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IMPROVEMENT OF THE SLITTING PROCESS FOR REBAR ROLLING TO INCREASE THE MATERIAL YIELD AND ROLLING MILL 370 UTILIZATION AT PJSC "MMK"

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rebars, slitting rolling process, dividing rollers, dividing roller guides, long products production, material yield, wear resistance, trial rolling, 370 rolling mill, tungsten carbide, titanium carbide.

ABSTRACT

The aim is to increase the stability of the MMK's mill 370 performance, and improve the material yield. We reviewed and analyzed the world experience in the rebar production using the slitting-process. There are two approaches to the slitting: by dividing a thick neck in the grooves of the working stand of the mill; by dividing a thin neck in the exit slitting guide after the stand. The reasons of downtimes of the mill 370 PJSC "MMK" during the production of rebars No. 10–14 by slitting were analyzed. A significant part of cobbles (sticking or choking) occurred at the stand 16. Technical and technological solutions have been developed to ensure stable rolling and an increase of the yield, in particular: an adjusted roll pass design for the stand 14; a proposal to improve the implementation schemes of slitting process using Danieli slitting guides; suggested the use of wear-resistant dividing rollers from TiC or WC; recommended to use higher quality bearings for dividing guide roller with elastic sealing devices capable to operate at elevated temperatures. Trial rolling was carried out using wear-resistant dividing rollers and the correct groove of the stand 14. As a result, the share of cobbles reduced significantly and the material yield improved. The share of the cobbles per ton during the experimental rolling almost halved (0.16%) compared to the average level of 0.34%. The measurements showed that the rolled material obtained after the 15th stand has the correct dimensions and sufficient symmetry.

Introduction

At present, there are quite a lot of solutions for improving the technological processes of long and section rolling producing [1–6]. There are two alternative approaches to the rolling-slitting process at the long product rolling mills [7, 8]. Features of rolling-splitting (slitting) are studied quite widely [9–12]. First, it is possible to split the bar's thick neck in the dividing grooves of the working stand of the mill. Second, it is possible to split the bar's thin neck in the slitting guide by idle rollers, while the rolling stand only prepares the rolled stock for the dividing process.

The technology of two-strand material splitting that uses idle rollers of roller guides was called abroad the "slitting process".

Each of the approaches has inherent advantagesand disadvantages.

The advantages of the first approach (slitting by rolling rolls) include:

• possibility of dividing large sections, for example, slabs into billets;

• absence of additional dividing devices (use only existing technological equipment of the mill);

• possibility to implement the process on in-line (old-fashioned) mills.

The disadvantages of this approach are as follows:

• poor quality of the divided zone (rough tears of the edge of the metal);

• low accuracy of slitting;

• practical complexity of implementation for the production of small sizes.

The advantages of the second approach (metal slitting by idle roller guides) include:

• high accuracy of slitting and high quality of the slitting zone;

• high process stability during the production of small profiles.

The following disadvantages of the second approach can be mentioned:

• need to use additional dividing devices in the mill's process flow;

• practical complexity of implementation during production of big size profiles, for example, billets; the complexity of implementing the process on linear mills.

Despite the fact that both versions of the rolling-slitting process have found wide application in domestic and foreign practice of long products, it seems more preferable to use the approach to the implementation of the rolling-slitting process based on the use of autonomous non-driven dividing devices as the most energy-efficient process [13].

In addition, the following options appear:

• decommissioning of rolling stands, the number of which coincides with the number of dividing passes, which reduces the consumption of electricity and rolling rolls during rolling;

• replace the sliding guides with non-driven devices with high-performance slitting rollers, which can significantly improve the culture and reliability of production;

• significantly improvement of the symmetry accuracy and the quality of slitting of the metal due to the high axial and radial hardness of the setting of the dividing rollers and to provide increased requirements for the adjustment of the rolling stands.

Technological solutions for metal slitting and their development

The following technological solutions that have been applied for slitting of metal can be noted:

- use of roll pass design that prepares a square cross-section for rolling in a rolling stand with a double circle groove, where the metal is prepared for longitudinal slitting, which begins in the next rolling stand, and ends in the exit rolling guide of this stand with the help of a divider device;
- improvement of metal accuracy by stabilizing the geometric parameters of the cross section and ensuring the equality of the sizes of the splitted sections of the profile, increasing the lateral stability of rolling in the rolls with the use of smoothed rolls directed technical solution, which provides for the use not only of autonomous non-driven dividers but also of non-driven universal rolling stands;
- requirement to reduce the unit cost of energy and materials, increase the competitiveness of products, reduce the cost of production and increase the production of small section rebar profiles, necessitated an increase in the number of threads to be divided. Three- and four-grooved rolling-slitting are developing abroad [9, 10, 12, 13]. Well-known companies such as Morgardshåmmar Guide Systems, Danieli, Ferrco Engeneering, Co-Steel of Canada and others work efficiently and purposefully in this area;
- solving the problem of expanding the technological capabilities of a small-section wire rod mill during the rolling of various profiles of the assortment, it was proposed to carry out synchronous production (at the same time) of section profiles and simple shapes profiles, for example simultaneous rolling of a wire rod and an equal-angle corner, by means of rolling-slitting;
- rolling of periodic profiles (such as rebar) by "slitting" at the Moldova Steel Works is characterized by the fact that the final slitting of metal is done by rolls, and not by exit rolling guides where after the slitting the metal rolling in four more stands, which allows to smooth the torn edge that is formed after slitting sufficiently well;
- solution providing reduce of the number of metal sticking (choking) that was put into practice at some mills in Greece, where passes with a consistent increase in the gap between the ledges of slitting passes were proposed to prevent the effect of "biting";
- slitting pass is designed so that during cutting of the connection strap there is no metal contact with the bottom and side faces of the pass or there was minimal contact with a slight reduction in height.

Concerning the solutions considered, it is worth noting that, in the implementation of the "slitting process", two factors are of great importance: the precise put of metal into the groove and the position of the exit dividing device relative to the groove.

Advantages of the process of longitudinal metal slitting by a controlled break are listed below:

- simplification of adjustment of the rolls in the case of dividing the metal at large gaps between the slitting ridges;
- absence of neck of rupture in the place of slitting of billets;
- reliable self-centering of the metal in a two-grooved pass;
- increase the service life of the rolls as a result of possibility of increasing the angle to 90° at the tips of the ridges of two-grooved pass;
- simplicity of the design of the exit rolling guides.

The disadvantages of the longitudinal metal slitting include:

- opening of the metal granular structure in the place of slitting of billets;
- need to carry out separation of rolled metal in a narrow range of roll gap ratio values between the slitting ridges and connection strap thickness that have the effect on the radius of curvature of the front ends of the slitted profiles at the exit of the rolls.

Advantages of the "slitting-process" technology are as follows:

- smooth surface of the neck of the rupture, stretching from the compression in the oval pass without leaving visible traces;
- presence of a dividing device that insures slitting process, which cuts the defective area from the crested ridges of the pass.

The disadvantages of the "slitting-process" technology include:

- separation of strip obtained in a pass with considerable wear of slitting ridges in a divider, what increases neck fracture and appears probability of backfins;
- need to form a very thin (appr. 0.8-1.0 mm) bridge on rolled metal reduces the service life of the rolls (low resistance of the forming pass);
- presence of a slitting device with complicated design requires qualified maintenance.

Improving the design of non-driven dividing devices

Special non-driven dividing devices are used for realization of the rolling-slitting process with metal separation into parts outside the working stand; these devices form a kind of dividing system "driven rolling stand - non-driven dividing device" with the driven rolling stand, where the dividing device is an exit rolling guide providing longitudinal metal slitting due to the wedging action of the dividing rollers.

There are many options for the implementation of dividing devices, which differ in the following key points:

- dividing devices with a specific form of dividing rollers [8,11];
- dividers with banded dividing rollers [7,8,11];
- dividing devices with centrally symmetric crest of dividing rollers [11];
- the design of the dividing device, which involves the use of two pairs of dividing rollers [8,11];

- improved cooling and lubrication systems for dividing rollers [11];
- block installation of pairs of dividing rollers [8];
- the method of longitudinal slitting of multi-strand rolled metal in a mill production stream by the special four-roll device with disc rolls having biconical surface or cylindrical shape [14,15], where the device can be driven or non-driven.

Analysis of technological schemes for the implementation of multi-strand rolling-splitting and retrospective of developments in the field of creation of non-driven dividing devices for implementation of this process allows to reveal the main trends in their development:

- increase of stability and produceability of the process, improvement of slitting accuracy and quality of finished products, increase of material yield;
- improvement of surface quality of finished products by reduce of probability of formation of backfins at the point of slitting;
- expansion of technological capabilities of the mill during rolling of various profiles in the framework of its dimension range;
- increase of the number of simultaneously divided strands while preserving the splitting accuracy, high operational resistance and stability of the slitting process, as well as simplicity of maintenance and operation;
- simplification and increase of reliability of technological equipment (rolling guides, equipment for longitudinal metal slitting);
- simplification of maintenance and operation - installation and dismantling, assembly and disassembly of dividing devices.

Analysis of the reasons for downtimes of 370 rolling mill of PJSC MMK during production of periodic profiles (rebars) No. 10–14 by the slitting process

Actuality of improvement of the actually applied rolling technology of slitting process is very important for production of rebar steel at the 370 PJSC "MMK" mill because the difficulties with ensuring the quality of rolled products and loading of the equipment are observed. To improve the quality (to rise material yield) and reduce downtimes, it is necessary to analyze the causes of the negative impact.

In order to identify the main reasons that influence on the downtimes of the 370 mill and reduce of the metal yield, an analysis of the statistical data has been conducted. These data were generated on the basis of the quality department control reports of OJSC MMK for the year 2015.

Below is the Pareto diagram (**fig. 1**), displaying that half of the whole mill's rejects falls on the rebar No. 12 and No. 14, i.e. on the profiles produced by the slitting process.

In this connection, the more detailed analysis of the causes of sticking (choking) and downtimes for these profiles was carried out. The results of this analysis are presented below (see the **fig. 2)** on the example of the amount of rejects in production of rebar No. 12.

As can be seen from the diagrams, up to 50% of all downtimes and rejects are caused by sticking (choking) in the dividing box behind No. 16 stand of the rolling mill, i.e. in the device, where the final slitting of the metal occurs. Thus, the issue of improving the reliability of the slitting process in the dividing box is very relevant. Most of the sticking (choking) occur because of the wear of the rollers in the roller box (dividing guides), which also leads to asymmetric cutting and reduced stability of the slitting process.

Development of technical and technological solutions ensuring stable rolling and improving material yield as well as carrying out industrial experiment

On the basis of the data obtained, the research objective was formulated, which consisted in the development of technical and technological solutions that ensure stable rolling and an increase in the yield of rebar, suitable for the production of rebar steel No. 10–14, by the slitting process at the 370 mill of PJSC "MMK".

The question of the construction of a dividing device.

A significant value for the symmetrical cutting of the metal has a stable feed of the strip into the groove with minimum width variations and high accuracy of the setting of the entry guides. These requirements are met by the entry roll-

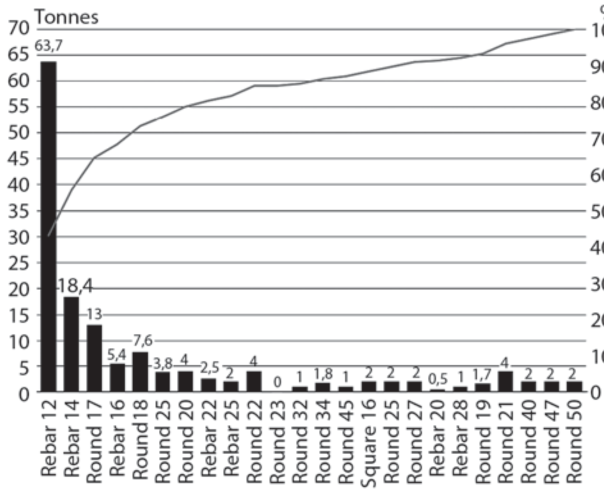

Fig. 1. The amount of rejects on the profile of the mill 370 (based on data for 2015)

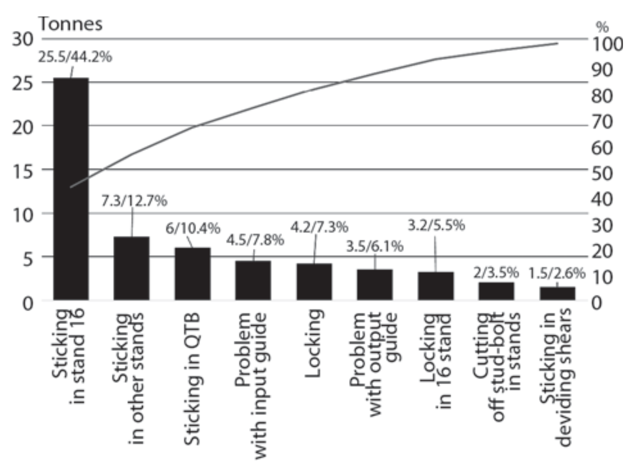

Fig. 2. The amount of rejects in the production of rebar No. 12, tons, %

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ing guides of the Danieli company with two rows of rollers, which is recommended for use.

The question of the tool for splitting.

The wear of the dividing rollers is also of considerable importance for stability of the cutting (slitting). In this connection, the material of the rollers is of particular importance.

Complex-alloyed white cast iron with a cast composite structure are widely used as tool wear-resistant alloys for rollers, rolls and bandages. The hardness of special carbides of vanadium, titanium, niobium, molybdenum exceeds by several times the hardness and energy content of iron and chromium carbides, which attracts the interest of researchers and industry to them. Solid sintered materials which are manufactured via the powder metallurgy method, can be also used for production of dividing rolls. They are spatially-reinforced composite materials.

Taking into account the experience of domestic and foreign manufacturers of rolling bandages for rolling mills, we consider it advisable to use carbide rolls formerly used in the finishing wire block of 170 rolling mill at PJSC "MMK" and consisting mainly of tungsten carbide, as divider rollers. In addition to increased wear resistance, the advantage of this solution is a smaller mass of cast iron rollers compared to carbide rollers, which reduces their inertia.

Solution of the problem by modifying of the roll pass design.

In addition to the above-mentioned decisions on the material of dividing rolling guides, and based on the analysis of the last campaign of rolling of rebar No. 12, we observed some overflow of the pass of No. 15 stand, which indicates the need to reduce the width of the pass of No. 14 stand, and the new shape of pass was developed.

Trial rolling.

To organize the trial rolling, the following measures were proposed to increase the material yield when the periodic profiles are produced by the slitting process:

• increase of the symmetry of the cutting of the metal and stabilization of the strip feed into the pass with minimum width variations requires installation of the Danieli entry rolling guides with two rows of rollers (**fig. 3**);

• replacement of the material of the dividing rollers with carbide to improve wear resistance, separation reliability and, as a consequence, increase of service life of the dividing equipment;

• reduce of the width of the pass in No. 14 stand during the rolling of rebar No. 12 in order to center the metal in the slitting pass of the No. 15 stand.

The following activities were carried out before the experimental rolling:

• development of drafts of the pass, templates and rolls of No. 14 stand for rolling of rebar No. 12 and their agreement with the pass design office of PJSC "MMK";

• fabrication of four pilot passes for the No. 14 stand according to the developed drawings;

• order for the dividing guide rollers of titanium carbide fittings in accordance with the recommendations of the section and long product rolling shop of PJSC "MMK". However, the long delivery time of these rollers did not allow to realize the experimental rolling of rebar No. 12 on this material. An attempt to manufacture test rolls of tungsten carbide (from decommissioned rolling rolls of the wire block of 170 mill) in the roll shop showed that it is not possible to process rolls of such hardness on the existing equipment. In this regard, the rollers for the experimental rolling were made from decommissioned rollers of the strip rolling shop No. 8 with their consequent quenching and tempering;

• two sets of roller dividing guides for the experimental rolling of the periodic profile (rebar) No. 12 were prepared.

In November 2015 experimental rolling of rebar No. 12 was carried out in 370 mill of PJSC MMK.

Results of industrial trial

After rolling of 1,000 tons of rebar No. 12, the first pair of dividing rollers was taken out of operation to assess their wear. A visual assessment showed that there was practically no wear of the rollers (see **fig. 4**), and the working area had a width of 5–8 mm, which indicates that the slitting process occurred in the correct mode.

Adjusting templates were also obtained during rolling in the experimental pass of No. 14 stand of the mill and during the subsequent cutting of the rolled metal in No. 15 stand. The conducted measurements showed that the metal obtained after No. 15 stand has correct dimensions and sufficient symmetry.

Further work on these rollers led to formation of chips on the working surface, which indicates that the use of this material (steel 9KhMF) is inappropriate, or that it is necessary to select the required heat treatment of the rollers. It should be mentioned that the rolls from the strip rolling shop No. 8 after quenching and tempering were used as dividing rollers.

Therefore, special hard-alloyed materials from titanium or tungsten carbide should be recommended as a wear-re-

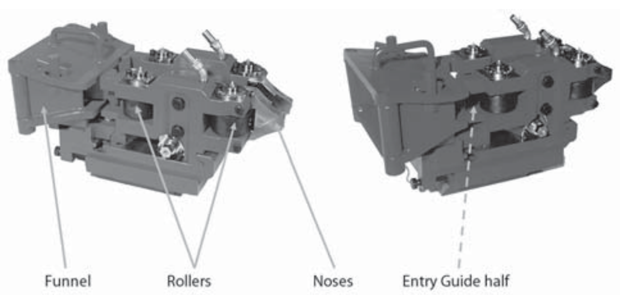

Fig. 3. Entry rolling guides with two rows of rollers of Danieli company

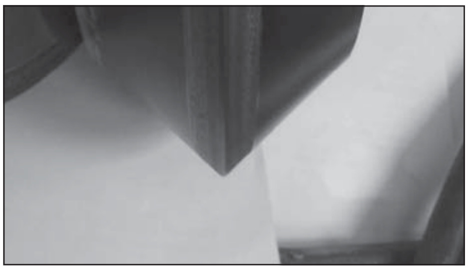

Fig. 4. Experimental dividing roller after rolling of 1,000 tons of rebars No. 12 in 370 mill

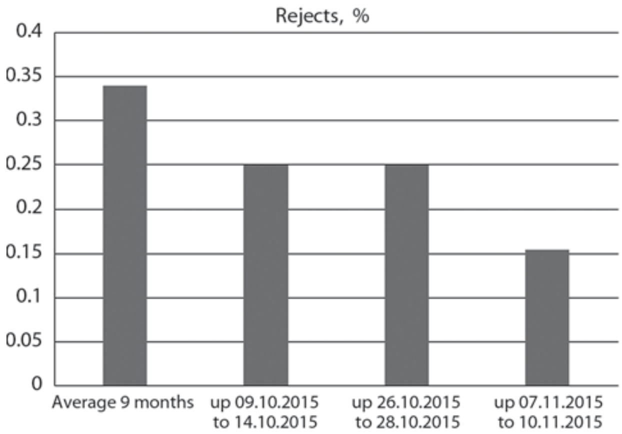

Fig. 5. The share of rejects during the rolling of rebar No. 12 in the 370 mill

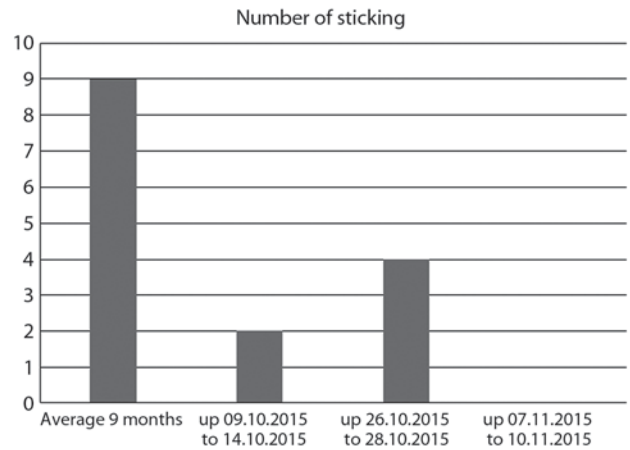

Fig. 6. Number of cobbles during rolling of rebar No. 12 at the 370 mill

sistant material. In this case, titanium carbide is more preferable, since it has lower specific weight and lower inertia.

It should be also noted that a significant part of the sticking (choking) in No. 16 stand occur due to use of ball bearings with insufficient quality in the dividing guides. Application of bearings without sealing or with seals of insufficient quality leads to their quick failure. To increase the service life of the dividing guides, it is recommended to use SKF high quality bearings with elastomer sealing devices capable of operating at elevated temperatures.

Use of high-quality bearings is of fundamental importance when replacing the material of the dividing rollers with carbide material, since fast bearing failure will lead to incomplete use of the roller resource and will negate the economic effect.

In general, it can be noted that the use of wear-resistant dividing rollers and correction of the pass of No. 14 stand allowed a significant reduction in the share of rejects and an increase in the material yield of the rebar No. 12 suitable for rolling (**fig. 5** and **6**). The share of rejects per ton of output during the experimental rolling has been almost halved (to 0.16%) compared to the average level (from 0.34%). Experimental rolling was carried out since 7th to 10th of November 2015.

Conclusions

1. Slitting of the bars by rolling rolls during the rebar No. 10–14 rolling is not possible at the 370 rolling mill of PJSC MMK due to the insufficient number of stands. This method is considered ineffective also from the point of view of rolling capacities utilization during slitting process, which is characterized by low energy-force parameters compared to the plastic deformation.

2. Analysis of the statistical data of the PJSC MMK quality control department for 2015 has revealed that the greatest downtimes and most rejects occur during rolling of rebars No. 12 and 14. Up to 50% of all cobbles during rolling of rebars No. 12 and 14 occur in the dividing guide box located on the exit side of No. 16 stand. Therefore, to improve rolling stability and material yield one should aim to increase slitting reliability.

3. The material yield in slitting process increased after using the dividing rollers with increased wear resistance for the roller guide in No. 16 stand and after correcting the pass shape in No. 14 stand. The share of rejects during the trial rolling decreased from 0.34 to 0.16%.

4. Titanium carbide or tungsten carbide should be used as the dividing rollers' material. Titanium carbide is more preferable, since it has a lower specific weight and inertia and a higher reliability.

5. The developed pass of No. 14 stand improves the material centering in the slitting pass of No. 15 stand. Installation of a Danieli design entry roller guide with two pairs of rollers will provide further improvement, because it ensures a stable strip feed into the pass and subsequent symmetrical cutting of rolled material.

6. Observations before the trial rolling displayed that significant part of the cobbles in No. 16 stand occur due to the use of low quality ball bearings in the dividing guides. Itxleads to the bearing failure and "welding" of the metal on the rollers. To increase the service life of the dividing guides, we recommend to use high-quality SKF bearings with elastomer sealing capable to operate at elevated temperatures. Use of high-quality bearings is fundamentally important when replacing the dividing rollers' material with carbide material, as soon as fast bearing failure will result in incomplete use of the rollers' resource and will significantly reduce the economic effect.

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SPRINGBACK COEFFICIENT OF ROUND STEEL BEAM UNDER ELASTOPLASTIC TORSION

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ABSTRACT

After the elastoplastic deformation of the metal structures and the metal products (for example, after a torsion, a bending, a compression, a stretching, the complex types of deformations), these bodies change their shape and partially springback. At the same time, the residual stresses arise in the bodies. Under the appropriate external conditions (for example, when the temperature changes), these stresses can lead to a significant distortion of the bodies' shape (adopted after deformation) and even destroy these bodies. To estimate the residual shape of the round steel beam, which it takes after the mechanical deformation (the forming), it is necessary to know the springback coefficient of the round beam at the torsion. At the torsion of a round steel beam, the torques (the torsional moments, the twisting moments) also appear in the beam. This moments are connected with the tangential stresses in its cross-section. The maximum of the tangential stresses occur on the surface of the round beam and can lead to the destruction of the metal beam. However, even at very strong elastoplastic torsion around the symmetry axis of the beam, the tangential stress in the center of the cross-section of the round beam is zero and the elastic zone in the beam's cross-section exists. Therefore, the destruction of the round steel beam and the defects of its metal under the torsion always start at the beam's surface. The magnitude of the tangential stresses and angular deformations, their distribution along the cross-section of the round beam are always associated with the torque of the external forces. The greater the torque, the greater the tangential stresses and angular deformations. In this paper we have obtained the springback coefficient and the torques of the straight round beam under a torsion for an elastoplastic medium with a linear hardening, depending on the beam's radius, the shear modulus, the yield strength and the hardening modulus of beam's material. The research results can be used in the metallurgical and machine-building factories.

1. Introduction

We consider a straight beam with a circular cross-section with the radius R. Further, we will assume that the material of the beam under the elastoplastic torsion has a linear hardening.

Let τ and γ be a tangential stress and a shear angle; G, L and τ_y be the shear modulus, the hardening modulus and the yield strength at shear of beam's material [1–39]. The diagram of tangential stresses of the beam for the medium with linear hardening at shear is shown in **fig. 1**.

In the field of elastic deformations, the tangential stresses obey the Hooke's law at shear

$$\tau = G\gamma.$$

In the field of material's hardening (the elastoplastic torsion), the dependence of the tangential stress τ on the shear angle γ has the form

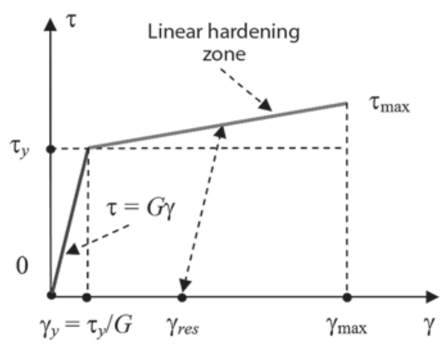

Fig. 1. The dependence of the tangential stress on the twist angle

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