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DETERMINATION OF COOLING PARAMETERS DURING CONTINUOUS CASTING OF BLOOMS

ODREĐIVANJE PARAMETARA HLAĐENJA ZA KONTINUALNO LIVENJE BLUMOVA

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Keywords
- continuous casting
- cracks formation
- heat transfer
- solidification
- mathematical modelling

Abstract

The quality of continuously cast steel is determined by the conditions existing during cooling and solidification of the steel. One of the causes of crack formation on the blocks in the continuous casting process is the cyclic recurrence of cooling. The periodicity of cooling depends on the distance between spray jets. Thermal and mechanical stresses acting on this shell can lead to crack formation and result in poor quality of the final steel product and to operational problems with the casting machine. The requirements for quality of blooms can be achieved by reducing spray water volume in the secondary cooling zone. Thus reduction of cooling intensity is limited by the height of the installation and distance between rollers. An investigation has been carried out on the operating and cooling parameters of a radial continuous bloom casting machine. A real time two-dimensional finite difference thermal model describing the solidification, bulging behaviour and metal stress state is used for calculation of temperature distribution and shell thickness during casting. Additional limitations are introduced in connection with the cooling rate on the block surface and the warm-up temperature after the block leaves the secondary cooling zone. The required heat transfer coefficients on the block surface that comply with the above-indicated requirements are determined. Results for thermocyclic recurrence along the block axis and surface areas, which shall be covered by water cooling jets, are obtained.

Ključne reči
- kontinualno livenje
- obrazovanje prslina
- prenos toplote
- očvršćavanje
- matematičko modeliranje

Izvod

Kvalitet kontinualno livenog čelika je određen uslovima koji se uspostavljaju tokom hlađenja i očvršćavanja čelika. Jedan od razloga za obrazovanje prslina u blokovima u procesu kontinualnog livenja čelika je ciklična promena u toku hlađenja. Periodična učestalost hlađenja zavisi od razmaka između struje mlaza. Termički i mehanički naponi koji deluju na ovu ljusku mogu dovesti do obrazovanja prslina i rezultirati u niskom kvalitetu konačnog proizvoda od čelika i problema u eksploataciji livenih mašina. Zahtevi za kvalitet blumova se mogu ispuniti smanjenjem zapremine vode u sekundarnoj zoni hlađenja. Zbog toga je intenzitet hlađenja ograničen visinom instalirane opreme i razmakom između valjaka. Izvedeno je istraživanje radnih parametara i parametara hlađenja u radijalnoj mašini za kontinualno livenje blumova. Termički model koji koristi metodu konačnih razlika u dve dimenzije tokom realnog vremena i opisuje očvršćavanje, ponašanje pri izbočavanju i stanje napona u metalu je korišćen za proračun raspodele temperature i debljinu ljuske prilikom livenja. Dodatna ograničenja su uvedena u vezi sa brzinom hlađenja na površini bloka i temperaturom zagrevanja nakon što blok napusti sekundarnu zonu hlađenja. Određeni su potrebni koeficijenti transfera na površini bloka koji zadovoljavaju gore navedene zahteve. Rezultati za termodinamičke ciklične promena u toku hlađenja duž osa blokova i spoljnjih površina, koje treba da budu oplakivane mlazom vode za hlađenje su izloženi.

INTRODUCTION

The quality of continuously cast steel is determined by the conditions existing during steel making, cooling and solidification of the steel. Close control of steel bath temperature and temperature distribution in the ladle for each stage of production technology is essential to improve both productivity and product quality and to ensure constant temperatures of steel. Efficient continuous casting requires interrelated planning and control of operations, starting with methods and regimes of ladle reheating, /1, 2/, steel making technology, and ending with parameters and regimes of cooling during the casting, /3-5/, to ensure a high quality of the cast metal, /6-9/.

One of the causes of cracks on block surfaces in the process of continuous casting is the cyclic recurrence of cooling. The periodicity of cooling depends on the distance between spray jets. This leads to changes in the mechanical properties of the block surface layers and necessitates introduction of additional limitations in the development of secondary cooling zone regimes (cooling rate and post-cooling reheating). These limitations of cooling intensity depend on the height of the machine, distance between the rollers, rate of cooling on bloom surface and warming up after exclusion of water-cooling. The cooling jets have also to provide for uniform temperature field (distribution) on the block surface.

The aim of the work is to investigate cooling processes in a radial continuous casting machine and to determine the necessary regime parameters and block surface areas, which have to be directly covered by the water-cooling jets.

INVESTIGATION

An investigation has been carried out on the operating and cooling parameters of a radial continuous bloom casting machine.

They have been worked out on the basis of a mathematical model describing continuous casting process parameters and cooling intensity. That model takes into account heat transfer, crystallisation, /3/, and stress-and-strain condition, /4/, of the shell in the block forming process.

The operating parameters of radial continuous casting machine with radius of the radial area 12 m, length of the mould 1.0 m and technological length 19.14 m are the object of the present study. The main design dimensions of the secondary cooling zone (SCZ) are given in Table 1, where R and r designate the big and the small radius of the machine.

Table 1. The main dimensions of the secondary cooling zone.
Tabela 1. Glavne dimenzije sekundarne zone hlađenja

Zone	Number collectors	Number nozzles	Length, m
I	2	8	625
II	2	8	620
III	2	8	620
IV	2	8	625

The interval of safe alteration of the cooling parameters is characterised by heat-transfer coefficient limit values. With values exceeding the upper limit there is danger of crack formation and with values below the lower limit there is danger of rupture because of the ferrostatic pressure. Also the temperature variation on the block surface during the directly covering of the metal by the cooling jets must be up to 80°C/min and the increasing after exiting from the secondary cooling zone must be less than 50°C, /1, 7/.

In the mathematical model the distance between the two rolls in the cooling system is divided into four sectors:
1. sector of contact between the block and upper bearing roller;
2. sector between the bearing roller and the jet;
3. sector of direct cooling from water spray jets;
4. sector between water-air spray jets and down roller.

A scheme of a secondary cooling zone is shown in Fig. 1.

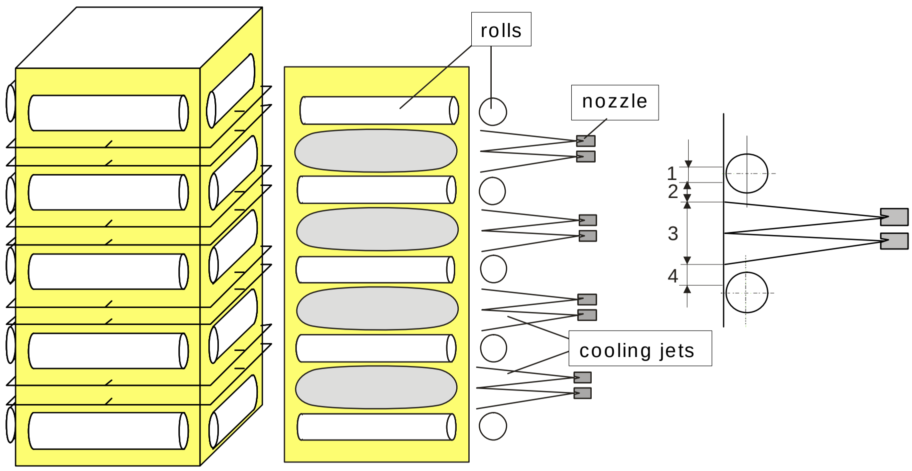

Figure 1. Scheme of the secondary cooling zone, 1–sector of contact between the block and the upper roller, 2–sector between the roller and the jet, 3–sector of direct cooling from the water spray jets, 4–sector between the water-air spray jets and down roller.
Slika 1. Shema sekundarne zone hlađenja, 1–sektor kontakta bloka i gornjeg valjka, 2–sektor između valjka i mlaza, 3–sektor direktnog hlađenja strujom mlaza vode, 4–sektor između struje mlaza vode i donjeg valjka

Based on the analysis of casting cooling parameters, constructive parameters, and experimental measuring of temperature on the block's surface with infrared camera, an adaptation and verification of the mathematical model is made.

Strand surface temperature of the blooms is measured at 6.4 m from the length of the machine.

A comparison between the theoretically predicted and the experimentally measured is shown on Figure 2.

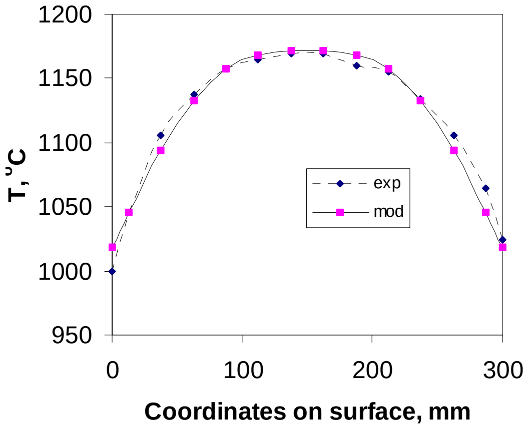

Figure 2. Comparison of experimental and calculated temperatures.
Slika 2. Poređenje eksperimentalnih i sračunatih temperatura

For the applied cooling conditions and characteristic values of spray water impingement density, the heat transfer coefficients for sprays are determined and are indicated in Table 2.

Table 2. Heat transfer coefficients in secondary cooling zone.
Tabela 2. Koeficijent prenosa toplote u sekundarnoj zoni hlađenja

Zone	α, W/m²K
Zone 1	340
Zone 2	280
Zone 3	260
Zone 4	–

The temperature distribution, necessary thermal flow values and related heat-transfer coefficients for each secondary cooling zone are determined.

Calculated results of cooling parameters and temperature variation on the vertical cross section axis of the block for the conditions of the experiment (cooling intensity and casting speed $V = 0.75$ m×min^{-1}) are given in Fig. 3. The solid line represents the temperatures at different distances (0–0.125 m) from the surface, and the dashed line – the variation of the heat-transfer coefficient α on metal surface.

It can be seen that after the metal leaves the secondary cooling zone, the surface temperature increases by 50°C. It can lead to deterioration of quality, because the temperature variation after leaving the secondary cooling zone shall be less than 50°C, /4-6/, and such regimes have to be avoided.

For that reason a series of calculations for different casting speeds are made. During the numerical investigation, additional limitations are introduced in connection with the cooling rate ($Vc < 80$°Cm^{-1}) on the block surface and the warm-up temperature ($\Delta T < 50$°C) after the block leaves the secondary cooling zone of numerical simulation. Using numerical simulation of the process, the required heat transfer coefficients on the block surface that comply with the above-indicated requirements are determined.

The results of the temperature variation on the vertical cross section axis of the block for the boundary cases of cooling at casting speeds 0.6 m×min^{-1} to 0.9 m×min^{-1} are presented in Figs. 4, 5 and 6.

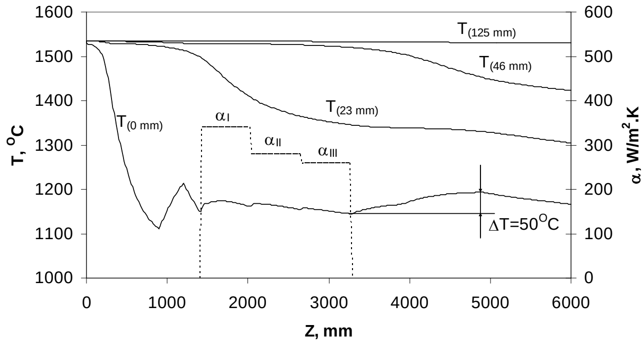

Figure 3. Temperature variation calculated in experimental conditions.
Slika 3. Sračunate promene temperature za uslove eksperimenta

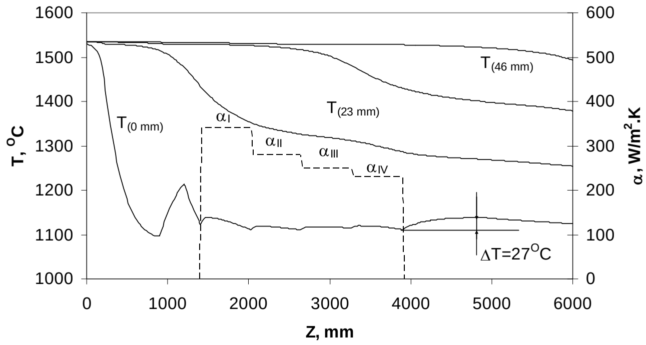

Figure 4. Temperature variation for casting speed 0.6 m/min.
Slika 4. Promena temperature za brzinu livenja 0,6 m/min

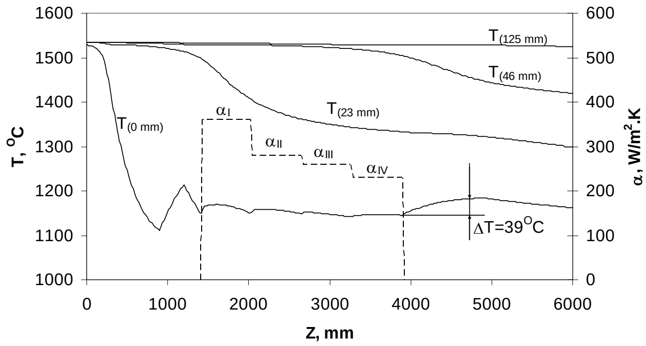

Figure 5. Temperature variation for casting speed 0.75 m/min.
Slika 5. Promena temperature za brzinu livenja 0,75 m/min

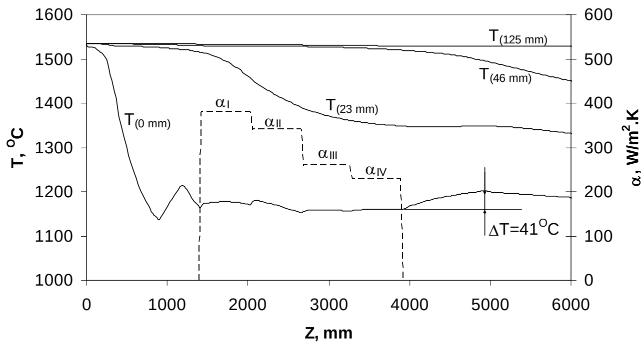

Figure 6. Temperature variation for casting speed 0.9 m/min.
Slika 6. Promena temperature za brzinu livenja 0,9 m/min

Figure 4 shows that the surface temperature in the SCZ has an approximately uniform slope at the cooling rate 11.4°Cm^{-1}. As it is shown in Figs. 5 and 6, these values for casting speeds 0.75 and 0.9 m×min^{-1} are, respectively 10.3 and 11.8°Cm^{-1}. For these casting speeds the warm-up temperature on the surface after the block leaves the secondary cooling zone is 27°C for 0.6 m/min, 32°C for 0.75 and 41°C for 0.9 m×min^{-1}. They are in agreement with the above-indicated requirements, /1, 7, 8/. Therefore it can be recommended that values of cooling heat-transfer coefficients must be as they are presented in Table 3.

Table 3. Required values of cooling parameters.
Table 3. Zahtevane vrednosti parametara hlađenja

Zone	α, W/m^{2}K		
	V = 0.6 m/min	V = 0.75 m/min	V = 0.9 m/min
I	340	360	380
II	280	280	340
III	250	260	260
IV	230	230	230

CONCLUSIONS

An investigation of cooling parameters of a radial continuous bloom casting machine is carried out with accounted surface thermocyclic recurrence.

The levels of the limit values of heat transfer coefficients in particular sections of secondary cooling zones are determined. They satisfy the required limitations in connection with the cooling rate (Vc < 80°Cm^{-1}) on the block surface and the warm-up temperature (ΔT < 50°C) after the block leaves the secondary cooling zone.

On the basis of the obtained results it can be asserted that the effect of surface thermocycles is within boundaries of 0.02 m from the surface.

The determined regime parameters provide more uniform temperature field on the block surface, enabling to avoid the occurrence of cracks in final steel products.

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