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INCREASING THE DURABILITY OF SEPARATING ROLLS DURING ROLLING RIBBED BARS IN THE THREE-STRAND TECHNOLOGY

The paper presents the results of investigations aimed at enhancing the durability of slitting passes in the process of three-strand rolling of 16 mm-diameter ribbed bars. Using the Forge2011® computer program, numerical modelling of the rolling process was carried out in order to examine the variations in band shape in individual rolling passes, to verify the correctness of the designed new slitting pass system, to determine the local strains in the rolled band, and then to determine the distribution of unit friction force work on the roll groove surface.

From the obtained investigation results it was found that the application of the new roll pass design in stands 13-16 increased their durability in the rolling process by approx. 30%. The wear of the roll sets for the stands under examination after rolling out the annual 16 mm-diameter bar production volume was determined in the study. The obtained numerical modelling results were verified in experimental tests.

Keywords: ribbed bar, slitting passes, wear, numerical modeling, FEM

1. Introduction

The production of ribbed bars takes place chiefly in the process of continuous rolling in shape mills. The increase in the rolling process output is achieved, e.g., by using multi-strand rolling, during which the division of the rolled band into 2 to 5 separate strands takes place in the finishing rolling stand group [1-5]. The rolled band is divided in special slitting rolling passes with the use of idle separation rollers. The job of the slitting passes is to precisely divide the rolled band into strand with appropriate cross-sectional surface areas. The strands being connected with thin bridges are subsequently divided in special rollers and then rolled separately into finished ribbed bars. During the rolling process, slitting passes suffer intensive wear, which effects directly the effectiveness of strand slitting, as well as the dimensional accuracy of the finished product. The wear of the separating passes results in a change in the cross-section of the band, and especially the bridge(s) connecting individual strands, which may lead to band wedging in the separating box and a break in process continuity [5-7]. Therefore, the determination of pass wear in the rolling process can prevent many difficulties encountered while running this process and ensure that a finished product meeting the requirements of applicable acceptance standards will be obtained.

The prediction of the three-dimensional flow of metal in various plastic working processes is among more complex engineering problems. The sole knowledge of the change in deformed metal shape and the deformation indices is not sufficient for the correct development of the tool shape and the process technology itself. The theoretical determination of the local velocity fields and the peculiarities of the deformed metal plastic flow, while considering the metal temperature, movement speed, changes in metal flow stress values and the friction conditions on the metal and tool contact surfaces makes it possible to considerably speed up and more efficiently design the technological process and to reduce the cost and time-consuming of empirical studies necessary for starting up the manufacture of new products [8-10]. Furthermore, by utilizing numerical computation results, the possibility of formation of many defects could be reduced to a considerable extent. By using numerical modelling results it will be possible to verify the correctness of developed roll shapes and adopted process parameters. For these reasons, it seems justifiable to employ the finite element method (FEM) to the analysis of the process of rolling ribbed bars. The use of the FEM for building the mathematical three-dimensional model of the ribbed bar rolling process will allow the aforementioned problems to be solved with an accuracy not lower than that attainable experimentally.

2. Experimental conditions and simulations

Studies to increase the durability of slitting passes were carried out for the D350 18-stand continuous bar rolling mill

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which is characterized by a horizontal-vertical roll arrangement [6]. A schematic diagram of the arrangement of the passes used in the Bar Rolling Mill under examination is shown in Fig. 1.

Using the results of previous investigations concerning the modification of the system of slitting passes for rolling 12 mm-diameter ribbed bars in four-strand technology to increase the durability of the slitting passes [5,7], a new slitting pass system was developed (Fig. 2), in which an additional pre-slitting pass was employed.

The first pre-slitting pass, whose job is to initially divide the band into 3 strands, was introduced in stand 13 in place of the „flat face"-type pass. The conventional edging pass (with a flat bottom) in stand 14 was replaced with a rounded-bottom edging pass, which is used for production of flat bars with rounded corners. Using this pass was expected to provide a greater capability to control the width of the pre-slit band in stand 15, which is of particular importance during the shift of the vertical band axis relative to the vertical axis of the pre-slitting pass.

Changes were also made to the pre-slitting pass. Thanks to using the pre-slitting pass already in stand 13 it was possible to increase the height of the knife parts of the pass groove (Fig. 2b). The shape of the pass in stand 15 will considerably relieve the slitting pass in stand 16, compared to the currently used system of passes. The slitting pass in both systems is identical [6].

For numerical modelling of the 16 mm-diameter ribbed bar three-strand rolling process, the Forge2011® computer

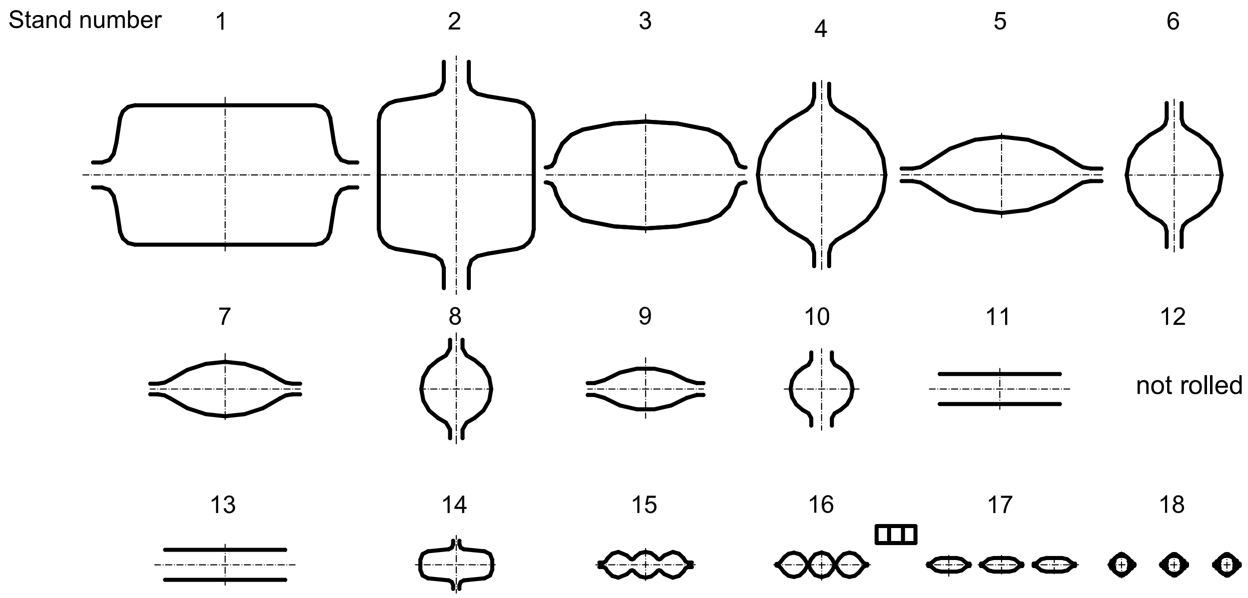

Fig. 1. Schedule of classical three-strand rolling process of 16 mm reinforcement bar

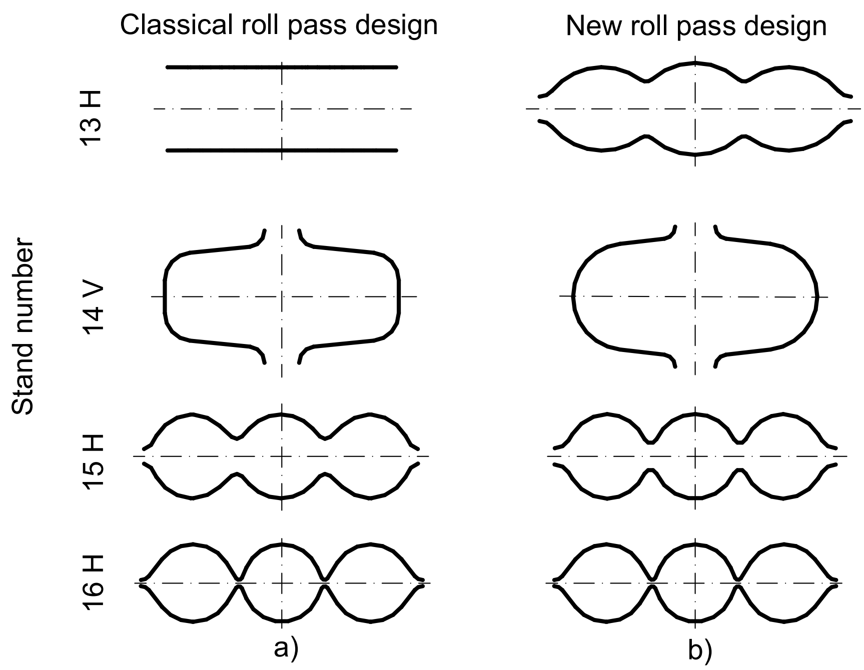

Fig. 2. Roll pass design to three-strands rolling process of 16 mm ribbed bar:a) classical, b) new [6]

program was employed. The boundary conditions and the initial parameters of the process, along with the mathematical model, are described in the authors' earlier works [5-7].

To perform numerical computations, it was necessary to make three-dimensional models of the working rolls and the band. The computer models of the rolls corresponded to the shapes and dimensions of the real rolls. A triangular finite-element grid was generated on the roll model surfaces in order to carry out numerical computations in the Forge2011® computer program. To increase the speed and accuracy of computations, a theoretical analysis of the ribbed bar three-strand rolling process was performed for the 1/4 of the band cross-section and for the symmetric half of one of the rolls.

3. Results and discussions

The performed numerical studies of the process of rolling 16 mm-diameter ribbed bars in three-strand technology have shown that the system of passes used so far ensures the correct fill of individual passes in the group of finishing stands. However, using two slitting passes in this system (stands 15 and 16) requires large reduction to be applied in order to form bridges in the multi-strand band with a height that will ensure longitudinal band separation with the idle separation rollers. The development of the new pass system allowed smaller reductions to be used in the regions of knife pass parts in stands 15 and 16, owing to the introduction of a third pre-slitting pass in stand 13. Thanks to this, the wear of slitting passes should decrease compared to the wear that occurs during rolling 16 mm-diameter ribbed bars in the conventional pass system.

Based on the obtained results of numerical simulations of the process of rolling 16 mm-diameter ribbed bars in three-strand technology, the cross-sections of bands were made after individual rolling passes in the plane of exit from the roll gap in the currently used and the new system of passes, respectively (Fig. 3).

The new roll pass design was made in such a manner that the preform for stand 13 was band of the same cross-sectional dimensions as that for the presently used system of passes. The same principle was adopted for stand 16. The band downstream this stand should be characterized by the identical shape and cross-sectional dimensions in both variants. Thus, the total band elongation factor in stands 13÷16 does not change; however, unit elongation factors in individual stands do change. This is due to the change in the shape of the passes in individual rolling passes.

The use of the new system of slitting passes had the effect of changing the distribution of deformation in those passes. Figure 4 shows the distributions of strain intensities for both rolling variants.

The obtained strain intensity distribution on the cross-section of band rolled in the new pre-slitting pass (Fig. 4b) differs from the distribution of strain intensity in the band rolled on the plain-barrelled roll (Fig. 4a). Over the entire cross-section of the plain-barrel rolled band, a uniform strain intensity distribution was obtained in the plane of strain exist from the roll gap. In contrast, in the band rolled in the new pre-slitting pass, a local increase in strain intensity value occurred in band regions

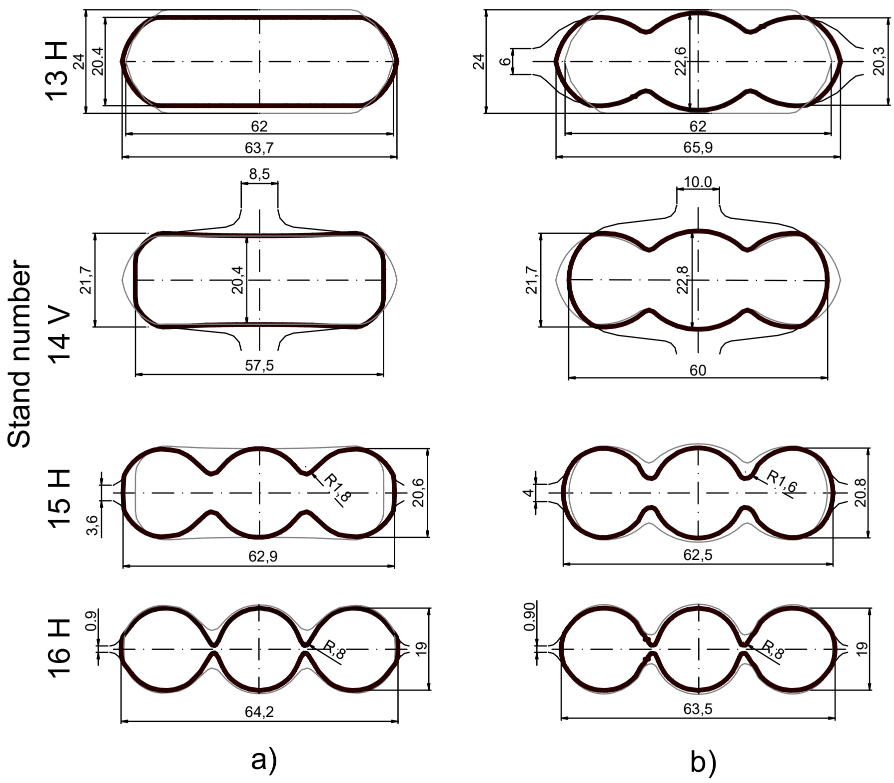

Fig. 3. Shape and dimensions of band obtained as a results of numerical modeling three-strands rolling process: a) classical roll pass design, b) new roll pass design

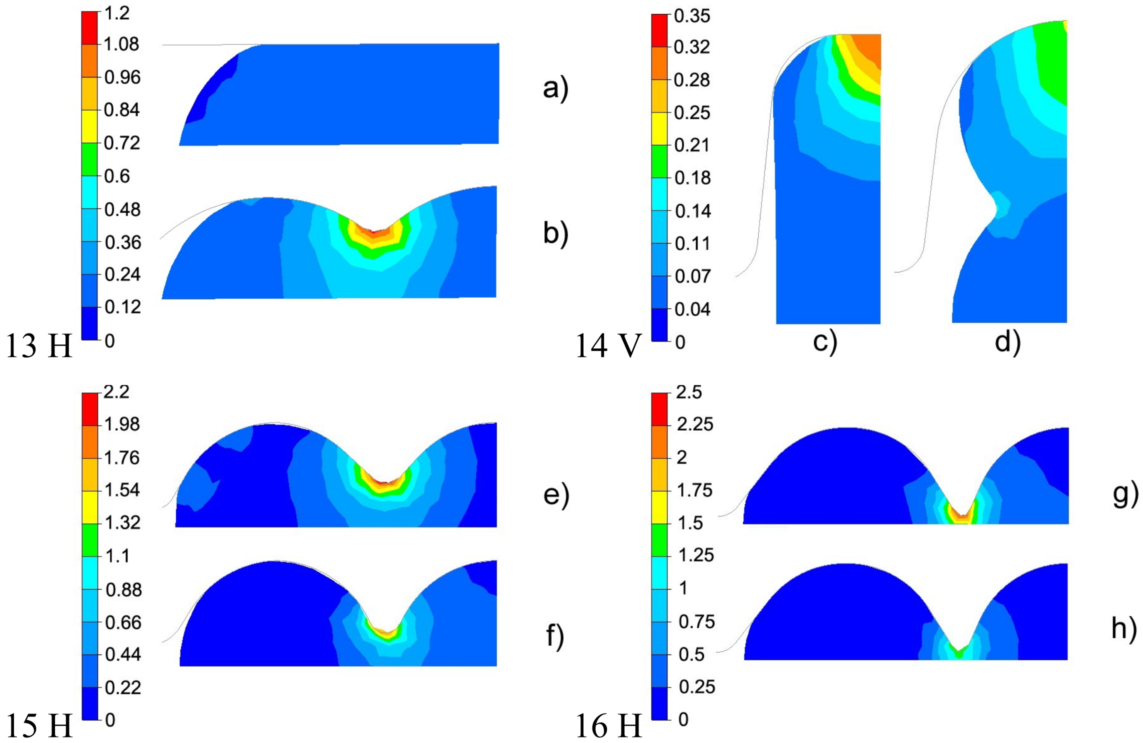

Fig. 4. Distributions of effective strain on the cross-section of band in exit plane of rolling gap: a,c,e,g) roll pass design used presently, b,d,f,h) new roll pass design

directly affected by the knife portions of the roll groove. By analyzing the strain intensity distribution on the cross-section of the band rolled in the conventional edging pass (the currently used system of passes, stand 14), it can be found that the band is more deformed in the flat portion of the pass groove bottom (Fig. 4c), while the middle part of the band is not deformed. The use of the rounding of the edging pass groove bottom (Fig. 4d) resulted in the obtained strain intensity values being smaller and more uniformly distributed on the band cross-section, compared to the strain intensity distribution obtained for the currently used edging pass. A localized, slight increase in strain values occurred in some regions of the band formed by the knife pass groove portions of the roll in stand 13 (Fig. 4d).

The character of the strain intensity distribution shown in (Fig. 4f) is similar to that of the distribution of strains obtained during rolling band in the first pre-slitting pass (Fig. 4b). As a result of increasing the number of slitting passes (the new system of passes) in the examined rolling pass (stand 15), it became possible to decrease the height of the pre-formed bridges connecting individual band strands (Fig. 4f) relative to the previously used pass (Fig. 4e). With a further reduction of the bridge height, a strain intensity distribution with a pattern similar to that of distributions in the preceding rolling passes was obtained; however, the values of strains obtained in those band regions are much smaller (Fig. 4h), compared to the values obtained when using the currently used slitting pass system (2 slitting passes), (Fig. 4g). For the other band regions, strain values obtained for both variants were similar. In either variant, the greatest strain intensity values occur in bridges connecting individual band strands.

The designed slitting pass system contributed to a change in strain intensity values during rolling band in individual rolling passes of the finishing stand group (stands 13÷16). The new shape of the passes provided a more uniform strain distribution on the band cross-section, which contributed to a reduction in the wear of passes during the rolling process (especially the pass in stand 16). To verify this hypothesis, a theoretical analysis of the change in the unit work of friction forces on the band and pass contact surface for stands 13÷16 (Fig. 5) [6]. Theoretical examination was carried out both for the currently used passes (with 2 slitting passes) as well as for the new passes (with 3 slitting passes).

Comparison of the obtained unit friction force work values for the passes in stand 13 shows that for the new pre-slitting pass these values are larger than the values obtained for the currently used “flat-face” pass. The maximum value of the unit friction force work on the surface of the presently used pass amounted to 157 J/mm^2, while on the surface of the new pass, this value increased to 845 J/mm^2. This is due to the fact that the first slitting pass was introduced in stand 13 to replace the flat-face pass. In regions where bridges are formed, the band is most intensively deformed, thus the wear of these pass elements will be the heaviest. For the remaining slitting pass portions, the obtained unit friction force work values are much smaller, compared to the values obtained for the knife parts of the pass, and approximately correspond to the values obtained for plain-barrelled rolls currently used in that stand.

During rolling band in stand 14, the obtained values of the unit friction force work on the surface of contact between the band and the new pass are smaller, compared to the values

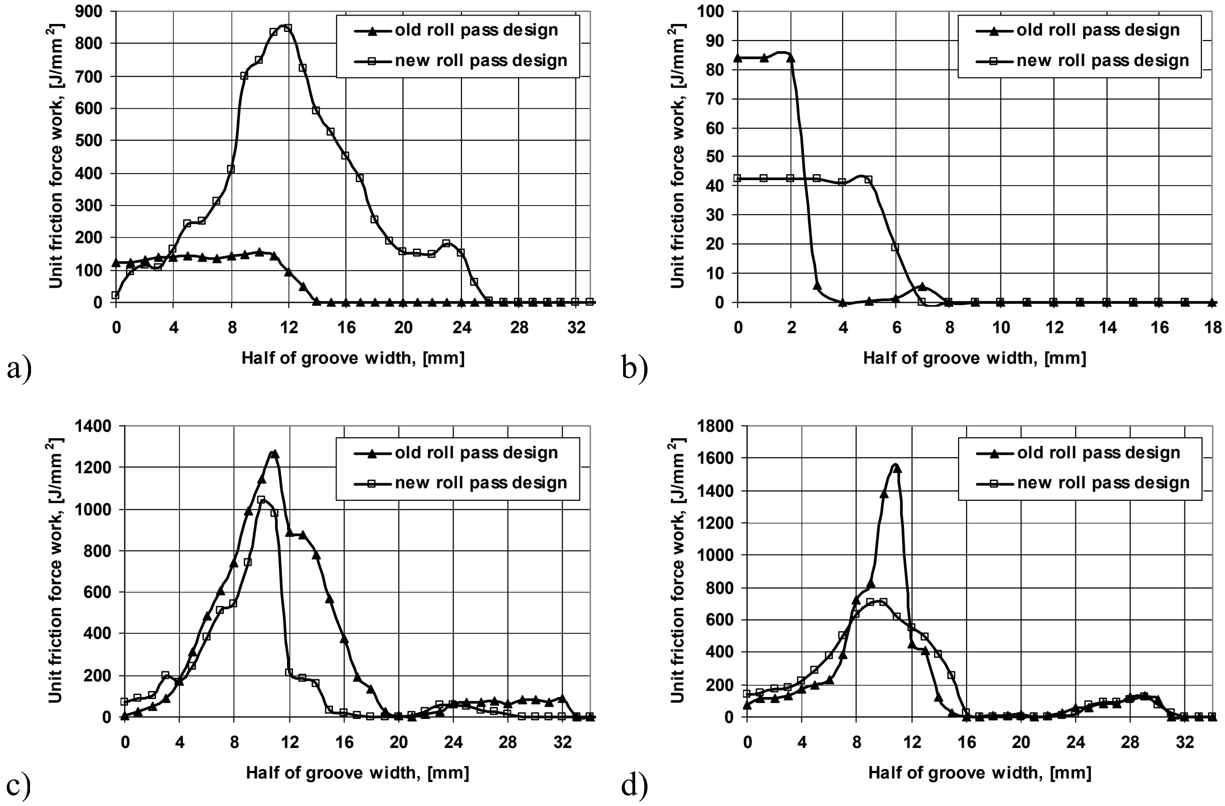

Fig. 5. Distribution of unit friction force work during three-strands rolling process of 16 mm ribbed bar: a) stand 13H, b) stand 14V, c) stand 15H, d) stand 16H

obtained for the pass being currently in use. The maximum value of the unit friction force work on the surface of the presently used pass amounted to 84 J/mm^2, while on the surface of the new pass, this value decreased to 42 J/mm^2. This difference resulted from exchanging the (flat-bottomed) edging pass for an edging pass with a rounded bottom. The new edging pass favours a more uniform band deformation. The shape of the band obtained in stand 13, and specifically its rounded lateral surface fits the rounding in the groove bottom of the new edging pass. By contrast, in the currently used pass system, the rounded lateral surface of the band obtained in stand 13 is deformed by the flat bottom of the grove of the edging pass turned on the rolls in stand 14.

In the next rolling pass (stand 15), the band is rolled in the first pre-slitting pass (the presently used pass system) and in the second pre-slitting pass (the new pass system). In both cases, the highest values of the unit friction force work occur in pass groove regions, where bridges connecting individual strands form. The use of 2 bridge pre-forming passes (the new pass system) had the effect of reducing the unit friction force work in those pass regions, compared to the values obtained for the pass system, in which only 1 pre-slitting pass was employed. The maximum value of the unit friction force work on the surface of the currently used pass amounted to 1268 J/mm^2, while on the surface of the new pass, it was 1044 J/mm^2. The difference is due to the fact that in the newly designed passes, the first slitting pass, in which the formation of bridges in the band begins, is used already in stand 13. Therefore, in this case, in order to form bridges of the appropriate height, a smaller reduction can be used in stand 15, compared to the reduction used in the pass system with one pre-slitting pass. In this variant, the pass in stand 15 is the first (pre-slitting) pass forming bridges connecting individual strands in the band being rolled.

The final formation of bridges connecting individual strands in multi-strand band takes place in the slitting pass in stand 16. In both analyzed systems, the shape and dimensions of this pass are the same. However, the obtained unit friction force work values were for the new pass system by over 50% smaller than the values obtained for the presently used slitting pass. The maximum value of the unit friction force work on the surface of the presently used slitting pass amounted to 1533 J/mm^2, while for the slitting pass used in the new system, this value decreased to 709 J/mm^2. The lower unit friction force work value for the slitting pass used in the new system resulted from applying a smaller reduction in band regions, where individual strand-connecting bridges are formed.

Based on the performed analysis of the unit friction force work and the actual measurements of roll wear taken during experimental rolling, using the methodology described in studies [7], it was possible to determine the durability of the rolls of stands 13-16. In the Rolling Mill under examination, the average annual production of 16 mm-diameter ribbed bars is approx. 90 000 Mg. Based on the results presented in this study, the number of roll sets necessary for rolling out the annual production volume of bars in the size under consideration has been determined.

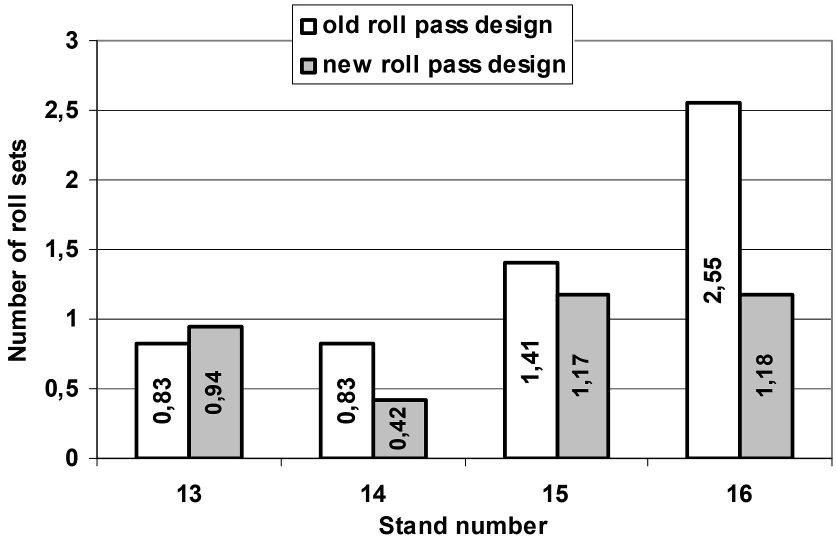

Fig. 6. Number of roll sets during three-strand rolling process of 16 mm ribbed bar about 90 000 Mg

The data shown in Figure 6 allows for the fact that there are 6 passes on the roll barrel width (in the case of a flat barrel, 6 rolling passes are also possible) and that the rolls can be redressed 6 times, before they have been completely worn (they will be turned to the so-called "dead diameter"). On these assumptions it was possible to determine the roll life and the annual demand for rolls.

Conclusions

From the investigation results it has been found that the use of the new slitting pass system causes a smaller band deformation in bridge formation locations, which results in a reduced wear of the knife portions of the slitting pass. The increased durability of slitting passes is also confirmed by the occurrence of a lower unit friction force work value for the slitting passes (of stands 15 and 16) used in the new pass system. This is due to the fact of applying a smaller reduction in band regions, where bridges connecting individual strands are formed, as the total reduction has been distributed into 3 rolling passes.

The use of the new system of slitting passes for the production of 16 mm-diameter ribbed bars in three-strand technology has the effect of extending the working life of rolls in the finishing stand group by 30% on average.

The greater wear of the pass in stand 13, and lesser in stand 16, has a favourable influence on the course of the rolling process, specifically the band separation process, as well as on the dimensional accuracy of ribbed bars obtained from individual strands.

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