A STUDY ON DESIGN OF SLITTING PASSES USED FOR REBAR ROLLING

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Abstract

Modern technology of bar rolling in many cases is based on the application of single or multiple longitudinal slitting, so-called Slit Rolling (SR). The slitting process uses special passes and guides to prepare, shape and separate the incoming billet into two or more individual strands, which will then be further rolled into finished sizes. The essence of this method is the application of two or three consecutive cutting-in passes, in which deformations of metal considerably differ from those occurring in conventional stretching passes.
In order to assess deformations in the slitting passes, finite element method has been applied in the essential part of the analysis. The computations were based on the assumption of thermomechanical model of deformation. The analysis of the influence of shape and width of slitting “knives” was performed with varying technological parameters. In particular, three values of relative height of slitting “knife”, three different shapes of “knife” as well as three different widths were analysed. Furthermore, physical modelling of the deformation in both slitting passes was realized with application of Gleeble simulator. The stress-strain characteristic of steel at relatively high strain rate condition was obtained. As a result of calculations, the complete metal flow patterns in the slitting passes were determined. The graphs presenting the distributions of stresses and strains in the deformation zone allow direct analysis, which gives better information about the phenomena in the roll gap. The obtained results allowed, in consequence, to design slitting passes more precisely and to better use slit rolling method in rolling mill.

Keywords: Rolling of ribbed bars, slit rolling, finite element analysis, metal flow

1. INTRODUCTION

The increasing demand for ribbed bars of the smallest diameters can be observed on the market of rolled products. This results from the tendency of reinforcing new concrete constructions with bars of smaller diameters, but made from steels showing higher mechanical properties, for example RB500W. In order to be up to marked demand, the rolling with single or multiple longitudinal slitting (*slit rolling - SR or multi slit rolling - MSR*) has been applied in the bar mills [1,2,6]. This is the most economical rolling process that allows high production rates also for small size bars and a significant reduction of production cost [7].The slit rolling method enables production of two, three, four or even five bars from one billet. 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. An efficient slitting process requires continuous upgrades of rolling technology and mill equipments in order to obtain the best performance in terms of quality and efficiency.

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 [1,4,5]. In these passes the metal is subjected to deformations considerably differing from those occurring in conventional stretching or shaping passes [5]. Hence, in this paper the process of deformation in slitting passes was analysed, applying computer technique based on the finite element method (FEM) as well as the data concerning the properties of metal being deformed. Furthermore, physical modelling of the metal flow in both slitting passes was realized with application of Gleeble simulator. The obtained results allow to learn more about the metal flow in slitting passes and, in consequence, to design the rolling process and grooves more precisely.

2. CHARACTERISTIC FEATURES OF SLITTING PASSES

Some of the outstanding advantages of the application of slit rolling technology for the production of ribbed bars are as follows:

- easy adaptation to existing rolling mills with low investment costs,
- reduction in number of passes and rolling stands,
- significant increase in production rates,
- reduction in operation costs.

The most important problem when designing the process of bar rolling with application of SR or MSR method is the determination of the shape of cutting-in passes 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. In slit rolling technology, beside the standard slitting of bar into two strands, the multiple slitting into three, four or even five separate strands is also being applied [5]. Example shapes of slitting passes used for single dividing of billet from two to five strands are presented in **Fig. 1**.

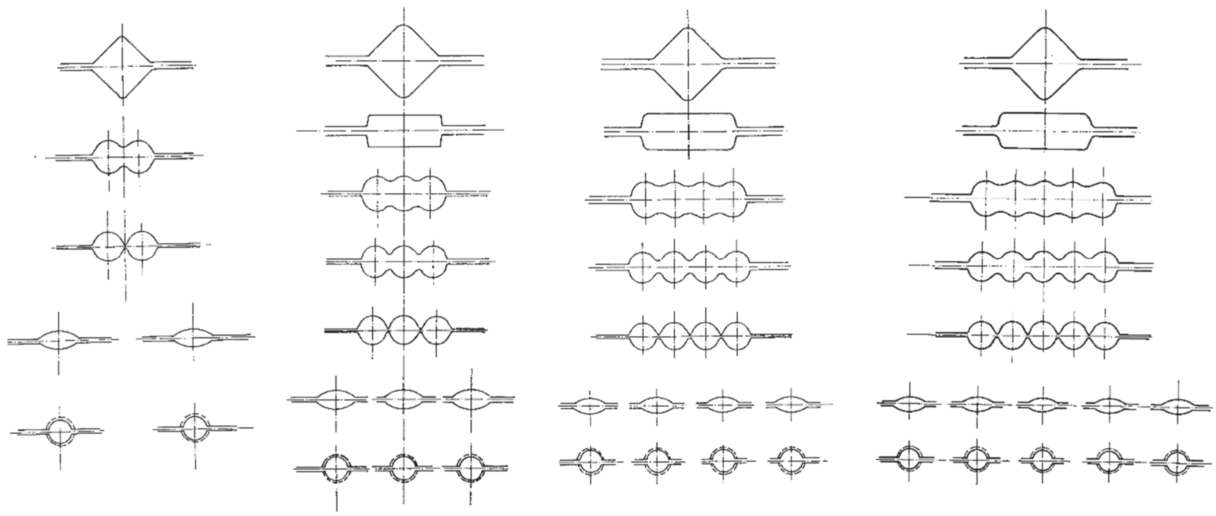

Fig. 1 Example of bar slitting for two, three, four and five strands

As mentioned before, the essence of the method is the application of two, more rarely three, consecutive shaping passes, in which deformations of metal considerably differ from those occurring in conventional stretching or forming passes.

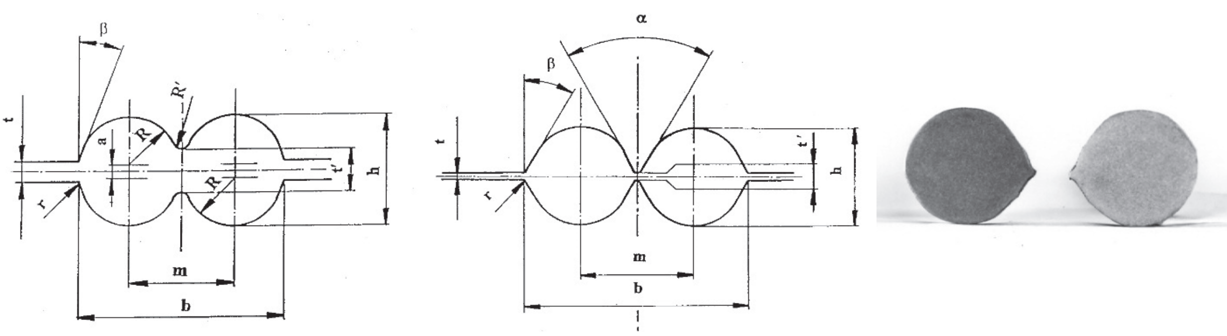

Fig. 2 The design of dog bone and slit grooves (left and middle) and view of divided bars (right)

The construction of the first shaping pass - so-called "dog bone" - is characterized by the symmetrical "knives" of quite large height, **Fig. 2**. 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 groove very high and narrow "knives" are situated, and the minimum distance between them is set. The material leaving the rolls should consist of two almost perfectly equal parts connected to each other with a narrow and thin web of 0.8 - 1 mm thickness. Apart from that, the shape and width of slitting "knives" are also crucial for rolling performance and wearing of the rolls.

3. METHOD OF ANALYSIS

Introduction of new technology into industrial operation, requires thorough examination and prediction of forming conditions in technological process. The complexity of phenomena taking place in slitting passes creates a wide range of possibilities of controlling process parameters and groove filling. However, the principal factor is the ensuring of symmetrical stock feeding and exact controlling the positioning of rolls. Numerical method was used to help the proper designing of both slitting grooves. The commercial computer program 3D (Abaqus/Explicit) has been applied. In order to assess design of slitting "knives" and metal flow inside these grooves, the analysis of the influence of shape and width of slitting "knives" was performed, with varying technological parameters. In particular, three values of slitting "knife" relative height (38 %, 44 % and 50 %), three different shapes of knife (**Fig. 3a**) as well as three different widths (**Fig. 3b**) were analysed.

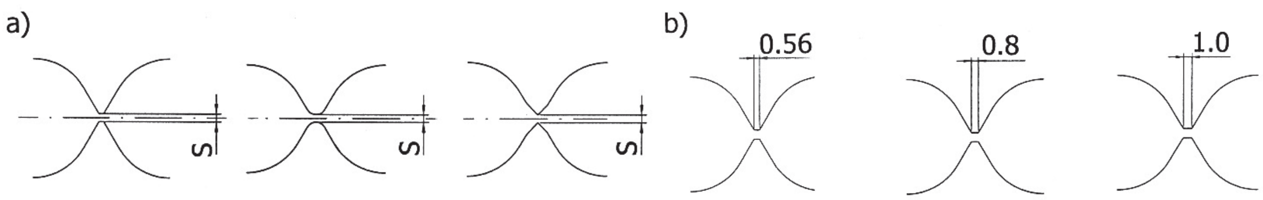

Fig. 3 Assumed in the analysis: a) shapes of slitting "knives", b) width of slitting "knives"

Prior to theoretical calculations a series of laboratory tests of metal properties was performed using torsional plastometer. The obtained results in a form of flow stress variations as a function of strain (**Fig. 4**) were loaded into the computer program as a data base. As a result of calculations, the complete metal flow patterns in the analysed slitting passes (dog bone and slit pass) were determined.

Apart from this analysis, physical modelling of the process of deformation in both slitting passes was realized with application of Gleeble simulator. The test parameters, i.e. temperature of rolled bar, strain, strain rate and idle time between passes, were selected to reflect the deformation conditions occurring in industrial bar rolling process as precisely as possible, similarly as was done in [3]. Example results, obtained for modelling of bars rolling from RB500W steel grade (**Table 1**), are shown in **Fig. 5**.

Table 1 Chemical composition of RB500W steel grade

Percentage of elements							
Steel grade	**C**	**Si**	**Mn**	**P**	**S**	**N**	**Ceq**
RB 500W	0.22	0.60	1.60	0.05	0.05	0.012	0.50

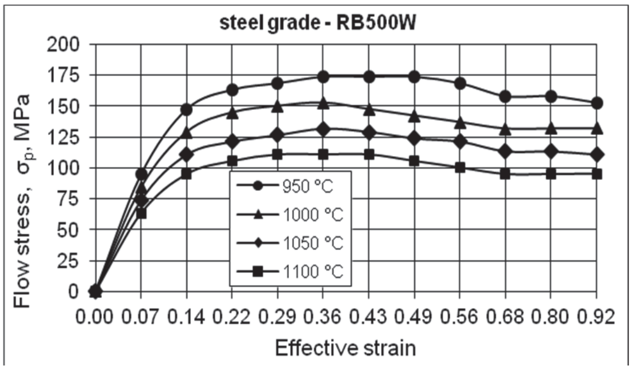

Fig. 4 Flow stress curves obtained from torsion tests for given temperatures ($\dot{\varepsilon}$ = 2 s^{-1})

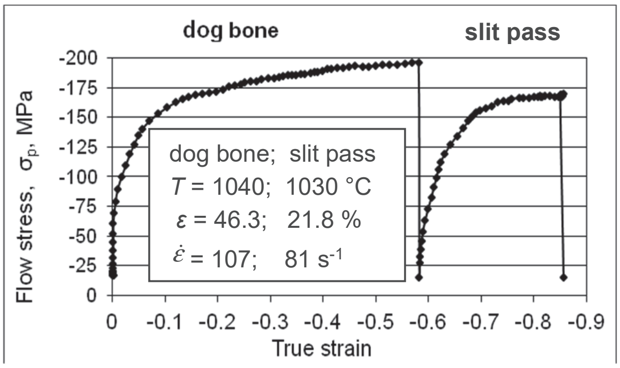

Fig. 5 Physical modelling of bar rolling in slitting passes using Gleeble simulator

4. DISCUSSION OF RESULTS

The main purpose of this investigation was assessing metal flow in the slitting passes, in which deformations of metal considerably differ from those occurring in conventional square-oval-square passes. Especially, the analysis of the influence of shape and width of slitting "knives" has been done. The design of slitting grooves with its knives has a great significance considering application of this method in rebar production. The results of calculation, concerning slitting passes, were obtained in a form of stress and strain components, effective strain, strain rate, temperature and distribution of stress on a contact surface between metal and rolls. Some of them, as an example part of whole results, are discussed in this paper.

Example distributions of effective stress and effective strain on a cross section of bar rolled in a dog bone pass are shown in **Figs. 6a** and **6b**. Distinct differences can be seen at the exit plane in the dog bone pass, concerning stress, as well as effective strain - reaching up to 1.8. The highest temperatures and the largest stresses occurring in the zone between slitting knives of the dog bone and slit grooves, where the largest effective strains are acting.

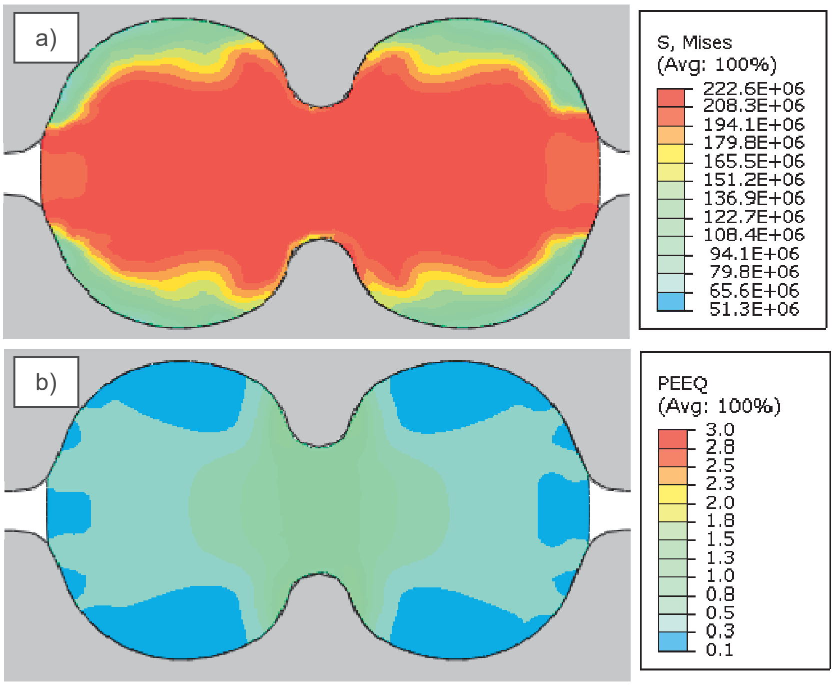

Fig. 6 Example distribution of: a) effective stress in Pa, b) effective strain at exit plane in dog bone groove

The influence of shape and width of slitting knives on metal flow in the roll gap was the next step of analysis. As the example, 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 for two strands. As the result of analysis, **the slitting knives with rounded corners and 0.8 mm width** (**Fig. 3a** and **3b** - middle shapes in both cases) **have been chosen for industrial application**.

Detailed analysis of rolling in slitting passes showed that in certain deformation conditions, especially when small reduction are applied, the phenomenon can be observed, in which the material moves away from the knife, **Fig. 8**. This effect is very unfavourable, particularly when it occurs in a slit pass, considering subsequent separation of a bar. The change in bar geometry manifesting itself in widening of a groove in the middle of a bar cross section, resulting from the above mentioned effect, makes it more difficult, and in extreme cases even impossible, to finally separate the two strands. Such failure is unacceptable and it causes immediate stoppage of the rolling process.

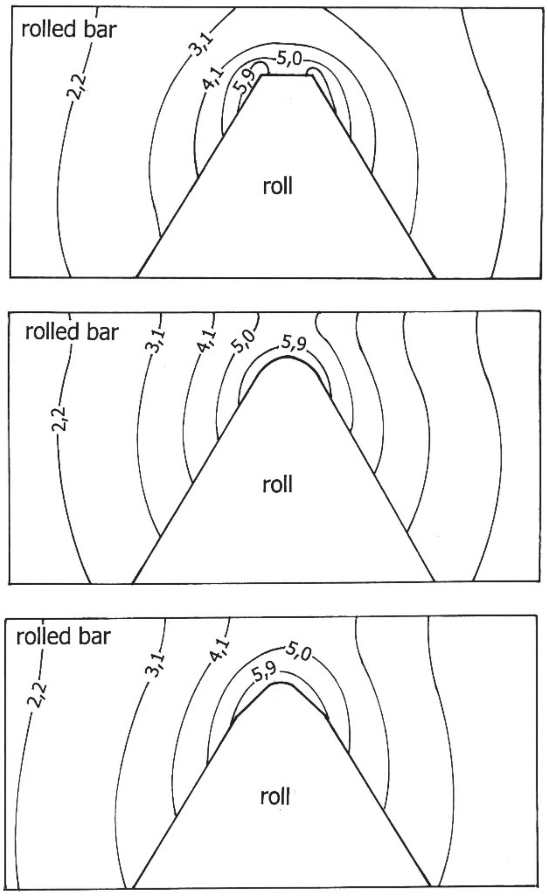

Fig. 7 The effect of shape of slitting “knife” on the distribution of effective strain

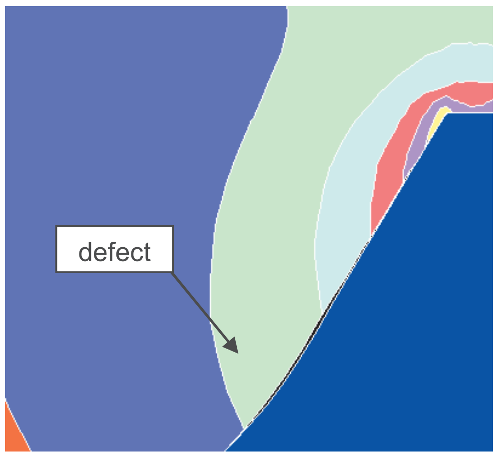

Fig. 8 Separation of the deformed metal from the slitting “knife”

The realized analysis of the state of stress and strain in the deformation zone in slitting passes allowed to learn more about the metal flow in these passes and significantly facilitated the design of passes and rolling equipment, where the knowledge of parameters such as strains, widening, pressures and bar shapes is required.

CONCLUSIONS

The rolling process with longitudinal slitting has become the standard for rolling of ribbed bars of the smallest diameter. Nevertheless, the slitting grooves and the shape of "knives" are continuously investigated and improved. The obtained results, presenting the distributions of stresses and strains in the roll gap gave important information about the phenomena during slit rolling process. They allowed to design slitting passes more precisely, especially the slitting "knives". In consequence, these results allowed for better use of the slit rolling method for the production of ribbed bars. To recapitulate, the analysis performed in the work and the obtained results allow to formulate the following conclusions:

1. The metal deformation in cutting-in passes, being the essential element of slit rolling technology, differs considerably from that occurring in typical stretching or forming passes like square-oval-square.
2. The results of analysis show significant influence of the shape and dimensions of cutting-in passes on the distributions of stresses, strains and other parameters in the roll gap.
3. The results of calculations and physical simulations provided a significant aid for roll pass design, especially the slitting "knives", where the knowledge of parameters such as grooves geometry, deformations, widening and contact pressures is required.
4. Physical modelling of the rolling in both slitting passes, realized in Gleeble simulator, gave stress-strain characteristic of steel being deformed at relatively height strain rate, close to industrial conditions.
5. As the result of analysis, the slitting knives with rounded corners and 0.8 mm width have been chosen for industrial application.
6. Generally, the performed analysis of the state of stress and strain in the rebar rolling process allows to learn more about metal flow in slitting passes and gives the basics for better design of slitting grooves.

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