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INFLUENCE OF ROLLING MODES ON THE ANISOTROPY OF SHEET METALS FROM CARBON STEEL ROLLED ON THE LONGITUDINAL WEDGE MILL (LWM) OF A NEW DESIGN

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The longitudinal wedge mill (LWM) of a new design is proposed in this article. By using the MSC.SuperForge software product which designed for the stress-strained state of the billet when rolling strips from steel S235JR on the LWM. The STD 812 plastometer analyzed the influence of temperature-deformation processing modes on the microstructure of S235JR steel which rolled on LWM, the conditions for the formation of a fine-grained structure were noted. The rational modes of hot and cold rolling and their effect on the anisotropy of sheet metals from steel S235JR have been defined. It was proved in our work that compared with cold rolling, during hot rolling of sheet billets in the sheet plane it does not appear the significant anisotropy of mechanical properties.

Keywords: steel S235JR, LWM, sheet, stress-strained state, temperature-deformation processing.

INTRODUCTION

Anisotropic metal made by hot or cold rolling and subjected to subsequent annealing and tempering is mainly used in cold stamping [1].

Researchers conducted in the works [2,3] have shown that the anisotropy of materials have mainly bad influence on the process of cold extract. It was noted in these works that to prevent the occurrence of goffers when extracting without clamping, in is necessary to increase the thickness of the anisotropic sheet billet in 1,6-2 times, compared with the isotropic material.

At work [4] it was noted that the anisotropy of sheet metal is found by stretching of special samples cut at an angle φ relative to the direction of rolling, i.e. at an angle of 0 °, 45 ° and 90 ° relative to the direction of rolling. Herewith, in order to determine accurately the anisotropy of the mechanical properties of the strips, the anisotropy coefficient is calculated using the formula $R\varphi = \varepsilon b / \varepsilon z$ (where, εb is the logarithmic deformation in the transverse direction; εz is the logarithmic deformation in a high-rise.

The authors of works [5, 6] came to conclusion that deformational anisotropy affects into the hardness of a given metal. Moreover, at each stage of metal deformation, physical value of hardness has the same value as the physics of the metal strength R_e and R_m when stretching. In these works, it is noted that when rolling sheet metals, the value of hardness varies depending on the direction of fibers.

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MATERIALS AND EXPERIMENT METHODS

For rolling sheets of steel and alloys, we proposed a multifunctional longitudinal wedge mill (LWM) of a new design [7]. Two of supporting rolls are installed at the first three stands of this mill, and four of supporting rolls at the last two stands. At this, the working rolls in each stand have a constant diameter, and in sequentially located stands the rolls diameter decreases in the direction of rolling. Rotation of working rolls is carried out through the bearing stands by five gear motors with an angular velocity $\omega = \upsilon \cdot R$ (where υ is the rolling speed in each mill stand; R is the radius of working rolls in each mill stand).

Stress-strained state (SST) was calculated using the MSC.Super Forge program. A three-dimensional geometric model of the billet and rolls was built on the Inventor CAD program and imported into the CAE program MSC.SuperForge. While creating the finite element model of the billet and rolls, the three-dimensional volumetric element CTETRA was used, which is used for modeling of three-dimensional bodies. The process calculation time was 30 - 40 minutes on a Pentium Duo computer with a clock frequency of 3,4 GHz and 2 GB of RAM.

For the calculation, rectangular samples of St3sp steel in cross section with size 5 × 20 × 50 mm were used – Table 1.

It launched the program “MSC.SuperForge” and estimated by step-by-step method the components of the strain and stress tensor and the temperature distribution over the billet volume.

To discover the effect of deformation and subsequent water cooling degree on the structure of S235JR steel,

Table 1 **Chemical composition / wt.%**

	Chemical composition / mas.%										
	C	Mn	Si	P	S	Ni	Cr	N	Cu	As	Fe
S235JR	0,18	0,55	0,24	0,04	0,05	0,3	0,25	0,007	0,25	0,07	bal.

samples of size Ø 10,0 × 15,0 mm were tested by compressing them on STD 812 plastometer [8]. This plastometer allows to test samples at high temperature- speed deformation modes. At the process of testing, continuous or fractional compression / tension or torsion with a given degree and strain rate at each pass is realized.

Tests were carried out in vacuum and at a constant strain rate and temperature. Cylindrical samples were used for the experiments, and the thermocouple of K (NiCr-Ni) type was used to measure and control temperature changes. Thermocouple of K type was welded onto the side surface of the samples. Samples in an induction heater were heated up to temperatures of 800, 900, and 1 000 °C at a constant speed of 5 °C / s, withstanded at this temperature for 10 s, and were deformed by cyclic compression at LWM rolling speeds. When making a plan of experiment, the time of the inter-deformation pause was determined on the basis of the second volumes constancy law when rolling strips in a LWM. In the intervals of cyclic deformation, after turning off the unit's electric drive, the sample remained clamped by the strikers and the active loading was replaced by the relaxation phase. After the test, the samples were removed from the container and, in accordance with the plan of experiment, were cooled in air and in water and by natural way up to room temperature.

Sections for metallographic research were prepared according to the traditional technique on grinding and polishing wheels.

Metallographic analysis was performed by using the universal microscope NEOPHOT 32 (Karl Zeiss, Jena) (Germany). The microscope Neophot 32 is intended for metallographic microscopy and for the creation of photographs. Observation can be carried out by the method of light and dark field, in polarized light, with a change in the magnification rate. Magnification of microscope, rate: from 10 to 2 000. The microscope is equipped with digital SLR camera Olimpus with output of the received image and saving images to computer.

The nature of the anisotropy of the mechanical properties of hot-rolled and cold-rolled strips was searched at this work. As the research material, we used samples of S235JR carbon steel rolled on LWM in cold and hot conditions from thickness of 8 mm to thickness of 1,5 mm.

Flat samples oriented at an angle of 0 ° 45 ° and 90 ° relative to the direction of rolling were cut from hot-rolled and cold-rolled strips rolled on a new mill for tensile testing. The samples had a width of 30 mm and a length of the working part of 240 mm. Before testing, the samples were degreased by using a water-alkaline solution and alcohol. For each orientation relative to the rolling direction, 3 tests were conducted according to GOST 1497–84. Stretching of samples was held on a "2161 P-5" stretching machine; the strain rate during testing was 0,00125 s^{-1}.

At this work, the anisotropy of the strips was also investigated by determining the mechanical properties on automated installation MV-01m. The automated installation MV-01m allows to carry out mechanical tests on constructed microsections and promptly evaluate the strength and plasticity characteristics without constructing samples for stretching [9].

Using the method described in work [9], the mechanical properties of St3sp carbon steel were determined on an MV-01m device in the following way. The measuring head was installed in the lower position. A microsection was installed on the lifting table and, by rotating the table; it was pressed down to the indentation head until the pyramid touched the surface of the microsection. The load indicator was set to zero. Then, using the PC keyboard, we entered into the catalogue "ISPYTAN DAT" and launched the program for reading and writing the results of «P - *t*» array registering.

It should be noted that the imprints were applied to the samples on the MV-01m device in three rays, the directions of which are oriented at an angle α = 0 °, 30 °, and 45 ° to the longitudinal axis of the sample, which coincides with the rolling sheet axis.

RESULTS AND DISCUSSION

VAT calculation and analysis shows that:

1 When rolling in the first LWM stand, the strain and stress intensity are localized in the zones of metal capture by rolls;

2 With an increase in reduction, the values of strain and stress intensity increase in the center and along the edges of the deformable billet;

3 Continuous rolling of the billet in the subsequent stands of LWM allows gradually transfer the areas of concentrated deformation from the center to the middle part of strip, and then into the rolls contact zone with the rolled billet;

4 The gradual transfer of areas with deformation localization from the center to surface leads to a more uniform distribution of the accumulated deformation;

5 The most uniform distribution of accumulated deformation along the height and length of rolled strip was obtained during rolling with a single reduction at the first stand 20 %, at the second stand 20 %, at the third stand 20 %, at the fourth stand 15 %; at the fifth stand, 10 %;

6 The temperature in the zones of contact "hot metal - rolls" decreases during the rolling process at the first stand

Analyzing the structure of S235JR steel samples, rolled at a temperature of 800, 900 and 1 000 ° C according to the above given rational rolling modes on LWM, but with different cooling conditions, we came to conclusion that the most rational is the rolling at a temperature of 900 ° C and cooling after deformation in the air and in the water in time of 8 and 4 s, respectively. This structure has thin-platy perlite with an interlamellar distance n = 0,22 – 0,32 μm and a colony size of 24 - 32 μm. In the process of such deformation, ferrite with sizes of 21 – 35 μm and excess cementite of 1 – 2 points are formed. Besides, the structure contains relatively long grains. These grains are divided into subgrains, which indicate the passing of dynamic and static recrystallization during processing according to rational deformation modes and interdeformation pause. It should be noted that the proportion of long grains is much smaller than the equiaxed ones.

On the basis of the obtained data, we have developed and tested a rational technology of strips rolling on the LWM.

According to this technology, rolling of strips at a temperature of 20 and 900 °C was carried out with the following reduction: first, second and third stand 20 %, fourth stand 15 % and fifth stand 10 %. Further, the hot-rolled strip was cooled in the air and in the water in time of 8 and 4 s, respectively. After rolling, samples were cut from the obtained strips according to the method described above.

By testing flat samples oriented at an angle of 0 ° 45 ° and 90 ° relative to the rolling direction, it was determined that there is almost no plastic deformation section in the cold-rolled samples. In our opinion, this is connected with decrease of plasticity reserve due to significant hardening of the metal after cold rolling. To determine the anisotropy of the material mechanical properties, we measured the value of temporary resistance (of tensile strength) $\sigma_в$.

It is established that the value of the temporary resistance of hot-rolled carbon S235JR steel in directions oriented at an angle of 0 °, 45 ° and 90 ° relative to the direction of rolling is almost the same. The uniformity of mechanical properties distribution and the appearance of small anisotropic properties in the strips can be explained by the intensive passing of dynamic recrystallization processes during the rolling of sheet billets on the LWM. These processes stabilize the structural state of St3sp steel.

Conducted researches have shown that the temporary resistance of cold-rolled carbon S235JR steel in directions oriented at an angle of 0 °, 45 ° and 90 ° relative to the direction of rolling changes on the average up to 6 %. That is, in the transverse direction, the value of temporary resistance is on the average for 6 % larger than in the rolling direction. In this way, the test results show that during cold rolling of carbon steel S235JR, hardening in the plane of the sheet is not uniform, which can be explained by the formation of a crystallographic deformational texture in the metal.

The study of the hot-rolled carbon steel S235JR mechanical properties anisotropy at the MV-01m installation showed that the value of temporary resistance, yield strength and relative elongation of this steel in directions oriented at an angle of 0 ° 30 ° and 45 ° relative to the rolling direction is approximately the same. As it was noted above, the uniform distribution of mechanical properties and the appearance in the strips of small anisotropic properties can be explained by the intensive passing of dynamic recrystallization processes during the rolling of sheet billets on the LWM. Given processes stabilize the structural state of S235JR steel.

The research of cold-rolled strips anisotropy from St3sp on the MV-01m installation showed that the mechanical properties of this steel in directions oriented at an angle of 0 °, 30 ° and 45 ° relative to the direction of rolling significantly change. The mechanical properties in transverse directions are larger at value than in rolling direction. Thereby, the test results show that during cold rolling of carbon steel St3sp, hardening in the sheet plane is not uniform, which can be explained by the formation of a crystallographic deformational texture in the metal.

At this work it also measured the geometric dimensions of imprints deposited on the surface of hot-rolled and cold-rolled strips of carbon steel St3sp. The studies established that if the imprints obtained on the cold-rolled thin strips are oriented at an angle to the direction of rolling, then the length of the imprint diagonals is different. In our opinion, the reason for obtaining of imprints with different diagonals length is an uneven elastic and plastic deformation of imprints. The experiments also found that the anisotropy of mechanical properties in the strips obtained by hot or cold rolling leads to different patterns of change in final dimensions of the hole. At this, obtained holes in hot-rolled strips have almost the same diagonal length, and in cold-rolled strips the diagonal size changes upwards. It should be noted that with an increase of imprint inclination angle α to the longitudinal axis of rolled strips, an average length of both diagonals of the imprint d_{cp} increases, further reaches a maximum at α = 45 °. Further increase of imprint inclination angle leads to decrease in d_{cp}.

Hereby, the research of the carbon steel S235JR properties anisotropy showed that during cold rolling in the sheet plane of this steel a significant anisotropy of mechanical properties appears. At the time, during hot rolling, this anisotropy disappears. During cold rolling, the metal fall under the maximum strain hardening in the transverse direction relative to the direction of rolling. We think that this phenomenon is related with the appearance of a deformation texture in the cold rolled sheet, and the absence of this texture in the hot rolled sheet. The deformation texture disappears on account of the passing of dynamic softening processes during the hot rolling of sheets on the LWM.

It should be noted that the found anisotropy of cold-rolled sheets mechanical properties must be taken into account when analyzing the stress-strain state of the extraction unit operation. Such a recording will make it possible to optimize the existing and create new technological regimes for sheet stamping of S235JR steel in the stamping shops of machine-building plants.

CONCLUSIONS

- It is shown that during cold rolling of sheet billets in the plane of carbon steel sheet, significant in size anisotropy of mechanical properties appears.
- It was established that during hot rolling of sheet billets in the plane of carbon steel sheet, significant in size anisotropy of mechanical properties does not appear.
- It is shown that the more material is inclined to the appearance of anisotropy of elastic and plastic properties, the greater an average value of imprint diagonals.
- To optimize the sheet stamping technological process, the anisotropy of cold-rolled sheets mechanical properties obtained during rolling must be applied into the analysis of the stress-strain state of the extraction operation.

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