

PHYSICAL AND COMPUTER MODELING OF A NEW SOFT REDUCTION PROCESS OF CONTINUOUSLY CAST BLOOMS

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ABSTRACT

The results of mathematical modeling study of a new two-stage soft reduction method of continuously cast blooms rolled in cross rolls are presented in a current work. For the initial stage of investigations, the mathematical model based on FEM method has been designed. As a result of conducted calculations the mechanism of an influence on the stress strain state which depends on deformation parameters and shape of a work tool has been clarified. Verification of a mathematical model adequacy with help of physical modeling has shown high reproducibility of results. The optimal parameters of deformation process, which provide the minimal stress level in metal, have been determined. It has been found, that effectiveness of deformation penetration into axial zone of continuously cast bloom using a new method is no less than 15 % higher than in case of one-stage deformation scheme.

Keywords: soft reduction, continuously cast bloom, deformations process, rolling.

INTRODUCTION

Continuous casting is globally one of the most noted processes for the production of metals. In recent years many firms (Concast AG, DANIELI, etc.) has conducted several trails with Mechanical Soft Reduction (MSR) of blooms and billets. These trails have shown the potential of this technique and given them a considerable amount of information on the design process.

A typical scheme MSR process is shown in Fig.1, where the chemically segregated liquid core of a continuously cast bloom [1] is squeezed in the direction opposite to casting. The process takes place by applying a small thickness reduction in the area where the liquid core closes at the final point of solidification. This action reduces centerline segregation and porosity. If the reduction parameters are chosen properly, it compensates

for the shrinkage of solidification and closes the voids formed along the blooms centralize [2, 3].

The new schemes MSR process was developed about 20 years ago for increasing the penetration of deformation in the axial zone of bloom. The main directions of improvement of the classical scheme of “soft” compression bloom [4] are given below and a few articles on them are available:

- change the form of the cross-sections differ under consideration bloom [5];
- improving the geometry of the working tools [6, 7];
- change the direction of application of external strain effects [8].

However, we can say that question of implementation of new schemes of MSR in which there are additional shear deformation are considered only at the level of primary assumption of practicability. At the

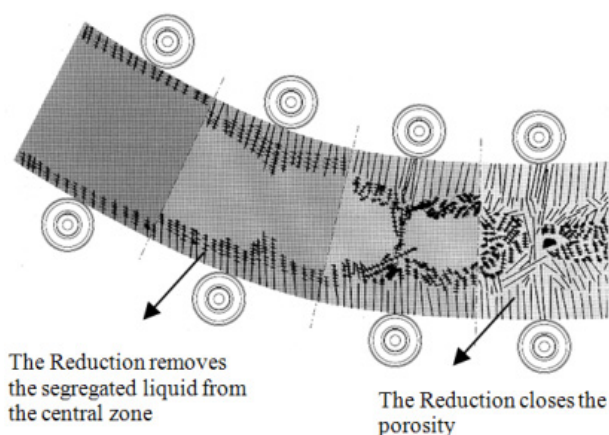


Fig. 1. Scheme of Mechanical Soft Reduction.

same time, the high efficiency of practical use for the rolling production of the three schemes, in which the possible appearance of a shear strain: rolling with different peripheral speed of the work rolls, asymmetric rolling, rolling in pairwise skew rolls [9].

The aim of this work performed by scientists of the Donetsk National Technical University (Donetsk, Ukraine) is the research distribution characteristics of the stress - strain state of the metal on the contact surface of continuous bloom during its reduction on the stage of partial crystallization in the crossed rollers finite element method.

EXPERIMENTAL

Conditions of FEM modeling

The model has been incorporated with each of the double roller stands. Reducing block bloom caster (6 stands) has single-axial symmetry with 180°C. Due to the symmetry of this nature, the problem was solved for one second cross-sectional bloom. Cross-section of bloom and the initial position of the rolls with crossed axes is shown in Fig. 2. In this model was used many elements mesh with four-knot tetrahedral, which allowed quite correctly describe the geometry of the billets. The maximum size of elements does not exceed 3 mm.

Modeling was performed for a stationary thermal regime bloom section 335x400 mm. Temperature field of blooms, the size of the liquid wells, the amount of solid phase (f_s) in the ingot obtained by means of mathematical modeling of the crystallization process of continuous bloom, using standard approaches. In this case, we assumed that f_s is used only as a function of melting

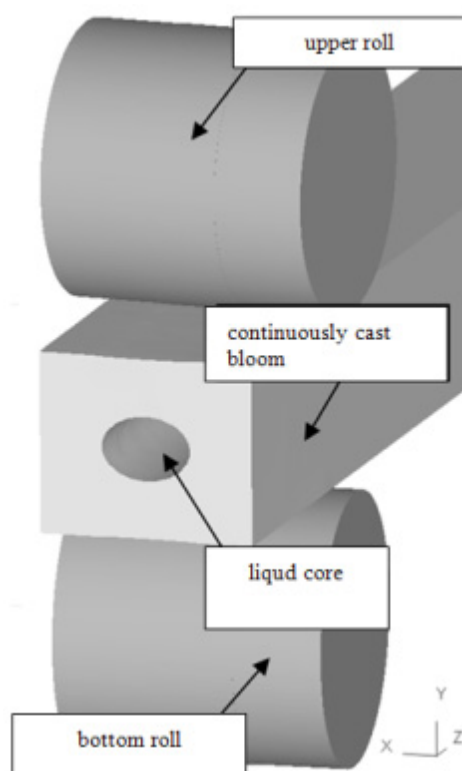


Fig. 2. Finite-element model of deformation of continuous bloom in smooth crossed rolls.

temperature: the liquidus and solidus.

The temperature of the liquid phase was evaluated as a function of steel composition. It was accepted that the temperature of solidus corresponds to the peritectic temperature.

The calculation of metal flow in the model was conducted on the base of the principle of minimum deformation work for the bloom of using elastic - plastic material model. To simulate the roll was chosen undeformable rigid material model (Fig. 2).

Material behavior bloom in the solution process is described by diagram "true stress - strain".

Rheology of the metal was determined by the flow curve in accordance with a given dependence of flow stress (σ) of strain (ε), strain rate ($\dot{\varepsilon}_{ij}$) and temperature (t):

$$\sigma = \sigma(\varepsilon; \dot{\varepsilon}; t) \quad (1)$$

Appropriate rheological curves in the investigated temperature range (1000 - 1300°C), necessary for the implementation of the modeling, have been constructed theoretically, taking into account the percentage of ele-

ment content in the steel in %: 0,12 C; 0,65 Si; 1,5 Mn; 0,3 Ni; 0,015 S; 0,016 P; $\leq 0,3$ Cr; $\leq 0,3$ Cu. Due to the fact that at temperatures above 1300°C the stress flow varies only slightly, to calculate its value was assumed to be 0,5 - 1,0 N mm⁻² [10].

This model can be used to simulate accept the concept of flow stress, according to which a material deforms plastically, and the amount of stress is determined from the incremental amount of strain on the flow curve. In this case, the calculation of elastic deformation was done using the equation Levy - Mises, which relates the stress tensor σ_{ij} and tensor strain rate $\dot{\epsilon}_{ij}$

$$\sigma_{ij} = \frac{1}{\lambda} \dot{\epsilon}_{ij} \quad (2)$$

where λ - a function depending on the stress - strain state and material properties.

The boundary conditions of the solid phase, including the surface of contact with the rolls, are taking the condition of no slippage.

As a model of contact friction model adopted by the shear friction:

$$\tau = m \cdot k \quad (3)$$

where τ - friction stress, m - factor of friction, k - the yield stress of billets material on the shift. The value of friction factor was chosen for the conditions of contact interaction bloom with rollers in the presence of a significant amount of scale and lack of lubrication. The value of m in this case amounted to 0,7.

Parameters of the simulated process are presented in Table 1.

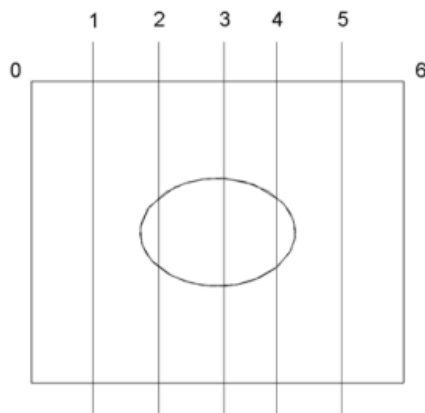


Fig. 3. Schematic of the control points on the contact surface bloom.

Table 1. Production parameters.

Parameters of the process	Value
Bloom-section, mm	335x400
The temperature of the working rolls, °C	400
The surface temperature of bloom, °C	1150
Ferostatic pressure at a given point of metallurgical length of bloom, N mm ⁻²	1,2
Speed drawing bloom, m min ⁻¹	0,6
Diameter work rolls, mm	500
Rolls crossing angle α , degree	0÷6
The relative degree of deformation ϵ , %	0,6÷1,2

All parameters are kept constant. Because the axis of the rolls are crossed relative to each other and by the width of the deformation zone has been allocated two characteristic regions (Fig. 3), located on the left and right of the longitudinal axis of symmetry. In one of them, the deformation of the upper roll is earlier (the shift inwards - 0, 1, 2), and in another - the deformation of the upper roll is later (the shift out - 4, 5, 6).

Physical modeling

Testing FEM modeling results are satisfied in the laboratory using the methods of physical modeling.

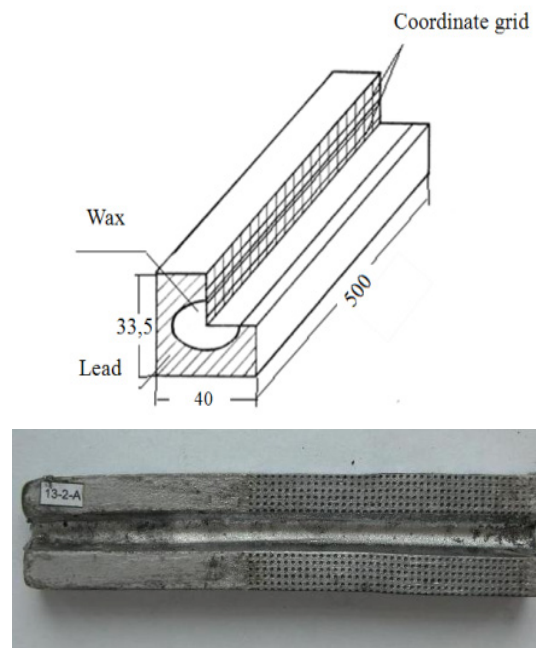


Fig. 4. Scheme of combination of the physical model (a) and form a coordinate grid (b) on the plane (section 3).

For this purpose, were made in 1:10 scale physical models combined from technical lead and wax. Scheme construction of physical model is shown in Fig. 4a. Stress-strain state of the metal was determined vertically -longitudinal flat of symmetry. For this purpose, it was deposited coordinate grid with cell size 2x2 mm (Fig. 4b).

Assembly was carried out by means of physical models by soldering the two halves of Wood's alloy in the flat of symmetry. The axial cavity, simulating the axial liquid-solid component, was filled wax. After holding patterns for two days under a perpendicular load to the flat of soldering, models were carried out their deformation by rolling on a laboratory mill with a diameter of 50 mm rolls. Obtained during deformation unfinished section versed and in measuring the deformed grid in vertically -longitudinal flat of symmetry. Primary experimental information is further processed in accordance with the method described in [11].

Comparison of results of mathematical formation data processing of physical modeling with the results of tests of numerical experiments performed for the equivalent conditions using the developed model showed that the discrepancies in the value of the strain tensor Almansi do not exceed 5 – 7 %. This circumstance allows us to speak about the correctness of the developed mathematical model.

SIMULATION RESULTS AND DISCUSSION

During the estimated study was investigated the effect of the angle crossing axes of rolls α and the relative degree of strain ε on the distribution of the accumulated strain Λ and the stress intensity σ_i on the plane of contact with metal rollers [12 - 14].

Selecting of parameters Λ and σ_i due to the ultimate goal of research initiated by the complex, namely: assessment of the impact of an additional shear strain on the possible nature of the destruction of the metal on the contact surface of the deformable bloom using the criterion of Cockcroft Latham [15]

$$D_f = \int_0^{\varepsilon} \frac{\sigma_1}{\sigma_i} d\varepsilon_i, \quad (4)$$

and the criteria of Kolmogorov V. L. [16]

$$\psi = \int_0^{\Lambda_i} \frac{d\Lambda}{\Lambda_p}, \quad (5)$$

where σ_1 - maximum principal stress, σ_i - intensity of normal stresses, ε_i - strain intensity, Λ_p - plasticity of the metal, determined experimentally.

The numerical investigation showed that the distribution of the accumulated strain Λ and stress intensity σ_i on the plane of contact metal with the rollers in each of the selected areas of a similar character. The existing difference in numeric values is insignificant and is caused, mostly like within the choice of location of control points in the finite-element model.

The results of estimated research for the points belonging to the vertical longitudinal plane of symmetry (section 3 - the plane of the identification of physical and mathematical models) and a plane with the highest probability of occurrence of discontinuities (section 0) in the case when the deformation of the upper roll is earlier

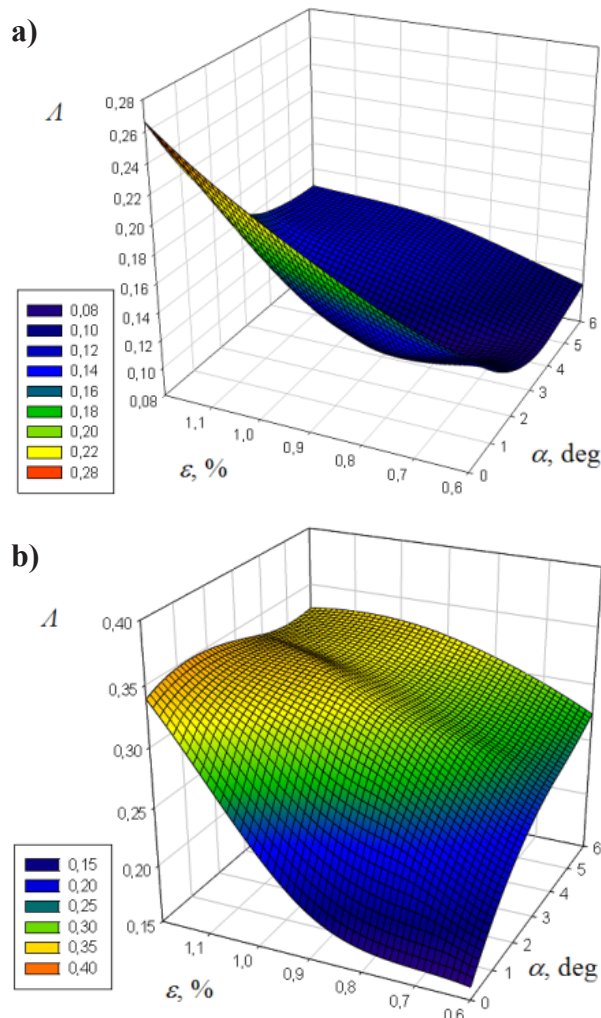


Fig. 5. Changing of Λ on the contact surface of α and ε : a - $x_i/b = 0$; b - $x_i/b = 0,5$ (x_i и b – current lateral coordinate of the control point and width of the bloom, respectively).

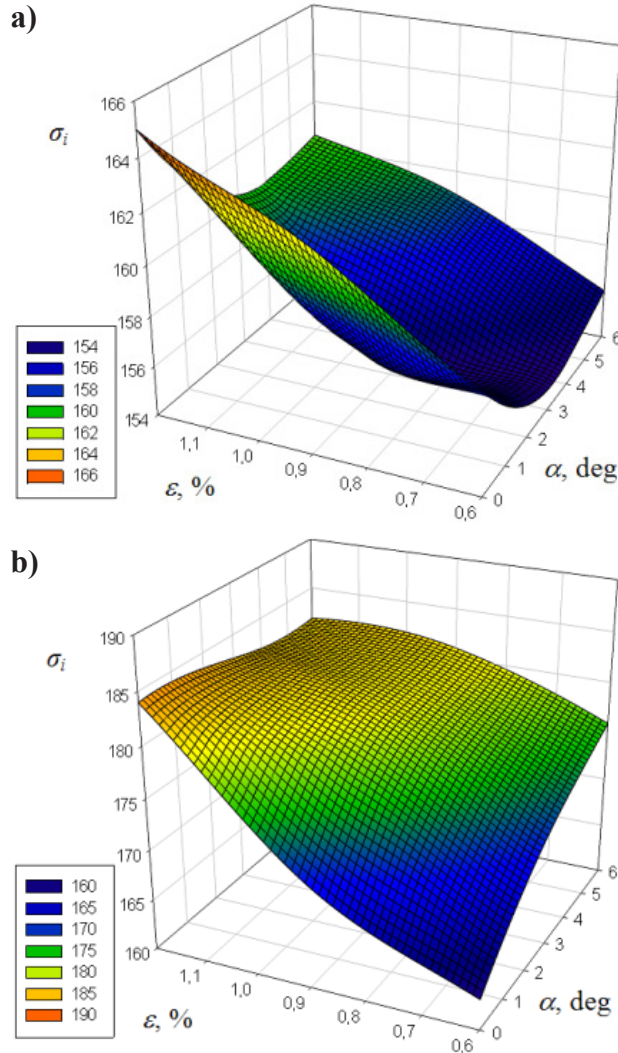


Fig. 6. Changing of σ_i on the contact surface of a and ε : a - $x_i/b = 0$; b - $x_i/b = 0,5$ (x_i and b - current lateral coordinate of the control point and width of the bloom, respectively).

(in the direction crossing - inside) are shown on Figs. 5 and 6. At the same time as an object of comparison was chosen the classical scheme of deformation in which the crossing angle roll is 0° .

Analysis of the data shows that the plane has a clearly defined minimum typical angle of 2° . Moreover, with increasing α range from 0° to 2° , the value of Λ , and σ_i down at the corner points (0 and 6) review section. The value of decrease σ_i at the corner points is not less than 3,7 ... 5,0 %, and Λ - 44,3 ... 45 %.

Further, with the increasing values of α from 2° to 6° and the rise of σ_i and Λ in corner areas. However, their value does not reach the level of values that are typical for the case of rolling in smooth rolls. The resulting

increment of σ_i and Λ for the corner sections (0 and 6) is not less than 2 % and 31.2 %, respectively. For the central points (points 1 - 5) was observed less intense increase of σ_i and Λ , by 1,69 % and 5,57 %, respectively.

Assessing the impact on values of ε , Λ and σ_i showed that unlike to the dependence of $\Lambda = f(\alpha)$ и $\sigma_i = f(\alpha)$, this dependence has an extremum, because with the growth of values ε the σ_i and Λ are growing too. However, the presence of crossed axes of the rolls leads to the fact that approximately the same values σ_i with the case of deformation with $\alpha = 0^\circ$, achieved in the angular region (0 and 6) for large values of ε . In particular, the conditions of deformation in the not crossed rolls of $\varepsilon = 0,9$ % $\sigma_i = 161 \dots 162$ N mm⁻². A similar value σ_i at the same points, but the deformation in the crossed rolls, achieved with $\varepsilon = 1,2$ %. In this case, at the midpoint we can see the rise of σ_i and Λ by a different law. In particular, at points 1 - 5 σ_i we can see the increase with 6,9...7,1 %. These results suggest that the most intense processes of deformation are localized on the width of the continuous casting bloom, which meets the width of the liquid phase inside. This will contribute to the better elaboration of the metal cross section.

CONCLUSIONS

Conducting research allows to draw practical conclusions on the effect of the crossed axes of rolls, which can be formulated as follows: crossing rolls on the angle of 2 - 3° helps to minimize the level of σ_i and Λ in the corner, most supercooled region of cross section of continuous bloom, thus minimizing the risk of discontinuities of the metal. At the same time increasing σ_i and Λ in the areas of metal, adjacent to the axial liquid-solid phase will contribute to a higher intensity of elaboration of metal layers, which have higher temperatures.

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