

THE INFLUENCE OF STEEL PREHEATING LEVEL IN THE TUNDISH ON THE PRIMARY STRUCTURE OF A CONTINUOUSLY CAST INGOT

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The article presents the results of industrial measurements carried out on continuous casting machine during its normal working operation. The aim of the research was to determine the influence of steel preheating level on the size of particular crystallization areas of ingot primary structure.

Key words: tundish, continuous casting, liquid steel, mold, industrial experiment.

INTRODUCTION

Metals and their alloys solidification defined as a change of state phenomenon (from liquid to solid) associated with emission of a certain amount of heat and the formation of the primary crystalline structure on the way of physically and chemically complicated crystallization process [1, 2]. The primary structure formation process consists of two sub-processes running successively:

- nucleation of solid phase,
- growth of nucleus to crystals form.

Because of the complexity of the solidification and crystallization process during steel casting in CC device the primary structure of continuous ingots may consist of differential character areas (frozen crystals, columnar crystal, equiaxed crystals). From the point of view of ingots quality the aim is to obtain a homogeneous primary structure with the smallest equiaxed grains throughout the volume of the ingot. To obtain required quality of ingots primary structure it is needed to identify process parameters that decides about the range of each crystallization zone on the surface of ingots cross-section. Identification of those parameters allows to efficiently control the CC process from the point of view of discussed issue.

THEORY OF SOLIDIFICATION AND CRYSTALLIZATION

The change of physical state of metals and alloys, but also crystallographic form, are classified as phase

transition of the first type from the thermodynamic point of view. Characteristic feature of all phase transitions is equality of Gibbs free energy in points of transitions. If the phase transition point is temperature then at constant pressure in the transition point Gibbs free energy of emerging solid phase is equal to Gibbs free energy of liquid phase. Phase's equilibrium state illustrates (see Figure 1).

Under the conditions different from equilibrium state, the permanent phase is characterized by the one with less free energy. Lowering the temperature of system below the equilibrium temperature T_r ($T_r = T_K$) leads to the formation of solid phase as a result of development of solidification and crystallization processes of liquid phase and reduction of system's Gibbs free energy by the ΔG amount (ΔG amount has a minus sign). This means that for the course of solidification and crystallization process is required determined undercooling state of the system - the temperature of the system has to be lower than the equilibrium temperature T_r , which is equal to solidification temperature T_K .

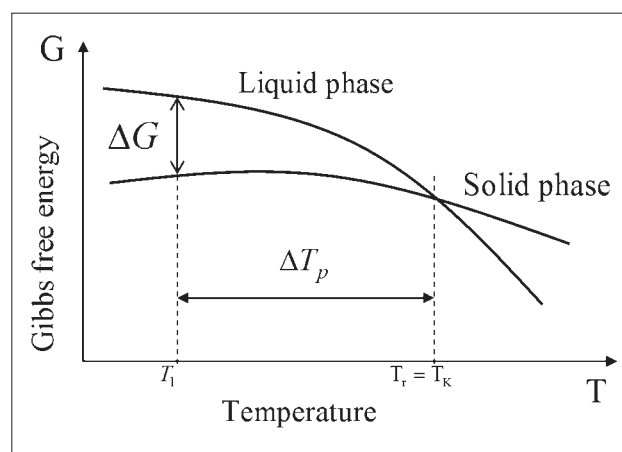


Figure 1 Diagram of equilibrium phase during metals' solidification [3]

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With the increase of undercooling occurs greater negative volume change of the Gibbs free energy, and thus the process of solidification and crystallization progress easier. In other words, the undercooling is the “driving force” of solidification and crystallization process of metals and their alloys [3].

$$(-)\Delta G = Q_K \frac{\Delta T_p}{T_K} \quad (1)$$

where: ΔG - change of Gibbs free energy; $J \times mol^{-1}$; Q_K - solidification heat, $J \cdot kg^{-1}$; ΔT_p - undercooling; K, T_K - solidification temperature, K

PRIMARY STRUCTURE OF A CONTINUOUSLY CAST INGOTS

From the thermodynamic point of view important impact on primary structure formation of ingot have steel cooling intensity and its degree of thermal undercooling, which are conditioning solidification rate.

The dependence of the concentrational undercooling on the chemical composition of the alloy, temperature and solidification speed of the liquid phase describes the inequality (7). It determines the stability of distribution of the phase planar border (planar solidification front), and thus the gradual way of solidification [4-7].

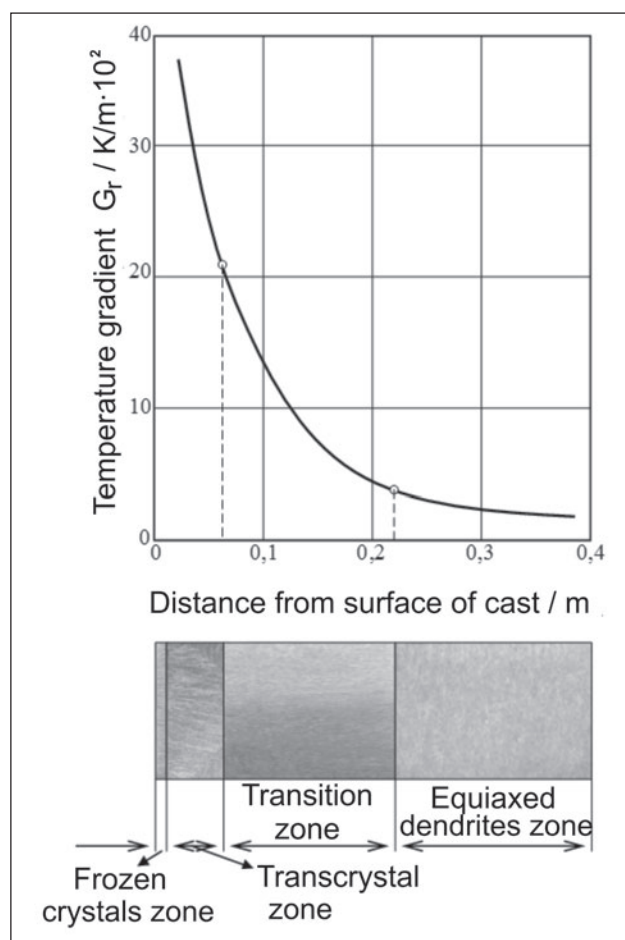


Figure 2 Effect of the intensity of liquid steel cooling on the steel cast's structural form [4]

$$\frac{G_r}{v_K} \geq -\frac{m \cdot C_0}{D_i} \cdot \frac{(1-k_0)}{k_0} \quad (2)$$

where: G_r - temperature gradient on solidification front, K; v_K - linear solid-ification speed, $m \cdot s^{-1}$; m - slope of the liquidus in the equilibrium system of base metal - components i , $K/\%$; C_0 - initial concentration of the component in the liquid phase, $kg \times m^{-3}$; D_i - diffusion coefficient of i component in the liquid phase, $m^2 \cdot s^{-1}$; k_0 - equilibrium distribution of i component coefficient.

At the reverse dependence the conditions of solidification favor the formation of dendritic crystal structure – very characteristic for steel ingots. It is graphically illustrated by Figure 2.

The quality and properties of the steel ingot macrostructure are determined by the size of equiaxed crystal zone referred to the cross-sectional area of the ingot. The larger the area of equiaxed crystals the better the quality of ingot's macrostructure.

INDUSTRIAL INVESTIGATION

As is apparent from the theory of solidification and crystallization of steel, a significant impact on the size of columnar crystal zones have a temperature gradient on the front of solidification G_r . It is closely related to the overheating temperature of liquid steel over the liquidus temperature of the casted steel. Such an assumption has allowed to develop a methodology of research on the impact of the overheating degree on the quality of the primary structure of ingots.

Developed test methodology of macrostructure of ingots has been divided into three stages:

- temperature measurement of liquid steel in the tundish,
- taking samples from ingots (templats) in the zones of temperature measurement,
- metallographic examination of taken samples.

For measuring the temperature of liquid steel in the tundish Contilance® system was used, mounted above the tundish with the sensor immersed in the liquid steel from the top through a layer of dusting powder. Diagram of the measuring system is shown in Figure 3.

The sensor is a tough integral construction of platinum rhodium thermocouple, giving accurate temperature measurement, combined with an outer sheath of graphite alumina refractory, giving extended protection against the liquid steel and slag.

Contilance® employs type B Pt30%Rh/Pt6%Rh thermocouple wire according to international standards, based upon the IPTS 1968 temperature scale. Wire is selected to an accuracy of 2 °C [8]. Thanks to such accuracy molten metal temperature is within strict limits determined.

Figure 4 shows an exemplary graph of the temperature measurement obtained by using Contilance® system. Sampling from ingots consist in cutting templats

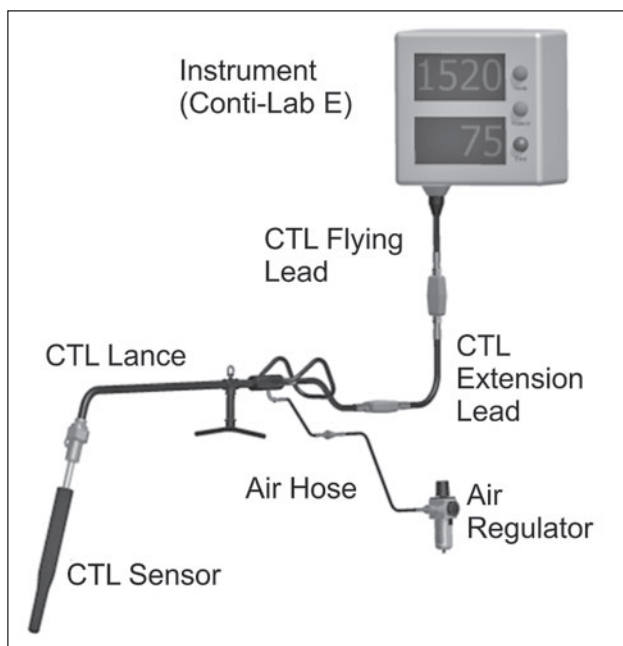


Figure 3 Contilance® system operation [8]

using gas burners. Templets were collected from beginning, middle and end of each experimental melts, pre-assigning to the measured temperature value in the tundish. Metallographic tests of samples were conducted by deep digestion. Chemical composition of the G3Si1 steel grade, cast on the CC device in the course of the study are presented in Table 1.

Table 1 Chemical composition of the steel grade (G3Si1)

	Chemical composition / wt. %							
	C	Mn	Si	P	S	Cr	Al	Cu
min.	0,06	1,3	0,7	-	-	-	-	-
max.	0,14	1,6	1,0	0,025	0,025	0,15	0,02	0,035

To distinguish between experimental melt (EM), those were marked with the symbol EM and consecutive letters of the alphabet A and B. Basic parameters of the technological process of CC experimental melts of G3Si1 steel contains Table 2.

Table 2 Technological parameters of the continuous casting process of steel experimental melts.

Parameters	Melt	
	EMA	EMB
Steel temperature in ladle / °C	1 587	1 594
Steel temperature in tundish / °C	1 541	1 553
Liquidus temperature T_L / °C	1 518	1 518
Steel overheating ΔT_p / °C	23	35
Casting velocity / $m \times min^{-1}$	3,0	3,0

Table 3 Percentage share of columnar crystal zone on the surface of metallographic sample

Exp. melt symbol		Fraction of columnar crystal zone / %		
		Ingot (nozzle) 1	Ingot (nozzle) 2	Ingot (nozzle) 3
EMA	Melt beginning	71,00	70,40	80,60
	Middle of a melt	61,82	65,32	65,39
	End of a melt	74,95	70,94	73,41
EMB	Melt beginning	98,5	98,2	99,0
	Middle of a melt	98,3	98,4	98,7
	End of a melt	99,2	98,3	99,1

The macroscopic analysis of the examined ingots primary structure allowed to determine significant differences in its construction, depending on the degree of overheat of the casted steel. In line with expectations arised from the solidification theory, there was a significant expansion of columnar crystal zone in the ingots

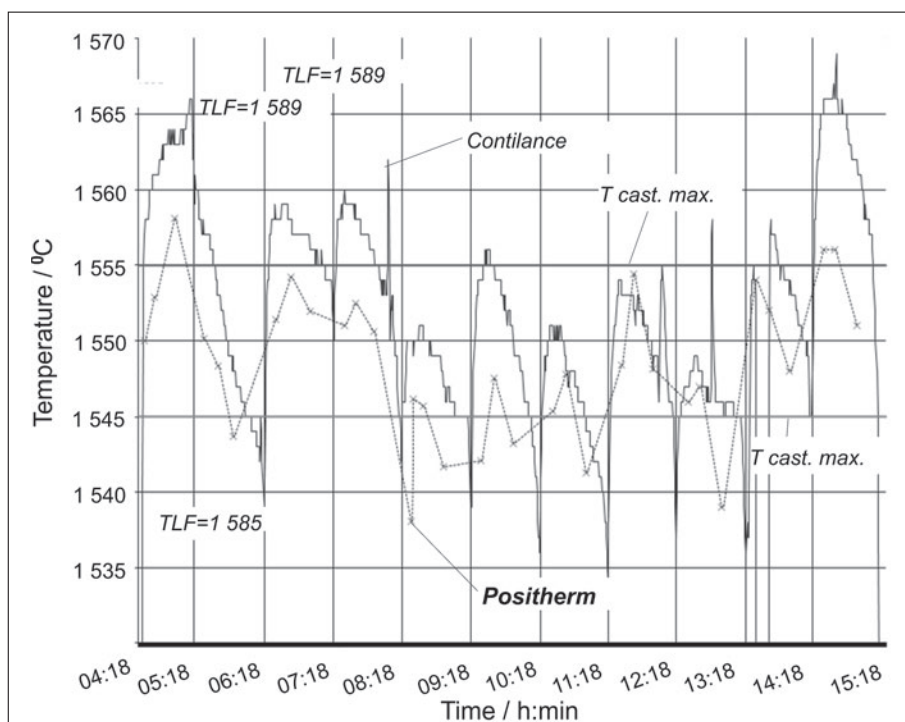


Figure 4 Example results of a Contilance® system

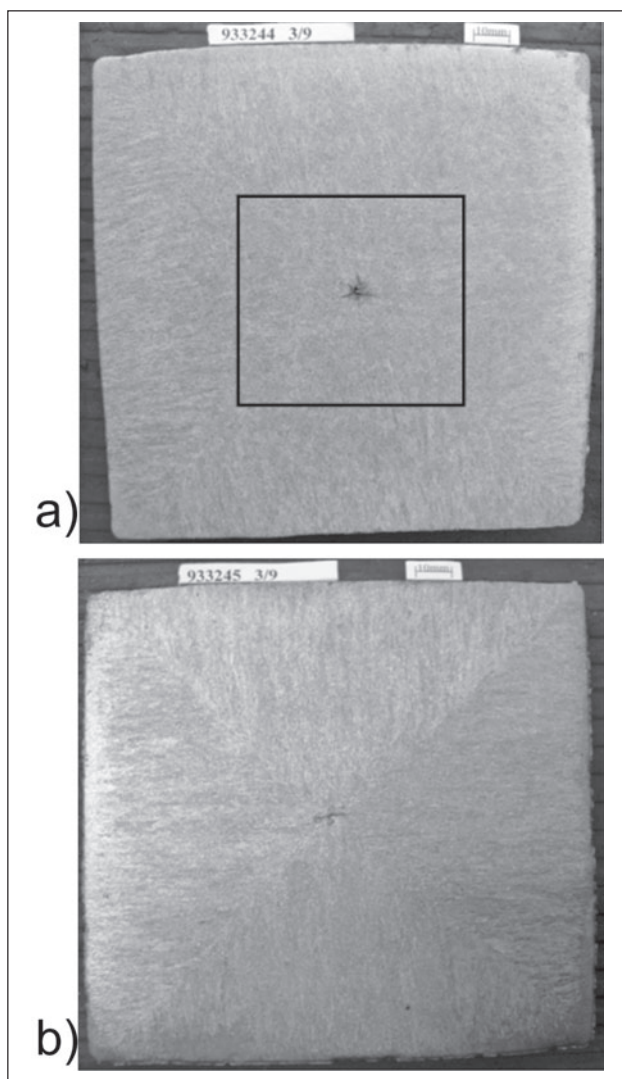


Figure 5 Example of metallographic probes: a) Melt EMA ($DT_p = 23\text{ }^\circ\text{C}$), b) Melt EMB ($DT_p = 35\text{ }^\circ\text{C}$)

cast from melts with higher degree of liquid steel overheating than in ingots casted from melts with a lower degree of overheating. It is illustrated by metallographic samples shown in Figure 5.

The measurement results of each crystallization zone in the examined ingots are shown in Table 3.

During the tests were also found similar nature of the primary structure of examined ingots cast from each

melts, in all veins of CC device. This indicates good homogenization of liquid steel in terms of temperature in the working space of the tundish.

CONCLUSIONS

Primary structure of ingots is a very important factor determining their quality.

In industrial practice the main focus is often on the right choice of parameters in each cooling zones of CC device. This applies not only to the mould but also to the secondary cooling zone. As can be seen from the research impact on the nature of the cast ingots primary structure have the processes in each construction element of CC device. The key thing is to adequately determine the value of the liquid steel overheating temperature after secondary metallurgy. This reduces the size of ingots columnar crystal zone emerging during ingots solidification.

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Note: The responsible translator for English language is inż. Jarosław Kuc