THE SELECTED CRACK CRITERIONS SENSITIVITY TO THE ARC CHANGING OF THE CONTINUOUS CASTING MACHINE

Agnieszka CEBO-RUDNICKA, Zbigniew MALINOWSKI, Andrzej GOŁDASZ, Beata HADAŁA
CRACOW, AGH University of Science and Technology, Faculty of Metal Engineering and Industrial Computer Science, Department of Heat Engineering and Environment Protection, Al. Mickiewicza 30, 30-059 Cracow, Poland, cebo@agh.edu.pl

Abstract

Formation of surface and internal cracks during solidification and cooling the steel while continuous casting process is very difficult to model. Crack formation depends on many different factors e.g. chemical composition of steel, type of the solidified metal structure, cooling parameters and casting technology. All these factors influence on the stress and strain field and may cause the failures formation. In these case the possibility of cracks formation prediction is a very important problem in the design of the continuous casting process. The effect the arc changing of the continuous casting machine on the possibility of cracks formation has been investigated. The analysis was taken on the ground of numerical calculations for selected fracture criterions and two different arcs of the casting machine. The temperature filed was computed based on the three dimensional steady solution to the heat transport equation. Heat of solidification has been included in the finite element model. The thermal strains and stresses which result from non uniform temperature field were computed. Also strains and stresses which are caused by bending and unbending of the strand were taken into account. Finite element method was used to compute the stress and strain field in the whole continuous casting line.

Keywords: Continuous casting of steel, fracture criterions.

1. INTRODUCTION

Continuous casting process is the mean process of steel slabs production. Solidification of steel that follows during continuous casting is nonequilibrium process and it is characterized by the large cooling rate [1]. These may cause defects at cast strand such as surface or internal cracks. On the cracks formation affect many factors. Two of them are casting technology and the arc of casting machine. The beginnings of continuous casting processes are dated at the second half of nineteenth century. The first continuous casting machines were vertical ones and they were over 40 m high. Pursuing to reduction capital costs of continuous casting lines caused development of radial machines. In such a case the arc of casting machine should be design so as to avoid cracks and hot-tearing formation, which may be caused by stresses develop at the surface layer while bending and unbending cast strand. At literature there are available formulas that describe approximate value of the arc of casting machine depending on cast strand thickness [2]. The experimental analysis of influence of any technical parameters of continuous casting line on quality of cast strand is difficult and very expensive [3]. Much more cost-effective are numerical methods and specialized software compiled specially for this technology of ingot production [4-6].

2. HEAT TRANSFER MODEL

The heat transfer while continuous casting is a very rapid process, that involves cast metal, casting equipment and environment. To model such a process it is necessary to formulate complicated mathematical model. The most difficult is to define the boundary conditions for each type of cooling which take place in the continuous casting process. The slab temperature field while cooling in casting mould, in secondary cooling...
zones and in air was computed using steady solution of Fourier–Kirchhoff equation. The heat of solidification has been included in the model in the form of the internal heat source. The more detailed description of the mathematical model of heat transfer has been presented in [7].

3. STRESS AND STRAIN MODEL
In order to analyze the cracks formation in cast strand the stress and strain field was determined. Stresses and strains resulting from nonuniform temperature field and bending and unbending of the cast strand were taken into account. The influence of the gravity forces on the liquid steel movement was neglected. Also the local changes of stress and strain fields at the rolls contact zones were not computed. Elastic–plastic finite element model was used to determine the stress and strain field in the cast strand. The more detailed description of the stress and strain model has been presented in [8].

4. CRACK CRITERIONS
The following fracture criterions have been selected to analyze the cracks formation:

- Rice and Tracy criterion
  \[ C_{RT} = \bar{e} \exp\left(-\frac{3}{2} \frac{\sigma_m}{\bar{\sigma}}\right) \]  
  where: \( \sigma_m \) – mean stress, \( \bar{e} \) – effective strain.

Rice and Tracy criterion [9] predicts that failures will form when parameter \( \sigma_m \) passes the critical value of effective strain \( \bar{e}_f \).

- Plastic work criterion
  \[ C_{EP} = \int_0^t \bar{e} \cdot \bar{\sigma} \, dt \quad \text{for} \quad \sigma_m > 0 \]  
  where: \( \bar{e} \) – effective strain rate, \( \bar{\sigma} \) – effective stress.

The criterion assumes that cracks will occur if strain energy is higher than the critical value \( C_{EP} \). Plastic strain energy is calculated only at points where mean stress is positive.

- Latham criterion
  \[ C_{LO} = \int_0^t \sigma_{max} \cdot \bar{e} \, dt \quad \text{for} \quad \sigma_m > 0 \]  
  where: \( \sigma_{max} \) - maximum stress.

Latham criterion [1] assumes cracks formation when strain work done by the maximum tensile stress passes the critical value \( C_{LO} \). The uniaxial tension test can be employed in order to determine the critical values of \( C_{EP}, C_{RT}, C_{LO} \) parameters. The tensile tests have to be performed in the wide range of temperature up the solidification temperature.
5. ANALYSIS OF THE RESULTS

Analysis of crack criterions has been performed for square cast strands. The following chemical compassion of steel has been assumed for calculations: 0.45% C, 0.65% Mn, 0.27% Si, 0.95% Cr and 1.55% Ni. Thermo physical properties of steel were selected on the ground of chemical composition of steel [10].

![Fig. 1. Temperature distributions at selected points of continuously cast strand for case I (left) and case II (right)](image)

Analysis has been performed for two different values of the arc of casting machine: case I (arc radius 6 m); case II (arc radius 10.5 m). Higher value of the arc of casting machine results in larger length of cast strand. For the first case metallurgical length of strand is about 17 m and for the second one is about 24 m. In order to get similar temperature distributions for both cases different values of casting velocity were assumed. The similar temperature distributions in the longitudinal section of the strand were obtained for casting speed equaled to 1.6 m/min in the case I and 2.1 m/min for the case II. The difference between the temperature distributions at characteristic points of cast strand did not exceeded 40 ºC (fig.1). The obtained temperature fields has been assumed as an input date used to calculated strain and stress fields and to analyse crack criterions. Calculated values of crack criterion parameters confirmed that the most susceptible to crack formation are inner and outer corners of the cast strand. Analysing crack formation on the ground of Rice and Tracy criterion is complicated. In both cases results given by this criterion are at the same level. The bigger values of Rice and Tracy criterion were observed at the corners of cast strand but on all of curves peaks are noted (fig. 2). That has made the proper interpretation of the results very difficulty. The places that are most exposed to crack formation are located at points where the rapid increase in criterion parameters is observed. According to the received results most probably cracks may developed at corners of the strand or on the side surface. In both cases the highest values of plastic work and Latham criterions have been obtained at the side surface and at outer and inner corner of cast strand.
Results of calculations given by plastic work and Latham criterions indicated as the most probable place of crack formation a domain between the 1th and the 4th meter of the outer corner of the cast strand in the case of 6 m arc radius and the domain between the 1th and 5th meter for 10.5 m arc radius (fig. 3, 4).

In these region the cast strand is subjected to bending. The inner corner of cast strand is exposed to crack formation after leaving the casting mould (at about 1th meter of the metallurgical length of strand for the both analyzed cases). In the case of 6m arc of casting machine between 5th and 8th meter of the length of cast strand where the strand is subjected to unbending the inner corner is exposed to further cracks development. In case of 10.5 m arc the increase at criterion values for the inner corner of cast strand in unbending zone is not so important. It should be noticed that while increasing arc radius, the values of plastic work and maximum stress work for each characteristic point of cast strand decreased significantly.
6. CONCLUSIONS

The results of calculation let to identify the regions were crack can be formed while continuous casting of steel. Among the selected crack criterions the most useful are plastic work and Latham criterions. Numerical calculation performed on the basis of these two criterions indicated the same regions of cracks formation as the well known from industrial practice. Increasing of the arc radius of continuous casting machine from 6 m to 10.5 m resulted in significant decrease in plastic work and work of maximum stress. These clearly indicates that the probability of crack formations in case of 10.5 m arc radius is much smaller.

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LITERATURE