OPTIMIZATION OF CCM CONTINUOUS CASTING PRACTICE FOR ROUND BILLETS

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Abstract

A great number of enterprises pay due attention to the development and implementation of innovations aiming to improve the quality of continuously cast billets and enlarge product assortment. In this respect the adjustment of CCM for casting of round billets seems to be an efficient way to develop mini steel mills.

Ukraine is known for its developed pipe production. Until now the Ukrainian mills used in their production process the rounds rolled from ingots. No doubt, the competitiveness of the Ukrainian pipes has increased.

The investigation was carried out in order to estimate the quality of continuously cast round billets, produced at six strand CCM in the EAF shop of CJSC “MMW ISTIL (Ukraine)”, Donetsk. Sections with different diameter were produced, namely: Ø120 mm, 150 mm and 180 mm.

The authors studied the dependence of quality parameters of round billets upon such factors as casting temperature, speed of casting, different schemes of steel flow from tundish to the mold, clogging of nozzles. The assessment of influence modes in the secondary cooling zone was carried out using mathematical model. The article presents the comparative analysis of solidification conditions for square and round billets. It has been found out, that hydrodynamics of liquid steel in the mold and fine control of water distribution in the secondary cooling zone are more important for casting rounds at CCM.

1. Technological and design improvements in CC for round billets

The main improvements are as follows:
- metallurgical requirements and castability criteria of steel grades;
- behavior of liquid steel in the system of tundish-nozzle-(submerged nozzle)-mold;
- mold design and square billets (rounds)/mold interaction (oscillation parameters, casting powder or lubrication);
- thermo-mechanical behavior of square billets (rounds) along the casting line;
- secondary cooling system;
- stabilization modes for CC during the period of ladle replacement.
1.1 Metallurgical requirements and castability criteria of steel grades

The use of continuously cast round billets enables to reduce the costs for pipe production by 20-30%, as well as to reduce steel consumption (30-150 kg/t), depending on the production process and initial section of a billet.

The primary round billets are mainly used for pipe production. At present bottom poured ingots are still used in Ukraine as primary billets for production of seamless pipes. In case of pipe ingot shaping in the moulds, the produced billets have shrinkage holes and are characterized by structural and chemical heterogeneity. This is the major reason for material rejection due to non-metallic inclusions, cracks or flaws, including rejection of pipes according to external and internal scabs. At the same time, the existing system of quality assessment of primary round small section billets is generally based on quality assessment of the billet, subjected to some definite reduction. It implies additional requirements to the quality of concast round billet.

The most typical defects for concast round billet, as compared to the round billet, rolled from an ingot, are the following:
- lateral grooves resulted from mold oscillation;
- longitudinal cracks (subsurface external and internal), caused by unevenness of billet cooling in the mold and secondary zone;
- internal cracks due to high strain caused in the process of billet unbending;
- higher contamination of surface layers of the billet with non-metallic inclusions;
- axial porosity due to extreme modes of casting and billet cooling;
- comparatively high physical heterogeneity across billet cross section;
- irregular geometry (out-of-roundness and deviation of diameter).

Besides, the concast round billet has a number of advantages, which cannot be ensured in case of ingot casting:
- high chemical homogeneity (significant reduction of center segregation zone);
- high chemical homogeneity in a billet along its length;
- the possibility of overall steel protection against secondary oxidation in the process of casting;
- reduction of specific consumption of steel (20-25%) per one ton of finished product.

Therefore, the development of continuous casting process for round billets shall conform to the requirements of the consumers to a particular type of product.

1.2 Liquid steel behavior in tundish - nozzle (submerged nozzle) - mold system

Open stream casting through the metering nozzle of limited diameter has been widely practiced at section CCM. In this case the level of steel in the mold is controlled by changing the speed of billet withdrawal. The process of open stream casting is generally applied to steel, which is subjected to rolling (without subsequent strict macrostructure control) into such steel products as: die-rolled sections, angles, channels, flanges, wire, etc. Generally, the cross-section of such billets does not exceed 140-150 mm in square side.
In contrast to ingots with rectangular cross section, the skin of round ingot is more rigid and less affected by ferrostatic pressure. It enables to cast round billets with the diameter, equal to rectangular ingot thickness, at higher speed (by 20-25%). At the same time the cross sectional area of a round ingot and, consequently, the weight of 1 running meter is 21.5% less, than the area of a square ingot with the side, equal to the diameter of the round ingot. Therefore, the production rate of a strand while casting the round billet and the square with a side, equal to the diameter, is almost the same. However, in case of continuous casting of round billets, especially with small diameters, the heterogeneity of ingot skin, crystallizable in the mold, is increased, resulting in out-of-roundness of cross section. The existing out-of-roundness is the major reason, causing the formation of longitudinal external and internal cracks. It has been found out, that in order to decrease out-of-roundness, it is necessary to eliminate the non-uniformity of heat removal at the beginning of solidification.

To ensure high quality of round billets, it is expedient to apply the scheme of steel flow from tundish into the mold providing for the system of “stopper-monoblock”-“metering nozzle”-“submerged nozzle” (Fig.1). In this case the flow of steel between the teeming ladle and tundish is protected by means of specially installed protective pipe. The said process scheme of casting ensures the following advantages:

- more symmetrical supply of steel to hot heel in the mold; optimum conditions for even solidification of round billet at the beginning;
- high level of steel protection against secondary oxidation all over the way from the teeming ladle to the mold;
- on-line control of steel flow rate by means of stopper-monoblock;
- significant increase of the metering nozzle diameter and allowable prolongation of the period of covering of the internal part of the nozzle;
- argon purging directly in steel flow coming to the mold;
- supply of steel flow in accordance with the level of steel in the mold, preventing bubbling within the interface;
- use of special slag-forming mixtures, which ensure high quality of billet surface, etc.

In case of casting the round billets, the availability of submerged nozzle, supplying steel to the level of steel in the mold, enables to improve significantly the hydrodynamics of convection current development in liquid steel of the mold. It also enables to exclude the involvement of protective slag coating, located on steel surface, into stirring. The researches, carried out using the physical model, and on-site examination evidence, that the general pattern of convection current development is not changed, even in case of 10-12 mm shift of the axis of submerged nozzle relative to the axis of a billet. Consequently, the said shift of submerged nozzle does not affect the quality of the surface layers of the billet.

At the same time, destabilisation of casting process while casting pipe steel grades with high content of acid-soluble aluminum (approximately 0.02%) is mainly caused by covering of the internal part of the metering and submerged nozzles resulting from non-metallic and slag inclusions build up. The researches carried out by the authors of the given article evidence, that the formation of build up on the surface of submerged nozzle is taking place during the whole operation cycle. However, the process of covering of the internal part of submerged nozzle is also characterised by a significant unevenness in the course of time, as well as by asymmetrical arrangement of build up areas relative to the vertical axis of product.
The said build up, probably, results from steel contamination with non-metallic inclusions due to the secondary oxidation of steel, while it flows from the teeming ladle to the mold. It is also caused by erosion of refractory and supplementary materials, interacting with steel in the process of technical overflow.

Fig. 1. – Scheme of open stream steel casting of sections a) providing for steel protection against secondary oxidation; b): 1 – teeming ladle; 2 – tundish; 3 – mold; 4 – protective pipe; 5 – stopper; 6 – submerged nozzle.

Asymmetric build up of non-metallic and slag inclusions on the internal wall of submerged nozzle seems to be negative factor, as it can erode the solid skin of steel in the mold (Fig.2). Since the process of build up formation is characterised by asymmetry and unevenness, which is beyond on-line visual control, the covering of the internal part of submerged nozzle can finally cause CCM shutdown or bleeding of molten steel below the mold. The comparative researches, carried out while casting the round billets with the diameter of 120mm, 150mm and 180mm, show that bleeding is more typical for round billets than for square ones.

The use of argon purging through stopper–monobloc for small section billets provides for the limitation of injected gas quantity due to the small volume of liquid steel in the mold. The industrial testing showed, that the maximum reduction in the rate of covering of submerged nozzle is ensured at the flow rate of 1,5-2,0 l/min. Further increase of argon consumption affects the quality of billet surface, which can be accounted for heavy bubbling of steel in the meniscus area. On the whole, argon purging through stopper-monobloc enables to increase by 1,8-3,0 times the service life of submerged nozzle, depending on the cast steel grade.
1.3. Mold design and billet (round)/ mold interaction

It has been found out, that temperature distribution in the skin and in the liquid phase of the crystallizing round ingot is characterized by apparent unevenness just within first moments of solidification. Such temperature distribution over the billet section results from continuous heat removal along the perimeter of the billet, shaped in the mold, and convection currents pattern in the top end of the billet. The degree of unevenness of solidification front is the major factor, determining the formation and development of surface defects, shape distortion of cross section and the pattern of distribution of non-metallic inclusions.

The rate of skin growth and its thickness in the given point is proportional to the temperature of billet surface. Considerable spread in values (up to 100-200° C) along the perimeter is already observed in 5-6 sec. after solidification initiation at the distance of 30-50 mm from the meniscus. Later on, the said unevenness increases and reaches 200-250° C at the distance of 0.4-0.5m from the meniscus.
The degree of temperature distribution unevenness, and consequently, the thickness of the skin around the periphery of circle of the given section is the more, the larger the billet diameter is. The most significant unevenness of solidification front is observed in the upper levels. However, at the distance of approximately 500 mm from the meniscus it is stabilized and then, within the mold, its value remains constant for each ingot (10-14%). The said stabilization can be affected in case of using the elongated mold. In this case it results from the alternate contact of the skin of the billet with the wall of the mold.

1.4. Secondary cooling system

Traditionally, the system of secondary cooling of section CCM provides for water cooling with the step change of intensity in 3-4 areas. The aforesaid system conforms to the requirements of casting square billets. At the same time, the conditions of round billet solidification require some change in supply of cooling water to the billet surface.

First of all, it results from possible change of symmetric position of spray jets, when casting round billets, relative to the axis of the billet. The observations show, that it is caused by improper fixing of the billet, while it shifts along the technological axis. Shifting of spray jet axis causes its uneven cooling and sets conditions for formation of some defects (cracks, improper geometry, etc.).

Second, the round billet has smaller surface of heat removal. The said factor together with asymmetric supply of cooling water causes temperature deviation from the optimum temperature values in the area of billet unbending, which increases the probability of inner cracks formation.

The system of air-and-water cooling in third and forth areas represents the more rational cooling method for round billets. It ensures more even water supply to the billet surface. In this case the cooling water is sprayed in small spherical drops. It enables to reduce the specific consumption of water per 1 ton of steel and to ensure on-line control of the modes of billet cooling, depending on the actual conditions of steel casting. Implementation of the aforesaid scheme enables the manufacturers to achieve high quality indices for the whole diameter range.

The optimum parameters for supplying the cooling water can be chosen using the mathematical model, describing the dynamics of cooling for round billet.

Consequently, while producing the round billet (as compared to the square billet) it is necessary to ensure more even distribution of skin thickness across section, the stable heat removal around the perimeter of the billet, reduced unevenness of surface temperature distribution and the observance of the optimum law of temperature distribution along the length of the billet.

1.5. Thermo-mechanical behavior of round billet

Assessment of stress condition of round billet is of utmost importance for optimization of casting modes, aiming to prevent crack formation. The industrial experience of CCM operation evidences, that assessment of the level of internal thermal and shrinkage stresses in concast billet represents a complex problem. For its solution it is necessary to consider a number of interrelated phenomena and factors, affecting the process of concast billet shaping.
Three-dimensional mathematical model of solidification was worked out for examination of initiation conditions and assessment of the level of internal stresses in a billet. The model takes into consideration shrinkage phenomena, uneven cooling of the billet in the mold and in the secondary cooling area, fluctuations in temperature and variations of steel chemical composition while casting, the conditions of billet unbending, etc. The said model enables to forecast stress condition of the billet as well as to forecast emergency, corresponding in practice to cracking.

2. Results

The process of casting the round billets was implemented at CJSC MMW “ISTIL (Ukraine)” (Donetsk, Ukraine). The main production facilities of Mini Steel Mill include two electric arc furnaces with the capacity of 120 t each, high speed six strand square/rounds billet continuous casting machine, ladle furnace and the vacuum oxygen degasser. The aforesaid process equipment of EAF shop enables to increase significantly the competitiveness of the Mill’s products. ISTIL (Ukraine) has been awarded ISO 9002 certification (both for square and round billet) by TUV-Nord, Germany.

The general view of the produced product (cross section) is shown in Fig.3.

In general, the round concast billet is characterized by the following parameters:
- clean billet surface, free from longitudinal and transversal cracks;
- the depth of marks caused by the tilting mold makes 0.4 – 0.7 mm, depending on the speed of casting and steel grade;
- variation of billet diameter does not exceed 2-3mm;
- lack of internal cracks;
- lack of severe segregation defects;
- minimum axial porosity;
- the minimum number of subsurface blisters.

3. Conclusions

The existing situation on the market of round billet for pipe industry evidences, that the quality requirements to the billet become more strict, while the prime cost of billet reduces.

Owing to the latest achievements in the field of continuous casting, all the necessary prerequisites have been created for production of round billets with Ø120-180 mm at steel mills with the main facilities of high capacity, equipped with modern CCMs. It is ensured by changing the casting mode at multi-strand section CCMs, providing for high speed billet withdrawal. The units of ladle-furnace type also ensure the required quality of liquid steel and its regular supply to the CCM. Further improvement of quality of concast billet and its competitiveness will be probably achieved through applying the methods of steel protection against secondary oxidation, e.g. in case of casting through the system of “stopper-monoblock” – “metering nozzle” – “submerged nozzle”. The other important method, enabling to reduce the prime cost of steel products, implies the development of CCMs, enabling to produce the billets within wide range of cross section.
Fig. 3. Cross sections from billet rounds Ø150, which had been cast with different speed (pos. a-b) and from pipe products (c-d).