NUMERICAL MODELING OF MACRO SEGREGATION EVOLUTION AND CHANGE OF STRESS-STRAIN STATE IN BILLET DURING CONTINUOUS CASTING WITH MECHANICAL SOFT REDUCTION

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One of the fundamental problems concerning continuous casting process (CCP) is formation of segregation of chemical elements in a cross-section of billet. It has significant influence on mechanical properties and microstructure of final products. The possibility of decrease of macrosegregation by deformation of billet in a semi–solid state (Soft Reduction, SR) was presented in [1]. Parameters of SR process (time and value of strain) significantly influence ratio of segregation together with the parameters of continuous casting process. The purpose of this paper is to optimize the parameters of SR using numerical modeling. In recent publications, several approaches for CCP modeling are presented [2-3], however neither of them takes into account all factor of SR.

The full numerical model of CPP processes should consists of the following components:

- model of the heat transfer phenomenon and crystallization processes;
- model of thermal stresses evolution;
- model of influence of constructive mechanism of the CCM on metal;
- the segregation evolution model [4];
- model of SR process;
- model of damage.

In order to model crystallization process, the heat transfer equation was used and modified by the method of effective specific heat. The elasto-plastic theory of plasticity was used for simulation of mechanical processes.

In present work three variants of simulation are considered: W1 – without SR and W2, W3 – with SR. Simulation conditions were equivalent to industrial conditions of continue casting (300x400mm bloom, St3S steel). SR prescribed before the end of crystallization process, for W2 SR started 1103s after beginning of CPP, and W3 – SR started 593s after beginning of CPP. Intensive cooling in mould follows to fast temperature decrease on the surface of ingot what induces beginning of solidification process. During the first steps of crystallization process, the carbon concentration decreases from 0.14% to 0.053% on the surface of ingot for each variant. In succeeding stages the carbon concentration increases due to backward diffusion phenomenon. The concentration attains maximum value when the last liquid fraction is crystallizing in the ingot. Maximum carbon concentration in center line billet was 0.292%, after crystallization process 0.278% for variant W1. The final difference between the surface and the center of ingot was 0.0575%. For W2 variant, deformation caused displacement some part of carbon to upper layer of liquid metal and decreased concentration of carbon after solidification in center line ingot (center – 0.185%, outside surface – 0.136% difference of concentration – 0.0492%). In W3 variant, deformation was prescribed considerably early then in variant W2 (when in ingot share liquid phase was grate). It caused on increase of carbon segregation as in variant W2 (center – 0.192%, surface – 0.137%, difference of concentration– 0.0546%).

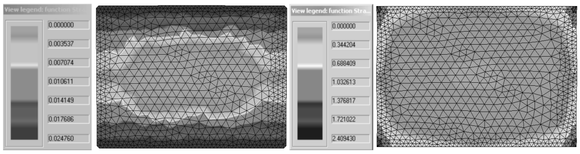

Fig. 1. Distribution of strain intensity in the cross-section in continuous cast billet, after finish of solidification process; a) for W1 variant; b) for W2 variant.

The strain intensity in billet during continue casting with SR is determined. The SR process essentially influences the distribution of strain intensity. Bending and straightening of billet cause that maximal values of strain intensity are attained on the ingot surfaces - W1 variant (fig. 1a). In the W2 variant strain intensity concentrates in ingot corners. (fig. 1b). The results presented in fig. 1 show an essential influence of SR on strain distribution. Therefore, a proper fracture model of billet during SR is so important and it was developed and added to the model of CCP in present paper. The forecast of the brings fracture on ingot surface was based on the theory of fracture described in literature [5 – 6]. In this model, as a key-parameter of fracture, the resource of plasticity ψ is proposed:

$$\psi = \frac{\varepsilon_i}{\varepsilon_p(k, \mu_\sigma, T)} < 1$$

where: ε_i – strain intensity; ε_p – critical strain before fracture metal as a function of parameters $k = \sigma/\sigma_s$ and Lode coefficient μ_σ; σ – mean stress; σ_s – yield stress; T – temperature.

The function $\varepsilon_p(k, \mu_\sigma, t)$ was determined in experimental investigations at Gleeble simulator. The critical strain was determined based on experimental tensile test and SICO test. For determination of empirical parameters of function $\varepsilon_p(k, \mu_\sigma, t)$ the inverse analysis was used. For simulation of tests the FORGE3 software was used.

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