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Radial-shear rolling as a new technological solution for recycling bar scrap of ferrous metals

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ABSTRACT

Waste recycling of both ferrous and non-ferrous metals is a useful process for the economy of any country. This paper proposes a new technology for recycling bar scrap of ferrous metals by rolling it in radial-shear rolling mills by producing a commercial product in the form of bars with an ultrafine-grained gradient structure. Studies have shown that the deformation of bar scrap in the form of pieces of reinforcement made of steel grade 18G2S in a radial-shear rolling mill makes it possible to significantly disperse its structure by producing a gradient ultrafine-grained structure, and this, in turn, leads to the elevating of the mechanical characteristics of this steel grade. Thus, the tensile limit of the 18G2S grade steel deformed on the radial-shear rolling mill was 620 MPa (at the initial value of 365 MPa).

Keywords: recycling, bar scrap of ferrous metals, reinforcement, radial-shear rolling, microstructure, mechanical properties.

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Introduction

The environmental problem has been a hot issue all over the world for more than a decade. Conventional waste disposal does not always solve this problem, since in many cases it also leads to significant environmental pollution, for example, in the case of waste disposal in a waste landfill or waste incineration. Therefore, at present, much attention is paid to the development of various methods of waste processing, i.e. recycling, including scrap metal, which is also the most economically profitable.

For example, the “3R Initiative” in waste management, based on three basic “coordinates”: Reduce – reduction; Reuse – reuse of waste; Recycle – use as secondary resources were proposed in Japan as far back as 2004 [1].

In the present case, we shall consider the problem of processing and using “iron waste”, a special category of waste called scrap metal, as secondary resources.

The sources of the formation of scrap metal can be conditionally divided into three categories: parts or mechanisms, as well as structures that have exhausted their service life; deteriorated metal products; waste generated during the production and processing of ferrous metals.

As is well known, the final stage of the life cycle of most metal products is most often their disposal in the form of scrap metal, followed by remelting and further recycling.

At the same time, it is difficult to disagree that this is one of the simplest ways to dispose of metal products that have served their service life.

Although there has long been another way of processing some metal products that have served their service life by various methods of hot pressure treatment to obtain a finished commercial product [2-10].

But a qualitatively new level of possibilities for the recycling of scrap metal processing, both in the form of some long metal products, such as rods, axles, shafts that have served their service life, and ordinary bar scrap of ferrous metals, including rebar, opens the radial-shear rolling process (RDR).

Radial-shear rolling is cross rolling of solid rounds mainly on a three-high screw rolling mill with large feed angles and high one-time draftings, the main difference of which is the feed angle increasing to $\alpha = 18° - 20°$ at a conventional rolling angle $\beta = 5°$ [11].

During the radial-shear rolling, the metal extrusion in the deformation zone along programmed trajectories creates the effect of volumetric macro-shear, which makes it possible to pick up the metal efficiently and squeeze throughout the volume. At the same time, the blank is squeezed in two directions and tensiled in one direction corresponding to the rolling progress in the longitudinal direction in the deformation zone during the RDR. In the transverse direction, the blank is rolled in addition to the drafting itself.

As a result, after passing the deformation zone in the rolls, the blank decreases in diameter lengthens, and also twists around its axis by a certain angle, which depends on the magnitude of the torque, blank material, and its geometric parameters. Such deformation conditions are favorable for defect-free rolling of practically any deformable materials.

Radial-shear rolling has currently found application in the recycling of pump rods in conditions of the Ocher Machine-Building Plant [12-14] and has been tested in laboratory conditions in the recycling of used railway axles [15]. We propose to use the radial-shear rolling technology to process common bar scrap of ferrous metals with producing bars with an ultrafine-grained gradient structure.

Experimental Procedure

To confirm the possibility of recycling various bar scrap of ferrous metals, a physical experiment was conducted at the SVP-08 radial-shear rolling mill, which allows deformation of blank with a circular cross-section from a diameter of 40 mm to a diameter of 8 mm. Pieces of reinforcement made of 18G2S steel grade of class A-II (A300) GOST 5781-82 with a diameter of 32 mm and a length of 250 mm were used as initial blanks, which were previously subjected to homogenizing annealing before deformation.

Deformation of the pieces of reinforcement was performed in two stages: 1st stage – rolling out of the reinforcing profile itself to obtain a common cylindrical blank; 2nd stage – rolling of the produced cylindrical blanks for producing ultrafine-grained gradient structure.

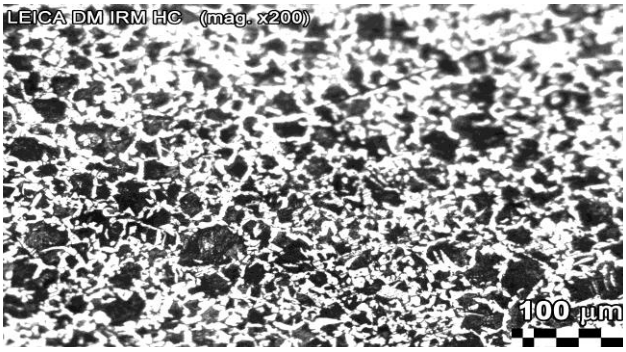
At the first stage, pieces of reinforcement with a 32 mm diameter were heated in a Nabertherm R120/1000/13 tube furnace to a temperature of 1100°C with equalizing during 32 minutes before deformation in the SVP-08 radial-shear rolling mill. After that, the deformation of these pieces of reinforcement was performed on the radial-shear rolling mill to a diameter of 28 mm in two passes with a step of absolute reduction in diameter of 2 mm according to the reverse scheme [16].

After producing blanks with a 28 mm diameter with a cross-sectional shape close to cylindrical, they were cooled at 700°C in a tube furnace Nabertherm R120/1000/13 to equalize the temperature over the blanks cross-section. At the second stage, the deformation of blanks with 28 mm diameter was also performed with a step of absolute reduction in 2 mm diameter according to a reversible scheme to 16 mm diameter in six passes.

Polished micro specimens for optical microscopy and TEM objects for studying the fine structure as well as standard samples for mechanical tests, were prepared from the initial sample (after homogenizing annealing) and after each pass. The microstructure was studied using an OLIMPUSBX53M optical microscope; the fine structure was studied using a JEM-2100 transmission electron microscope (JEOL, Japan) at an accelerating 200 kV voltage. The microstructure was investigated in the center and at the periphery of the bar section.

Mechanical properties were determined by the tensile strength test of standard cylindrical specimens on an Instron 5966 testing machine. In this case, three duplicate specimens were taken for tensile strength test for each point of the experiment (after each pass), [17, 18, 19, 20].

Analysis of the microstructure evolution showed that 18G2S grade low-alloy steel has a ferrite-pearlite structure in the initial state (after homogenizing annealing), secondary cementite is located along the grain boundaries (Fig. 1), the average grain size is 25 µm.



Picture 1 – Microstructure of 18G2S steel grade in the initial state (after homogenizing annealing)

Results and Discussion

The analysis of the microstructure after 2 preliminary deformation passes at 1100°C on the SVP-08 radial-shear rolling mill showed the recrystallization in the structure of the deformed 18G2S grade steel.

Since the deformation temperature during rolling was higher than the temperature of the steel allotropic transformation upon heating, cementite decompositions, and ferrite transition to austenite, the steel had an austenite structure upon deformation.

Austenite, on the other hand, is very plastic and mobile at high temperatures; accordingly, during rolling, the grains underwent a very significant deformation, began to stretch and turn in the direction of rolling. Besides, large grains began to disintegrate into small grains. After cooling, the blank has a ferrite-pearlite structure with 17-18 microns grain size.

Analysis of the microstructure after eight deformation passes (2 preliminaries at a deformation start temperature of 1100°C and 6 main ones at a deformation start temperature of 700°C) deformation showed that grain fragmentation was observed as a result of the formation of dislocation walls and the formation of deformation cells in the peripheral part of the 18G2S steel bar.

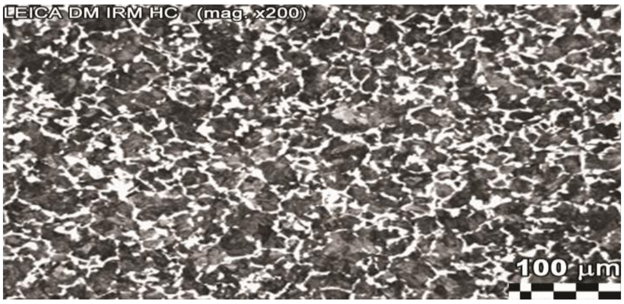


Figure 2 – Microstructure of 18G2S steel grade after 2 preliminary deformation passes at 1100°C

Despite the high dislocation density, a large number of dislocation-free subgrains were also observed (Fig. 3a). Recrystallized regions with a low dislocation density describing themselves as a sign of the development of dynamic recrystallization during deformation were also found in the microstructure.

The detected recrystallized grains are distinguished not only by the absence of dislocations in the grain body but also by the close-to-equilibrium structure of the disorientation boundaries, as evidenced by the weak streaky electron microscopic contrast at these boundaries. The structure of the central zone consisted of long and narrow grains elongated in the rolling direction with a size ranging from 1 to 2 µm (Fig. 3b).

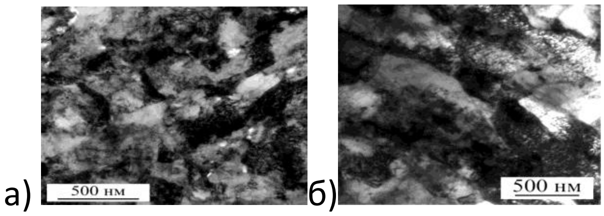


Figure 3 - Microstructure of the peripheral (a) and central (b) parts of the low-alloy 18G2S grade steel bar after 6 passes of the RSP

After analyzing the microstructure evolution, mechanical characteristics of bars made of 18G2S grade steel, produced after 8 passes (2 preliminary and 6 main) of reversible radial-shear rolling was studied. The mechanical characteristics were also determined for the initial non-deformable sample, previously subjected to homogenizing annealing.

The average static value of properties was determined and passes number-strength and plastic properties charts were constructed according to statistically processed results of mechanical tests (Fig. 4).

The results of mechanical tests have shown that the initial (averaged) values of mechanical properties are: ultimate strength is 365 MPa; relative elongation is 36%.

After all 8 passes in the radial-shear rolling mill, the mechanical properties of 18G2S grade steel change as follows: the strength properties increase, and the plastic ones fall.

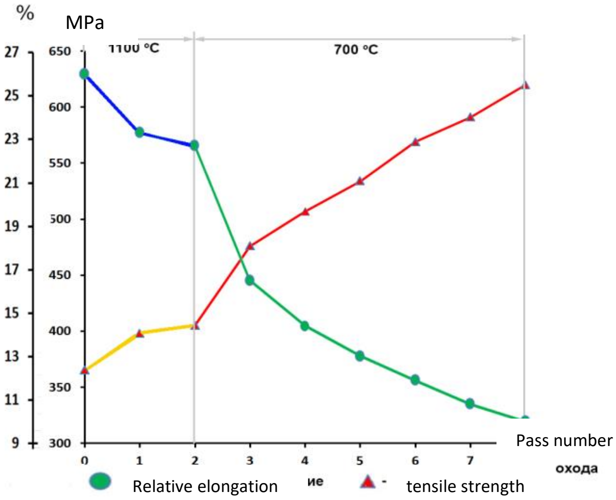


Figure 4 – Passes number-strength and plastic properties chart of 18G2S grade steel

So the value of the ultimate strength (σB) after 8 passes increased to 620 MPa, and the relative elongation, which is one of the indicators of the plastic properties of any material, decreased to 10%. At the same time, it can be seen from the charts that these changes do not occur monotonously: after the first pass of deformation, when the temperature of the beginning of deformation of the reinforcing profile was 1100°C, a sharp increase in the strength index and a drop in the value of the relative elongation were observed, while during the second pass these values did not change significantly.

After cooling the blank obtained after 2 passes at a temperature up to 700°C and the subsequent 3rd pass, we again observe the intensive change in the mechanical properties of 18G2S steel (there is a sharp increase in ultimate strength and a significant drop of relative elongation). Later (after a sharp spike in properties during the implementation of the 3rd pass), a smooth change in the mechanical characteristics of 18G2S steel is observed.

Conclusions

Thus, it may be concluded that deformation in the SVP-08 radial-shear rolling mill makes it possible to disperse significantly the structure of bar scrap, and the degree of structure refinement is the higher, the greater the degree of deformation. Thus, eight passes of deformation made it possible to reduce the average grain cross-sectional size by almost 30 times (from 25 to 0.8 µm) in comparison with the initial state.

The change in the size of the initial grain led to a significant change in the mechanical characteristics of the bars obtained after deformation in the radial-shear rolling mill.

So the tensile strength of 18G2S steel after deformation increased by almost 1.7 times to a value of 620 MPa. The relative elongation, which is one of the indicators of the plasticity of the material, decreased 2.6 times 10%, against the initial 26%. Such a decrease in the plasticity index, in this case, is within the normal range for materials after severe plastic deformation.

Conflicts of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Қара металдардың шыбық сынықтарын қайта өңдеу бойынша жаңа технологиялық шешім - радиалды-жылжымалы жұқарту (прокаттау) туралы

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ТҮЙІНДЕМЕ

Қара және түсті металдардың қалдықтарын қайта өңдеу кез-келген елдің экономикасы үшін пайдалы үдеріс болып табылады. Бұл жұмыста қара металдардың шыбық сынықтарын радиалды-жылжымалы жұқарту орнақтарында прокаттау арқылы ультра түйіршікті градиент құрылымы бар шыбықтар түрінде тауарлы өнім алынатын қайта өңдеудің жаңа технологиясы ұсынылған. Жүргізілген зерттеулер көрсеткендей, 18Г2С маркалы болаттан жасалған арматураның бөліктері түріндегі шыбықтарды радиалды-жылжымалы жұқарту орнағында деформациялау, градиентті ультра ұсақ түйіршікті құрылымды алуға мүмкіндік береді, бұл өз кезегінде болаттың осы маркасының механикалық сипаттамаларының өсуіне әкеледі. Сонымен, 18Г2С маркалы болатты радиалды жылжымалы орнағында деформациялағанда болаттың беріктік шегі 620 МПа құрады (бастапқы мәні 365 МПа).

Түйін сөздер: Қайта өңдеу (рециклинг), қара металдардың шыбық сынықтары, арматура, радиалды-жылжымалы жұқарту, микроқұрылым, механикалық қасиеттері.

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О радиально-сдвиговой прокатке как новом технологическом решении по рециклингу пруткового лома черных металлов

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АННОТАЦИЯ

Рециклинг отходов, как черных, так и цветных металлов является полезным процессом для экономики любой страны. В данной работе предложена новая технология рециклинга пруткового лома черных металлов путем его прокатки на станах радиально-сдвиговой прокатки с получением товарного продукта в виде прутков с ультрамелкозернистой градиентной структурой. Проведенные исследования показали, что деформирование пруткового лома в виде кусков арматуры из стали марки 18Г2С на стане радиально-сдвиговой прокатки позволяет существенно диспергировать его структуру с получением градиентной ультрамелкозернистой структуры, а это в свою очередь приводит к росту механических характеристик данной марки стали. Так предел прочности продеформированной на стане радиально-сдвиговой прокатки стали марки 18Г2С составил 620 МПа (при исходном значении 365 МПа).

Ключевые слова: рециклинг, прутковый лом черных металлов, арматура, радиально-сдвиговая прокатка, микроструктура, механические свойства.

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