POLISH ACADEMY OF SCIENCES - COMMITTEE OF MATERIALS SCIENCE
SILESIAN UNIVERSITY OF TECHNOLOGY OF GLIWICE
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS
ASSOCIATION OF ALUMNI OF SILESIAN UNIVERSITY OF TECHNOLOGY
Conference Proceedings
AMME'2003
12th INTERNATIONAL SCIENTIFIC CONFERENCE
ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

Modeling of thermal stresses in the continues casting bloom of LH15SG steel accounting phase transformation

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In the paper it is proposed a thermal stress model based on the theory of viscous-plastic deformation, which is adjusted to the heating and cooling of continues casting bloom. The model is developed on the basis of the finite element method. To take into account the changes of metal behaviors the plastometer and dilatometric research was fulfilled.

1. INTRODUCTION

The phase transformations in steel during the heating and cooling processes provide to appearing additional thermal stresses associated with nonlinear volume changes of metal with the temperature changes.

The problems of identification and reckoning steel behavior, which is complicated by theoretical description of influence of the phase transformations on stress, are following:

a) Volume changes caused by temperature changes and phase transformations.
b) Cooling or heating rate dependence of the phase transformation temperature.
c) Necessity of mechanical behavior research of steel in different temperature, strain and strain rate.

The object of the paper is development of the mathematical model of the thermal stresses, which reckons volume changes during allotropic transformation.

2. MATHEMATICAL MODEL OF HEAT EXCHANGE AND METAL CRYSTALLIZATION

To model crystallization process it was used the heat transfer equation modified by method of effective specific heat. The method is based on the following equation:

$$c_{eff}\,\rho\frac{dt}{d\tau}=k\left(\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}\right) \tag{1}$$

where ρ – metal density, t – temperature, τ – time, c_{eff} – effective specific heat, which in the simplest cases is described according the following order:

$c_{eff} = c_s \qquad \forall\ t<t_s$,

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$c_{eff} = c_f+L/(t_L-t_S) \qquad \forall\ t_s<t<t_L$,
(2)
$c_{eff} = c_L \qquad \forall\ t>t_L$,

c_f – specific heat in the temperature range of alloy crystallization, $c_f = f_s c_s + (1\text{-}f_s)c_L$, t_L – liquidus alloy temperature, t_s – solidus alloy temperature, L – hidden crystallization heat, f_s – fractional part of solid phase, c_s – specific heat of solid phase, c_L – specific heat of liquid phase.

Algorithm of 3D solution of heat transfer and crystallization of the casting bloom is build upon the sequent solutions of the plane tasks which is corresponding to the movement of the cross-section of bloom with the casting speed through crystallizator, secondary cooling zone and air cooling zone.

3. MATHEMATICAL MODEL OF THERMAL STRESSES DEVELOPMENT

Lets consider the plane deformation task formulation. The solution is searched from the necessary condition of the minimum of the Lagrange variation functional:

$$J = \frac{1}{2}\int_V E'\varepsilon_i^2 dV + \frac{3}{2}\int_V \frac{E'}{1-2\nu}(\varepsilon_0 - \beta\Delta t)^2 dV + \int_S \sigma_i u_i dS \tag{3}$$

where E' – the modulus of plasticity (correspondent to Young's modulus in elasticity). The value of E' could be determined by following equation:

$$E' = \frac{\sigma_s(\dot{\varepsilon}_i, \varepsilon_i, t, \tau)}{\varepsilon_i} \tag{4}$$

where $\sigma_s(\dot{\varepsilon}_i, \varepsilon_i, t, \tau)$ – dependence of effective stress on effective strain rate $\dot{\varepsilon}_i$, effective strain ε_i and temperature t with accounting of stress relaxation, τ – time.

Term $\beta\Delta t$ can be evaluated in dilatometric test:

$$\beta\Delta t = \frac{\Delta l(t,\Delta t)}{l_0} \tag{5}$$

where $\Delta l(t)$ – changes of specimen length during temperature changes (Fig. 1), l_0 – initial specimen length.

Dependence $\Delta l(t)$ is presented in the table with linear interpolation between points.

Term E' is not known at advance and it is obtained as result by method sequential approach (method of Iliushin's conjugate solutions [1].

Thus the material dilatometric curve is used directly in the model. It allows to breaking away from ordinary method, which volume changes in the allotropic transformation reckon by temperature expanse coefficient β .

4. EXPERIMENTAL EVALUATION OF THE STRESS CURVE AND DILATOMETRIC RESEARCH

The dilatometer 805A/D was used to plastometric and dilatometric research [2]. The standard specimen from the LH15SG steel were examined. The specimen sizes are: height – 10 mm, diameter – 5 mm. Temperature was varied from 700 to 1200°C, strain rate was 0.001, 0.01 and 0.1 s^{-1}. The maximal strain was 0.4. The results of plastometric tests were approximated by the equation:

$$\sigma_s = 32600\ \varepsilon_i^{0.1815}\ \dot{\varepsilon}_i^{0.07089}\ \exp\left(-\,0.005454\ t\right). \tag{6}$$

Heating and cooling rate in the dilatometric research was 3 and 10°C/s. During modeling there are used appropriate dilatometric curve [3].

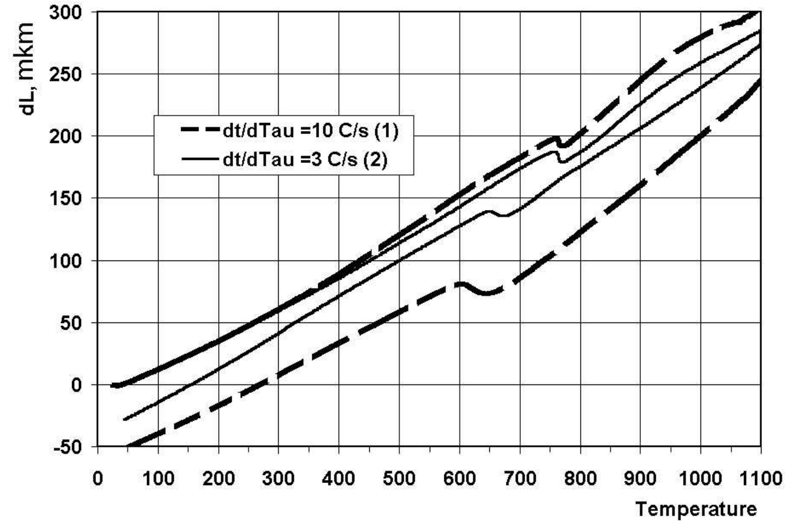

Figure 1. Dependences of elongation on the temperature under the heating (upper curves) and cooling (lower curves) with different rate

5. RESULTS OF STRESS AND STRAIN CALCULATIONS BY THE FINITE ELEMENT METHOD

The cooling of the rectangular 300x400 mm for SH15SG steel is presented. The initial temperature is 1200°C. Heat exchange coefficient for the upper surface is set $\alpha = 100$ W/m^{2}K, for the other surfaces – $\alpha = 80$ W/m^{2}K.

On the Fig. 2a it is shown the points in the cross-section. The points were used for the control of stresses, strain and temperature. The temperature distribution after 3500 s cooling is presented on the Fig. 2a. There is average stress is exposed on the Fig. 2b.

The changes of both temperature and average stress in the control points are presented on the Fig. 3. Average stress changes in the points 2 to 5 has undulated character (Fig. 3b), that is caused by the sequences of phase transformation in that points.

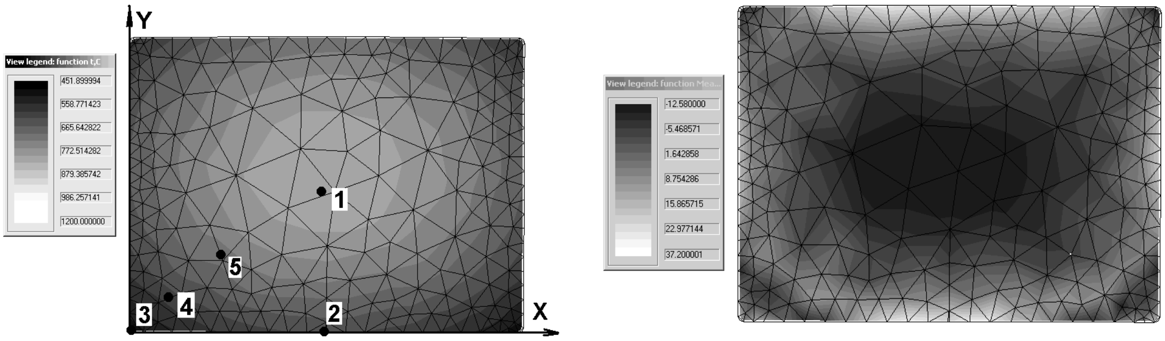

Figure 2. Temperature (a) and average stress (b) distribution by the end of cooling

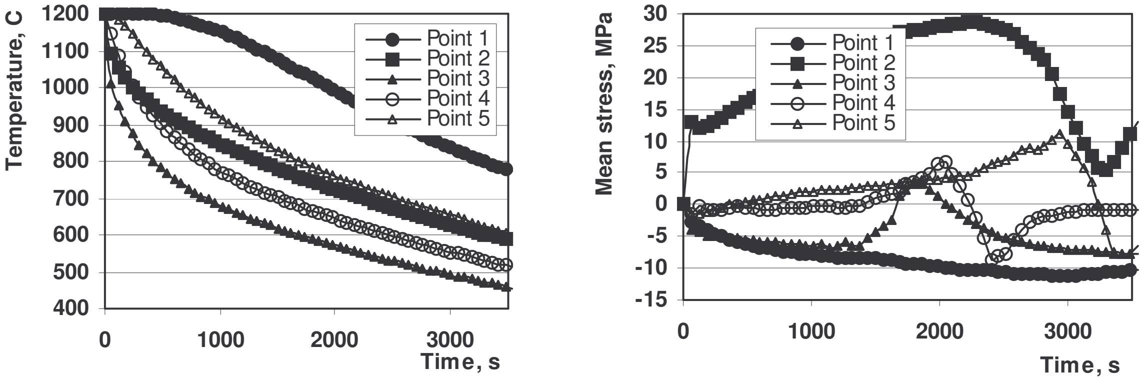

Figure 3. Temperature (a) and average stress (b) changes in the control points

6. CONCLUSIONS

The mathematical model of thermal stress development in the billet during the continues casting process which takes into account the processes of crystallization, thermal volume changes and phase transformation in the viscoplastic rheological formulation for the steel in the high temperature is developed.

Having analyzed the results one could attend to high influence of the phase transformation on the strain-stress state of metal. Undulant character of the transient process is reflected sequences of phase transformation in different points of cross-section.

REFERENCES

1. Iliusin A.A. Plastichnost. – Moskwa, GOSTECHTEORIZDAT, 1948. – 376 s.
2. Operating instructions for the Type 805A/D dilatometer // B*ƒ*HR Thermoanalyse GmbH 1997, 32 p.
3. Milenin A., Dyja H., Steblov A.B., Timospolskij V.I. Modeling of the thermo-mechanical processes during continuous casting and rolling of steel SH15// IV Międzynarodowa Sesja Naukowa "Nowe technologie I osiagniecia w metalurgii I inzynierii materialowej, Czestochowa, 2003, s. 168−131.