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DEVELOPMENT OF MATHEMETICAL MODELLING FOR HOT ROLLING OF CONTINOUS-CASTED SLABS

Наведене описання кінцево-елементної математичної моделі процесу гарячої прокатки безперервнолитих слябів. Модель дозволяє враховувати неоднорідність механічних властивостей матеріалу по його перетину, котра обумовлена існуванням ліквацій, й може бути використана при вивченні напружено-деформованого стану сляба і розробці рекомендацій з метою зниження ймовірності виникнення дефектів під час прокатки.

Ключові слова: *математична модель, ліквація, напружено-деформований стан.*

Дано описание конечно-элементной математической модели процесса горячей прокатки непрерывнолитых слябов. Модель позволяет учитывать неоднородность механических свойств материала по его сечению, обусловленную наличием ликваций, и может быть использована при изучении напряженно-деформированного состояния сляба и разработке рекомендаций с целью снижения вероятности возникновения дефектов при прокатке.

Ключевые слова: *математическая модель, ликвация, напряженно-деформированное состояние.*

A problem and its connection with scientific and practical tasks. Nowadays, considering a number of advantages, a process of continuous steel casting has obtained a wide spread and fast development. But one disadvantage greatly influencing the quality of continuous casting slab is liquation. The heart of the problem is irregular growth speed of columned crystals at various areas of slab cross-section. So, in finally crystallized ingot there can appear sink (shrink) microholes, and close to them there can be areas of both positive and negative liquation.

Irregular distribution of chemical elements along the cross section of continuous casting slab results in anisotropy of its mechanical properties that increases the probability of defects depending on technology of the process.

Analysis of the latest achievements and publications. In spite of the great number of carried investigations and tremendous volume of information there is lack of existing knowledge for reliable control for crystallization and liquation processes in continuous casting slab. As numerous researches indicate the main factors which influence the liquation are casting and cooling speed of slab as well as its dimensions. Meanwhile depending on steel grade such impact can have conflictive character [1-4].

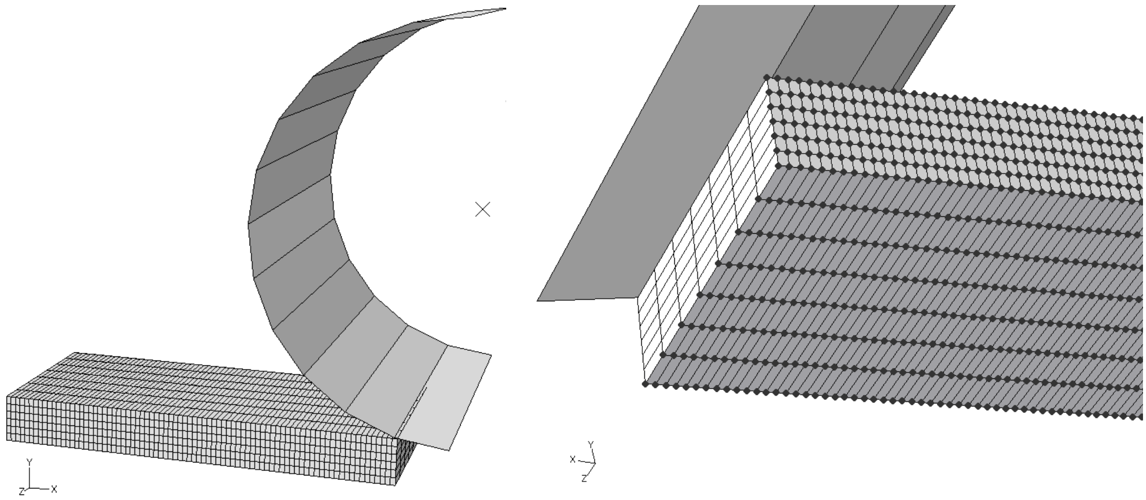
As far as it's impossible to exclude entirely the distribution unevenness of chemical elements in continuous casting slab then it's necessary to consider that fact when investigating the draft mode on the rolling machines. But, existed mathematical models of stress and strain state for continuous casting slabs are based upon hypothesis on uniform distribution of chemical elements over entire slab volume [5-7], that decreases the opportunity of their application and the adequacy of given results.

Setting the task. Aim of such work was development of mathematical model on the base of finite elements method for determining the stress and strain state during hot rolling process considering the existing liquations.

Presentation of the paper content and the results. Having based upon method of finite elements widely used in mechanics of deformed body [8-11], it was designed the mathematical model. On the analogy of the work [11] the model describes both transitional and steady condition of rolling process of continuous casting slab. Considering the fact that there is a presence of great number of deformations when describing the deformed area it was used the Lagrange approach using ALE (Arbitrary Lagrangian-Eulerian) adaptation of mesh [11-13], which allows getting more precise result at minimum expenses.

The model contains one fourth part and consists of non-deformed (absolutely flexible) roll and deformed beam (fig. 1 a). Beam's mesh consists of isoparametric hexahedral linear elements with eight point and reduced integration [11], which have properties of entire deformed environment. A roll is modeled like analytical rigid non-deformed cylindrical surface. Symmetrical boundary conditions are placed onto the right (surface at Z=0) and lower (surface at Y=0) surfaces of beam (fig. 1 б).

Friction between contacting surfaces of beam and roll simulate the Coulomb's law. Meanwhile the friction index is constant and characterizes the relationship between the contact pressure and equivalent tangential (contact) stress.



а) б)

Figure 1 – Initial configuration of the model (а)
and a surface of symmetry (б)

Cylinder axis is limited on moving in all three planes and is allowed to turn only around the axis Z. During mathematical realization the roll gets constant angle speed.

To initialize contact between a roll and a beam the latter gets initial linear speed in X direction.

Material is modeled like elasto-plastic with isotropic hardening. Mechanical properties of the material are presented as dependence of yield plastic stress from conditions of rolling process and fields of distribution of chemical elements.

$$\sigma_S = f\left(\varepsilon, \dot{\varepsilon}, T, F_1 \ldots F_{12}\right), \tag{1}$$

where ε and $\dot{\varepsilon}$ – respectively strain and strain rate;

T – temperature of deformation;

$F_1 \ldots F_{12}$ – percent content of chemical elements at the cross section of slab (maximum number of variables 12).

To obtain numbering values σ_S from expression (1) in model the well-known analytical dependences of Andreyuk-Tyulenev were used [14]. A sample of initial field of distribution one of the chemical elements is given at fig 2.

Mathematical calculations are finished when stable state of rolling process is achieved, that is accepted a such one under condition, that criteria, determining it reach their set values with certain (or set on default) accuracy. As the criteria of stable state one can use the standards – plastic strain, spread, force and a moment norms of a plane of elements. The exit plane for each norm is defined as the plane passing through the center of the roller with the normal to the plane coincident with the rolling direction.

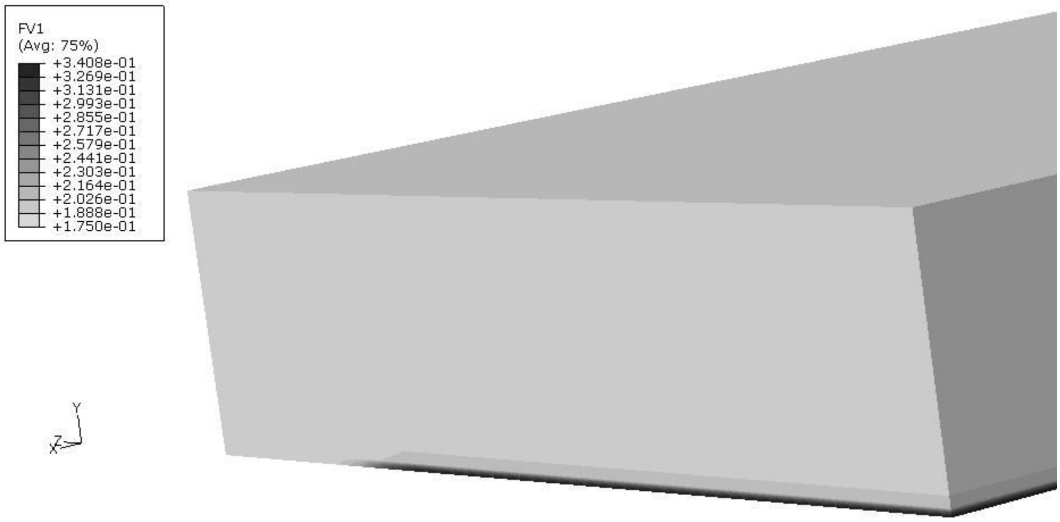


Figure 2 – A sample of initial distribution field of one of the chemical elements

For estimation the probability of occurring possible defects use the ductility curves, which give the relation between the equivalent plastic strain at fracture $\bar{\varepsilon}_f^p$ and the index of tensely state k. Index of tensely state is determined by ratio of hydrostatic pressure σ_h to equivalent Mises stress σ_{eq}:

$$k = \sigma_h / \sigma_{eq} . \tag{2}$$

For estimation of operation ability of the model it was necessary to get the solution, which could be applied for estimating the stress-deflected state of slab during rolling process and to compare it with known solutions.

As simulating sample we used steel grade 17Г1С. Meanwhile the initial thickness of rolled slab was 230 mm and width 900 mm. roll's diameter is 1000 mm. Angle roll's rotation speed is – $8\,\text{sek}^{-1}$. Initial speed of slab – $4\,\text{m/sec}$. Friction index $\mu = 0{,}4$. Drafting schedule modeling is 30 mm.

Changing factors of stable state are given at figure 3. From given dependences and analysis of results obtained the stable state is achieved at $\approx 0{,}0931$ sec of rolling process, and calculations stop at $\approx 0{,}095$ sec of rolling process.

Analysis of the deformation and strain distribution fields obtained during mathematical modeling has shown the sufficient integrity level of obtained results comparing with known solutions [15], which show the adequacy of developed finite-element mathematical model. In its turn this shows the possibility of its using for investigating stress and strain state of slab during hot rolling considering uneven distribution of chemical elements over the section of continuous casting slab.

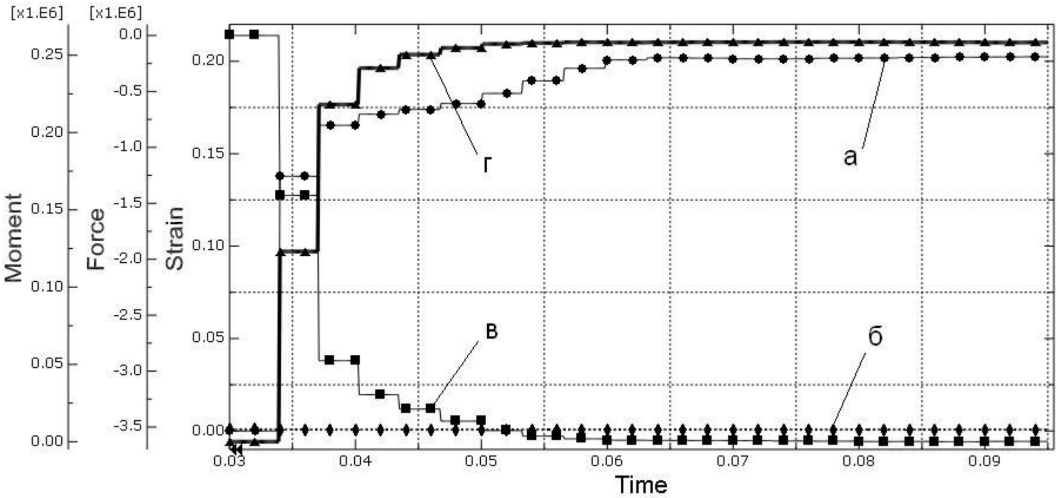


Figure 3 – Dependences of changing the criteria of stable state:
norms – for equivalent plastic strain (а); location of elements' surface (б); force (в) and moment (г)

Conclusions and further investigations. Requirement in development of mathematical hot rolling modeling of continuous casting slabs is caused by the necessity to study its stress and strain state during rolling process that allows prognostication of probable occurrence of defects subject to liquations.

For the first time developed finite-element model of slab's hot rolling process allowed to consider the unevenness of mechanical properties of material over its cross-section caused by liquations.

Mathematical model can be used when study the influence of liquation onto stress and strain state of slab at hot rolling process aimed at development of technological conditions allowing to decrease the defects occurrence.

Considering, that for the present day new steel grades being produced by iron-and-steel industry and which meet higher requirements, while known calculation methods of mechanical properties of material have limited range of application on temperature and chemical composition, then there is a necessity to carry out additional experimental researches of mechanical properties of the material. Realization of such kind of investigations is possible using the physical simulator Gleeble® in the laboratory of Dunaujvarosh College within the frames of Ukrainian-Hungarian scientific cooperation. Application of the results of these investigations will promote spreading the opportunities of developed mathematical model and to increase the accuracy and value of calculations.

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