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EXAMINATION OF ENERGY AND FORCE PARAMETERS DURING ROLLING PROCESS USING LONGITUDINAL SLITTING PASSES

Rolling of rods with slitting of the strip calls for the use of special mathematical models that would allow for the tearing of metal. For the numerical modelling of strip slitting and for the examination of energy and force parameters the Forge3® computer program was applied. The separation of the band is effected by means of separating rollers, whose shape must be properly designed to suit to the slitting pass. In the process of rolling with longitudinal strip splitting, the separating rollers are not driven. The energy and force parameters needed for the rollers to rotate derive from the driven working rolls. Therefore, the empirical relationships for the calculation of energy and force parameters, which are known from literature, cannot be employed for the proper determination of these parameters during rolling a band in the slitting pass and the separation itself. Using FEM-based computer programs for solving the problems of the theory of plasticity enables, in addition to determining the energy and force parameters in complex plastic working processes, also accounting for a number of process specificities, which are not provided for by the empirical formula.

Прокатка катанки с продольной резкой требует использования специальных математических моделей, которые будут учитывать образование трещин в металле. Компьютерная программа Forge3® применялась для численного моделирования продольной резки и для изучения энергетических параметров и показателей усилий. Разделение ленты происходит посредством разделительных роликов, чья форма должна быть специально разработана для соответствия разрезному калибру. В процессе прокатки с продольной резкой разделительные катки не имеют собственного привода. Энергетические параметры и показатели усилий, необходимые для вращения роликов, передаются от приводимых во вращение рабочих роликов, поэтому эмпирические зависимости для расчета энергетических параметров и показателей усилий, известные из справочной литературы, не могут быть применены для правильного определения данных параметров при пропуске прокатной ленты через разрезной калибр и при собственно продольной резке. Использование компьютерных программ, базирующихся на методе конечных элементов, для решения задач теории пластичности позволяет кроме определения энергетических параметров и показателей усилий в сложных процессах пластической обработки учитывать определенное количество специфических аспектов процесса, не учитываемых в эмпирических формулах.

Introduction

One of the prospective directions in the intensification of production of shape mills is rolling in multi-strand passes. The main idea of the technology is the capability of producing two, three, four and even five rods simultaneously from a single strip (a continuous casting or billet) in a hot rolling process. 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 is the pattern of metal flow in the slitting pass and the strip 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 and also the special mathematical models that would allow for the separating of metal. For the numerical modeling of strip slitting the Forge3® [1] computer program was applied. The strip slitting is implemented by the algorithm of removing elements for which the critical value of the normalized Latham-Cockroft [2] criterion has been exceeded.

The proper design of the slitting pass rolling process requires taking into account several

limitations that affect this process. When developing a technology, energy & force parameters should be considered, among other things. Many approaches to the determination of these parameters can be found in literature. Each of them has some simplifications which, more or less, affect the correctness of the solution. In addition to the yield stress, important parameters influencing the result of the rolling technology design include also rolling the rolling force and the rolling moment. In many instances, they are of paramount importance. The use of the computer program enabled the determination of energy & force parameters during rolling rods in slitting passes. During their determination, it could be possible to consider the complex shape of particular passes.

Experimental conditions and simulations

For the examination of energy & force parameters during rolling with longitudinal strip splitting, a two-strand of Ø 20 mm ribbed rod roll pass design, as used in one of the Polish steelworks, was utilized. Obtaining templates originating from the real technological process of ribbed rod manufacture is very difficult. Therefore, templates taken during the preliminary rolling mill setting were used (Fig.1).

The theoretical analysis was performed for the real rolling conditions: the initial strip temperature – 1000 °C, the rolling speed in the slitting pass – 5.9 m/s, the working roll diameter $D = 350$ mm, the slitting roller diameter $D_{sr} = 164$ mm. Moreover, the following input data were taken for the simulation: tool temperature – 60 °C; ambient temperature – 20 °C; friction factor – 0.8; 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] and value of the normalized Latham-Cockroft criterion – 0.7 [3]. In order to reduce the computation time, a ¼ of the band was used. The distance between the working rolls axis and the slitting rollers axis was 350 mm. The slitting rolls did not have a constant speed and were not propelled.

Results and discussion

The empirical relationships for the calculation of energy and force parameters, which are known from literature [4], cannot be employed for the proper determination of these parameters during rolling a band in the slitting pass and the separation itself. Using FEM-based computer programs for solving the problems of the theory of plasticity enables, in addition to determining the energy and force parameters in complex plastic working processes, also accounting for a number of process specificities, which are not provided for by the empirical formula. Therefore, a theoretical analysis of the obtaining values of the rolling torque and power in the manufacture of 20 mm-diameter ribbed rods with the two-strand technology was performed within this study.

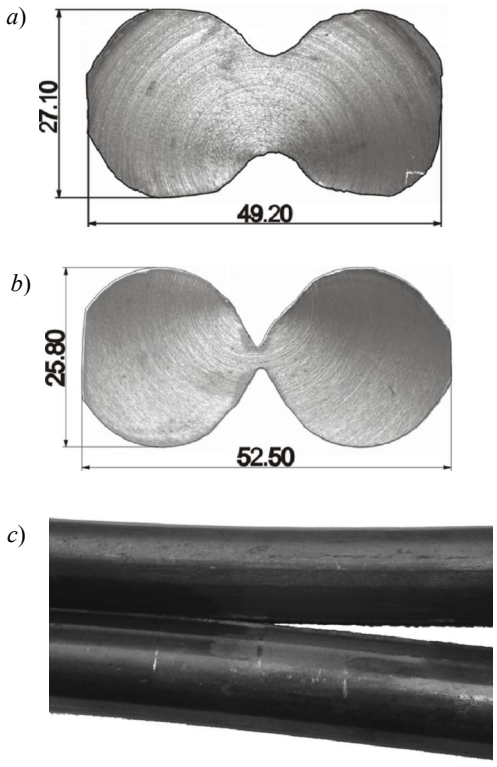


Fig.1. Shape and dimensions of templates of 2 × 20 mm taken after: *a*) pre-slitting pass, *b*) slitting pass, *c*) split parts obtained from experimental tests

In the numerical examination carried out, similarly as in the industrial conditions, the moving band caused the rotation of the separating rollers. The torque and the power needed for the rollers to rotate derive from the driven working rolls. Figure 2 shows the distribution of the rolling torque and power on the working roll during the production of 20 mm-diameter

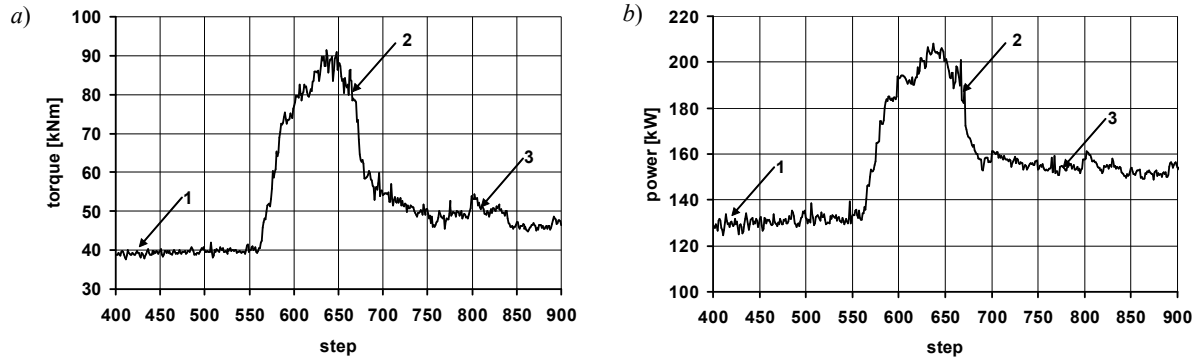


Fig.2. Distributions of the rolling torque – *a*) and power – *b*) on the working rolls (slitting pass) during the production of 20 mm-diameter ribbed rods with the two-strand technology

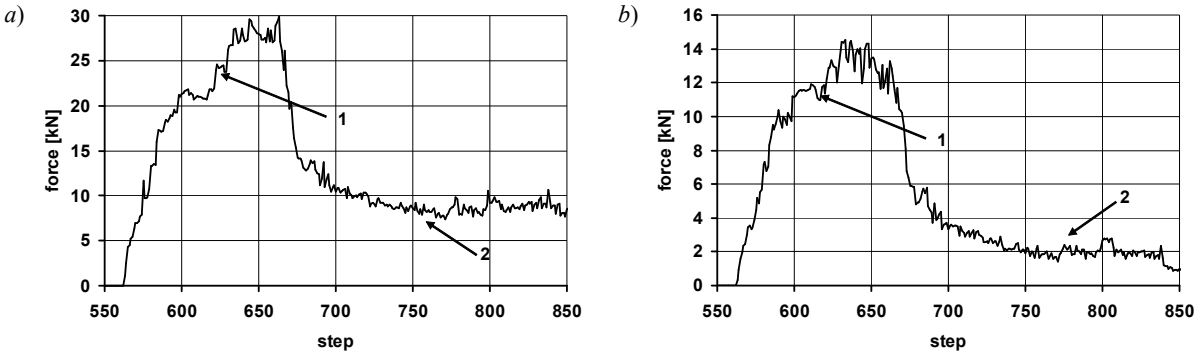


Fig.3. Distribution of the force on the slitting rollers obtained from numerical modeling: *a*) in the direction of rolling reduction, *b*) in the direction of rolling elongation

ribbed rods with the two-strand technology. The strip separation stage was divided into the 3 following stages: 1 – steady process of rolling in the slitting pass, 2 – strip impact against the separating rollers, setting the rollers in rotation, and the start of strip separation 3 – steady process of strip separation.

Table shows averaged rolling torque and power results obtained during the production of 2 × 20 mm-diameter ribbed rods in the slitting pass.

Calculated rolling torque and power during the production of 2 × 20 mm-diameter ribbed rods in the slitting pass

	Rolling torque [kNm]	Power [kW]
Stage 1	39.5	130.9
Stage 2	83.9	197.1
(Stage 2/Stage 1)	+112.4	+50.6
Stage 3	47.1	154.5
(Stage 3/Stage 1)	+19.2	+18.0

The analysis of the rolling torque and power distributions (Fig.2 and Table 1) indicate that there are a considerable increase in rolling torque and power in stages 2 and 3 compared to stage 1. The greatest change in the rolling torque and power magnitude was observed in stage 2, during which the moving strip must set in rotary motion both rollers, and in which the strip separation process is initiated. This phase is discussed in a greater detail in work [3].

A theoretical analysis of the force distributions during the splitting process was carried out within this study. Figure 3 shows the forces of metal pressure on the slitting rolls during strip slitting in the designed rollers. The strip separation stage was divided into the 2 following stages: 1 – strip impact against the separating rollers, setting the rollers in rotation, and the start of strip separation 2 – steady process of strip separation.

It can be found by analyzing the information given in Fig.3 that there are two stages of

slitting, which differ in obtained values of the force. The first stage is from the 600^{th} to the 670^{th} computation step, where increased pressures exist, and the second stage between the 700^{th} and the 850^{th} computation steps, where the pressures considerably decrease. The first stage is associated with the fact that the slitting rollers are not propelled and their rotation is caused by the moving strip. At the moment of its contact with the rollers, the strip must overcome their inertia, and only then do the rollers start rotating. At this particular time, the rollers start to slit the strip and to rotate at the same time, which requires larger forces to be used. In the second stage the rollers have been speeded up to reach the speed of the moving strip, therefore the force has significantly fallen.

Conclusions

The use of numerical modeling for the analysis of the strip separation process has enabled the determination of energy and power parameters, which would have been possible based on the known empirical relationships.

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