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RECYCLING OF STAINLESS STEEL BAR SCRAP BY RADIAL-SHEAR ROLLING TO OBTAIN A GRADIENT ULTRAFINE-GRAINED STRUCTURE

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Preliminary Note – Prethodno priopćenje

The paper presents the results of the conducted experiments confirmed not only the possibility of processing bar scrap from stainless metals to produce a marketable product, but also confirmed the possibility of obtaining high-quality bars with a gradient fine-grained structure and an increased level of mechanical properties. In the course of the research conducted on deformed bar scrap in the form of pins from 12X18N9T austenitic stainless steel at the radial-shear rolling mill the microstructure of two different types was obtained: on the periphery - equiaxed ultra-fine-grained structure with a grain size of 0,4 – 0,6 µm; in the axial zone - oriented striped texture. This discrepancy in the structure of the peripheral and axial zones, together with the results of microhardness measuring across the cross section of samples with a total degree of deformation of 44,4 %, indicates the gradient nature of the formed microstructure.

Keywords: stainless steel, recycling, radial-shear rolling, microstructure, mechanical properties

INTRODUCTION

Recycling of waste, both ferrous and non-ferrous metals, is a useful process for the economy of any country. This is due, firstly, to economic aspects, since the processing and reuse of these wastes has a positive effect on the extraction of natural resources, since the need for them is reduced and there is a saving of minerals, as well as labor and economic reserves. Secondly, this is due to environmental aspects, since in most modern metal products, in addition to iron, a large number of other chemical elements are contained, which when destroyed gradually fall into the soil and groundwater, and many of these elements are toxic. Therefore, in any country, special attention is paid to the development of technologies for recycling metals and their scrap for further processing.

One of the most used methods of recycling metals and alloys is its remelting and further secondary use.

At the same time, the following categories of scrap metal can be distinguished: iron scrap; stainless metal scrap; cast iron spent elements; non-ferrous metal scrap.

In some countries of the world, another method of processing ferrous metal scrap has come into practice, namely, recycling of some metal products that have served their service life by various methods of hot forming to obtain a ready-made commercial product [1-6]. Recently, a fairly new method of processing failed metal products is gaining popularity, by deforming them in the hot state on radial-shear rolling mills [7-8]. Radial-shear rolling [9] makes it possible to obtain long products from various materials with a gradient ultrafine-grained structure [10-11]. This method is the most technologically advanced and easy to implement in comparison with many other methods of metal forming, which cause severe plastic deformations. The direction of radial-shear rolling began its development at NUST MISIS by S.P. Galkin [12] and is a screw rolling on a three-roll scheme, similar to the scheme that is used for piercing pipes in the pipe rolling industry [13].

The main difference is the increased feed angle to α = 18 – 20 ° with the usual rolling angle β = 5 °. This is what contributes to the development of the strongest vortex deformation from the surface to the center during the implementation of radial-shear rolling, and the possibility of avoiding the appearance of tensile stresses in the axial part of the workpiece. Based on the proposed scheme of radial-shear rolling, a number of rolling mills were developed and put into small-scale production at NUST MISIS, and one of these mills is the SVP-08 mill, where experimental studies were conducted, the results of which are presented in this paper.

EXPERIMENTAL PROCEDURE

The bar scrap in the form of pins with a diameter of 36 mm made of 12X18N9T austenitic stainless steel (0,12 % C, 18 % Cr, 9 % Ni, 2 % Mn, 0,8 % Ti) as material for study was selected, which were previously used as parts of metal structures at the Temirtau electrometal-

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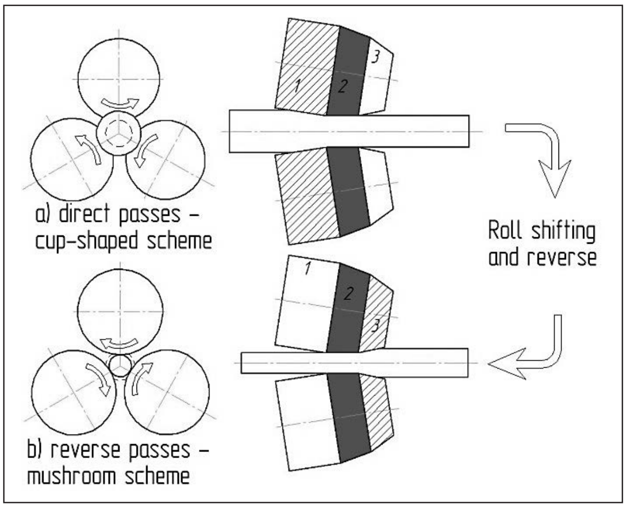

1 - compression section for direct passes;
2 - calibration section for all passes;
3 - compression section for reverse passes
Figure 1 Scheme of the reverse radial-shear rolling

lurgical plant, and after the end of their service life were melted down at the same enterprise. Austenitic steel is a special type of stainless steel that is widely used in various industries due to its properties: heat resistance, cold resistance, corrosion and electrochemical resistance. Therefore, this material is widely in demand in the following areas of the national economy: construction; pulp and paper production; food industry; transport engineering (including space and aircraft construction); chemical industry; electric power and electronics, etc. The melting technology of this steel and further manufacturing various metal products and parts of metal structures from it is quite expensive. That is why it is offered to use the technology of radial-shear rolling for processing scrap metal, which is included in the category of "stainless metal scrap" in order to obtain a high-quality commercial product in the form of round cross-section bars.

To conduct the experiment, samples with a diameter of 36 mm and a length of 200 mm were prepared from this steel grade by sawing the available pins. Prior to deformation, the obtained samples were subjected to homogenizing annealing.

Before deformation at SVP-08 radial-shear rolling mill, the bars were heated in a Nabertherm R120/1000/13 tube furnace to a temperature of 850 ºC with an exposure time of 36 minutes. Rolling a bar with a diameter of 36 mm was carried out on a radial-shear rolling mill up to a diameter of 20 mm in four passes with an absolute compression 4 mm per step according to the scheme proposed in [14] and presented in Figure 1.

After each pass, i.e. from the initial sample with a diameter of 36 mm and rolled to diameters of 32, 28, 24 and 20 mm, the cylinders with a length of 30 mm were cut out, which were subsequently used for preparing micro-grinding and cutting samples for mechanical testing. The first batch of cylinders was cut on a high-precision cutting machine Struers AccuTom-5 lengthwise. The first half of the samples (central sections), were used to prepare transmission electronic microscopy (TEM) objects for fine structure research. The samples were prepared by electrolytic method in the following solution: 600 ml Methanol, 360 ml Butylcellosolve, 60 ml Perchloric Acid. Remaining second half was used for microhardness measurement on the cross section of the rod. From the second batch of cylinders, samples for mechanical testing were cut along the bar using a high-precision Struers AccuTom-5 cutting machine in the form of 30 x 3 x 0,3 mm strips. The microstructure was studied using a Transmission electron microscope (TEM) JEM-2100 at an accelerating voltage of 200 kV. The microstructure was studied in the center and on the periphery of the bar section. The mechanical properties were determined by a tear test of flat samples on an Instron 5966 testing machine. The test was performed at a tensile speed of 0,5 mm/min. Microhardness measurements were performed on a hardware complex based on Leica DFC290 inverted microscope, equipped with a microhardness meter. At the same time, three duplicate samples were taken after each pass for the tensile test and microhardness determination.

RESULTS AND DISCUSSION

The analysis of the microstructure of the obtained bars with a diameter of 20 mm showed that ultrafine-grained microstructure with equiaxed grains and a size in the range of 0,4 - 0,6 microns was obtained in the peripheral part of the bar (Figure 2a).

In the structure of the sample, it can be seen structural elements surrounded by both thin boundaries characteristic of the grain structure and wide non-equilibrium boundaries more inherent in the subgrain (cellular) structure. As well as areas that are practically free of dislocations and areas with increased dislocation density. Electronograms has separate reflexes, arranged circumferentially and having an azimuthal blur. Therefore, the structure can be characterized as an equiaxed grain-subgrain.

The structure of the central zone consisted of long and narrow grains stretched in the direction of rolling with a size lying in the range of 3 - 4 microns (Figure 2b). The grains contain some very thin deformation twins, the proportion of which does not exceed 6 %.

After metallographic analysis, the microhardness and mechanical properties of 12X18N9T austenitic stainless steel bars obtained after each pass of radial shear rolling, as well as the initial non-deformable sample, were studied.

The results of mechanical tests showed that the initial (average) values of mechanical properties were: tensile strength 525 MPa; elongation 38 %; microhardness 180 HV. After all passes (the total degree of deformation of 44,4 %), the average microhardness level for 12X18H9T steel increased to 341 HV (with a maximum value of 359 HV). At the same time, there is an almost smooth growth of this indicator from pass to pass. The mechanical properties of 12X18N9T steel also change

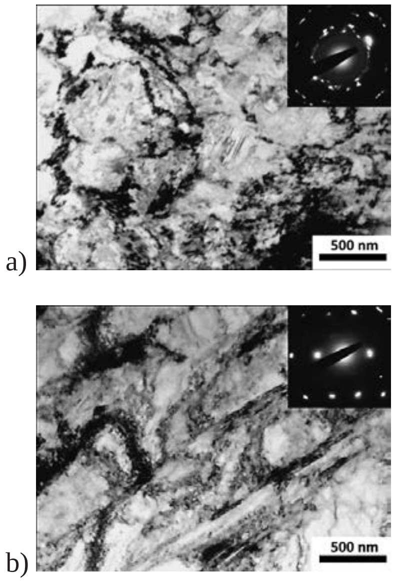

Figure 2 Microstructure of the peripheral (a) and axial (b) zones of 12X18N9T steel after radial-shear rolling

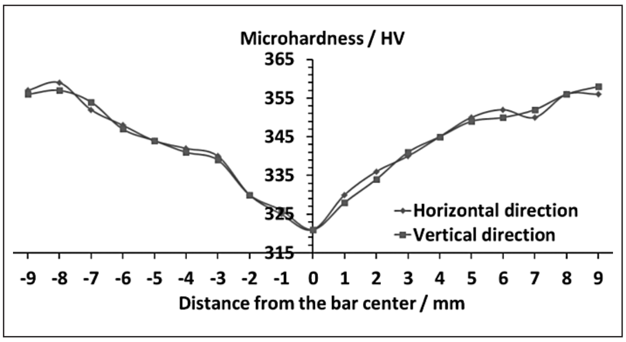

Figure 3 Microhardness (HV) of 12X18H9T austenitic stainless steel after radial-shear rolling

monotonously depending on the number of passes, with only one difference: strength properties increase, and plastic properties fall. So the value of the tensile strength after 4 passes increased to a value of 1 092 MPa, and the elongation, which characterizes the material plasticity, decreased to a value of 15 %.

In order to further confirm the presence of structural heterogeneity in stainless austenitic steel subjected to deformation on a radial-shear rolling mill, microhardness was measured along the cross section of a bar rolled up to a diameter of 20 mm. Microhardness measurements were recorded at every millimeter of the cross section. The results of the microhardness measurement are shown in Figure 3. The distribution graph shows that the results of metallographic studies on structural heterogeneity in the cross section of a 12X18N9T stainless austenitic steel bar subjected to radial-shear rolling are confirmed, since there is a smooth decrease in the microhardness level in the central zone of the bar by an average of 10,3 %.

CONCLUSIONS

As it is known, one of the most common ways to improve the strength properties of metals and alloys is to grind its microstructure to an ultrafine-grained state, but at the same time there is an inevitable decrease in the plastic properties of these materials and it becomes brittle and susceptible to destruction during tension. From a number of works, including [15 - 16], it is known that to solve this problem, namely, to increase the plasticity of metal products in general, it is possible by using metal materials with a gradient structure in which the grain size from the coarse-grained state in the central part of the workpiece decreases to the ultrafine-grained state on the surface. The results of the conducted experiments confirmed not only the possibility of processing bar scrap from stainless metals to produce a marketable product, but also confirmed the possibility of obtaining high-quality bars with a gradient fine-grained structure and an increased level of mechanical properties. In the course of the research conducted on deformed bar scrap in the form of pins from 12X18N9T austenitic stainless steel at the radial-shear rolling mill the microstructure of two different types was obtained: on the periphery - equiaxed ultrafine-grained structure with a grain size of 0,4 - 0,6 μm; in the axial zone - oriented striped texture. This discrepancy in the structure of the peripheral and axial zones, together with the results of microhardness measuring across the cross section of samples with a total degree of deformation of 44,4 %, indicates the gradient nature of the formed microstructure. Obtained after the implementation of the proposed method of recycling metal products made of stainless asthenitic steel, which have served their service life, can now find further application in the manufacture of parts for responsible purposes, including those working in aggressive environments.

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