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Change of Mechanical Properties of Bars in the Process of Deformation by Combined Method

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A new combined deformation technology combining radial-shear broaching and drawing technology is developed in this work, which makes it possible to improve the mechanical and operational properties of carbon-steel bars. As a result, during three straining cycles, the average value of microhardness in the central zone is of 2085 MPa, in the neutral zone, it is of 2505 MPa, and in the surface zone, it is of 2915 MPa. In addition, the strength properties are increased by almost 2 times, the plastic characteristics are reduced not much, but remain at a fairly good level for steel 45 due to obtaining gradient microstructure during straining.

Key words: steel, bar, drawing, radial-shear broaching, severe plastic deformation.

У роботі розроблено нову комбіновану технологію деформування, що поєднує в собі технологію радіяльно-зсувного протягування та волочіння, що дає змогу підвищити механічні й експлуатаційні властивості прутків із вуглецевої криці. У результаті за три цикли деформування середнє значення мікротвердости у центральній зоні становило 2085 МПа, у нейтральній зоні — 2505 МПа, а в поверхневій зоні — 2915 МПа. Такий розкид мікротвердости підтверджує наявність ґрадієнтної мікроструктури. Також відбулося збільшення міцнісних характеристик майже у 2 рази, пластичні характеристики зазнають пониження, але залишаються на доволі хорошому для криці 45 рівні за рахунок одержання ґрадієнтної мікроструктури під час деформування.

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Ключові слова: криця, пруток, волочіння, радіяльно-зсувне протягання, інтенсивна пластична деформація.

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1. INTRODUCTION

Bars made of carbon steel grades are one of the main types of products of hardware processing of ferrous metallurgy and are widely used in almost all sectors of economy both in the form of marketable products and in the form of products from it. To ensure efficient use, sustainable exports and real import substitution, bars must be highly competitive, the main directions of which are: reduction of material and energy consumption, development and manufacture of advanced equipment for the new enterprises existing and construction technological re-equipment. In this regard, it is necessary to develop and investigate more new and effective technologies to improve performance and strength properties of long bars. Therefore, development of new combined methods of pressure treatment, allowing increasing significantly the level of original material processing is an urgent task.

Reinforcing bars are widely used in construction. With their help, reinforcement of reinforced concrete products in the form of slabs, blocks, beams, *etc*., as well as the construction of building structures. Reinforcement is in the form of metal bars made of low-alloy or carbon steel. Currently, the rebar is used in the construction of various buildings. Because of its excellent performance, characteristics can give more strength to concrete: foundations, walls and floors.

In recent years, a lot of research has been carried out to improve mechanical and operational properties of carbon steels by means of obtaining ultrafine grains and nanostructure by intensive plastic deformation methods. Methods of severe plastic deformation (SPD), in contrast to traditional methods of metal forming, aimed mainly at shaping, are used to significantly change the structure, phase composition, physical and mechanical properties [1–3]. As a result of SPD in metallic materials, lengths of grain and subgrain boundaries increase by orders of magnitude, static and dynamic dilatation of crystal lattice atoms changes markedly. Materials obtained in this way, such as nanostructured aluminium or copper, can become harder than high-strength steel, but these materials will be very brittle and break during use, apparently due to strain localization [4–6].

One of the techniques that improve performance of products is the use of metallic materials with a gradient structure [7–9]. It has been found that gradient microstructures, in which the grain size increases from nanosize state on the surface to a coarse-grained state in the centre, are an effective approach to increasing the plasticity of the product as a whole.

In recent years, study of gradient structural states in metallic materials has formed into a new scientific direction [10–12]. Within this framework, it is of interest to study the formation of gradient structures in long metal products (rods, strips). Combination of harder surface layers with a relatively 'soft' core in such products makes it possible to increase wear resistance, distribute loads, relax stress concentrators, and increase plasticity of the product as a whole. As an example, we should point out the use of nonmonotonic shear deformation by shear drawing of low-carbon steel bars, which leads to the formation of a gradient structure up to the formation of nanostructured surface layers with ultrahigh microhardness ($HV \cong 7$ GPa) and to a noticeable increase in wear resistance.

It is also possible to obtain a gradient structure in long bars by the type of helical rolling, separated by its authors into a unique method called 'Radial Shear Rolling' (RSP) and patented [13].

Thus, it can be summarized that during radial shear rolling, in the deformation zone, stress state scheme is realized that is close to all-round compression with large shear deformations [14]. The most intense shear deformations are localized in the zone of metal slip lines intersection—the annular cross-sectional zone characteristic of three-roll scheme. In other words, conditions are created in the deformation zone that is optimal for the gradient structure formation.

In addition, heat treatment increases the processing cycle time and increases the cost of manufacturing bars. Therefore, the development of technological processes for the manufacture of bars should follow efficiency-increasing path of methods used for processing of metals by pressure.

Instead of radial-sliding rolling, in our case we will pull the bar on a helical rolling mill. Since by pulling the billet simultaneously through the crossing rolls and the draw, tensile stresses arise that leads to a reduction of the drawing force. Due to the tensile stresses along the billet, the profile of the stretched billet is formed more evenly.

2. EXPERIMENTAL

A laboratory experiment on annealed bars of carbon steel AISI 1045 was carried out to study the efficiency of the developed technology. Before straining, the bars were annealed at 740°C to obtain a more homogeneous structure and to eliminate the impact of other production processes.

Since our university does not have planetary stands for the production of long bars, it was decided to implement radial-displacement drawing instead of radial-displacement rolling of bars on the mill PCP-10/30 and combine this process with traditional drawing on the mill B-

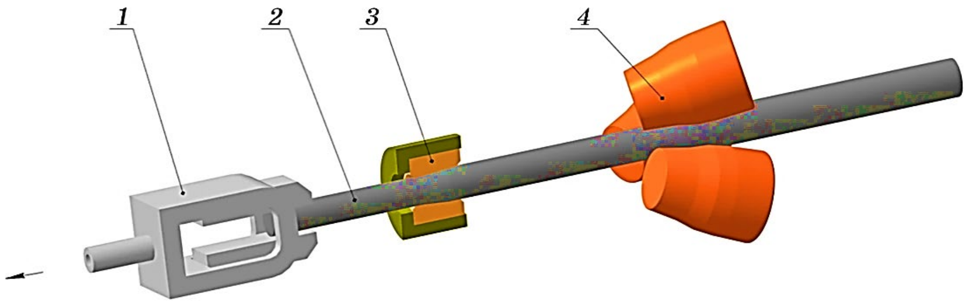


Fig. 1. Schematic diagram of new bar straining process: *1*—gripping device; *2*—bar; *3*—drawing rolls; *4*—broaching rolls.

I/550 M. Since, by pulling the workpiece simultaneously through the crossed rolls and the drawbar, tensile stresses are generated which result in a reduction of the drawing force. The profile of the drawn workpiece is formed more uniformly due to tensile stresses along the workpiece.

The process we are developing is based on radial-displacement drawing technology, which makes it possible to produce long bars with enhanced mechanical properties. During pulling, the workpiece is strained in cross-section by pulling it through tapered rollers that are positioned at a 120° angle to each other. The surface layers of the workpiece undergo radial torsion, which in combination with reduction results in a high degree of strain allowing for better surface finish. There is greater refinement of the structure in conjunction with radial-displacement straining.

Straining of bars was carried out according to the modelled scheme shown in Fig.1.

Microhardness was determined on Anton Paar hardness tester in accordance with GOST 9450-76 by the method of diamond pyramid indentation with the angle between opposite sides 136° under the load 1N and duration of loading 2 s. The average value of 5 measurements in each considered area was used to calculate the microhardness value.

Tensile tests were carried out in accordance with GOST 1497-2000 at room temperature. Tenfold samples d =10 mm was used.

3. RESULTS AND DISCUSSION

Figure 2 shows the microhardness distribution along the cross section of the bar after each straining cycle. The graph above shows that the microhardness is higher in the surface zone. Thus, for three straining cycles, the average value of microhardness in the central zone was of 2085 MPa, in the neutral zone, it was of 2505 MPa, and in the surface

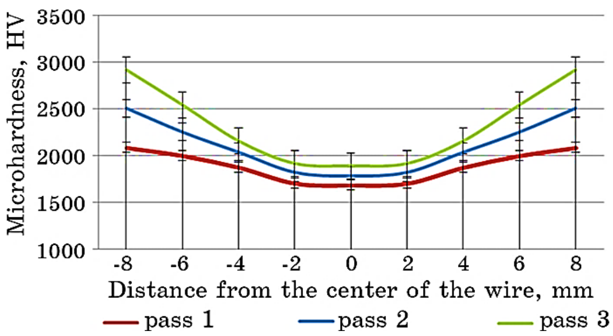


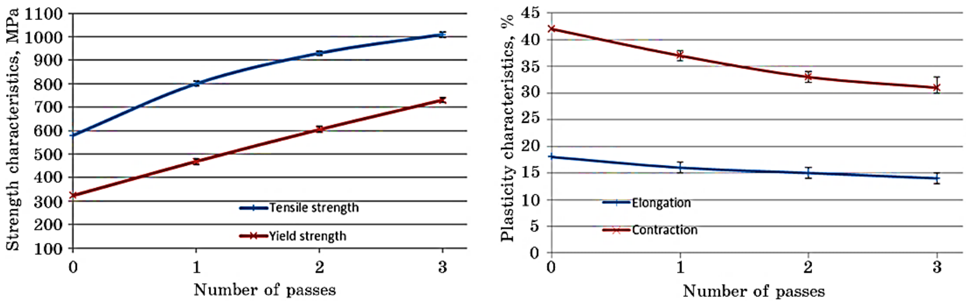
Fig. 2. Graphs of microhardness distribution along the bar section.

zone, it was of 2915 MPa. This variation of microhardness confirms the presence of a gradient microstructure.

Figure 3 shows graphs of strength and plastic properties of carbon steel bar plotted before tensile testing. Analysis of the graph shows an increase in strength characteristics for 3 straining cycles by almost 2 times, so, the tensile strength increases from 580 MPa to 1010 MPa, and yield strength from 325 to 730 MPa. Plastic characteristics undergo a decrease, so relative reduction changes from 42% to 31%, and relative elongation from 18 to 14 MPa. The plastic characteristics remain at a fairly good level due to the gradient microstructure obtained during straining. Plastic characteristics in this steel are obtained at a lower level when deformed by other SPD methods [15, 16].

4. CONCLUSIONS

Bars from carbon steel grade AISI 1045 strained by a new technology



a *b*

Fig. 3. Diagrams of mechanical characteristics of carbon steel bar depending on the straining cycle: *a*—strength characteristics; *b*—plasticity characteristics.

are studied in this work. Physical experiment has shown that the application of radial-displacement drawing helps to reduce the number of straining cycles and, as a result, to reduce the cyclic nature of the technological process, as well as to increase the depth of structure development due to the penetration of reduction straining along the cross-section of the bar. Such bars together with their increased strength and plastic properties provide good prospects for their application in construction.

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