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MODIFICATION OF THE ROLL PASS DESIGN TO THE BAR ROLLING PROCESS WITH LONGITUDINAL BAND SEPARATION

MODYFIKACJA KALIBROWANIA WALCÓW DO WALCOWANIA PRĘTÓW Z WZDŁUŻNYM ROZDZIELANIEM PASMA

A new roll pass design and a new method of rolling in slitting passes of bar with longitudinal band separation have been developed within this work, which reduce the energy consumption and increase the durability of slitting passes compared to the methods used so far. The theo-retical examination results were verified based on the measurements of rolling power taken during bar rolling according to the multi-strand rolling technology. The Forge2007® computer program was employed to the theoretical analysis of the process of rolling with band slitting

Keywords: slitting passes, band slitting, energy and power parameters, FEM

W pracy zaprojektowano nowe kalibrowanie walców i nowy sposób walcowania w wykrojach rozcinających prętów z wzdłużnym rozdzielaniem pasma, dzięki czemu zmniejszyło się zużycie energii oraz uzyskano większą trwałość wykrojów rozcinających, w porównaniu z metodami walcowania stosowanymi dotychczas. Wyniki badań teoretycznych zweryfikowano na podstawie przeprowadzonych pomiarów mocy walcowania podczas walcowania prętów według technologii wielożyłowej. W niniejszej pracy do teoretycznej analizy procesu walcowania ze wzdłużnym rozdzielaniem pasma wykorzystano program komputerowy Forge2007®.

1. Introduction

Increasing demand for round ribbed bars intended for reinforcing concrete has been observed in recent years in the world's rolled product market, with high strength requirements being imposed on them. This is dictated by economy reasons and constant seeking to reduce the mass of structures. In order to increase the productivity of already existing rolling lines, rolling of ribbed bars with multiple longitudinal partition of the strip is applied, among other methods [1, 2].

When implementing new technologies of ribbed bar rolling with longitudinal strip partition, two or three additional slitting passes should be introduced in the rolling train (Fig. 1), whose purpose is to form individual strands joined with each other with a thin connector only.

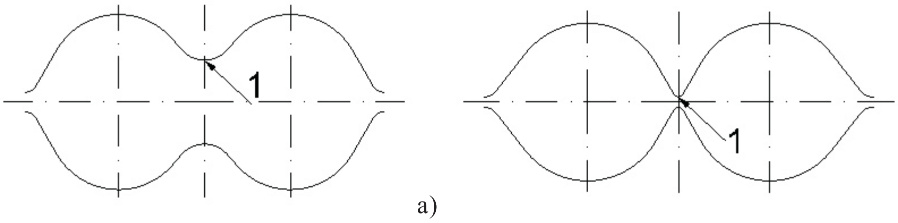

Fig. 1. The shape of passes used for two-strand rolling with longitudinal strip partition: a) pre-slitting pass, b) slitting pass, 1 – pass combs (cutters)

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The final, longitudinal partition of the strip into individual strands takes place using ***Idle Partition Rollers*** (*IPR*) that are incorporated in specialized rolling rigging positioned down-stream the slitting passes (Fig. 2). After partition of the multi-strand strip, individual strands are rolled in finishing passes according to the single-strand rolling technology.

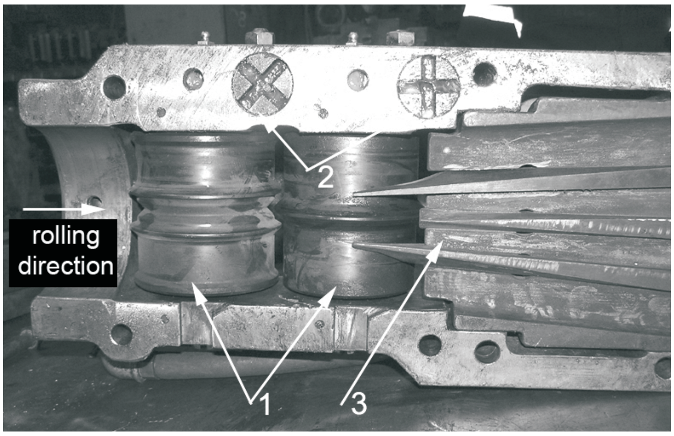

Fig. 2. View of the lower body of the partition rigging used for the partition of the strip into four strands: 1 – *IPR*, 2 – adjusting screws for setting the spacing between the *IPR*, 3 – exit separation cutters

During bar rolling with longitudinal strip separation, considerable wear of the slitting pass rolls occur, and in particular their combs (cutters) in the finishing stand group [1-3], (Fig. 1). The mechanism of tool wear is very complex, with wear intensity being dependent, among other things, on friction conditions, the character of distribution and the magnitudes of unit pressure forces, the continuous change in friction surfaces, the difference in relative speeds between the tool and deformed metal, the temperature of rolled strip, the presence of foreign matter, such as oxides and lubricants on the surfaces of contact between metal and the tools [4, 5]. In order to reduce the wear of the slitting passes, a new method of roll pass design has been developed for rolls used in rolling 12 mm-diameter ribbed bars according to the four-strand technology. The main purpose of the performed modification was to determine the fac-tors that contribute to the reduction of slitting pass wear.

2. Experimental conditions and simulations

The application of the computer program Forge2007® using the thermo-mechanical models that it contains requires the definition of boundary conditions which are decisive to the correctness of numerical computation. Therefore, computation results are particularly affected by: The properties of the steel examined, friction conditions, and the kinetic and thermal parameters describing the rolling process.

For the computer simulations of rolling 12 mm-diameter ribbed bars in the four-strand technology, the roll pass design used in one of the Polish metal processing plants [6] and a new roll pass design were utilized. The selection of kinetic parameters for the working rolls-*IPR* system involved the determination of the rotational speed of rolls in particular stands of the rolling line consisting of 18 horizontal-vertical rolling stands [1]. The actual rotational speeds of rolls were determined based on the performed electromechanical examination of the condition of the roll drive. The theoretical analysis was performed for the real rolling conditions: the working roll diameter D = 350 mm, coefficient of friction – 0.3, coefficient of heat exchange between the material and the tool, α – 3000 [W/Km^2]; coefficient of heat exchange between the material and the air, α_{air} – 100 [W/Km^2], tool temperature – 60°C; ambient temperature – 20°C. The temperature of strip rolled in slitting passes was determined based on measurements taken using a thermovision camera in industrial conditions. The average temperature of the rolled strip was approx. 940°C.

2.1. Materials

The yield stress (σ_p) as dependent on the rolling process parameters was determined by hot compression tests. The tests were performed in the Gleeble 3800 simulator. BSt500S steel (according to the Polish standard) was used for the tests, as it is most often used for the pro-duction of ribbed bars. Chemical composition of the steel used for the tests is given in Table 1.

TABLE 1

The chemical composition of steel

C	Mn	Si	P	S	Cr	Ni	Cu	V
0.21	1.40	0.45	0.04	0.04	0.25	0.25	0.25	0.13

The tests in the Gleeble 3800 simulator were planned so that the yield stress function and its coefficients could be developed for deformation process conditions during the hot rolling of ribbed bars with longitudinal strip slitting. Examples of graphs of the relationship of yield stress versus actual strain for variable temperature and strain rate are shown in Fig. 3.

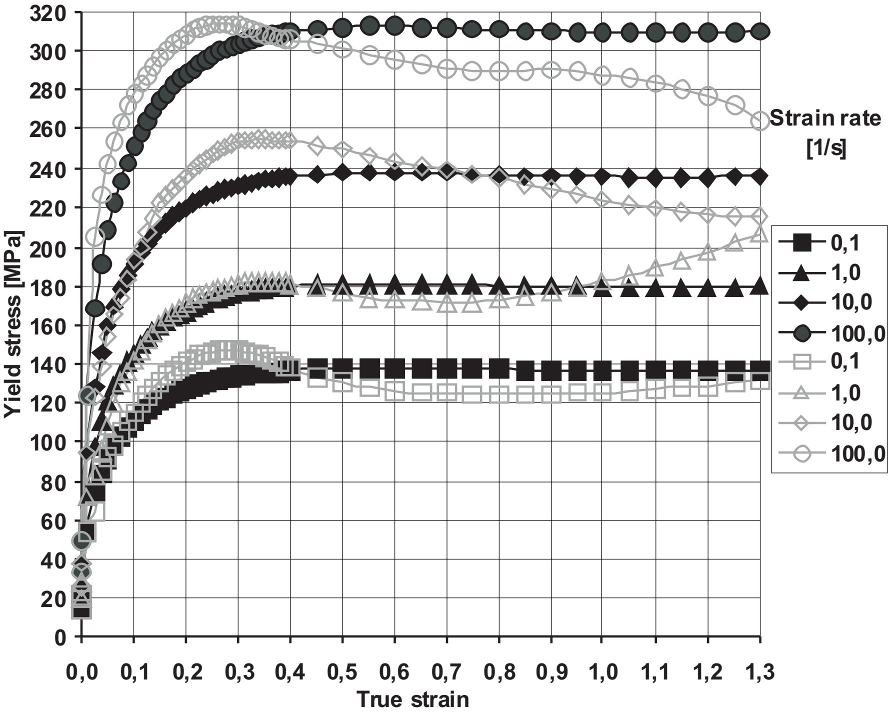

Fig. 3. Curves of BSt500S steel flow at a temperature of 900°C; blackened symbols – data from plastometric tests; empty symbols – results from approximation acc. to function (1)

For the description of yield stress variation for BSt500S steel, function (1) was taken. This relationship is often used for the determination of the value of σ_p in software applications designed for numerical modelling of plastic working processes.

$$\sigma_p = K \cdot \exp^{m_1 \cdot T} \cdot T^{m_9} \cdot \varepsilon^{m_2} \cdot \exp^{\frac{m_4}{\varepsilon}} \cdot (1+\varepsilon)^{m_5 \cdot T} \cdot \exp^{m_7 \cdot \varepsilon} \cdot \dot{\varepsilon}^{m_3} \cdot \dot{\varepsilon}^{m_8 \cdot T}, \qquad (1)$$

where: σ_p – yield stress, T – temperature, ε – true strain, $\dot{\varepsilon}$ – strain rate, K, $m_1 \div m_9$ – coefficients of function. After the approximation of plastometric test results, the coefficients of function (1) were determined. The values of these coefficients are given in Table 2.

TABLE 2

Parameters of function (1) for the BSt500S steel

K	m_1	m_2	m_3	m_4	m_5	m_7	m_8	m_9
$1.78 \cdot 10^{-05}$	$-4.87 \cdot 10^{-03}$	0.180758	-0.279711	-0.007881	-0.004401	2.049118	0.000429	3.070798

3. Results and discussions

In order to reduce the wear of the slitting passes, a new method of roll pass design was developed for rolls used for rolling 12 mm-diameter ribbed bars according to the four-strand technology. To achieve the defined goal, it was necessary to change the roll pass design for the rolls of the finishing stand group (Stands 13 to 15 in the rolling train). The main modifications adopted when working out the new roll pass design consisted in the addition of a third new slitting pass in lieu of the "smooth face" – type pass previously used in Stand 13. The previous traditional edging pass (with a flat bottom) in Stand 14 was substituted with the edging pass that is used in the rolling of flat rounded-corner bars. The preslitting pass used in Stand 15 was replaced with a new pass having larger comb indentations. The pass corrections discussed above are shown in Fig. 4.

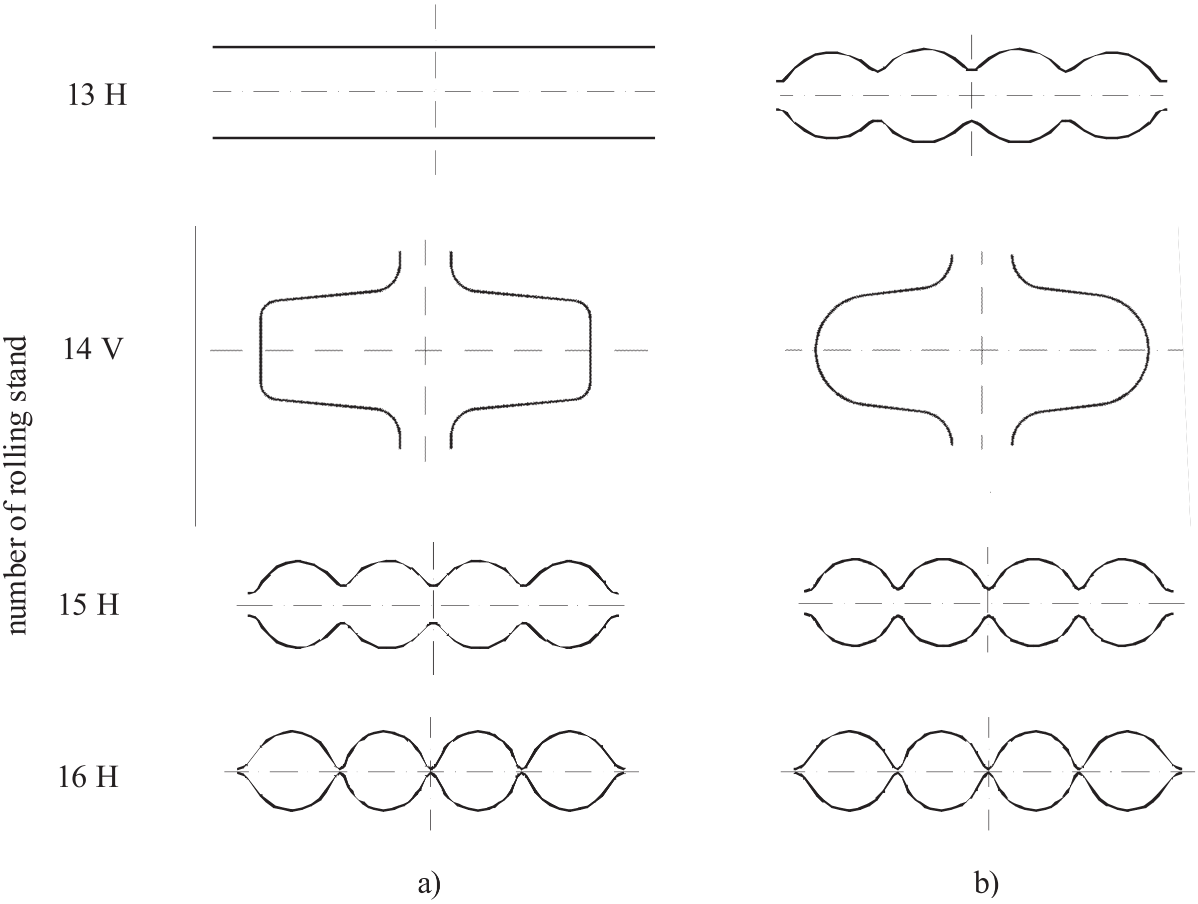

Fig. 4. The shape of passes for rolling 12 mm-diameter ribbed bars acc. to the four-strand technology: a) passes used so far, b) new passes; H – horizontal roll stand, V – vertical roll pass

As a result of the change of comb heights in the slitting passes (Stands 13 & 15, Fig. 4b), the rolling reduction of the strip in those groove parts has decreased, which will contribute to a reduction in the wear of these pass areas compared to the wear of the passes used so far.

On the basic of the results of the numerical examination of the 12 mm-diameter ribbed bar rolling process using the four-strand longitudinal strip separation technology it can be concluded that the roll pass design used so far assured the correct filling of individual passes in the finishing stand group [6]. At the same time, the use of two slitting passes positioned successively one after another in the rolling train would make it necessary to apply a large rolling reduction in the strip regions in contact with the combs of those passes (Stands 15 & 16, Fig. 4a). The considerable rolling reduction caused by the slitting pass combs resulted from the necessity of forming the bridges in the multi-strand strip of a height allowing the correct longitudinal partition of the strip in the *IPR*.

The implementation of the new roll pass design (Fig. 4b), where, among other things, a third slitting pass is introduced additionally, has caused the total required rolling reduction to be distributed among three passes. By adding the third slitting pass, a considerable reduction in the wear of slitting passes has resulted compared to the wear of the passes made according to the roll pass design used at present.

Though the use of three slitting passes has already been a successful practice in the metallurgical industry [1, 2], the solution presented herein, consisting in the utilization of an intermediate rounded-bottomed edging pass that enables the correction of the width of rolled strip, is innovative and unusual in existing industrial practice. By using an intermediate rounded-bottomed edging pass in Stand 14 (Fig. 4b), the possibility of controlling the width of rolled strip has been obtained, which is particularly important when the vertical strip axis is offset in relation to the vertical axis of the pre-slitting pass.

The article provides results of the numerical computation of strain intensity distribution on the strip cross-section in the plane of exit from the roll gap, for rolling in the passes used presently and in the new passes, respectively. At the same time, the focus of interest has been limited to the analysis of the strain intensity distribution obtained from multi-strand strip rolling in passes cut out in the rolls of Stands 15 & 16, as those most prone to wear.

Figure 5 shows the distributions of strain intensity in rolled strips, for the application of the presently used pre-slitting pass (Fig. 5a) and the new pass (Fig. 5b).

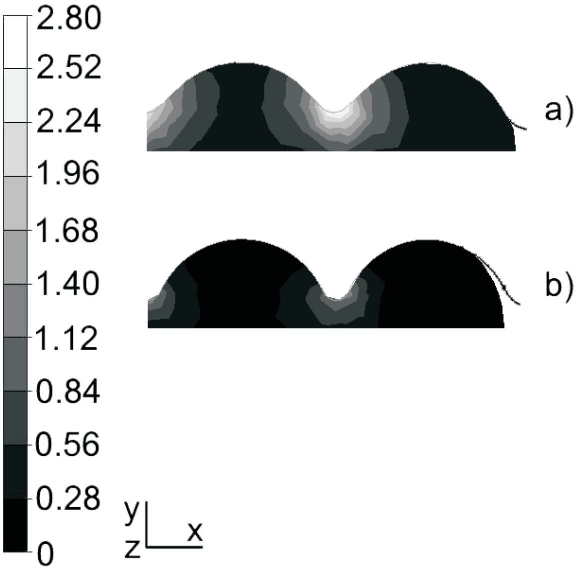

Fig. 5. The distribution of strain intensity on the strip cross-section in the plane of exist from the roll gap, Stand 15: a) for the roll pass design used presently, b) for the new roll pass design (1/4 of the strip)

From the character of the strain intensity distribution shown in Fig. 5a it can be found that a local increase in strain intensity magnitude has resulted in the regions affected by part of the pass combs. The maximum values of strain intensity have occurred in the regions of action of the pass combs. Through the implementation of a second pre-slitting pass turned in the rolls of Stand 15, the height of bridges preformed in the rolls of Stand 13, (Fig. 4b), connecting individual strip strands (Fig. 5), has been reduced. As a result of the bridge height reduction, a distribution of strain intensity isolines is obtained, which has a character similar to that of the distributions shown in Fig. 5a, except that the values of those strains are much lower.

The final stage of multi-strand strip formation takes place in the slitting pass, in Stand 16 (Fig. 6).

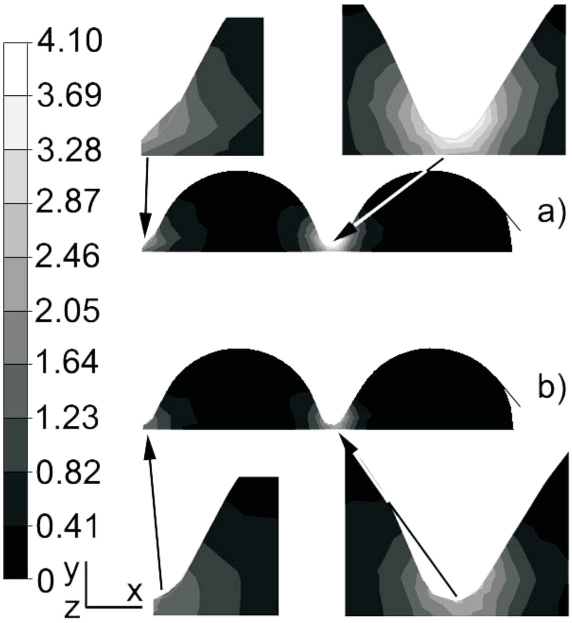

Fig. 6. The distribution of strain intensity on the strip cross-section in the plane of exist from the roll gap, Stand 16: a) for the roll pass design used presently, b) for the new roll pass design (1/4 of the strip)

The obtained strain intensity distribution is similar in character for both roll pass design cases (Figs. 6a & 6b), with the strain magnitudes being, however, different. By implementing two pre-slitting passes in Stands 13 & 15 (the new roll pass design, Fig. 4b), strain intensity values have been obtained, which are more than two times smaller than the values obtained during traditional rolling in a single pre-slitting pass in Stand 15, Fig. 4a. In both roll pass design cases, the greatest strain intensity magnitudes were observed in the strip regions cov-ered by the direct action of the pass combs.

The developed new roll pass design had the effect of changing the strain intensity magnitudes in individual finishing passes. The new shape of the passes has provided a uniform distribution of rolling reduction in individual passes. The change of those parameters should have resulted in a reduced wear of passes during rolling. To verify this hypothesis, a theoretical analysis of unit friction force work on the surface of contact between the strip and the pre-slitting and slitting passes, for the presently used and the new ones, was performed.

Figures 7 & 8 show the distribution of unit friction force work on the surface of contact between metal and the roll in the pre-slitting pass (Stand 15) and in the slitting pass (Stand 16), used presently and new, respectively.

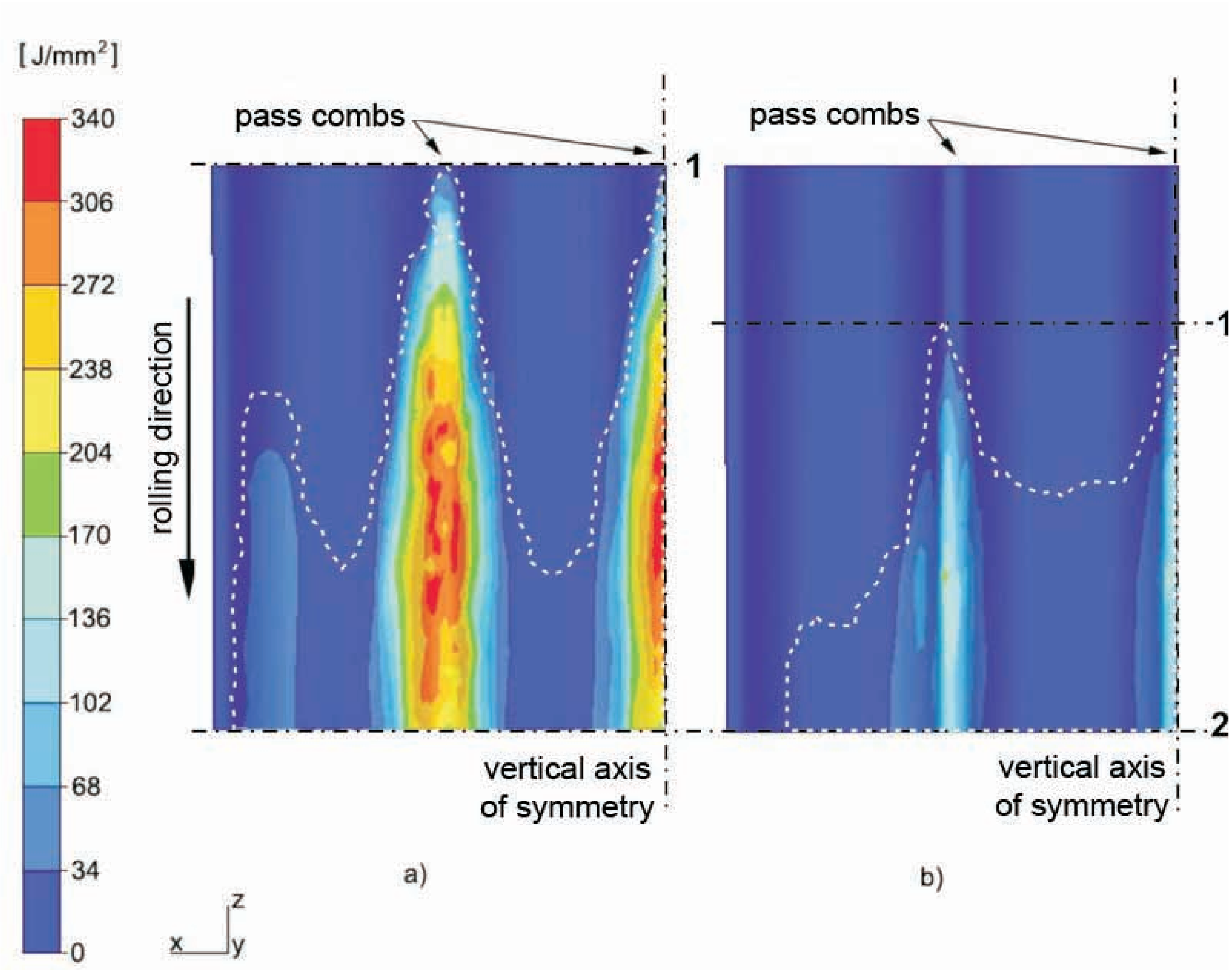

Fig. 7. Distribution of unit friction force work W on the $^1/_2$ of the projection of the metal-upper roll contact surface during the four-strand rolling of 12 mm-diameter ribbed bar in the pre-slitting pass (Stand 15): a) for the roll pass design used presently, b) for the new roll pass design; 1 – the plane of strip entrance to the roll gap, 2 – the plane of strip exit from the roll gap

Comparison of the obtained values of unit friction force work on the surface of strip con-tact with the pre-slitting pass (Fig. 7) and with the slitting pass (Fig. 8) shows that for the new passes (Figs. 7b and 8b) these values are much lower compared to the values obtained for the passes used so far (Figs. 7a and 8a). The maximum value of unit friction force work on the sur-face of the presently used pre-slitting pass amounted to 343 J/mm^2, while on the surface of the new pass this value was reduced to 234 J/mm^2. In the slitting pass used so far, on the other hand, the maximum value of unit friction force work was 326 J/mm^2, while the application of the new roll pass design resulted in a substantial decrease in unit friction force work down to 220 J/mm^2. Both during rolling in the system of passes used presently, and during rolling in the new arrangement of passes, the most vulnerable to wear are the surfaces of both combs, for both the middle and outer strands. With the combs, bridges (their height and width) are formed, which join individual strands of strip being rolled. These are the areas, where the metal undergoes the greatest rolling reduction; therefore, it is also here that the wear of those pass elements will be the highest.

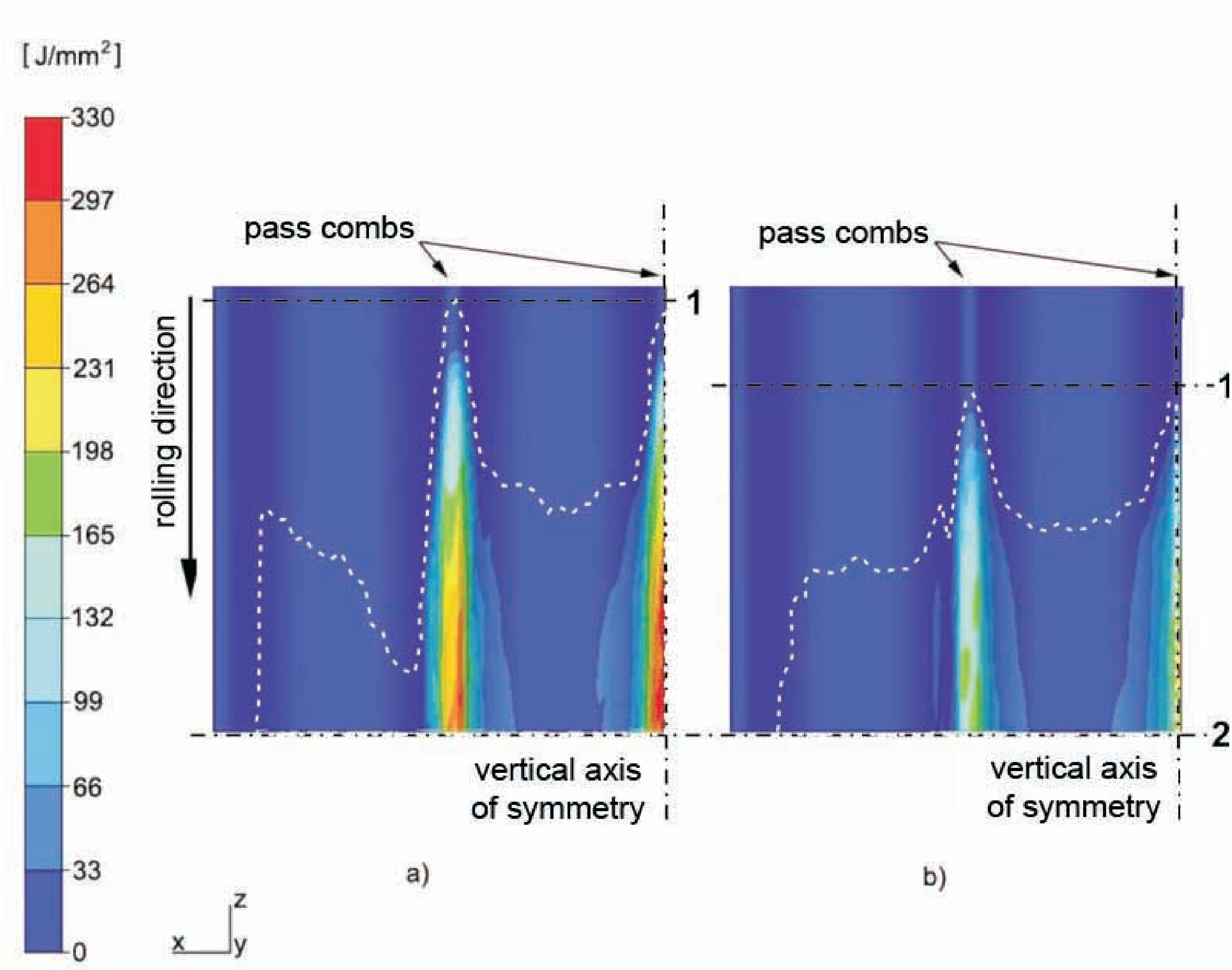

Fig. 8. Distribution of unit friction force work W on the $^1/_2$ of the projection of the metal-upper roll contact surface during the four-strand rolling of 12 mm-diameter ribbed bar in the slitting pass (Stand 16): a) for the roll pass design used presently, b) for the new roll pass design; 1 – the plane of strip entrance to the roll gap, 2 – the plane of strip exit from the roll gap

The verification of the results of theoretical studies on the wear of the slitting passes de-signed within the new pass design was performed during rolling 12 mm-diameter ribbed bars in a Bar Rolling Mill. Within the experimental tests, the mass of finished products rolled in one roll assembly with a slitting pass (Stand 16) was determined. As the slitting pass, the one was selected, which wears most rapidly in the whole rolling train due to its unique shape. The mass of 12 mm-diameter ribbed bars rolled in four strands according to the existing and new roll pass designs, respectively, is shown in Fig. 9. It can be stated that the change of the previ-ous roll pass design in four stands of the finishing group for the new one resulted in a significant reduction of slitting pass wear.

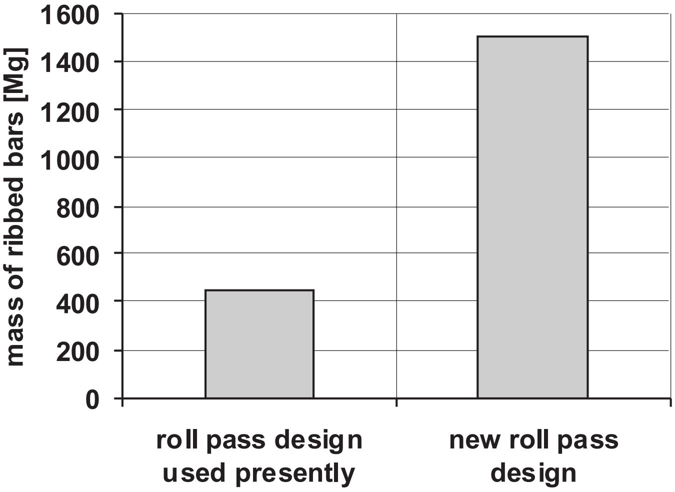

Fig. 9. The mass of 12 mm-diameter ribbed bars rolled in passes made according to the presently used and the new roll pass designs, respectively

The application of the new roll pass design in the finishing stand group made it possible to roll out three times the mass of finished products without having to replace the rolls. Extending the rolling campaign time will increase the productivity of the Rolling Mill.

Theoretical computation of the energy-force parameters was made within the present work using the computer program Forge2007®. The obtained results were verified during tests car-ried out in industrial conditions (Fig. 10).

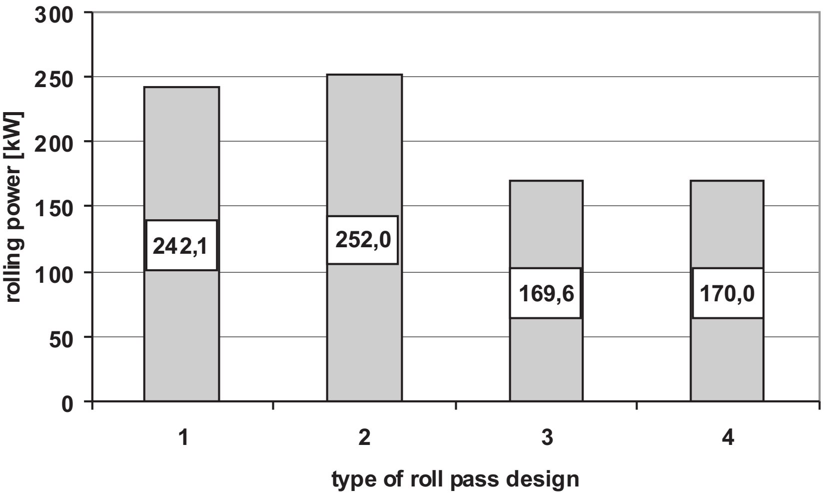

Fig. 10. Rolling power demand in the slitting pass in Stand 16 during rolling 12 mm-diameter ribbed bars according to the four-strand technology: 1 – roll pass design used presently (industrial measurements), 2 – roll pass design used presently (FEM simulation), 3 – new roll pass design (industrial measurements), 4 – new roll pas design (FEM simulation)

Comparison of the test results indicates that by using the new roll pass design a considerable reduction in rolling power can be achieved, compared to the rolling in the present pass system. For the presently used pass system, the average rolling power demand for the steady rolling process was 242 kW, while for rolling in the new passes the power demand substantially decreased, amounting to 169.5 kW. As a result of the roll pass design change for the finishing stand group during the four-strand rolling of 12 mm-diameter ribbed bars, a very significant rolling power decrease by up to 30% was achieved for Stand 16 (the slitting pass). Moreover, it was found that the results obtained from experimental tests and theoretical studies differed only slightly, for both the presently used and the new roll pass designs. The relative difference amounted to, respectively, +4.0% for the roll pass design used presently and +0.2% for the new roll pass design.

4. Conclusion

It was established from the obtained results of both theoretical studies and experimental tests that the implementation of the new roll pass design in industrial conditions enabled the application of smaller metal deformations in individual passes, owing to which the wear of the slitting passes decreased significantly compared to the existing roll pass design. The addition of the intermediate edging pass with a rounded bottom provided the capability to control the width of strip being rolled. This is an innovative solution, unusual in the present industrial practice. The implementation of the new roll pass design has increased the durability of rolls by three times and markedly extended the rolling campaign. The application of numerical modelling to the analysis of the bar rolling process with longitudinal strip partition makes it possible to optimize the roll pass design and enables a more favourable distribution of energy-force parameter values to be achieved in individual passes of the Shape Mill.

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