deformation twinning, which together will accelerate grain refinement. In this regard, in this work, we studied the drawing of steel wire under cryogenic cooling in liquid nitrogen. The results of the laboratory experiment show that the application of cryogenic deformation treatment after wire drawing improves mechanical properties compared to conventional wire drawing. In this case, after two cycles of deformation, the relative contraction after stretching decreases by 8 %, the ultimate strength increases by 40 %, and the conditional yield strength by 26 %. The results show that the deformation conditions during cryogenic drawing are an additional factor for the realization of structural resources of steel wire physical and mechanical properties optimizing.

Keywords: drawing, microstructure, cryogenic cooling, steel, wire.

INTRODUCTION

To implement the plans facing the economy of the Republic of Kazakhstan, it is necessary to provide key industries with high-quality metal products with unique physical, mechanical and other performance characteristics. In many cases, solution of these problems is associated with high energy costs. From the point of view of saving energy and raw materials resources, question of energy and resource saving methods is of great practical importance, allowing processing products with minimal time and obtaining materials with properties that combine high strength and ductility at the same time, using relatively simple and cheap equipment [1 - 3].

Currently, technologies are relevant that produce metal products on one continuous line by combining or combining several operations. This approach leads to a significant increase in competitiveness by reducing the number of intermediate processes.

One of the most demanded types of metal products is steel wire, which is widely used as an element in the production of steel cord, hawsers and bimetallic steel products. These metal products determine safety and reliability such objects operation as railways, equipment for lifting people and goods, building supports for various objects and structures, telephone lines, special microcables, aviation and seismic cables, defense industry and aviation. At present, more stringent requirements are imposed on the level of regulatory properties of these metal products. Traditional technologies for steel wire mechanical characteristics improving do not have significant reserve for such technical and economic indicators as profitability, energy intensity, limited ability to quickly change both the entire technological process and its individual parameters. Therefore, development of technical and technological means for the comprehensive improvement of steel wire mechanical properties using innovative methods of deformation processing is an important scientific and technical task.

Based on many articles it is well known that by reducing the grain size of structural materials, it is possible to significantly improve strength properties during cold deformation and plastic properties during hot deformation [4 - 8]. Therefore, practical interest is focused on the development of methods for limiting grain size reduction. Currently, materials scientists are faced with the task of obtaining submicro - and nanocrystalline structures in quantities suitable for industrial use. One possible solution to this problem is deformation at liquid nitrogen temperature (so-called cryogenic deformation). It is assumed that extremely low deformation temperatures will significantly complicate the recovery processes and, thereby, significantly accelerate the refinement of the microstructure [9, 10].

Over the past few years, scientists have begun to show an increased interest in cryogenic cooling using liquid nitrogen during deformation by metal forming methods [11 - 13]. Cryogenic or cold processing was first proposed by the Soviet scientist Gulyaev in 1937 and has been used abroad since then [14]. For many alloyed and carbon steel grades, the complete cessation of martensitic transformation occurs at sub-zero temperatures, therefore, when cooled to room temperature, a certain amount of austenite remains in the structure. But repeated high temperature quenching cannot change microstructure further. This suggests that the steel cannot reach the maximum possible hardness value. It is also desirable to convert the austenite to martensite as completely as possible, since retained austenite may gradually change to bainite over time. This is achieved by cooling to the final martensitic transformation temperature, which can be in the range from plus to -140°C for industrial steel grades [15]. In addition, no dynamic recovery or recrystallization occurs during cryogenic processing, which allows for more efficient refinement of the granular structure. Another advantage of such deformation is a significant increase in strength at lower deformation forces compared to traditional metal forming methods [16, 17].

Therefore, intensive cooling at the exit of the wire from the die with liquid nitrogen can give the best compromise between the strength and ductility of the material. This can be achieved by increasing the mobility of dislocations and simultaneously increasing their density.

In this regard, the purpose of this study is to study the patterns of evolution of the microstructure and mechanical properties of low-carbon steel wire during its deformation by drawing at room and cryogenic temperatures.

EXPERIMENTAL

The cryo-cooled wire drawing process is a combined process in which wire drawing and subsequent heat treatment are carried out in one line of the machine. The process of setting the wire does not differ from the existing technology of wire drawing and setting the wire into the drawing mill. Pointed end of the wire is fed into the die installed in the die holder of the mill, then passed through an empty tank-chamber for cryogenic cooling. Further, the end of the wire is fixed on the drum of the drawing mill, and several turns of wire are wound. Next, mill reaches working drawing speed. At the same time, cryogenic cooling chamber is filled with liquid nitrogen. The chamber is equipped with a recirculating nitrogen supply system.

The research material is steel wire SAE 1020 (0.2 % C; 0.6 Si; 1.8 % Mn; 0.8 % Ti). Technological process is the drawing of a wire through a die with a decrease in the cross section and subsequent intensive cooling. In deformation zone, an intensive heating of the wire occurs, temperature reaches 393 - 423 K, then the wire enters cryogenic cooling chamber, where intensive cooling takes place up to 77 K. The wire diameter before deformation was 6 mm, and after each deformation cycle, the diameter decreased by 0.5 mm. Thus, after 2 deformation cycles, the wire diameter was 5 mm.

Metallographic analysis was carried out on an optical microscope at a magnification of 1000 times.

Micromechanical properties were monitored during all periods of the study by measuring the microhardness. To measure the microhardness, an imprint was made on the sample surface under static load in accordance with GOST 9450-76. The indenter was a diamond tip in the form of a square pyramid with a square base. The load was 1N. The root mean square error of the micro-hardness determination on many prints is an indication of the accuracy of the instrument.

Mechanical tensile tests were carried out at room temperature on standard specimens according to GOST 1497-84 recommendations on an Instron 5882 machine. 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).

To assess the uniformity of mechanical properties, we used the coefficient of variation of a random variable (a measure of the relative degree of dispersion of random variables, which indicates the degree of their averaging), calculated as the ratio of the arithmetic mean and standard deviation of the samples. The error in the mechanical tests did not exceed 3 %.

RESULTS AND DISCUSSION

Fig. 1 shows the results of the metallographic analysis of steel wire after deformation at various temperatures.

The metallographic analysis of the steel wire microstructure after 2 drawing cycles at room temperature and cooling with liquid nitrogen shows that strongly deformed grains are formed in both cases. However, in experiments with nitrogen, the structure turned out to be more dispersed with a smaller grain size (Fig. 2b), since cryogenic treatment suppresses spontaneous (metadynamic) recrystallization and limits the movement of dislocations. Thus, after 2 cycles of deformation, the microstructure of steel wire deformed at room temperature was crushed from 26 μm to 15 μm (Fig. 1a). And the microstructure of the wire deformed in liquid nitrogen is up to 8 microns (Fig. 1b).

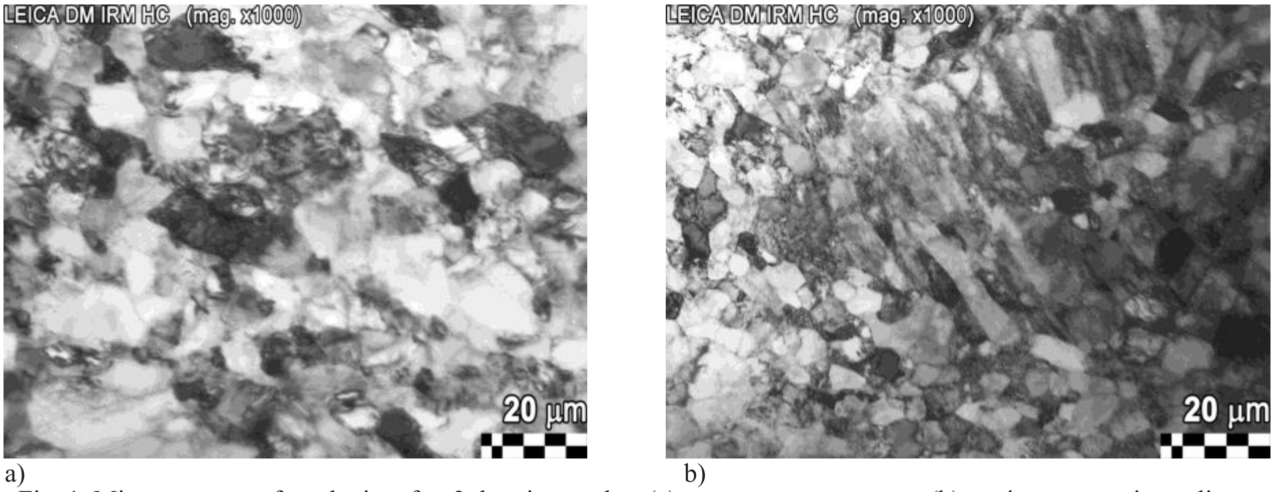
The results of the laboratory experiment show that the application of cryogenic deformation treatment after wire drawing improves the mechanical properties compared to conventional wire drawing. In this case, after two cycles of deformation, the relative contraction after stretching decreases by 8 %, the ultimate strength increases by 40 %, and the conditional yield strength by 26 %. With traditional drawing, without the use of nitrogen, following mechanical characteristics were obtained: tensile strength increased by 14 %, conditional yield strength by 11 %. Compared to drawing at room temperature, improvement in strength properties after cryogenic drawing may be associated with the degree of microstructure defectiveness, its fragmentation, and changes in the state of fragment boundaries.

Also, cryogenic cooling increased microhardness in the center from 1250 MPa to 1615 MPa, changing it from 1345 MPa to 1830 MPa on the surface.

The impact strength of steel wire after a single drawing is like that of the original material, in the temperature range of 77 - 153 K, a decrease in viscosity is observed. Although the KCU value of 24 J cm^{-2} at 77 K is quite high.

To determine the homogeneity of mechanical properties, we used the coefficient of variation of a random variable (a measure of the relative spread of a random variable, which shows how much of the average value of this value is its average spread), calculated as the ratio of the arithmetic mean of the sample to the standard deviation. Evaluation of mechanical properties uniformity according to the scheme showed that the spread of mechanical properties along the length of the resulting wire does not exceed the values allowed by the international standard.

When analyzing fracture fractography after steel drawing at room temperature, the crack is ductile, it passes through a granular body, which is typical for fibrous fracture. The crack surface in the crack initiation zone is represented by deep separation pits, which are elongated in the direction of crack propagation. The crack propagation zone is represented by equiaxed pits of various sizes. Dolom's pits look like depressions with more or less thin bridges. The fracture after testing at cryogenic temperature looks like a dry fibrous fracture, it is a homogeneous surface of a ductile intragranular fracture with less pronounced signs



a) b)

Fig. 1. Microstructure of steel wire after 2 drawing cycles: (a) - at room temperature; (b) - using cryogenic cooling.

of plastic deformation over the entire surface of the fracture than in a fibrous fracture. Relatively thin bridges between belts in cracks at room and cryogenic test temperatures indicate an energy-intensive process of destruction.

CONCLUSIONS

In this work, changes in the mechanical properties of steel wire during cryogenic cooling during drawing were studied and following conclusions were drawn: cryogenic treatment of mild steel wire increases tensile strength by 21 %, yield strength by 18 %. Relative contraction after rupture is reduced by 5 %. Deformation conditions during cryogenic drawing are an additional factor in the implementation of structural resources to optimize physical and mechanical properties of steel.

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