MICROALLOYED PIPE LINE STEEL FRACTURE ANALYSIS DURING CONTINUOUS CASTING PROCESS

Vasiliy MISHIN[a], Pavel GLUKHOV[a], Mikhail MATVEEV[a], Yuri BEZOBRAZOV[a], A. SHIRYAYKHIN[b]

[a] *Saint Petersburg State Polytechnical University, Saint Petersburg, Russia*n Federation, glukhovpavel@gmail.com

[b] *JSC «Severstal», Cherepovets, Vologda region, Russia*n Federation

Abstract

Cracking problem in slab during continuous casting using finite element method in Deform computer program was solved. The computer model of continuous casting machine (CCM) includes crystallizer, rollers and secondary cooling sections. The rheological properties of investigated steel required for model were received on Gleeble-3800. The thermal stresses in the slab, the strains and stresses during solid crust buckling due to ferrostatic pressure between CCM rollers, strains and stresses in the extension zone were determined. Analysis was carried out using maximum stress fracture criteria, the built-in Deform program. Temperature dependence of fracture criterion limits values obtained by physical simulation of crystallization and slab cooling for different operation modes of CCM on Gleeble-3800.

Keywords: Fracture criteria, continuous casting, physical simulation, finite element method

1. INTRODUCTION

Huge amount of metal loss occurs by cracks in edge slab area during hot rolling. Researches of continuous cast billets and rolled sheets shows that such cracks usually occur due to casting defects. **Fig. 1** shows defects location in casting billets [1].

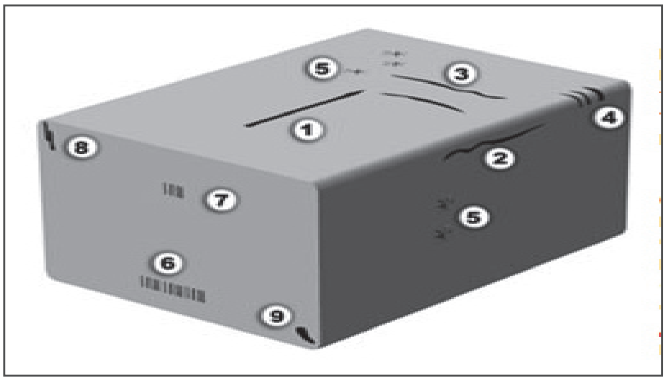


Fig. 1 Scheme of cracks location in continuous cast

The main purpose of this work is predicting fracture methods develop during continuous casting and develop modes that prevent crack formation for microalloyed low carbon steel.

Numerical simulation of casting conditions and fracture analysis for radial type continuous casting machine (CCM) was made using finite element method (FEM) in Deform program. Following problems were solved:

- Temperature fields in the slab determination during each stage of continuous casting;
- Thermal stresses occurring in the slab during cooling in the mold and in the secondary cooling sections (SCS) determination;
- Stresses determination in the edge slab area by ferrostatic pressure of liquid metal;
- Determination of stresses in the slab during bend and straightening.

2. NUMERICAL MODEL OF CCM

The CCM numerical model includes crystallizer and secondary cooling sections. SCS includes guide rollers and cooling nozzles. Slab cooling is carried out by water flow from nozzles. Industrial research and paper [1] shows complex temperature changes of the metal during casting. Continuous cooling of slab surface is occurred due to contact with water-cooled copper sides in the crystallizer. Slab surface temperature in SCS changes under cyclic law, shown in **Fig. 2**.

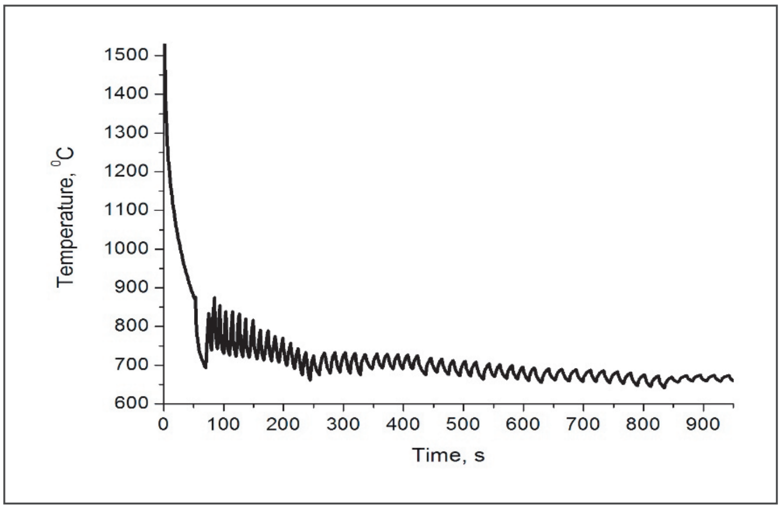


Fig. 2 Temperature change in the SCS

Cyclic law of cooling slab surface during casting caused following: in contact with the rollers, SCS occurs heating the slab surface, and in the intervals between the rollers surface cooling occurs under the cooling jet. These conditions were simulated with heat transfer windows (environment windows) in Deform program. Heat transfer windows were located between the guide rollers in the SCS. Slab cooling simulation in the mold was made also using environment windows. General view of the CCM model with heat transfer windows is shown in **Fig. 3**. The study was performed for ninth different operating modes of CCM with the low, average and high casting speed. Three water discharges for each casting speed was examined minimum possible, actual (in production), maximum possible.

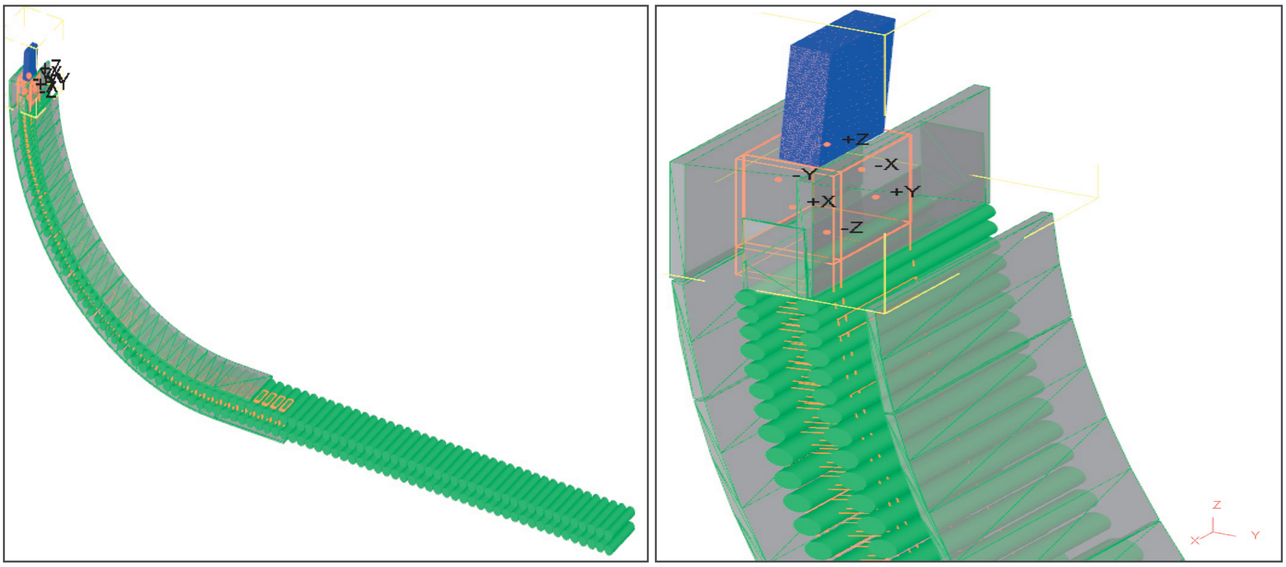
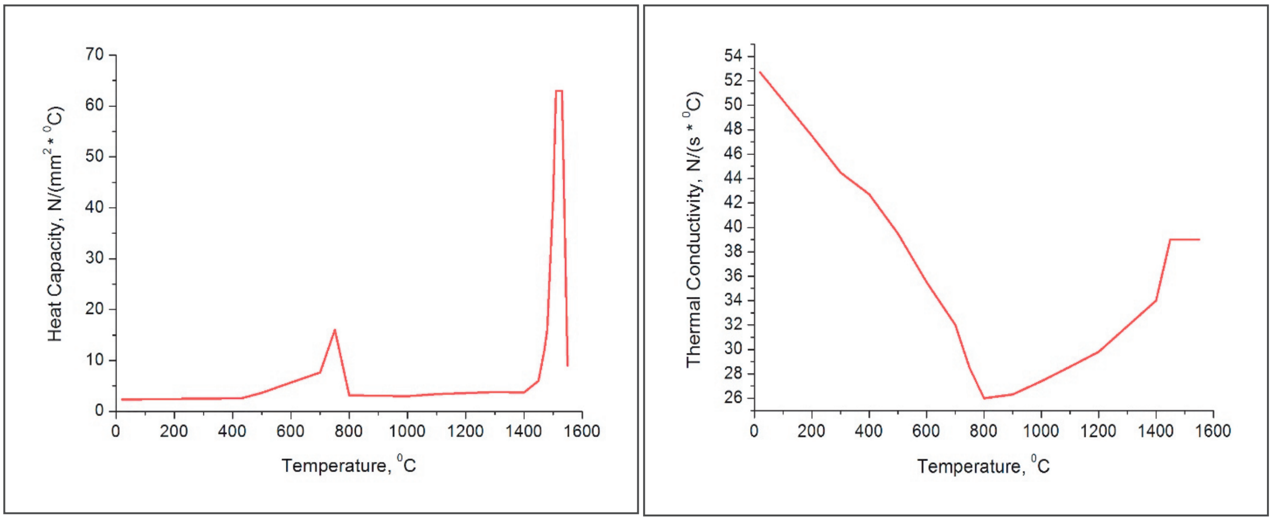


Fig. 3 FEM of the CCM in Deform-3D

Temperature problem solution defined thermal properties, which will be included in the model. Thermo physical properties of the investigated steel was set from literary sources [2]. In the model were set temperature dependences of heat capacity, thermal conductivity and body emissivity (**Fig. 4**). Rheological properties of steel were given flow stress curves for various temperatures and deformation rates obtained on the complex Gleeble-3800 [3]. Low values of deformation resistance (0.5-1 MPa) was set for properties of liquid metal.



a) b)

Fig. 4 Properties of investigated steel a) heat capacity temperature dependence b) thermal conductivity temperature dependence

3. THE COMPUTER MODEL CALIBRATION

Industrial data of slab surface temperature changes was used for computer model calibration dependence on slab cooling rate and water flow at secondary cooling section. **Fig. 5** shows industrial temperature date, used for computer model calibration. In **Fig. 5** T5 curve corresponds temperature changes at 5 mm from the narrow side of the slab. T6 curve corresponds temperature changes at mid-surface of the slab.

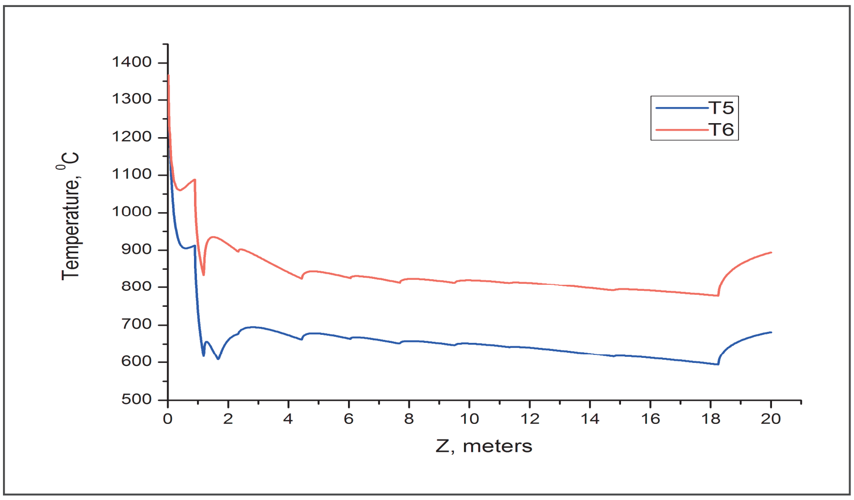


Fig. 5 Industrial data of slab surface temperature changes

Main method of temperature model calibration based on selection of convection coefficients in utility "environment windows". Convection coefficients was chosen so that calculated temperature values coincide with the experimental data. Temperature problem was solved in Deform-2D to both different section: side (point T5) and mid-surface (point T6). **Fig. 6** shows results of CCM model calibration for points T5 and T6.

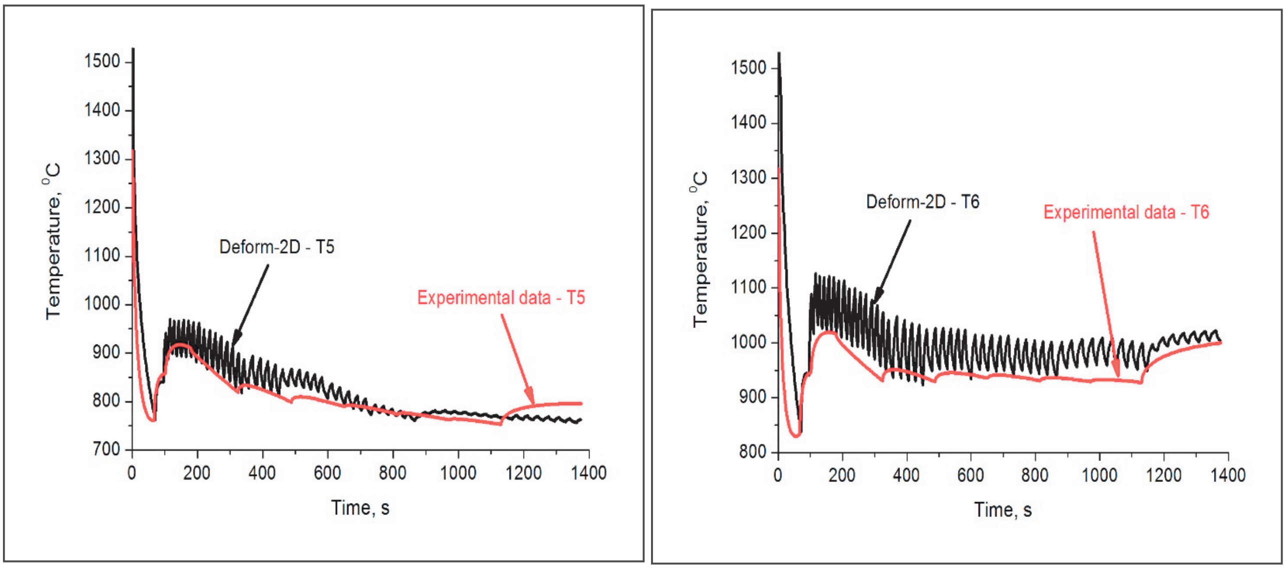


Fig. 6 Results of CCM model calibration for points T5 and T6

Results of numerical simulation in Deform show temperature distribution in the slab during continuous casting (**Fig. 7**). Temperature problem results for different continuous casting velocities in wide range at real water flow were found.

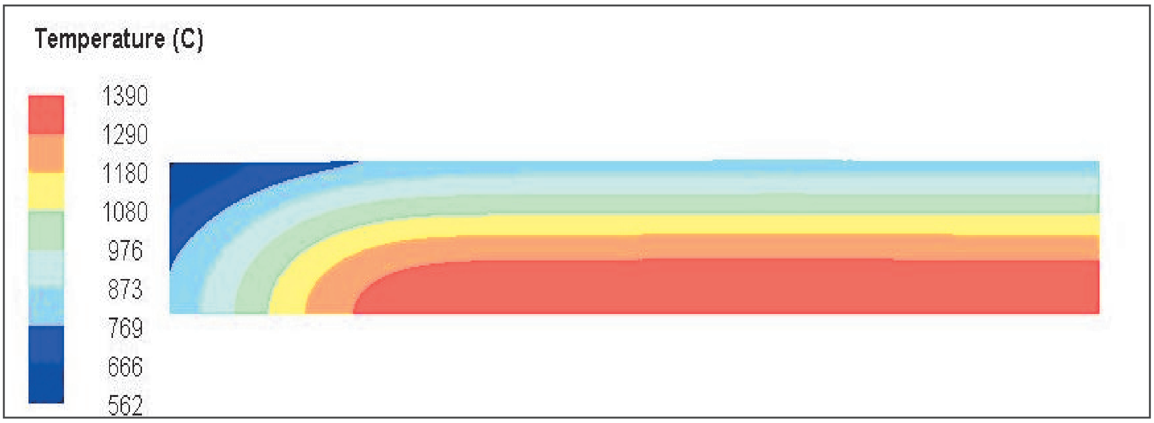


Fig. 7 Temperature distribution in the 9th section of the slab (average speed casting)

4. DETERMINATION OF THERMAL STRESSES IN THE SLAB

Main causes of cracks formation in continuous casting slab is thermal stresses [1, 4]. Thermal stresses occur because of a large temperature gradient over the cross section in the slab. Thermal stresses are generally depend on three parameters:

$$\sigma_t = E \cdot \alpha_t \cdot \Delta T \qquad (1)$$

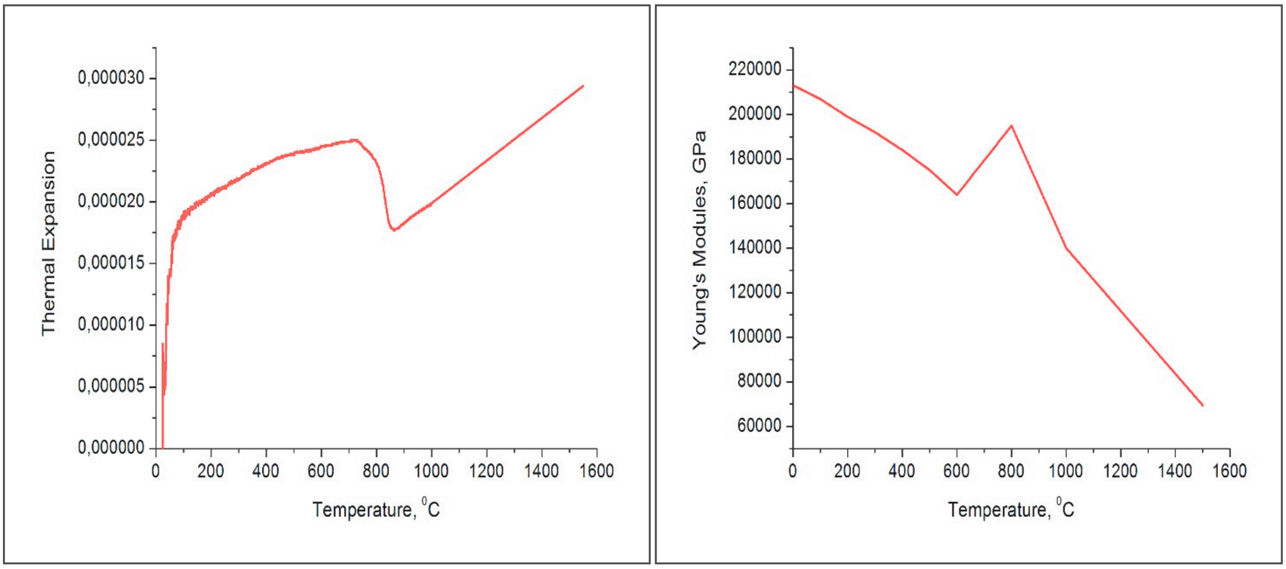
Where:

E - Elastic modulus of steel (GPa);

α_t - Thermal expansion coefficient of steel (1/ ^{0}C);

ΔT - Temperature gradient (^{0}C).

To determine thermal stresses, the problem was solved in the elastic-plastic formulation. To solve this problem in Deform program were added: the thermal expansion and modulus of elasticity depending on temperature for investigated steel (**Fig. 8**). These curves were obtained on the Gleeble-3800 complex.



a) b)

Fig. 8 Properties of investigated steel a) thermal expansion b) elastic modulus temperature dependence

Numerical simulation results show stresses distribution in the slab during continuous casting. Figure 9 shows the distribution of principal tensile stress in the cross section of the slab at the exit from crystallizer for three different speeds at actual water flow.

Fig. 9 Principal tensile stresses in the slab (average speed casting)

Fracture analysis in steel during continuous casting were used the maximum stresses criterion [5]. Mathematical formulation of the criterion can be written as:

$$\frac{\sigma_{max}}{\sigma_{ult}} = 1 \qquad (2)$$

Where:
σ_{max} - maximum principal stress (MPa);
σ_{ult} - ultimate tensile strength (MPa).

This criterion shows when tensile stresses are equal limiting stresses at a given temperature, metal fracture occurs. The limiting stresses are obtained by physical simulation of crystallization and cooling conditions of the slab on Gleeble-3800 complex as described in [3]. Physical simulation results represented as limiting stresses temperature dependence (**Fig. 10**) for different CCM operation modes. Obtained dependence has been integrated in Deform.

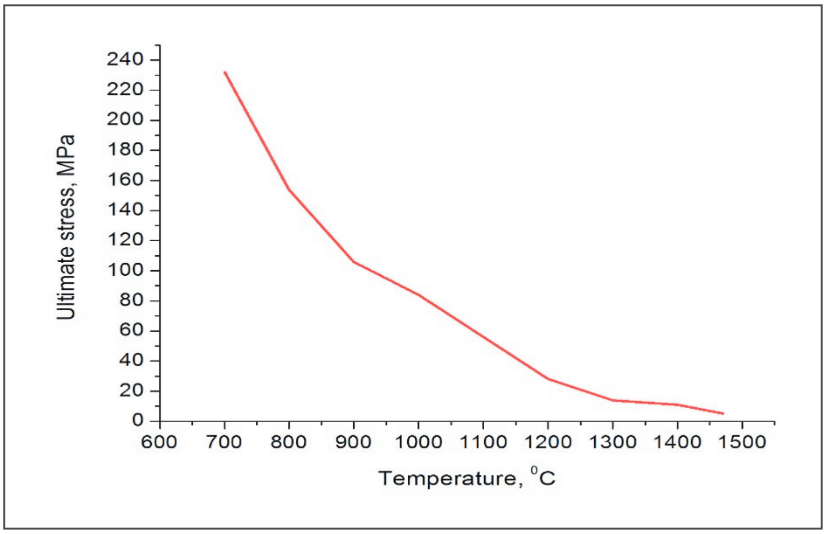


Fig. 10 Ultimate stresses temperature dependence

Using the obtained dependence of limiting stresses, metal fracture analysis all through continuous casting was made. Typical field distribution of fracture criterion at the exit of crystallizer has the form shown in **Fig. 11**. It is evident that fracture can occur in the surface and subsurface layers of the slab. In addition, cracks can form on the slab corner.

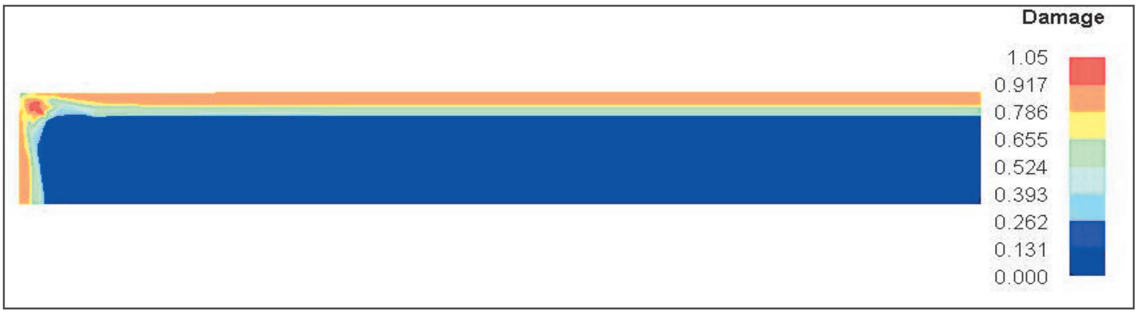


Fig. 11 Fracture criterion fields distribution (first section SCS, average speed casting)

Fig. 12 shows fracture criterion changes for different CCM operation modes in the corner area of the slab.

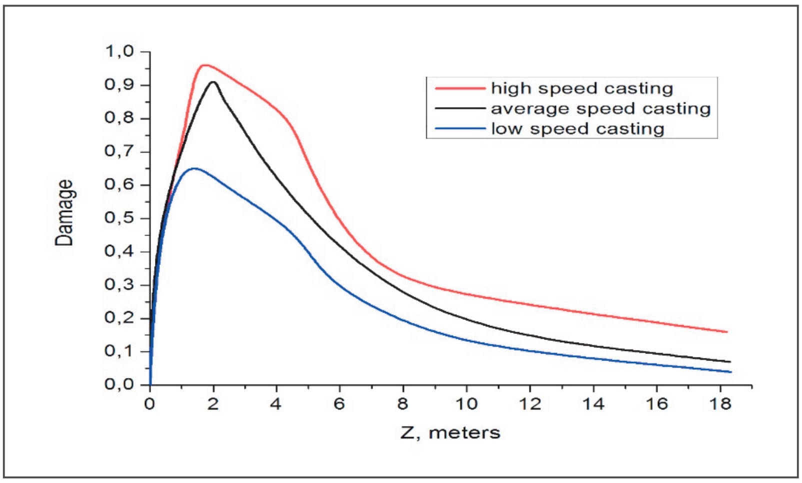


Fig. 12 Fracture criterion in the corner area of the slab for different speeds casting

CONCLUSIONS

Fields of temperature distribution in the slab during continuous casting for ninth CCM modes were identified using a new created in Deform computer model. It was found that the main possible reason for cracks formation is thermal stresses that depend on casting conditions. The analysis of metal failure under thermal stresses during a continuous casting process has been implemented using the criterion of maximum stresses and limit values. The first sections of SCS are the places of the possible cracks formation on the surface of the slab and inside of it under thermal stresses. Also, the following article will consider the solution of problems №№ 3 - 4.

REFERENCES

[1] SMIRNOV A.N., CUBERSKY S.V., SHTEPAN E.V. *Continuous casting steel*. Donetsk: NTU, 2011. 482 p.

[2] YA MENG, THOMAS B.G. *Heat-transfer and solidification model of continuous slab casting.* Metallurgical and Materials Transactions. 2003, vol. 34B.

[3] KOLBASNIKOV N.G., MATVEEV M.A., ZOTOV O.G., MISHIN V.V., MISHNEV P.A., NIKONOV S.V. *Physical simulation hot ductility of microalloyed pipe steel during continuous casting steel and hot rolling.* Steel. 2014, nr. 2, pp. 59-65.

[4] BROVMAN M. *Continuous casting metals.* Moscow, 2007. 484 p.

[5] *DEFORM™ 2D-3D v10.0. User's Manual.*