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Examination of the effect of slitting roller shape on band slitting during the multi slit rolling process

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Analysis and modelling

ABSTRACT

Purpose: Basing on the results of computer simulations, it will be possible to choase proper technological parameters for the slitting rollers (such as shape), which will assure the slitting of the band and verify the force parameters.
Design/methodology/approach: Using FEM-based computer programs for solving the problems of the theory of plasticity enables determining the force parameters during the band separation and enabled also the determination of the tools abrasive wear.
Findings: Longitudinal band separation depends on the shape of the used slitting rollers. Increasing the roller opening angle has an effect on the force parameters and on the tools abrasive wear.
Practical implications: The use of commercial software applications in the design of process technologies will allow for the development of a multi slit rolling technology with a minimum number of laboratory and industrial trials.
Originality/value: Using the cracking (element removal) algorithm implemented in the Forge3® program, it was possible to carry out the numerical modiling of the proces for rolling with band slitting.
Keywords: Numerical techniques; FEM; Slitting rollers; Multi Slit Rolling (MSR) process

1. Introduction

One of the prospective directions in the intensification of production of shape mills is rolling in multi-strand passes. The main idea behind this technology is the possibility of producing two, three, four and even five rods simultaneously from a single band (a continuous casting or billet) in a hot rolling process [1-3].

To separate the band into separate strands, a special exit rig box is used, where breaking of the band connecting bridge takes place; band separation is done by dividing rollers, which shape is designed according to the slitting pass shape of an "eight" type. The slitting rollers did not have a constant speed and are not propelled. It is essential that the pre-slit band is accurately introduced to the second slitting pass [4-5].

The processes of rolling in multi-strand passes are characterized by a spatial state of strain and are difficult to be accurately described by mathematical models. Particularly difficult to define the pattern of metal flow in the slitting pass and the band slitting process itself. In order to carry out computer simulations of these processes, it is necessary to use mathematical models that utilize the complete three-dimensional solution by the finite-element method. The finite-element method is one of the effective methods of the spatial solution of the rolling problem, which has been widely applied recently [6-8].

The use of commercial software applications in the design of process technologies, and the number of laboratory and industrial tests can be limited to an indispensable minimum [9-13]. In this study, the Forge3® [14] computer program was employed to the analysis of the process of rolling with band slitting. The band slitting is implemented by the algorithm of removing elements for which the critical value of the normalized Latham–Cockroft [15] criterion has been exceeded.

Basing on the results of computer simulations, it will be possible to chose proper technological parameters for the slitting rollers (such as shape), which will assure the slitting of the band and the tools abrasive wear.

2. Conditiona adopted for numerical computation

For the examination of the rolling with longitudinal band slitting, a three-strand roll pass design, as used in one of the Polish steelworks for the rolling of Ø 8 mm was utilized [5].

For the computer simulation of multi-slit-rolling on a D350 continuous rolling mill, the following rolling conditions were adopted: the working roll diameter D = 356 mm, the slitting roller diameter D_{sr} = 164 mm; rolled material – steel BSt500S (according to the Polish standard), rolling temperature – 1070°C; friction factor = 0.8; tool temperature – 60°C; ambient temperature – 20°C; 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. In order to determine the limiting value of the criterion of separation during multi-slit-rolling process, the inverse method was used [4]. Rolling speed was 9.7 m/s in the slitting pass.

A theoretical analysis of the effect of the shape of slitting rollers on the process of band slitting during the rolling of 8 mm-diameter ribbed rods rolled according to the three-strand technology was carried out within this study. Figure 1 shows the shape of rollers used during numerical tests. Four shapes of slitting rollers were used in the numerical tests, which differed in the magnitude of the angle used: Variant A – opening angle of 80°; Variant B – opening angle of 90°; Variant C – opening angle of 100° and Variant D – opening angle of 110°.

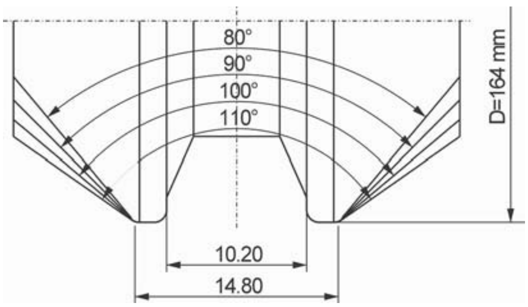

Fig. 1. Shape of slitting rollers used in numerical tests

Figure 2 shows the assembly (band, a working roll and a slitting roll) used in computer simulations. In order to reduce the computation time, a ¼ of the band was used. In industrial conditions, the distance of the working rolls axis from the slitting rollers axis is 350 mm; to reduce the computation time this distance was reduced by 250 mm to 100 mm in the study. The slitting rolls did not have a constant speed and were not propelled.

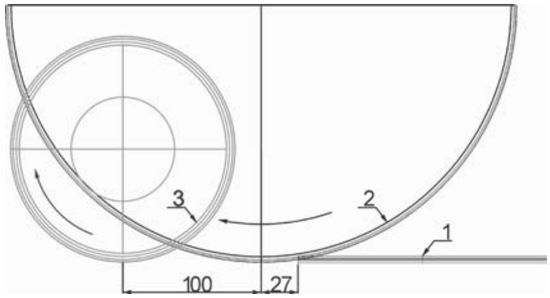

Fig. 2. Schematic diagram of the system used in the numerical modeling of band slitting: 1) stock, 2) working roll, 3) slitting roller

3. Results and discussion

Figures 3-5 show variations of the total force of metal pressure on the separation rollers, as obtained for three mutually perpendicular directions, during the separation of band on the rollers designed.

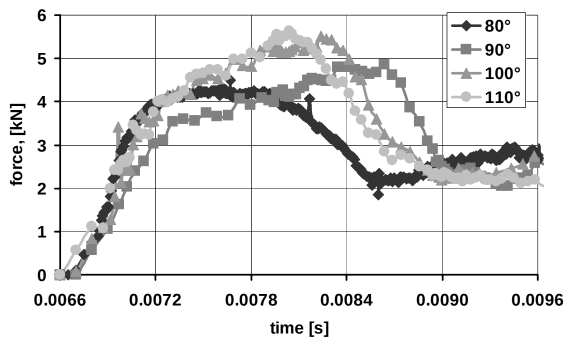

Fig. 3. The variation of the force of metal pressure on the separation rollers during band movement within the rolling line in the direction transverse to the rolling direction

It can be found by analyzing the information given in Figs. 3-5 that there are two stages of slitting, which differ in obtained values of the pressure force. The first stage is from the 0.0072 to the 0.008450 seconds of the slitting process duration, where increased total force, and the second stage between the 0.0087 and the 0.0096 seconds of the slitting process duration, where the forces considerably decrease, irrespectively of the shape of slitting rollers.

From the data in Figs. 3-5 it can also be found that there is an effect of the separation roller shape on the variation of the force of metal pressure on the separation rollers, irrespective of the direction analyzed. This effect is particularly visible for the first separation stage. The use of separation rollers with angles of opening of 110 and 110° resulted in the occurrence of local maximum values, compared to the results obtained for rollers with angles of opening of 80 and 90°. With the use of rollers with angles of opening of 80 and 90°, the variations of the force of metal pressure on the rolls followed a straight line. This shape of the representation of overall pressure force variations indicates a smooth progress of the first, transient separation stage. For rollers with angles of opening of 100 and 110°, on the other hand, the appearance of the local maximum values in the first separation stage suggests a more uniform and more impact behaviour of the transient separation stage.

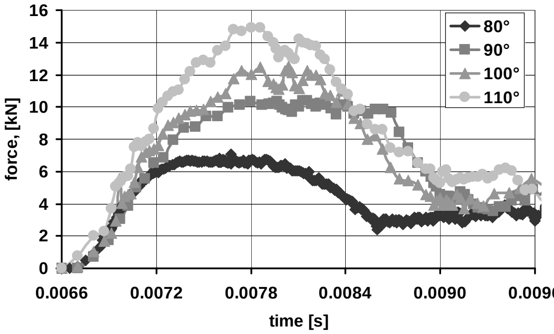

Fig. 4. The variation of the force of metal pressure on the separation rollers during band movement within the rolling line in the direction vertical to the rolling direction

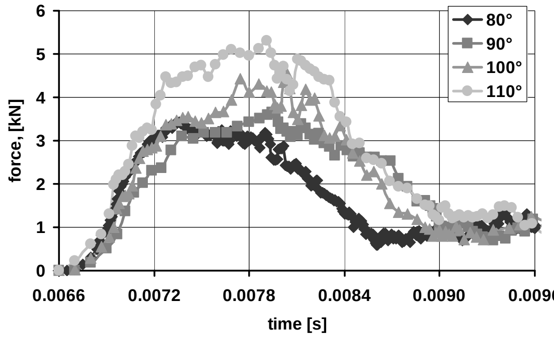

Fig. 5. The variation of the force of metal pressure on the separation rollers during band movement within the rolling line in the direction longitudinal to the rolling direction

From the analysis of the separation process in the second stage, as shown in Figs. 3-5 (between the 0.0087 seconds and the 0.0096 seconds of the process duration), it can be observed that the effect of the separation roller shape on the overall pressure force was only slight.

From the analysis of the data in Figs. 3-5 it has been concluded that the shape of separation rollers influences most the value of the vertical component of the force of overall metal pressure on the separation rollers. For both Stage I and Stage II, maximum force values were noted for this direction. It has been found from the analysis of the data in Figs. 3-5 that the use of separation rollers with an angle of opening of 110° results in an increase in this force by over two times in Stage I and by over 1.6 times in Stage II, compared to the values obtained for the separation rollers with an angle of opening of 80°. The pressure force values obtained for the two remaining directions (respectively, transverse and parallel to the rolling direction) do not exhibit so substantial differences as for the vertical direction.

To better illustrate the effect of the separation roller shape (angle of opening) on the value of the force of overall metal pressure on the rollers, its values, obtained from the first separation stage, have been averaged. Figure 6 shows the average values of the force of overall metal pressure on the separation rollers for three mutually perpendicular directions during the separation of band on the rollers designed.

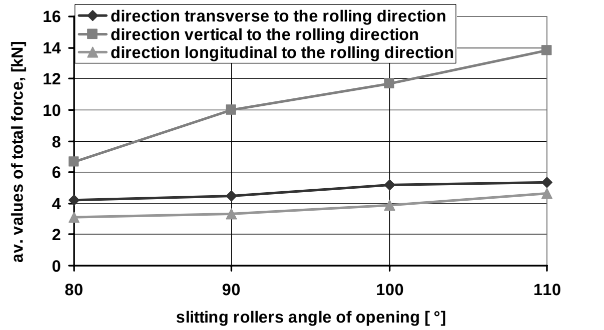

Fig. 6. Comparison of average values of the total force of metal pressure on the separation rollers

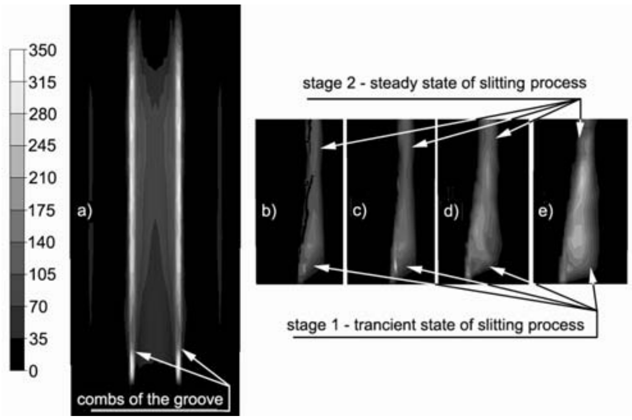

Fig. 7. Distribution of wear during rolling 8 mm-diameter ribbed rod: a) the working roll, b) ½ the slitting roller – Variant A, c) ½ the slitting roller – Variant B, d) ½ the slitting roller – Variant C, and e) ½ the slitting roller – Variant D, [MPa mm/s]

From the data in Fig. 6 it can be found that there is an effect of the separation roller shape on the overall pressure force values occurring in the three mutually perpendicular directions. During the first separation stage, the largest forces are needed for setting the rollers in rotary motion and the initiation of band separation. The highest forces occurred for the use of rollers with an angle of opening of 110° (the force value was 13.8 kN for the direction vertical to the rolling direction), whereas the lowest forces occurred, when rollers with an angle of opening of 80° were used (the force value was 6.6 kN for the direction vertical to the rolling direction). For the two remaining directions, i.e. the directions, respectively, transverse and parallel to the rolling direction, no significant effect of increasing the roller angle of opening on the obtained pressure force values was found. Increasing the angle of opening of separation rollers influences most the force values obtained in the direction vertical to the rolling direction, i.e. the rolling reduction direction. The considerable increase in the overall pressure force value depended, *inter alia*, on the area of metal contact with the rollers during the first separation stage, which substantially increased with increasing roller opening angle.

A correctly designed rolling tool, in addition to imparting an appropriate shape to the product rolled, must exhibit high durability. Figure 7 shows the distribution of the relative wear of a working roll and slitting rollers during rolling 8 mm-diameter ribbed rod by the three-strand technology.

The distributions of roller wear, shown in Figures 7b-7d, represent the contact of the band with the separation rollers. The analysis of the data showed that increasing the roller opening angle has an effect on the shape and size of the area of contact between the band and the separation rollers, both in the transient stage and the steady stage of band separation. Increasing the roller opening angle caused the band in the first stage to contact a larger roller area, and larger roller separation surfaces were prone to wear, compared with the rollers, in which smaller opening angles were used. Increasing the contact areas for rollers with larger angles of opening contributes to an increase in the force of overall metal pressure on the rollers.

4. Conclusions

From the performed analysis of the separation process It can be found that the shape of separation rollers has a great effect on the from the performed analysis of the separation process of the initial band separation stage.

An analysis carried out reveded that the shape of separation rollers significantly influenced the band separation process. The greatest effect of the change of separation roller shape was observed as a considerable increase in the value of the component of the force of overall metal pressure on the rollers, vertical to the rolling direction.

The use of numerical modeling enabled also the determination of the tools wear.

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