MODELING OF THE SKIN-PASS ROLLING PROCESS AND STUDYING THE FORMATION OF PROPERTIES USING HIGH-CARBON HOT ROLLED PICKLED STEEL NARROW STRIPS AS AN EXAMPLE

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ABSTRACT

Specialists of PJSC Magnitogorsk Iron & Steel Works in cooperation with Nosov Magnitogorsk State Technical University scientists have developed a technology for the production of hot-rolled pickled steel strip with an “additional” quality level using high-carbon steel as an example in order to expand the range of sizes of hot-rolled metal products. This process is characterized by a unique combination of heat treatment and tempering operations at the finishing stages of the strip production. The article presents the results of studying the influence of finishing processing operations, in particular rolling with small reductions, on the formation of the final properties of the strip.

Keywords: cold-rolled mill products, hot-rolled strip, heat treatment, skin-pass rolling, mechanical properties, multi-scale modeling.

INTRODUCTION

At present, in the market there is a demand for steel products with a controlled level of a set of consumer properties, including norms for surface roughness, mechanical properties and geometry. In view of this, the object under study is hot rolled strips, including pickled, skin-passed strips with high accuracy of manufacturing, as well as a lower level of surface defects. Such strips may be commercial steel products as an option to cold rolled products. Applications of such strips include production divisions using cold stamping and blanking of car components [1 - 3].

Available experience in learning how to produce hot rolled pickled narrow strips as commercial products revealed some problems with ensuring a controlled level of surface roughness and achieved values of geometric accuracy. The limited options of the technological effect on the parameters at the pickling stage are the reason [4 - 5].

One of the current trends in rolling is development and application of improved technological solutions to create an innovative product range of hot rolled narrow strips. It is proposed to use a multi-stage processing at the finishing stage combining heat treatment and skin-pass rolling. The quality level of narrow strips should be formed similar to a regulated standardized quality level of the cold rolled products. Subcritical annealing contributes to the formation of an equilibrium, uniform structure, further skin-pass rolling – the formation of high accuracy of thickness, better flatness, elimination of the yield plateau, formation of controlled surface cleanliness and roughness [6 - 8].

Therefore, one of currently important tasks of performed research is study on the formation of an additional level of quality of steel hot rolled skin-passed narrow strips at finishing stages.

There are many available studies on a skin-pass rolling process in its conventional application, i.e. when manufacturing cold rolled or cold rolled annealed steel products with accumulated strain [9 - 10]. Meanwhile, the effect of skin-pass rolling on the formation of properties of hot rolled products is under study. The paper presents the findings on high-alloy steel grade 65G as one of the most representative steel grades in terms of complex microstructural components and their mechanical properties, influencing the formation of final performance properties, when manufacturing products for the automotive industry. In view of the above, we developed
an innovative manufacturing technology of hot rolled pickled, skin-passed narrow strips, which can be used at the production facilities of PJSC Magnitogorsk Iron and Steel Works.

**EXPERIMENTAL**

When carrying out the investigations, the NMSTU researchers developed and implemented at PJSC MMK a new process flow chart (Fig. 1) of hot rolled pickled steel narrow strips with a thickness of 4.0 mm from steel grade 65G. Its chemical composition is given in Table 1. The cold rolling stage was excluded and subcritical annealing at a final soaking temperature of 670°C and skin-pass rolling were proposed as finishing operation [11]. Narrow strips are used for further manufacturing of clutch discs requiring significant durability and wear resistance.

A metallographic analysis was performed using Axio Observer optical microscope with the magnification range of 200 to 1000x and Thixomet PRO image analyzer. When magnifying over 1000x, the microstructure was analyzed using JSM 6490 LV scanning electron microscope in secondary electrons. The samples of original hot rolled pickled annealed steel grade 65G have a ferrite-cementite structure - 68 % cementite, 32 % ferrite, (Fig. 2).

Microhardness was determined with Buchler Mikromet hardness testing machine by pressing a diamond pyramid with an angle of 136° between opposite faces under GOST 9450-60 at load of 200 g and loading time of 10 s. Microhardness was tested on original annealed samples at 600°C, 640°C, 670°C and 700°C and on skin-passed at the same threshold maximum reduction degree of 2.5 %.

To study the influence of deformation parameters of steel treatment processes and consider relevant changes in its microstructure, we used a computer modeling technique using Abaqus software. The formation of properties was tested at Nanosteels Research Institute at NMSTU.

The nature of the multiscale computer modeling is a pair interaction of a conventional macromodel of isotropic medium and a representative volume element. A macromodel promptly shows a distribution of studied parameters of the stress and strain state along a total volume of a deformed body at a macrolevel, and

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**Table 1. Chemical composition of steel grade 65G.**

<table>
<thead>
<tr>
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<th>wt. %, not more or within the range</th>
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<tbody>
<tr>
<td>C</td>
<td>0.49-0.55</td>
</tr>
<tr>
<td>Si</td>
<td>0.17-0.37</td>
</tr>
<tr>
<td>Mn</td>
<td>0.60-0.90</td>
</tr>
<tr>
<td>S</td>
<td>0.010</td>
</tr>
<tr>
<td>P</td>
<td>0.020</td>
</tr>
<tr>
<td>Cr</td>
<td>0.95-1.20</td>
</tr>
<tr>
<td>Ni</td>
<td>0.20</td>
</tr>
<tr>
<td>Cu</td>
<td>0.20</td>
</tr>
<tr>
<td>N</td>
<td>0.008</td>
</tr>
<tr>
<td>Al</td>
<td>0.025-0.045</td>
</tr>
<tr>
<td>V</td>
<td>0.15-0.20</td>
</tr>
</tbody>
</table>

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a micromodel is used to analyze behavior of a point representative volume under such macroload (Fig. 3).

The macromodel is built according to a conventional method of creating a metal forming process model with isotropic deformed material. Therefore, we describe only the micromodel built in Abaqus. As for the prepared representative volume (Fig. 4a), similar microstructural components (ferrite and cementite) were combined into relevant groups building a set of finite elements of the grid to form their properties (Fig. 4b).

RESULTS AND DISCUSSION

When studying how microhardness is distributed from the strip surface to its center, it turned out that when varying annealing temperature and at the same maximum deformation degree of 2.5 %, the nature of microhardness distribution along the sample section is rather steady. Quantitatively, skin-pass rolling reduces microhardness of strip annealed at 670°C approximately by 300 units to the maximum extent.

As a result of modeling the process of skin-pass rolling of hot rolled pickled annealed narrow strips, we got distributions of axial longitudinal deformations and transverse stress (Fig. 5) and results of calculations of the von Mises stress in pearlite colonies (Fig. 6).

As a result of modeling the skin-pass rolling process, we determined the transformation of microstructural components, consisting in a rotation of pearlite colonies along the deformation axis of narrow strips from high-carbon steel 65G. This feature contributes to maintaining the resource of metal ductility, entailing a reduction of energy consumption in further processing of materials.
into finished products.

For visual clarity of studies performed, we marked for reference vectors of pearlite colonies in the electronic pictures of the microstructure of annealed steel 65G before and after skin-pass rolling (Fig. 7).

A visual analysis of the microstructure of 65G steel narrow strips before and after skin-pass rolling using computer graphics tools also confirms the model results, i.e. there is a clear change in the orientation of pearlite colonies along the deformation axis.

CONCLUSIONS

Thus, by modeling the skin-pass rolling of hot rolled annealed narrow strips from high-carbon steel 65G, we got a rationale for controlling the finished properties. By keeping constant size parameters of the microstructure (an interlamellar distance) after skin-pass rolling, we form a favorable orientation of pearlite colonies maintaining the value of ductility of narrow strips. Taking everything into account, at subsequent processing stages,
in particular when stamping components from narrow strips, defects are minimized due to a reduced number of stress concentrators.

Besides, the studies performed contribute to learning resource-saving production technology of hot-rolled pickled skin-passed narrow strips excluding a cold rolling stage.

REFERENCES