EFFECT OF CROSS ROLLING ON THE MICROSTRUCTURE OF STEEL

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Abstract

One way of plastic processing, which can produce long products with significant changes of the microstructure is the cross rolling. However, deformation and motion path of the metal is very heterogeneous across the section of the rolled piece. This paper presents the finite element modeling of hot cross rolling of steel in the software package DEFORM-3D features implemented and studied the stress-strain state. An experimental study of the effect of the cross rolling on a three-roll mill on the microstructure of structural alloy steel and stainless steel AISI321 in different zones of the bar. Analysis of microsections made after rolling with high total stretch and the final pass temperature 700^{o}C, shows the formation of equiaxial ultrafinegrain structure on the periphery of an elongated rod and streaky "rolling" texture in the central zone. The resulting microstructure corresponds to that obtained in models of stress-strain state.

Keywords: cross rolling, ultra-fine grain structure, steel

1. INTRODUCTION

Most of metal product making industrial processes are oriented to manufacturability of metal deformation, and mechanical properties are obtained by means of using appropriate steel grades. Generally, after traditional plastic processing metal products have granulated structure. In the meantime, it is known that ultra-fine grain metals and alloys with grain size of about 1 micron and special condition of edges can significantly (2-3 times) increase durability of pure metals and 1,5-2 times increase durability of alloys along with quite high plasticity [1-2].

Of all kinds of severe plastic deformation which are used to receive long products with significant changes in microstructure and mechanical properties there is one that should be noted – cross rolling, particularly one of its kinds which is defined by its authors as a separate way called radial-displacement rolling (RSP) [3-4]. Its difference from cross rolling [5] used, for example, in pipe piercing is that there is rolling of solid bar using three-high mill arrangement with large feed angles [4]. However, in order to avoid confusion, later the more common name – cross rolling – will be used.

2. PECULIARITIES OF CROSS ROLLING AND EQUIPMENT USED FOR IT

In process of cross rolling stressed state close to triaxial compression with big shear deformations appears in the deformation zone.

Main peculiarity of cross rolling is nonmonotonicity and turbulency of deformation; there are also differences in plastic flow and structure elaboration of different bar zones due to trajectory speed features of the process. Because of this features of metal flow the most intensive shear deformations are concentrated in the metal flow lines crossing zone – the cross-section circle common for triaxial scheme, which is confirmed by the model. In the outer layer every small trajectory-oriented element is exposed to compression in direction of bar radius, compression in direction of metal flow (along cross rolling trajectory) and, accordingly, tensile strain across the cross rolling trajectory. It is important that there is constant radial gradient of velocity and flow direction which adds more shearing elements into overall complex strain-stress state. Metal structure composition elements exposed to dilatable flow with double-sided sinking strain (along the trajectory and along radius) obtain the form of isotropic insulated high dispersion particles [3].

Speed of particles in axial grain and its length increases proportionately with elongation ratio in the same way as in longitudinal rolling. Cross section of central flow tubes decreases. Metal structure elaboration works in a way similar to longitudinal rolling in multisided grooves or compression. Structural composition elements become longer and thinner, obtaining distinctive structural streaky [4]. These peculiarities are described and illustrated in details in the works of S. P. Galkin [3-4, 6].

Based on the works named above, cross rolling mills using intensive plastic deformation of solid round bar rolling were created in Moscow Institute of Steel and Alloys. These mills include RSP "10-30" mill [6] delivered to Karaganda State Industrial University. The exterior view of the mill is shown at the Figure 1.

Fig. 1 RSP "10-30" mill

RSP "10-30" mill is designed for hot deformation of solid round bars of practically any materials, including low-ductile, continuously cast and powder-metallurgical. Rolling of bars with 10-25 mm diameter is done in three-high mill of special rigid structure from 15-30 mm billets by means of their diametrical pressing in one or several passes using special calibrated rolls and, if necessary, with intermediate heating. Rolls diameter is 56 mm, elongation ratio reaches up to 1,1-5,0; mill capacity is 0,1-0,3 tons per hour; main drives power is 3×5,5 kW [6].

This mill was selected for running experiments on looking into impact of cross rolling on steel microstructure because it provides wide range of sizes, rigid structure of the stand and is convenient to use.

3. FINITE-ELEMENT MODELING OF CROSS ROLLING

In order to look into the scheme of strain-stress state implemented by RSP "10-30" mill finite-element modeling of steel bar rolling from 25 mm to 15 mm diameter in several passes was done using DEFORM-3D software complex (SFTC company, USA). The material of the bar was chosen AISI-5140 steel (equivalent of 40X grade) as one of the most common alloyed construction steel grades worldwide. Rolling temperature was 800^{o}C as corresponding to low limit of rolling temperature for steel grades of this class. The result of last pass modeling are shown at the Figure 2.

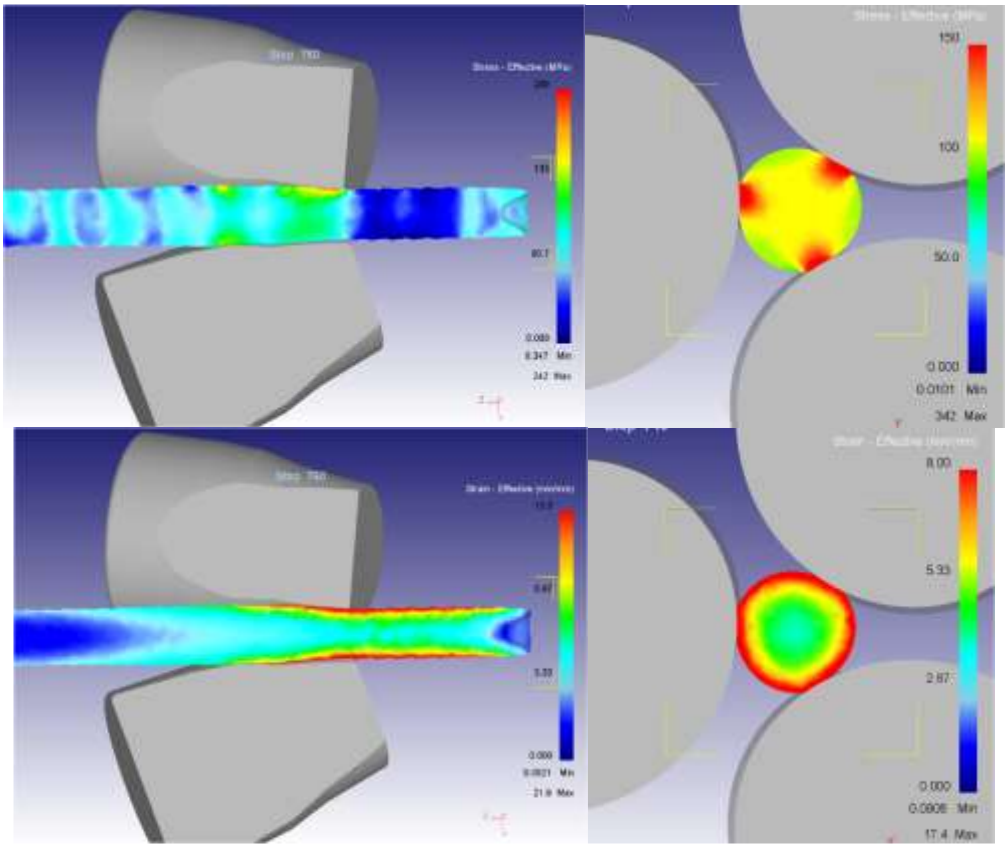


Fig. 2 Strain-stress state of deformation zone at the last pass

At the cutaway section have lamination of strain distribution at the billet cross section can be seen. In this case degree of cumulative deformation in outer areas of the bar after the first pass (at the Fig. 2 – before deformation zone) reaches 3-4, after the second pass 6-8, which, according to R. Z. Valiyev [1], should facilitate obtaining fine-grain structure in bar periphery after just two or three passes.

Strain-stress state received at models corresponds to theoretical outline given above, is appropriate for intensive structure refinement and complies well with data given in works [6-7] on cross rolling modeling.

4. EXPERIMENTAL PART

After receiving modeling results in a similar way the experiment was implemented on RSP "10-30" mill for the purpose of looking into steel microstructure changes. Two experiments have been done with two different steel grades. For the first experiment alloyed construction steel of GOST 40X grade (analog of AISI-5140) was used. For the second one stainless heat-resistant steel of austenitic class AISI-321 grade was used. Experiment conditions were slightly different.

4.1 Rolling of 40X steel

For the first experiment a bar with 25 mm initial diameter was used. Chemical content of 40X steel - 0,36-0,44 % C; 0,8-1,1% Cr; 0,5-0,8 % Mn. This steel is widely used in mechanical engineering for making high durability parts (shaft axles, spindles, gear wheels). At RSP "10-30" rolling mill two consequent deformations during one heating were done – from 25 mm to 20 mm at 900 ^{O}C and from 20 mm to 15 mm at 700 ^{O}C with intensive water cooling of the bar. Similar temperature setting was used in works [7-8] for receiving ultra-fine grain structure of alloyed steel.

4.2 Rolling of AISI-321 steel

For the first experiment a bar with 30 mm initial diameter was used. Chemical content of AISI-321 steel - 0,08 % C; 17-19 % Cr; 9-11 % Ni; 2 % Mn; 0,8 % Si; 0,5-0,7 % Ti. Equivalent of this steel is 08X18H10T grade. It is used for making equipment working in extremely aggressive environment (heat-exchanging units, pipes, parts of furnace and reactor carcass, electrodes of spark ignition plugs).

Rolling temperature was chosen to be constant and equal to 700 ºC. In several passes the billet was rolled from 30 mm to 15 mm with intensive water cooling of the bar. Similar temperature setting was used in work [10] for receiving ultra-fine grain structure of stainless steel. After the rolling some slices were cut off the bar longways which were used to make samples for looking into the structure using transmission electron microscope.

5. RESULTS AND ITS DISCUSSION

5.1 40X steel

Because of cross rolling metal flow peculiarities samples for the research were cut only longways. From these samples longitudinal micro-sections were made, which were analyzed using Quanta 200i 3D scanning election microscope (FEI Company, USA). Photographs of distinctive microstructure views in the centre and edges of the bar are shown at the Figure 3.

Original structure in regular shipping state has typical for these kind of steel grades large grain ferrite-pearlite type with grain size 40-60 micron and microhardness 150-160 HV. Microhardness of the bar after the rolling was measured at FM-800 microhardness tester (FUTURE-TECH CORP., Japan) aid was on average 428-432 HV at the edge and 400 HV in the centre of the bar.

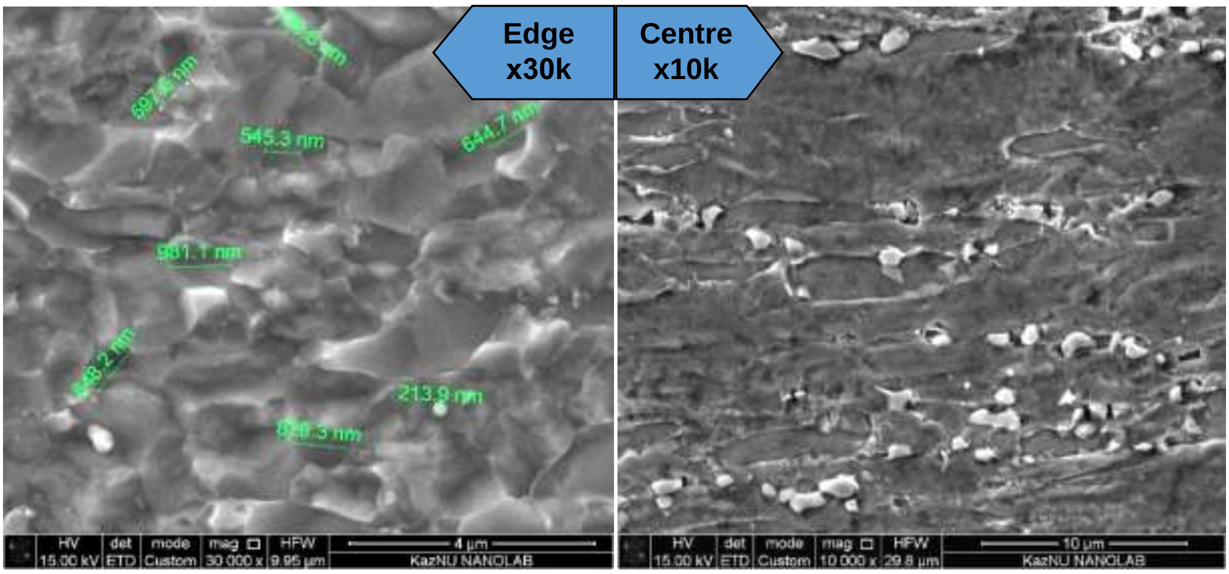


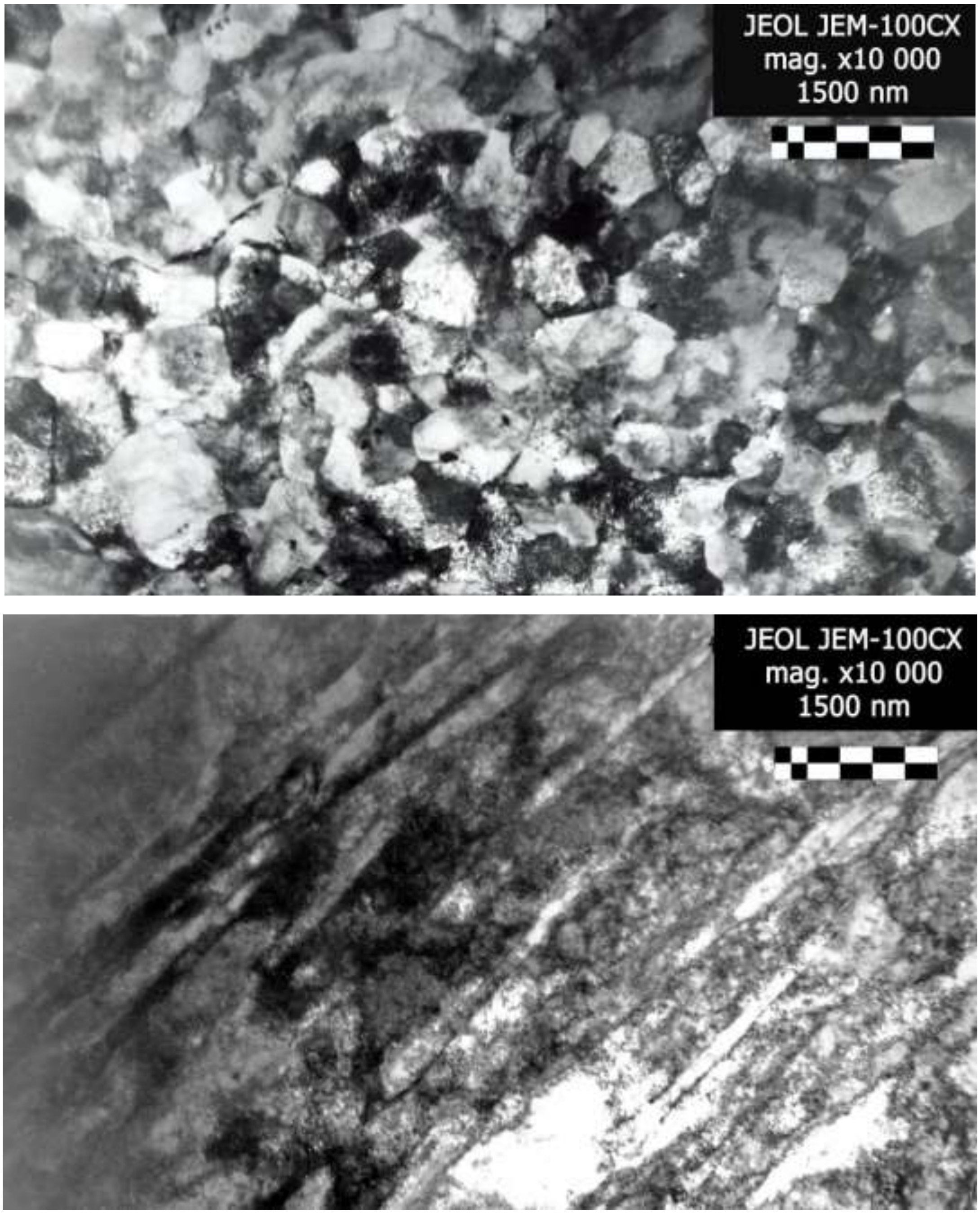
Fig. 3 40X steel grade microstructure after cross rolling

At the Fugure 3 on the left and right there is structure of (accordingly) peripheral and central parts of the bar after after cross rolling from 25 to 15 mm diameter. Microstructure of peripheral area has mostly equiaxial subultrafinegrain view with grain size about 5 micron. Central area of the bar has distinctive streaky (like a ordinary «rolling») texture of long narrow grains stretched along the rolling direction with size of 5-10 x 0.9-1.5 micron and chains of chromium carbide crystals (white phase). Chromium carbide was identified by means of energy-dispersive analysis (EDX). The size of separate chromium carbide crystals is 200 nm or smaller.

This way, after deformation with total stretching of 2.8 on reaching cumulative deformation of 6-8 in appropriate stressed state ultrafinegrain microstructure providing 2.7 times hardness increasing was obtained.

5.2 AISI-321 steel

The samples were analyzed at transmission electron microscope JEM-100CX (JEOL, Japan) at 100 kV accelerating voltage. Photographs of distinctive microstructure views in the centre and edges of the bar are shown at the Figure 4.



A) B)

Fig. 4 Microstructure of peripheral (A) and axial (B) parts of the AISI-321 steel bar after cross rolling

Original structure in regular shipping state has grain size about 40-60 micron. After deformation with total stretching of 4 on reaching cumulative deformation of (approximately) 11-13 in appropriate stressed state ultrafinegrain microstructure in the peripheral part of the bar with grain size 600-900 nm was used, which correlates with results of previous experiment. It also should be noted that comparing to the previous experiment peripheral area structure is significantly less anisomerous and has more equiaxial view. Central area structure includes long narrow grains stretched along the rolling direction similar to the first experiment.

CONCLUSION

This way, by means on cross rolling with total stretching of 2.8 and 4 for two steel grades microstructure of two different kinds was received. In the peripheral area there is more or less equiaxial ultrafinegrain structure, and in the central bar area there is longways oriented streaky texture. Peripheral area grain size was 600-900 nm for both materials. At this time, AISI-321 steel microstructure which had higher deformation was less anisomerous.

Received microstructure correlates well with research data [7-10]. Receiving of this structure by means of one of the most common ways of severe plastic deformation – equal channel angular pressing requires not fewer than 6-8 pressing cycles [1-2, 10] and is available only for small length billets, meanwhile at the cross rolling mill it can be obtained for 3-4 passes for billets of any length. The problem is inhomogeneity of structure in central and peripheral areas of the bar.

Further improvement of cross rolling ways with purpose of receiving more homogeneous structure in bar cross section will provide an opportunity to get large amounts of ultrafinegrain materials with the least time and energy consumption, which will make commercial efficiency and cheapening of UFG materials production available.

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