Development of a new technology for carbon steel bars processing

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Abstract: *In this paper, bars from carbon steel grade 45 deformed by a new technology are studied. This technology consists in drawing bars from medium carbon steel on a radial-shift rolling mill and subsequent drawing. As a result of deformation, bars with gradient microstructure were obtained. The surface zone of the bar is significantly crushed, the average ferrite size is 0.5 µm. In the neutral zone the deformation is not large enough, so the structure is not so strongly crushed, the ferrite grains are reduced to 2 microns. In the central zone, the microstructure consists of large grains with an average size of 7 µm. The quantitative ratio of large-angle boundaries in the surface zone is much higher than the central zone. To understand the relationship between strength and microstructure, the microhardness of the bar was determined. Thus for three deformation cycles the average value of microhardness in the central zone was 2085 MPa, in the neutral zone - 2505 MPa, and in the surface zone - 2915 MPa. As it can be seen, the hardness decreases as we move away from the surface zone to the central zone, this can be explained in terms of dislocation and boundary hardening.*

***KEYWORDS*:** BAR, MICROSTRUCTURE, DRAWING, STEEL, RADIAL SHEAR ROLLING.

1. Introduction

Modern methods of metal forming are widespread and allow solving large number of problems, including production of parts (and semi-finished products) of a given shape with an improved set of mechanical properties. Traditional methods, such as pressing, forging, stamping and rolling, are aimed at obtaining products of a given geometric shape (profile) and size. In addition, some methods, such as the method of severe plastic deformation (SPD), make it possible to create ultrafine structures of materials with an increased level of mechanical properties [1-3].

Production of materials with a fine-grain structure after plastic deformation is based on the use of SPD methods. The purpose of SPD is the accumulation of large degrees of deformation (the true degree of deformation is 6-8 or more). But SPD methods have a large number of disadvantages, one of the main ones being the limitation on workpiece size [4-6].

To obtain long cylindrical semi-finished products with improved mechanical properties, the radial shear rolling (RSR) method was studied and applied. A number of studies have shown that this method can be used to process almost any metals and alloys, including those with high strength and low resistance to deformation. Compared to conventional spiral rolling, the FSR process produces a finer grain structure and compresses the metal throughout the entire volume of the bar. This process also improves the properties of rolled products by obtaining a unique microstructure. The results of study [7] show that at small feed angles, metal loosening appears in the central part of the workpiece. By increasing the feed angle from 18 to 240, metal is compressed and intensively processed to obtain a finer-grained structure.

Research shows that the RSR method allows one to obtain a gradient fine-grained structure. The material in the surface region is deformed more intensely, forming both a fine-grained microstructure due to dynamic recrystallization and a coarse-grained microstructure formed as a result of recrystallization process development. Central layer retains deformed, non-recrystallized structure. As a result, after RSR it is possible to form so-called gradient structure, which simultaneously imparts high strength and toughness to the processed material. In this case, final level of workpiece mechanical properties is comparable to the indicators obtained by SPD method.

In 2001, research on applied radial shear broaching (RSB) were began at the faculty of Moscow State Technical University named after G.I. Nosov [8]. Its prototype is radial shear rolling. The possibility of combining the processes of cross-helix rolling and drawing was considered in [8]. Using traditional drawing as a final process after various SPD processes is a good option, as it eliminates all the disadvantages of pre-deformation (e.g. non-uniform geometry, porosity, etc.).

2. Material and research methodology

Technology of radial shear broaching is lying in the basis of the process, developed by us, which allows us to obtain long rods with improved mechanical properties. During the process of pulling, the workpiece is deformed in the cross section due to pulling it through conical rollers, which are located at an angle of 120° to each other. The surface layers of the workpiece experience radial twisting, which, together with compression, results in a high degree of deformation, allowing for better surface development. And in combination with radial shear deformation, are subjected to greater refinement of the structure .

Deformation of the rods was carried out according to the simulated scheme shown in Fig. 1.

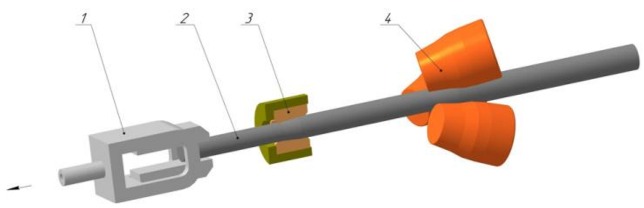

Fig. 1 *Scheme of a new process for deforming rods: 1 – gripping device, 2 – rod, 3 – drawing dies, 4 – broaching rolls*

To study the effectiveness of the developed technology, laboratory experiments were carried out on annealed rods of carbon steel grade 45.

The preparation of thin sections for metallographic studies was carried out according to standard methods; a Leica optical microscope equipped with a microhardness tester was used for the investigation. The operation of cutting samples from wire was carried out using a Lobotom-3 cutting machine. To facilitate processing, samples were filled with a special epoxy resin. Next, the samples filled with epoxy resin were sanded using coarse sandpaper to remove the top layer of epoxy resin and obtain a more even surface. Than the samples were ground on a Tegra grinding and polishing machine Pol - Tegra Force from Struers, using grinding and polishing discs. After grinding the surface of the sample, polishing followed, which completely eliminated the risks remaining from the impact of abrasive particles (Fig. 2). Etching was carried out with a solution of 2% nitric acid and 98% ethanol. The effectiveness of hardening after deformation was assessed by measuring Vickers microhardness at a random load of 0,5H.

3. Experimental results

Metallographic examination of the rod in cross section shows that a gradient ferro-pearlite structure was obtained as a result of deformation by the method of radial shear broaching and drawing (Fig. 3). Therefore, for a better understanding of the distribution of properties, in accordance with work [1], we divide the rod into 3 zones: surface, neutral and central.

Surface zone of the rod, compared to the central zone, is significantly crushed over 3 deformation cycles. So the average ferrite size is 0,5 microns. Ultrafine grains of almost equiaxed shape can be traced here. Ferrite grains are also observed to split into smaller ones. The grains have thin straight boundaries that are free of dislocations. The pearlite plates are crushed and the distance between them is reduced to 0.2 mm. In the neutral zone, the deformation is not large enough, so the structure is not refined so much, the ferrite grains are reduced to 2 microns. Both large grains with a developed substructure and small grains with a fine structure with the presence of a large number of dislocations are observed. The heterogeneity in the structure could be explained by the presence of recrystallization processes, but in our case, deformation occurs at room temperature, and heating in the die does not exceed 150-165^{o}C, so the recrystallization process can only occur by a diffusion-free mechanism. In central zone microstructure consists of large grains of deformation origin, both with a small number of subboundaries and with a large content of them.

Further quantitative analysis was carried out using EBSD analysis, the number of high-angle boundaries was determined in all three zones of the rod (Fig. 2). It was revealed that the maximum number of high-angle boundaries is observed in the surface zone. After three cycles of deformation, about half of the formed ultrafine ferrite grains have a misorientation above 30°. Figure 2b shows the neutral zone; elongated areas separated by low-angle boundaries, as well as areas separated by high-angle boundaries, are observed on it. The largest number of low-angle boundaries is observed in the central zone, since it was least subject to shear deformation. Thus, the share of high-angle boundaries in the surface zone is 65%, in the neutral zone ≈ 49% and in the central zone ≈ 28%.

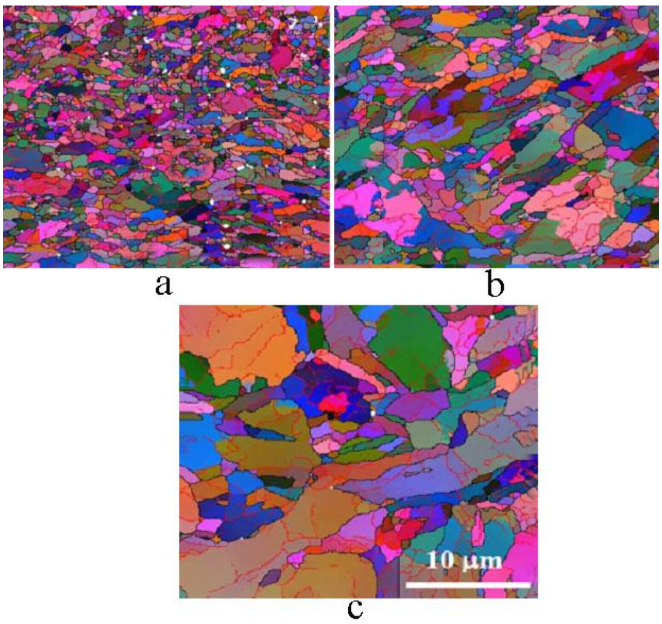

Fig. 2 *Microstructure orientation maps: a – surface zone, b – neutral zone, c – central zone*

Taking into account the resulting gradient structure, it was decided to study the change in microhardness over the cross section of the rod. Thus, over three deformation cycles, the average value of microhardness in the central zone was 2085 MPa, in the neutral zone – 2505 MPa, and in the surface zone – 2915 MPa. Such a spread in microhardness confirms the presence of a gradient microstructure (Fig. 3).

The tensile strength (σ_B) is growing from 580 MPa in the initial state to 812 MPa after the third pass. The yield strength ($\sigma_{0,2}$) increases from 380 MPa in the initial state to 562 MPa after the third pass. And as can be seen from the curves, the main increase in strength occurs in the first two passes of deformation. So on the first pass, the tensile strength increases by 22%, and the yield strength by 23%. Plastic characteristics, on the contrary, decrease with an increase in the number of passes, so the relative elongation from 34% in the initial state to 22% after 3 passes.

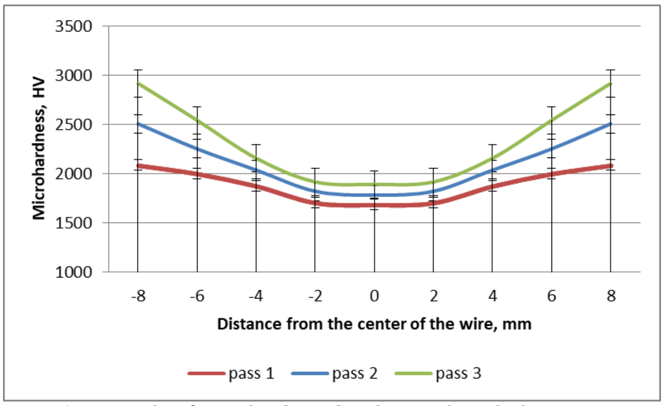

Fig. 3 *Graphs of microhardness distribution along the bar section*

An analysis of the change in microhardness from the center of the wire to the periphery showed that this parameter is directly dependent on the level of accumulated strain. Thus, obtained hardness values of copper exceed the hardness of annealed copper by 315 MPa, due to work hardening during deformation using the ECAP-drawing method and amount to 663 MPa. The microhardness of the steel core in the initial state is 600 MPa, and after three passes of deformation it is 985 MPa.

4 . Conclusions

The work examined carbon steel rods deformed using new technology. This technology consists of drawing medium-carbon steel rods in a radial shear rolling mill and subsequent drawing. As a result of deformation, rods made of steel 45 with a gradient structure were obtained. As a result of deformation, rods with a gradient microstructure were obtained. The surface zone of the rod is significantly crushed, the average ferrite size is 0.5 microns. In the neutral zone, deformation is not large enough, so the structure is not refined so much, the ferrite grains are reduced to 2 microns. In the central zone, microstructure consists of large grains with an average size of 7 µm.

To understand the relationship between strength and microstructure, the microhardness of the rod was determined. Thus, over three deformation cycles, average value of microhardness in the central zone was 2085 MPa, in the neutral zone – 2505 MPa, and in the surface zone – 2915 MPa. As can be seen, the hardness decreases with distance from the surface zone to the central one; this can be explained from the point of view of dislocation and boundary hardening. Such high values of microhardness of the surface layer help to increase the wear resistance of the rods, and the soft center increases their plastic properties.

5. Financing

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6. Literature

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