The possibilities of hydrogen removal from continuously cast steel with flake susceptibility in the tundish

Boichenko S. B.

D.Sc. in engineering
National Metallurgical Academy of Ukraine
Dnipro, Ukraine

Boichenko B. M.

D.Sc. in engineering
National Metallurgical Academy of Ukraine
Dnipro, Ukraine

Sinegin E. V.

Ph.D. in Engineering Science
National Metallurgical Academy of Ukraine
Dnipro, Ukraine

Molchanov L. S.

Ph.D. in Engineering Science
National Metallurgical Academy of Ukraine
Dnipro, Ukraine

Abstract
The layout in the bottom of continuous casting machine tundish, construction and operation modes of porous purging blocks designed to improve the quality of casted steel with flake susceptibility are given in the article.
Key words: TUNDISH, CONTINUOUS CASTING MACHINE, STEEL WITH FLAKE SUSCEPTIBILITY, HYDROGEN, NON-METALLIC INCLUSIONS, ARGON

The relevance of research

Intermediate ladle (tundish) of continuous casting machine (CCM) becomes increasingly the final link in the process of refining of molten steel from hydrogen, immediately prior to its crystallization [1, 2]. Efficiency of technological operations on the removal of hydrogen, non-metallic inclusions and homogenization of the molten bath is highly dependent on the nature and stability of molten steel flows in the tundish.

From this position, favorable hydrodynamics of the liquid bath in the tundish creates an opportunity to improve the quality of continuously cast billet.

Formulation of research problem

When tracking the gradual change in the content of hydrogen [H] in steel with flake susceptibility the authors found the following. When the initial [H] = 5.0 ppm before degassing its concentration under vacuum is gradually reducing to 0.5 – 1.0 ppm, however, during the first 5 heats of casting series it increases to 4.0 ppm in the tundish and unstably varies in ranges from 1.5 – 2.5 ppm in subsequent heats. Thus, the conditions of steel in the tundish are the "culprits" of [H] increasing, especially in the first heats in the series and associated rejection on flakes.

This work is aimed at a sustainable reduction of [H] prior to crystallization - below the level of 2.0 ppm, eliminating the risk of rejection of billets on flakes, with simultaneous purification of steel from difficult removable large non-metallic inclusions.

Increasing of argon consumption blown into the liquid steel is a mean of removing the hydrogen from this steel due to, firstly, the difference of its partial pressure in the metal and gas bubble and, secondly, as a result of mixing that simultaneously accelerates the coagulation, surfacing of nonmetallic inclusions in slag and stabilizes the liquid flows in composition and temperature.

However, injection of argon and hydrodynamics of melt in the tundish should exclude involvement of non-metallic inclusions from the slag in the steel flows.

The results of research

The simulation of processes in the physical and isothermal ladle model made in 1:10 scale according to the linear dimensions of the prototype with 38 tons capacity by Froude criterion (Fr) is carried out. Steel is imitated by water, slag – by benzene (C_6H_6) of "PS" grade according to GOST ГОСТ 9572 – 93. By the nature of wetting with these liquids of non-metallic inclusions finely dispersed graphite is defined as an inclusions simulator. The supply of neutral gas is si-mulated using air. The probable distribution of the motion rates of molten steel flows vectors at different positions of the porous purging blocks is obtained. The aim of experiments planning in accordance with the π-theorem is the organization at the expense of the bottom argon supply regimes and liquid flow in the tundish so that they move in upper horizons mainly along the mirror in the direction of metal reservoir to the tundish ends and in the opposite direction to the metering nozzles mostly in lower horizons.

The picture of liquid and gas flows impact has been detected (Fig. 1), as in [3], during which "plume" of water (melt) rises above the blower from which benzene (slag) is partially drained. Under normal conditions of tundish operation the slag layer is relatively thin and can be easily moved to the side with the melt "denudation" and form a so-called "eye" of the round form with a much larger surface area than the "plume" (Fig. 2). It is established [3] that the rate of return flows W_{rf} is related to $W_{g.l.}$ gas-liquid mixture flows rate rising up over the blower, ratio:

$$W_{rf} = \frac{S_c}{(S_r - S_c)\cdot \cos\theta}\cdot W_{gl} \quad (1)$$

,

where S_p and S_g – respectively "plume" area at the interfacial boundary of the liquid–gas and denuded liquid ("eye").

Liquid flows rate $W_{g.l.}$ and W_{rf} near the metal heel according to our data is not more than 0,015 m/s, and the angle θ varies between 18 – 20°, i. e. the active metal stirring with slag and involving the nonmetallic inclusions downwards do not happen. Calculations have shown that the rate of floating of large inclusions (over 60 microns) significantly exceeds W_{rf}.

It should be emphasized that the "denudation" of molten metal in S_g area in this case does not lead to oxidation of its gas phase, usually taking place in the ladle furnace, because of the stable enough damping layer of argon protection over it kept by the tundish cover.

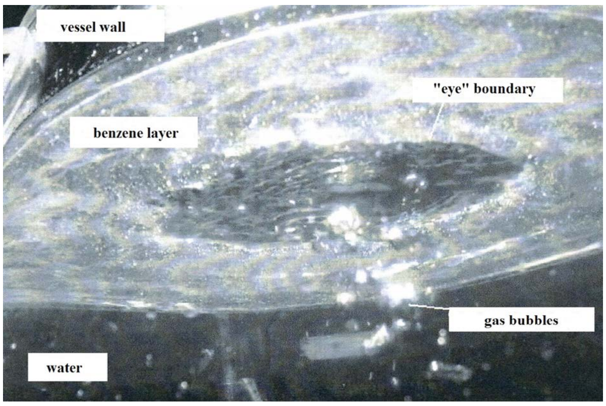

Figure 1. "Denudation" of the water surface (simulation of liquid steel) from benzene (molten slag). Photo is done from the bottom at an angle 60° to the horizontal

Hydrodynamics of the melt in the tundish of six strand CCM applied to the casting of high-strength steels with flake susceptibility was refined by mathematical modeling taken into account an adequate picture of flows in a wide range of Reynolds numbers. The hydrodynamic equations were placed in the basis of a mathematical model representing the mathematical operators: the laws of conservation of mass of liquid; Newton's second law (momentum change equals the sum of forces acting on the fluid); first law of thermodynamics (energy change equals the sum of the additional heat and work carried out on the liquid) [4]. The input parameters for the calculation were changed in accordance with the results of physical simulation and based on their own practical experience.

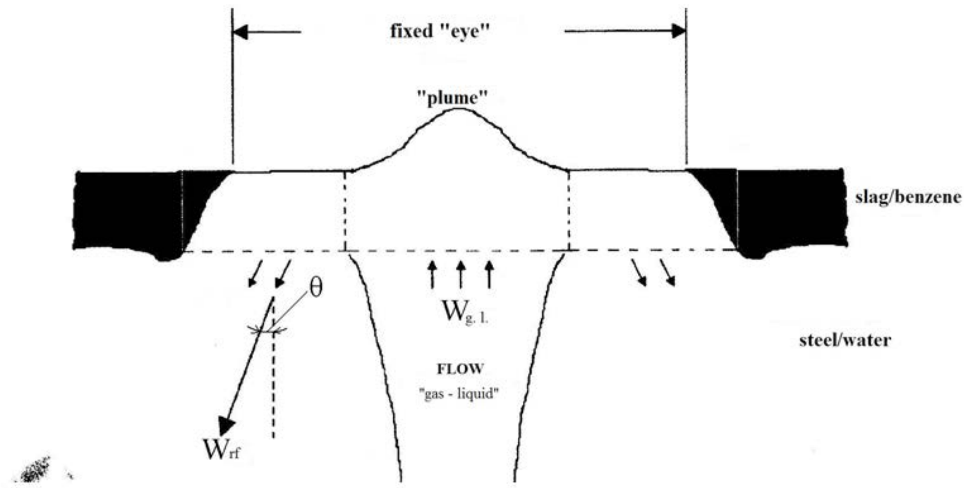

Figure 2. The scheme of benzene (slag) draining process from the "plume" of water surface (molten steel) and involving the benzene portion to the reverse flows [3]

Mathematical modeling had complemented the scheme with appropriate hydrodynamic when moving steel in the tundish (Fig. 3-4), the blowers location and their design, the argon flow modes from heat to heat in a continuous series of stable obtaining of content of [H]≤2 ppm, velocity vectors and total velocity of the melt flows, nonmetallic inclusions and gas bubbles.

The six-strand tundish equipped with an argon supply system for injecting into molten steel, metal reservoir ("turbostop" type) of "bucket" type was adopted as the initial component for creating a geometric model of the computational domain. Internal volume of tundish occupied by the liquid steel was accepted as the computational domain when creating a geometric model.

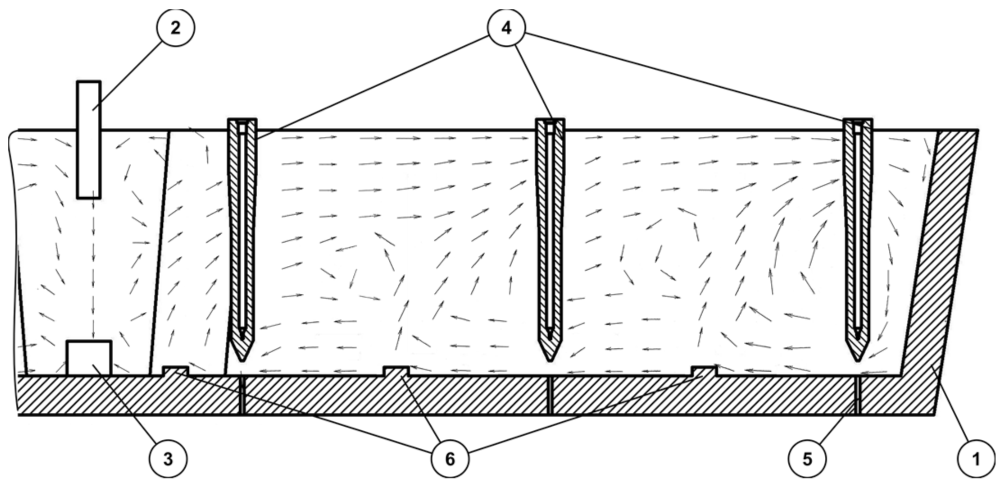

Figure 3. Scheme of the circulation of molten steel flows in tundish of CCM of the proposed design: 1 - tundish; 2 - protective pipe; 3 - turbostop; 4 - stoppers; 5 - nozzle; 6 - purging blocks

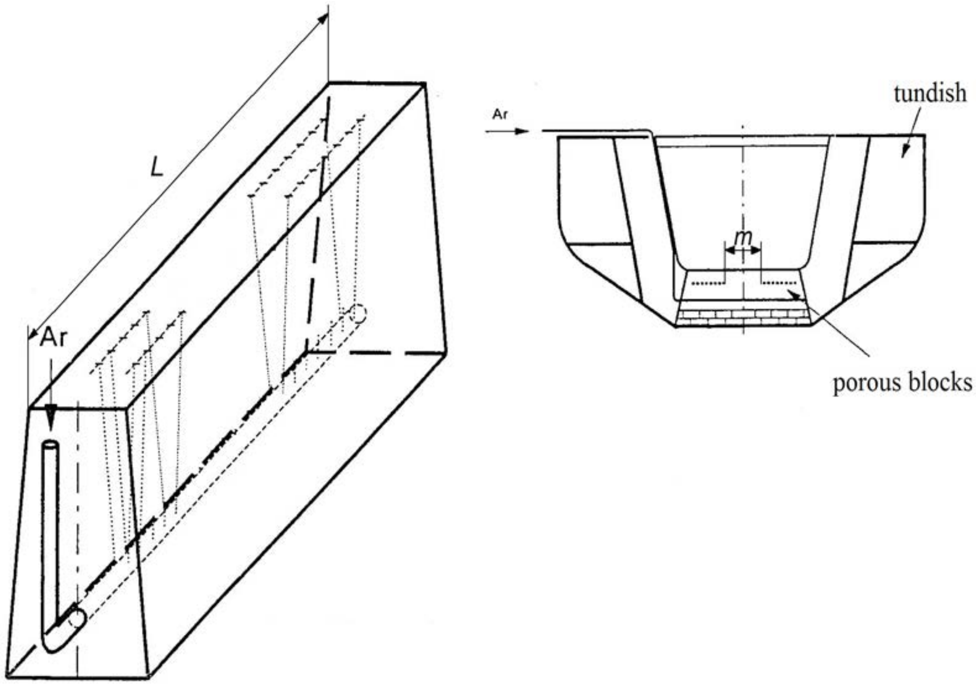

Figure 4. The design of tundish purging block

Steel flows hydrodynamics organization in the tundish in accordance with Fig. 3 ensures the achievement of the target set by physical and mathematical modeling due to the modes of bottom argon supply. In this scheme melt flows are processed several times with argon to remove the hydrogen and to transport the nonmetallic inclusions to the slag layer. The new design of purging block (Fig. 4) having no pores for supplying argon at both sides of the tundish axis at a distance $m = \frac{1}{3}L$ contributes to this in a certain extent.

The intensity of the argon supply I_{Ar} through the bottom porous devices in the tundish should be the maximum in the first 1-5 heats of the continuous series when casting of steel with flake susceptibility. And it should reduce with decreasing as we have found in [1], of the hydrogen material balance input due to extra roasting of lining, slag components in contact with the liquid metal and the appearance of argon layer above them, which protects from the contact with atmosphere.

After statistical data processing in industrial production of steels with flake susceptibility, wherein credit and expenditure items of hydrogen balance are estimated from heat to heat in the series [5], the following recommendations are developed to determine the intensity of argon blowing in bubble mode through the porous blocks I_{Ar}.

When casting a first heat in the series blowing is carried out with argon consumption 7.1÷7.8 dm³/(t·min), when casting the next four heats argon consumption I_{Ar} per 1 t of ladle capacity is maintained in accordance with the equation:

$$I_{Ar} = (7{,}1 \div 7{,}8)\sqrt{\frac{E}{\rho \cdot n \cdot a \times b \cdot V \cdot \tau}}, \ \mathrm{dm^3/(t \cdot min)}, \quad (2)$$

where 7.1÷7.8 – specific consumption of inert gas when casting the first heat, dm³/(t·min);
E – ladle capacity, t;
ρ – solid steel density, t/m³;
n – the number of CCM working strands;
a×b –billet thickness and width respectively, m;
V – working speed of billets withdrawal, m/min;
τ – the duration of casting, min.

When casting the next heats and to the end of series I_{Ar} is maintained within 3.2-3.5 dm³/(t·min).

Conclusion

The scheme of layout and operating modes of porous purging blocks, as well as the design of the latest, installed in the bottom of CCM tundish was developed with the use of methods of physical and mathematical modeling the statistical processing of the results of the continuous casting of steels with flake susceptibility. This creates possibilities for removing hydrogen and nonmetallic inclusions from molten steel, and its sufficiently homogeneous composition when entering in the molds.

References

1. Boychenko S. B. (2013) The mechanism and kinetics of the processes determining the hydrogen content in the steel in the CCM tundish, *Casting processes*, No 3, p.p. 12 - 16.
2. Smirnov A. N., Kuberskiy S. V., Podkorytov A. L.

Nepreryivnaya razlivka sortovoy zagotovki [Continuous casting of billet], Donetsk, Tsifrovaya tipografiya, 2012, 417 p.

3. Krishnakumar K. A Model Study of Slag Eye Formation during Gas Purging at the Surface of a Metal Bath / K. Krishnakumar and G.A. Jrons, The 3rd International Congress on the Science and Technolodgy of Steelmaking, May 9 – 12, 2005, Charlotte, North Carolina, USA, *JCS Proceedings*, 2005, p.p. 833 – 844 p.
4. Jiguan Tu. Computational Fluid Dynamics of Practical Approach / Jiguan Tu, Guan Heng Yeoh, Chaugun Liu, p.p. 65 – 105.
5. Boychenko S. B. (2012) To a question about the quality of continuously cast billets of high-strength steels, The collection "Actual problems of modern metallurgy", Mariupol, *SHEI "PSTU"*, p.p. 208 - 217.