ROLL PASS DESIGN FOR RIBBED BARS

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Abstract

The aim of the present work was to develop a safe and reliable roll pass design for producing ribbed bars. For this purpose slit rolling method with use of dog-bone and slit-pass grooves was applied. The cases of roll pass design using various shapes of dog-bone and slit-pass grooves were considered. For this purpose the stress and strain fields were calculated from finite-element method, assuming viscoplastic model of the deforming body. The obtained results allowed for direct analysis and gave better information about metal flow in the roll gap when slitting passes are used. The paper describes also the problems during industrial application of roll pass design when dog-bone and slit-pass grooves are used.

Keywords: rolling of ribbed bars, roll pass design, slit rolling method, finite-element analysis.

1. SLIT ROLLING FEATURES

The market demand for rolled bars of the smallest diameters caused that steel producers began to employ single or multiple longitudinal slitting during rolling, so called Slit Rolling (SR) or Multi Slit Rolling (MSR) \cite{1-3,5}. These methods resulted also from the necessity of increasing the productivity of light and medium-section mills without bearing high investment cost. At the same time, the application of this technology enables a decrease of production costs with maintaining the high quality of products. The slit rolling technology as applied to rolling mills enables production of two, three, four or even five bars from one billet, Fig. 1 and Fig. 2. The slitting process uses special passes and guides to prepare, shape and longitudinally separate the incoming billet into two or more individual strands, which will then be further rolled into finished sizes. The advantages of above method brought about changes of roll pass design in Light Section Mill at Celsa Huta “Ostrowiec”. This continuous mill consists of 25 stands arranged in 5 groups and is able for rolling in two strands. The schematic layout of rolling stands is presented in Fig. 8.

\textbf{Figure 1.} Comparison of roll pass design for: a) conventional bar rolling, b) and c) rolling with longitudinal slitting.
One of the main tasks of modernisation was to increase mill productivity without bearing high investment cost. The introduction of slit rolling technology enabled to reach this target.

The aim of the present work was to develop a safe and reliable roll pass design for producing ribbed bars using slit rolling method. For this purpose the stress and strain fields were calculated from finite-element method (FEM), assuming viscoplastic model of the deforming body. Furthermore, physical modelling of workpiece deformation in both slitting passes was realised with application of Gleeble simulator. Different cases of roll pass design using various shapes of dog-bone and slit-pass grooves were considered. The obtained results allow to learn more about the metal flow in slitting passes and, in consequence, to design the rolling process and tools more precisely.

2. ROLL PASS DESIGN USING SLITTING PASSES

Roll pass design in case of ribbed bars with longitudinal slitting is based on the application of special shaping passes – so-called cutting-in passes – in the final stage of the rolling process [1,6,7]. Rolling in slitting passes is of great significance considering succeeded application of SR method in bar production. In these passes the metal is subjected to deformations considerably differing from those occurring in conventional stretching or shaping passes [4].

The most important problem when designing the process of bar rolling with application of SR method is the shape determination of the grooves called “dog bone” and “slit pass”. The remaining passes, before and after slitting, are most often standard stretching passes typical for round bar rolling, e.g. square-oval-square. Example shapes of slitting passes used for dividing the billet into two and more strands are presented in Fig. 2, Fig. 3 and Table 1. As mentioned before, the essence of the method is the application of two or three consecutive shaping passes, in which deformations of metal considerably differ from those occurring in conventional stretching passes.

The construction of the first shaping pass – so-called “dog bone” – is characterized by the symmetrical “knives” of quite large height, Fig. 4a. The essence of rolling in this pass is to provide precise dividing of square into two equal parts. Precise inserting of a bar into the pass and holding it in a right position is realized with application of rolling guide systems. Any irregularities such as asymmetrical slitting are impossible to be corrected subsequently and lead to rejects.
The second shaping pass – so-called “slit pass” – is the final one dividing the bar into two strands. In the axis of the pass very high and narrow “knives” are situated, and the minimum distance between them is set, Fig. 4b. The material leaving the rolls should consist of two almost perfectly equal parts connected to each other with a narrow and thin web of 1 mm maximum thickness.
3. METAL FLOW IN SLITTING PASSES

Introducing new rolling technologies into industrial operation requires thorough examination and prediction of forming conditions in technological processes. Hence, for this purpose various methods of computer calculation and physical modelling are used.

In order to assess the metal flow in slitting passes, the analysis of the influence of shape and width of slitting “knives” was performed, with varying technological parameters such as temperature of rolled material and roll diameter [4, 7]. In particular, in case of three values of slitting “knife” relative height (38 %, 44 % and 50 %), three different shapes of knife (Fig. 5a) as well as three different widths (Fig. 5b) were analysed.

Finite element method was selected to be applied in the essential part of the analysis of metal deformation in slitting passes. The commercial computer program was used for calculations.

Figure 4. Roll pass design of slitting grooves: a) dog-bone, b) slit pass.

Table 1. Typical application of slitting grooves for various profile dimensions.

<table>
<thead>
<tr>
<th>shape</th>
<th>flat</th>
<th>DB</th>
<th>SP</th>
<th>oval</th>
<th>round</th>
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<tbody>
<tr>
<td>![shape_icon]</td>
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<td>![DB_icon]</td>
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<td>![oval_icon]</td>
<td>![round_icon]</td>
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<tr>
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<td>![SP_icon]</td>
<td>![oval_icon]</td>
<td>![round_icon]</td>
<td>φ 18</td>
</tr>
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Figure 5. Assumed in analysis: a) shapes, b) width of slitting knives.
Thermomechanical analysis of metal flow was based on the assumption of viscoplastic model of deformation, in which the stress deviator is proportional to the strain rate

\[ \dot{\sigma}_{ij} = \dot{\gamma}_{ij} \alpha \]

where:
- \( \dot{\sigma}_{ij} \) - deviator of the Cauchy stress tensor,
- \( \dot{\gamma}_{ij} \) - strain rate tensor,
- \( \alpha \) - viscosity.

The stress and strain fields in a rolled bar were found from the minimum of the following power functional:

\[ J = \int \frac{1}{2} \sigma_{ij} \varepsilon_{ij} - \int F \cdot dV \]

where:
- \( \sigma_{ij} \) - effective stress,
- \( \varepsilon_{ij} \) - vector of strain rate components,
- \( F \) - external traction,
- \( \varepsilon_{ij} \) - effective strain rate,
- \( F \) - external traction,
- \( \alpha \) - Lagrange multiplier,
- \( v \) - velocity.

For calculation the field temperature within the rolled material Fourier quasiharmonic differential equation is applied. This equation is describing temperature variations at unsteady heat flow, in the following form:

\[ \frac{\partial T}{\partial t} = \frac{k}{\rho c_p} \nabla^2 T + Q \]

where:
- \( k \) - heat conduction coefficient,
- \( \rho \) - density,
- \( c_p \) - specific heat,
- \( Q \) - rate of heat generation,
- \( T \) - temperature.
Prior to the theoretical calculations a series of laboratory tests of metal properties were performed using torsional plastometer and Gleeble simulator. The obtained results in a form of flow stress variations as a function of strain were loaded as a data base into the computer program. As a results of calculations, the complete metal flow patterns in dog bone and slit pass grooves were determined. Example distributions of temperature and effective strain on a cross section of bar rolled in a dog bone pass are shown in Fig. 6a and 6b. Distinct differences can be seen, concerning temperature – reaching almost 50°C, as well as effective strain – reaching up to 1.7. The effect of the shape of slitting knife in a dog bone pass on the distribution of effective strain is presented in Fig. 7. In the zone of knife acting the strains occur which show similar magnitude, but different distribution, as influenced by the shape of a knife. Larger strains occurring at knife corners result in increased wear of knife and increased thickness of a web connecting two parts of a bar, which in turn makes it more difficult to finally separate the two strands.

![Figure 6](image)

**Figure 6.** Example distribution of: a) temperature (°C), b) effective strain during rolling in a dog bone groove.

The graphs presenting the distributions of stresses, strains and temperature in the deformation zone allow direct analysis, which gives better information about the phenomena in the roll gap and it confirms the differences of metal flow when slitting passes are used. The obtained results allow, in consequence, to design roll grooves more precisely.

4. **INDUSTRIAL APPLICATION**

Following the modernization, the light section mill is now able to produce round bars using slit rolling method. The longitudinal slitting of incoming billet for two or three bars was put into use for rolling ribbed bars of the smallest diameters. Figure 8 shows the comparison of production routes for conventional rolling and rolling with slitting for two bars.
Figure 7. The effect of the shape of slitting knife on the distribution of effective strain.

Some of the outstanding advantages of the application of roll pass design with slitting for the production of ribbed bars in light section mill are as follows:

?? reduction in operation costs, mainly due to energy and gas consumption, Fig. 9,
?? reduction in number of passes and used rolling stands, Fig. 8,
?? significant increase of productivity, Fig. 10,
?? possibility of using of heavier incoming billets.

Finally the product range was extended, production rate was increased and operation costs were reduced thanks to the opportunities of new roll pass design with longitudinal slitting.

Figure 8. Comparison of process routes for a) conventional and b) slit rolling (2 x SR 2).

Figure 9. Comparison of energy consumption during rebars rolling (d = 10 mm).
Figure 10. Comparison of productivity for rebars rolling (d = 10 mm).

5. CONCLUSIONS

The conducted investigations of the state of stress and strain as well as distribution of temperature in slitting passes allowed to learn more about the metal flow in these passes and significantly facilitates the roll pass design and rolling equipment, where the knowledge of
parameters such as strains, widening, pressures and bar shapes is required. To recapitulate, the analysis performed within this work and the obtained results allow to formulate the following conclusions:

1. Roll pass design with longitudinal slitting has become not only the standard for small diameter bar rolling, but also a necessity considering high effectiveness of this process.

2. Workpiece deformation (slitting) in the cutting-in passes, being the essential element of slit rolling method, differs considerably from that occurring in typical stretching or forming passes.

3. The performed analysis of the state of stress and strain in the bar rolling process allows to learn more about metal flow in slitting passes and gives the basics for a rational design of slitting grooves as well as the whole process of rolling with longitudinal slitting.

4. Basing on the results of analysis, significant influence of the shape and dimensions of cutting-in passes on the distributions of stresses, strains and temperature in the roll gap was found.

5. Following the industrial application of roll pass design with longitudinal slitting, the product range of light section mill was extended, production rate was increased and operation costs were reduced.

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BIBLIOGRAPHY