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Determination of the energy and power parameters during groove-rolling

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Analysis and modelling

ABSTRACT

Purpose: In order to correctly design the process of bar rolling in grooves it is required that several limitations affecting the rolling process be considered. When developing a technology, energy and force parameters, among others, are needed to be taken into account. Therefore, it is purposeful to examine variations in the energy and force parameters during the rolling of bars.
Design/methodology/approach: Using FEM-based computer programs for solving the problems of the theory of plasticity enables determining the energy and force parameters in complex plastic working processes and also accounting for a number of process specificities, which are not provided for by the empirical formula.
Findings: The theoretical values of the rolling torque and power during the rolling of band in the grooves, as determined using the Forge3® software and the engineering method proposed by Chekmarev, were compared with the experimental values obtained from the measurements of current loads in a plant manufacturing bars. The current loads of the main drive of the continuous rolling mill for rolling bars were measured in one of the Polish steelworks.
Practical implications: Change in the band temperature over its length influences the variations in the magnitudes of widening and advance. Its variations lead to a change in energy–force parameters.
Originality/value: Using the FE programs for the computation of the values of the energy–force parameters can take into account the distribution of temperature over the band length.
Keywords: Numerical techniques; FEM; Groove-rolling; Energy and power parameters

1. Introduction

The proper design of the groove-rolling process requires a number of limitations that influence its run to be taken into account. When developing a technology, energy–force parameters should be considered, among other things. There are many empirical solutions available in literature, which concern the determination of these parameters [1-4]. Each of these solutions has certain simplifications which more or less affect the correctness of the solution.

Change in the temperature of band over its length, associated with the stock being non-uniformly heated in the furnace, influences the variations in the magnitudes of widening and advance. In continuous rolling mills, the temperature of metal being rolled has also an effect on the process kinematics. Its variations lead to a change in energy–force parameters and inter-stand tension forces which, in turn, by acting within the deformation zone, lead to changes in the dimensions of the band being rolled [5-8].

By applying computer programs relying on the finite element method to solving plasticity-theory tasks within the metal working process technologies, the number of laboratory and industrial tests can be limited to an indispensable minimum [9-15]. Within the present work, the computer program Forge3® [16] was used for

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the analysis of plastic metal flow and the determination of the rolling moment and the rolling power. On the basis of computer simulation results, the effect of the initial distribution of temperature over the band length on the engineering parameters of the rolling process was determined.

The results of the theoretical computation of rolling moment and rolling power values, performed by employing the Forge3® computer program and using the engineering method proposed by Chekmarev [1] during the rolling of oval band in a round groove, were compared with experimental values obtained from the measurements of current loads in the continuous bar mill of an industrial plant.

2. The roll pass design scheme and initial conditions assumed for numerical computation

The analysis of the process of rolling oval band in a round groove was carried out in the present work in order to determine the causes of the non-uniform distribution of energy–force parameters during bad rolling and the unstable flow of the band in the oval groove. Technological data concerning the rolling of flat bars from continuous castings in a D350 continuous rolling mill were used for computation. Oval stock of initial dimensions of 116.4x61.0 mm was assumed for modelling. The round groove used for numerical modelling was of 74 mm diameter. It was assumed for computation that the roll diameter was D=472 mm, the rolling speed was equal to 1.3 m/s, and the material to be rolled was steel St37 (according to the Polish standard). To shorten the numerical computation time, the ¼ part of the stock and rolls was used.

It was found from the experimental test results that a considerable inequality in temperature distribution occurred over the rolled band length, reaching 70°C. It was assumed for computation that the temperature difference along the stock length amounted to 50°C.

2.1. The measurements of currents loads of the main drive of the rolling mill

The current loads of the main drive of the rolling mill were measured in one of the Polish steelworks. During the tests, the values of the rolling torque and power were determined. The measurements of currents during the steady process of rolling in the round groove were performed using a HIOKI 8855 fast-transient recorder. The tests encompassed the performance of 5 measurements. Examples of electromechanical signal transients recorded for the rolling process are shown in Fig. 1.

When analyzing the data shown in Fig. 1 it can be found that local fields occur, which are characterized by larger current values compared to the remaining part of the curve. The peaks which were recorded at the beginning (after approx. 14 seconds) and at the end (after approx. 56 seconds) of measurement duration result from the band entry to, and exit from the deformation zone. Whereas, the six peaks occurring after 19; 24; 32, 38, 46 and 51 seconds of measurement duration are the result of a non-uniform heating of the continuous casting in the furnace (a temperature drop).

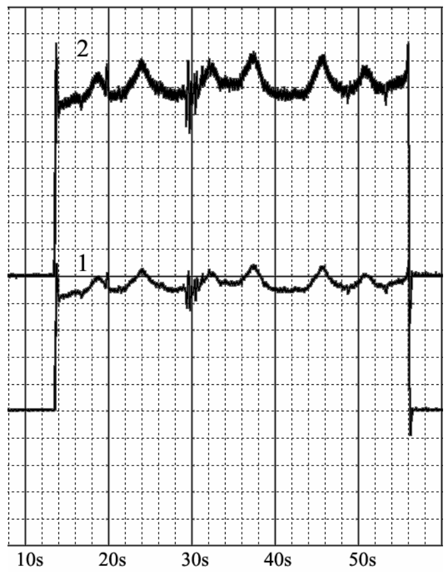

Fig. 1. Change of electromechanical signal for the main drive motor: 1 - values of current intensity measured for the computation of rolling torque, 2 - values of current intensity measured for the computation of rolling power

3. Comparison of theoretical and experimental torque and power parameters during rolling

By using the results of current measurements of electromechanical forces, obtained from the frequency converter, it is possible to determine the actual electromechanical values (e.g. rolling moment and rolling power). Figures 2 and 3 show the values of rolling moment and rolling power measured in industrial conditions and the values computed using Chekmarev's formula [1].

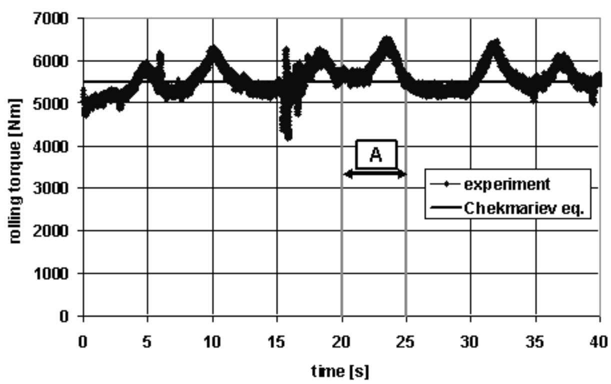

Fig. 2. Distributions of the rolling torque in the oval-circle pass

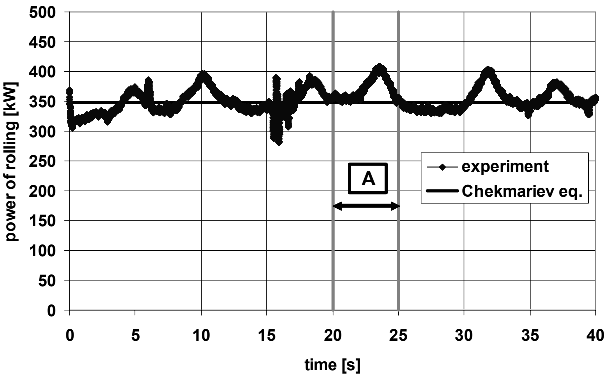

Fig. 3. Distributions of the rolling power in the oval-circle pass

Comparing the data shown in Fig. 2 and in Fig. 3 it can be found that the non-uniform heating (local overcooling) of the continuous casting in the furnace results in a local increase in the values of rolling moment and rolling power by approx. 13%.

On the basis of the analysis of the data in Figs. 2 and 3 it can be stated that by using the engineering method it is possible to predict the value of both rolling moment and rolling power (for band sections at an initial temperature of 970°C) with a high accuracy. While the correct determination of energy–force parameters for band areas characterized by a lowered initial temperature (920°C) – the characteristic peaks in Figs. 2 and 3 – on the basis of the empirical relationships is not possible. The relative error, obtained using the engineering method for band sections at an initial temperature of 970°C, amounted to approx. 2% for both rolling moment and rolling power. Whereas, for the lowered initial-temperature band sections, the relative error for rolling moment and rolling power increased to approx. 14%.

Allowing for the inequality of temperature distribution over the rolled band length is possible during the numerical modelling of the groove-rolling process. The rolling process for the band section designated with the letter A in Figs. 2 and 3 was modelled in the present work.

Figures 4 and 5 show the distributions of the measured and computed values of rolling moment and rolling power for the rolled band section.

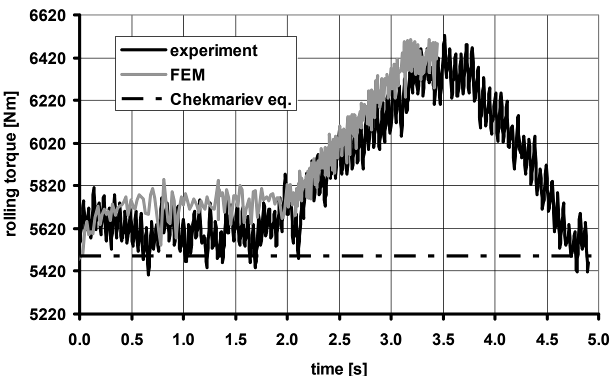

Fig. 4. Comparison of theoretical and experimental rolling torque values

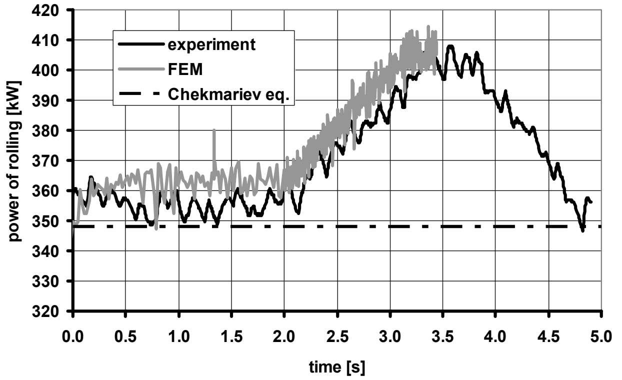

Fig. 5. Comparison of theoretical and experimental rolling power values

When analyzing the data shown in Figs. 4 and 5 it can be found that using a FEM-based computer program for the computation of energy–force parameters allows a number of rolling process specificities (e.g. the non-uniform heating of the continuous casting along its length) to be taken into account, which cannot be considered when using engineering methods. The character of the distribution of rolling moment and rolling power, obtained from computation using the FEM, is consistent with the measurements carried out in industrial conditions during an actual rolling process. The obtained relative error amounts to 1.8% for rolling moment and 0.8% for rolling power – for the initial temperature of 970°C, and 1.8% for rolling moment and 1.3% for rolling power – for initial temperature of 920°C (casting sections locally overcooled).

According to the data reported in works [6÷9], a non-uniform temperature distribution over the stock length affects the process kinematics. Figure 6 shows the distribution of temperature and variations in band width in the plane of exist from the deformation zone, obtained from numerical modelling.

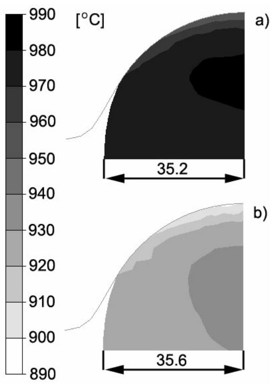

Fig. 6. Distribution of temperature and variations in band width in the plane of exist from the deformation zone: a) initial temperature of 970°C; b) initial temperature of 920°C

It can be found from the data in Fig. 6a that the plastic deformation has resulted in an increase in temperature value by approx. 20°C in the deformation zone compared to the initial value. When analyzing the data in Fig. 6b it can be noticed that the average temperature on the band cross-section is equal to the initial temperature. For the case shown in Fig. 6b, the temperature increase caused by plastic deformation has been done away by a longer band cooling time compared to the case shown in Fig. 6a. Therefore the temperature distribution on the band cross-section, shown in Fig. 6b, is less uniform than for the case shown in Fig. 6a.

The non-uniform temperature distribution over the band length has also an effect on the magnitude of widening. The local temperature decrease in the rolled band has resulted in an increase in band widening after the pass, as a consequence of which the band with has increased from b_1 = 70.4 mm for the band at the initial temperature of 970°C (Fig. 6a) to b_1 = 71.2 mm for the band at the initial temperature of 920°C (Fig. 6b).

The local increase in rolled band width can be explained by the increase in the friction coefficient for this region, which increases the resistance to plastic metal flow in the rolling direction. According to the least resistance law, the deformed metal will displace more intensively in the transverse direction (along the groove width).

4. Conclusions

On the basis of the results of experimental tests and theoretical studies presented in this work it can be stated that the non-uniform temperature distribution over the continuous casting (rolled band) length, resulting from the method of heating the casting in the furnace, influences the magnitudes of rolling forces, rolling moments and rolling power. When using the empirical relationships for the computation of the values of these parameters, one cannot take into account the distribution of temperature over the band length.

The use of an FEM-based computer program for solving plasticity-theory tasks in the design of groove-rolling process technologies has enabled the distribution of rolling moment and rolling power to be determined correctly, in agreement with the results of measurements carried out in industrial conditions.

The incorrect determination of the force–energy process parameters might result in substantial design errors.

Uniform plastic metal flow in the deformation zone depends, among others, on the proper heating of the stock (uniform along its length).

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