Identifying the main defects appeared in the structure of continuous blanks

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***Abstract*—** The study we carried out aims at defining and sorting the internal flaws specific for continuous cast semi-finished products, in order to enable the identification of their source and to help in taking the appropriate steps meant to prevent or to correct them, as the case may be. Industrial research has been done on the five-strand continuous casting machine over a period of several months, when we focused on the nature of the internal flaws that were found on reception of the material under study.

***Keywords*—** *continuous casting, steel, internal flaws, fissures, micro-shrinkage, central porosity, inclusions, longitudinal cavity.*

I. Introduction

Full liberalization of prices of raw materials, materials, electric energy, as well as steel product trade; alongside with a decline of home market demand have affected most steel producing companies.

The need to turn and adapt to market economy has required a new program of orientation and optimization of their activity. In this sense, we have in view a strategy aiming at several targets: reinforcing the position of the company on the home and foreign market, a permanent growth of the quality of products and their being up to European standards, according to the requirements of the market, as well as achieving a profitable activity.

At the same time, the ever lower demand for steel products from the clients both on home and foreign markets has lead to a decrease in the production of rolled profiles and to the downsizing of some production facilities [1-2].

The major issue of continuous casting is steel solidification, i.e. the possibility of achieving the (direct and indirect) cooling conditions, in order to allow the dissipation of the heat from the molten metal [2].

The theoretical basis of continuous casting resides in the research and knowledge related to the conditions of solidification, which determine the cooling conditions according to the cross section and the chemical structure of the material, as well as some of the technological and constructive parameters of the installations (casting rate, number of strands, height and curve radius of the installation, etc.).

The solidification process during the continuous casting of steel can be explained as follows: at a first stage, a thin crust is quickly formed at the upper side of the crystallizer, the thickness of this crust increasing abruptly as a result of the direct contact between steel and the crystallizer walls, which are water cooled.

At a short distance from the liquid meniscus, the solidified crust is cold enough to shrink, which eliminates the contact between the metal and the crystallizer, and because of the air layer between the metal and the crystallizer, the conditions of heat exchange grow worse, and the solidification rate diminishes.

The solidification of the core, under the effect of secondary water cooling, triggers a great difference of temperature between the surface and the centre of the continuous cast semi-finished part.

Further on, temperature turns even in the cross section of the completely solidified semi-finished part, due to the air cooling after the secondary cooling area, the heat in the core being transmitted towards the exterior, which leads to the cooling of the entire section in contact with the air [3].

Steel temperature at various stages of the technological process depends on the following factors: steel quality (the liquidus and solidus temperatures), the size of the charge and the location of the casting shed within the technological flow (which determines the heat loss of the metal in the ladle, until it is positioned above the continuous casting machine).

Steel temperature at the beginning of casting can range within large limits (1600–1700°C), according to the factors mentioned above; with most modern machines, it is somewhere between 1620–1650°C.

The rate of metal cooling inside the ladle depends on the quantity of the charge, respectively on the capacity of the ladle.

For a correct functioning of the continuous casting machine, steel temperature has to be rigorously controlled. The needed precision of the prescribed temperature on entering the crystallizer should be ± 5...10°C.

II. Experiments

The study we carried out analyzed the elaboration and continuous casting of steel into semi-finished products, as well as their quality level, depending on the number of internal flaws we found out.

Figure 1 shows the continuous casting installation used by the company where the charges were elaborated and cast.

The steel is elaborated into an EBT-type electric arc furnace, and then it undergoes a first secondary treatment by bubbling with inert gases into the furnace and later on, into a LF-type installation.

Figure 1. The continuous cast installation

Casting is done exclusively on a continuous casting installation with curved strands (5 strands), allowing the casting of semi-finished products with the following cross-sections: round Ø150mm, Ø180mm, Ø250mm, Ø270mm and Ø310mm diameter and bloom 240x270mm meant to be further rolled. In terms of assortment, the steel that is to be continuous cast ranges within the category of mass, carbon superior, low alloy and alloyed steels shown in figure 2.

For this study we only selected the steel charges which were cast into pipe billets Ø250mm respectively Ø270mm, using all steel grades (carbon, low-alloyed, respectively alloyed) used in making these two types of pipe billets.

According to reference literature, the flaw can be defined as any deviation from the exterior aspect, shape, dimension, macrostructure and chemical characteristics with respect to the standard specifications or any other technical documentation in force [1].

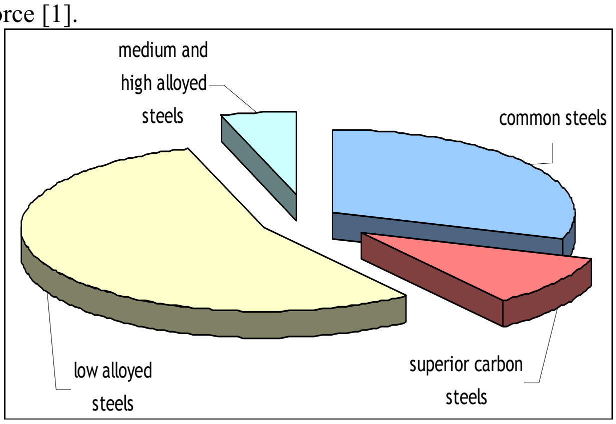

Figure 2. The weight of mass, superior carbon, low alloyed and alloyed continuous cast steels

The flaws are found on the billets' reception by visual control of their surface quality on the inspection beds or on the control of the sample macrostructure in the laboratory. Most often, they are the result of the interaction of several causes, which depend on a variable number of parameters.

III. Results and discusion

Material flaws on steel continuous casting arise during the solidification of the semi-finished products and their cooling, often leading to important metal loss. In order to prevent this loss, metallurgical technologies and constructive solutions aim at spotting the causes and implementing prevention and removal steps to be taken.

Most often, the same billet shows several flaws. One of the flaws found in the charges under study are fissures. They are cracks into the billet, made visible by macroscopic analysis and they can be: marginal internal fissures, longitudinal fissures and central fissures [2,3,4].

The internal marginal fissures (figure 3.) are short fissures, very close to the surface, under depression and are caused by: high casting temperature, high casting rate, intense, jet secondary cooling, and the uneven distribution of the casting powder into the ladle and the steel crust of the semi-finished product.

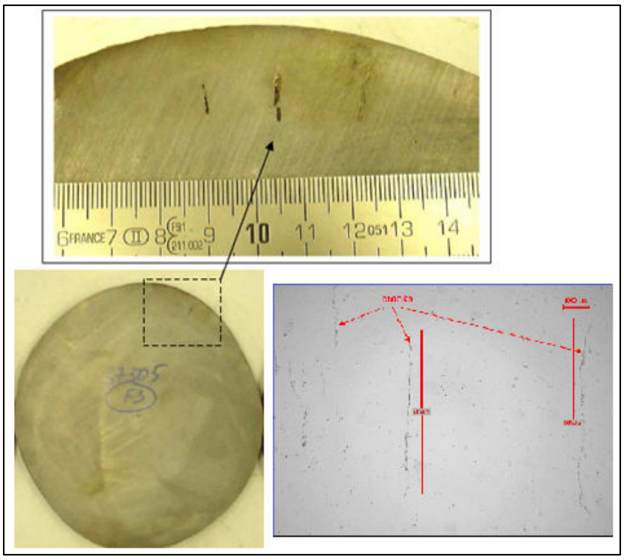

Figure 3. Marginal internal fissures

The remedy for these types of flaws can consist in observing the maximal values of temperature gradient ΔT (calculated as difference between the casting temperature and the temperature of the liquidus of the grade under study), correlation of the casting rate with ΔT and the flow rate of the cooling water, a correct adjustment of the spraying nozzles for the secondary cooling, an even infiltration of the casting powder between the ladle and the crust of the semi-finished product. Longitudinal internal fissures arise in the central area as interdendritic separations (figure 4).

Figure 4. Central internal fissures

The main cause is the high casting temperature, as well as the high pressure of traction rolls along the incompletely solidified strand. These flaws can be corrected if the variation of temperatures is kept within the established limits; a correlation should exist between the casting rate ΔT and the cooling regime, and the casting rate also has to be reduced [1].

The micro-shrinkage shown in figure 5 represents a hollow in the central part of a cross section (the sample), collected from a steel bar and it appeared as the result of material shrinkage on passing from the liquid state into solid state. If the diameter of the hollow is below 5mm, it is ranked as material imperfection.

Figure 5. Micro-shrinkage

The micro-shrinkage shown in figure 5 represents a hollow in the central part of a cross section (the sample), collected from a steel bar and it appeared as the result of material shrinkage on passing from the liquid state into solid state. If the diameter of the hollow is below 5mm, it is ranked as material imperfection.

The causes of this flaw are high casting temperature, high extraction rate, intense secondary cooling, maintenance of temperature gradient ΔT within the established limits, the correlation of the casting rate ΔT with the cooling regime, the reduction of the casting rate, lowering the cooling intensity by maintaining the water flow rate within the minimal established limit [3,4,7].

Central porosity shown in figure 6 is an inner non-homogeneity of the continuous cast strand and can sometimes be accompanied by shrinkage, both caused by the same factors.

Central porosity appears because of the high casting temperature, the high rate of extraction and by the intense secondary cooling.

On further heating, it welds and there is no reason for dumping it. The remedy of thee types of flaws can consist in maintaining ΔT within the established limits, a good correlation of the casting rate with ΔT and the cooling regime, a reduction of the casting rate and intensity of cooling by maintaining the water flow rate at the established minimum limit.

Figure 6. Central porosity

Another type of internal flaw found in the charges under study was the presence of inclusions. Inclusions (figure 7.) are macroscopic and microscopic impurities imbedded unwillingly into the steel; they can be avoided by: a careful deoxidizing of steel, protecting the steel strand against reoxidizing, controlling the level of steel in the ladle in order to prevent steel flowing over the casting dust and its inclusion into the steel, the use of an appropriate casting dust, avoiding large and frequent variations of the casting rate, avoiding high casting temperatures, the use of an appropriate refractory material [1].

The segregations noticed in the charges under study are generated by an increase of the content in C, Mn, P, S in the core of the billets and represent non-homogeneities of the material resulted during the solidification of steels containing high percentages of these elements.

Complete avoidance of segregations is not possible because they are conditioned by physical phenomena taking place during solidification. But they can be reduced by using a homogenous chemical composition, by steel deoxidizing with silicon and aluminum and by the use of a low casting temperature; these are not dangerous as long as certain limits are not surpassed.

They can be brought into relief by the method of sulphur imprint and are assessed by comparison with certain conventionally established standards. [1,6,8].

The analysis of the factors determining the appearance of flows in tube billets shows that the maximum weight is held by the casting parameters (casting temperature and drawing rate) as well as the chemical composition and degree of steel purity.

The chemical composition of the steel to be continuous cast has to meet the standards for each steel grade to be elaborated, the chemical elements to be ranging within precise limits, without high variations.

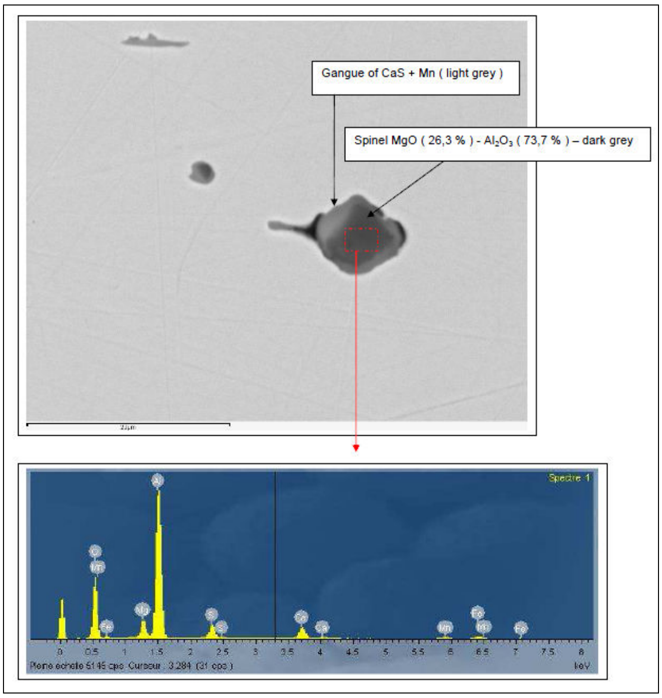

Figure 7. Inclusions

The contents of unwanted elements have to be very low; it is necessary to ensure a content of S<0,015÷0.020% (respectively a value of the ratio Mn/S >25÷30), a content of P<0.020÷0.025%, and that of As and Cu of max. 0,03%. At the same time, the sum of these four elements should not exceed 0,067%; if these conditions are met, the tendency of fissure appearance is dimmed to a minimum. In the case of carbon, it has to be maintained within very low limits, as close as possible to the inferior admitted limit for each steel grade to be elaborated.

In order to grant homogeneity and adjust the chemical composition of the continuous cast steel, as well as for its thermal homogeneity, the casting temperature has to be kept under control and the drawing time has to be adjusted according to the technological parameters that are specific for ladle treatment. With respect to the ladle treatment of steel, it is to be noticed that the longitudinal surface fissures shown in the figures above are more frequent with the general use carbon steels, most likely to be found in steels whose carbon content ranges within 0,08…0,14 % i.e. those in the peritectic domain and the micro-alloyed steels. The tendency of longitudinal fissuring grows with the casting rate and temperature and in the case of a lower ratio Mn/C alongside with a higher content of S.

The value of the drawing rate v_{tr} has to be equal to the value of the filling rate v_u and is correlated to the diameter of the circle inscribed in the cross section of the semi-finished product D_m the height of the ladle, the thickness of the desired crust and the duration of the casting process [1].

The cracks (fractures, flaws) are openings on the billet surface having variable lengths and widths which sometimes go along the whole billet, on a thread or even on a whole heat. They are not always straight, sometimes they are broken and go on alternating in zigzag. They are longitudinal or cross fractures function the direction they are made.

The longitudinal fractures, shown in figure 8, are formed in the direction of extracting the thread from the mould; the blank having this defect is completely rejected, as a rule. The causes for these fractures are: the irregular removal of the heat from the mould, the inappropriate thickness of the shell, the tumultuous flow of the steel, respectively the meniscus level variation in the mould, too intense or inconstant secondary cooling, unequal and advanced wearing of the mould, the high pouring temperature, high speed at the thread extraction and inadequate behaviour of the casting powder.

Figure 8. Longitudinal fractures

The cross-section fractures presented if figure 9 are seldom met at the round profiles, arising due to the strain in the longitudinal direction of the thread. They are ground if they are not deep (within the admissible limits foreseen for diametre and ovality).

The causes leading to cross-section fractures are: thermal stress due to the irregular solidification of the shell and the additional stresses due to the tumultuous flow under the meniscus, the meniscus level variation and the thread friction in the mould.

The star fractures, shown in figure 10, are determined by the hot brittleness, and they are very fine and visible only on the surface cleaned of scale. In order to remove the defect the blank is polished locally. The causes leading to the occurrence of the star fractures are: the intense local cooling that induce local stresses and the copper presence at the austenitic grain limit. Some measures to avoid the star fractures are: the correct adjustment of the outlet spray nozzles and the correlation between the spray flow rate and the casting speed (the automatic control of the flow rate); to provide a uniform layer (film) of casting powder melted between the thread and the mould and also the cooling with a moderate intensity at the thread outlet from the mould in order not to increase the thermal stresses which develops fractures.

The longitudinal cavities are local strains of the continuous cast thread surface and they may develop either in the thread drawing direction (longitudinal cavities) or along the oscillation mark (cross-section cavity).

The longitudinal cavities are developed especially at the round billets from peritectic carbon steel and look like superficial channels oriented on the drawing direction of the thread. Sometimes this defect is accompanied by slag resulted from the powder used in the mould, being also known as slag band.

Figure 9. Cross-section fractures

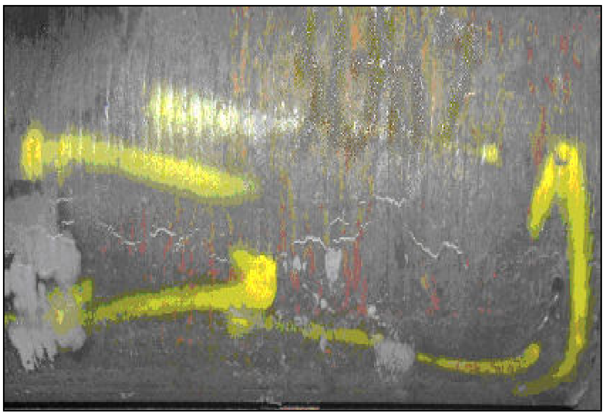

Figure 10. Star fractures

The longitudinal cavities are shown in figure 11 and the arise because of: the non uniform heat transfer in the mould which determines an unequal development of the boundary shell; to the steel level fluctuation in the mould and to a too high amount of flow melted within the space between the mould wall and the thread, to the tumultuous flow under the meniscus level and to the unequal and advanced wear of the mould, having as a result a different heat conductibility coefficient.

The longitudinal cavities can be avoided thus: by a light, uniform and steady cooling of the thread in the mould, centering the casting jet in the mould, by controlling the steel level fluctuation in the mould, eventually using a mould having parabolic taper, by employing ointment powder with an adequate melting speed and viscosity, by reducing the surface turbulence and stirring at minimum by optimizing the inlet nozzle position and of its seating, respectively by checking the wearing degree and wearing uniformity of the moulds before and after the use.

Figure 11. Longitudinal cavity

The cross-section cavities are formed in the transversal direction and they can appear cyclically related to the thread length. Such a defect is illustrated in figure 12. The peritectic steels with low % C and high Mn (%) content and the stainless ones are sensible at developing this type of defect due to the much higher shrinkage interfered during the solidification.

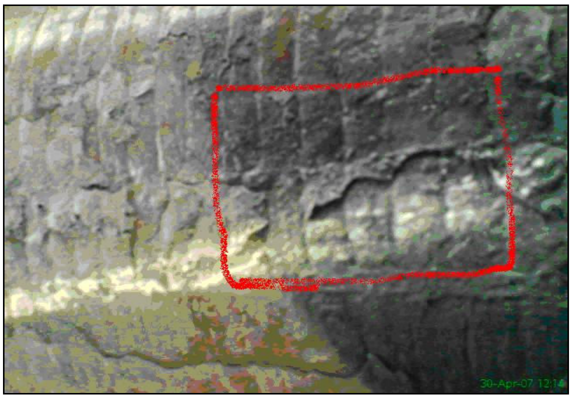

Figure 12. Cross cavity

The cavities forego the occurrence of the longitudinal shrinkage fractures (cracks) and the internal boundary cracks. The material having this defect is polished locally and cyclically in order to check the presence of under-shell ("hypodermal") fractures.

The cross-section cavities are caused by: the fluctuation of steel level in the mould, by the too high quantity of flow melted within the space between the mould wall and the thread and by the tumultuous flow under the meniscus level.

These can be avoided by: by controlling the steel level fluctuation in the mould, using a mould having a parabolic taper by employing ointment powder with an adequate melting speed and viscosity, by reducing the surface turbulence and stirring at minimum by optimizing the inlet nozzle position and of its seating

The holes are cavities on the external surface or in the under-shell area of the billet at about some tenths of millimeters from the shell surface and they are presented in figure 13.

Figure 13. Holes

They have a diametre up to 3mm and a length (depth) that can reach 25 mm. As usually they contain CO, H_2, Ar and most of all they are associated with the inclusions.

In case that they are superficial and/or few, these are polished (ground). They are determined by: the insufficient deoxidation of steel (gases occurrence: hydrogen, nitrogen, oxygen), the quality and humidity of the casting powder, the quality and homogeneity of its distribution, the variation of the steel level in the mould and the humidity existence in the refractory clay work of the tundish.

The measures taken in order to avoid these defects are: the corresponding steel deoxidation by using dry material and additions and also by protecting the ladle and the tundish, the use of dry casting powder, correlating the quantity of casting powder with the casting speed, the control of the fluctuation of steel level in the mould in order to prevent the steel flowing over the casting powder and its immersion, the control of the depth of the immersion nozzle, the use of nozzles having no defects, avoiding the high casting temperatures, respectively keeping the argon flow rate under the critical value in order to avoid capturing the argon bubbles, the slag formed around the nozzle by the meniscus[10].

The defect called breaking the casting is determined by a short breaking of the casting process and the defect is eliminated by shortening the bar containing it.

This defect is shown in figure 14 and it appears because of: the sudden variation of the casting speed, of the variations of the steel temperature in the tundish, of the level variation and of casting mode.

The main measures to avoid the defect occurrence consist of: keeping a constant casting speed by providing a limited range of the temperature variation in the mould and by keeping the level in the mould within the limits foreseen, respectively by casting on the automatic mode.

The ovalisation (figure 15) represents a defect of shape, concretized by the deviation from the ideal geometrical shape of the slab billet and it is often accompanied by internal cracks.

The occurrence of this defect is caused by: the primary non-uniform cooling and by the secondary intense non-uniform cooling; the inadequate mould profile or the advanced wear of the mould profile, the incorrect alignment of the casting machine; the improper roller position, the gap or the absence of the rollers in the stand [9].

Figure 14. Breaking the casting

Avoiding these defects can be made by: aligning the casting jet in the mould, keeping a constant water flow rate or with the same flow speed for water and checking the water spray outlet in order to assure a uniform distribution, the correlation of the spray flow rate with the casting speed; checking the mould wearing and the wear uniformity before and after the use; the correct alignment of the casting machine and the periodical control of this alignment; the correct placing of the rollers in the stand.

Figure 15. Oval bars

Another shape defect detected is the "curvature defect" (figure 16). This defect is the result of the bending of the steel bar under its own weight and it is determined by the inadequate placing of the bar on the cooling beds and this can be prevented by the correct disposal of the bars on the cooling beds.

Figure 16. Bars showing a curvature defect

The "dent of roller" in the figure 17 is a shape defect and it is characterized by continuous and periodical scratches and blanking out of the rollers on the material surface [11,12].

If the dent of the roller is not deep the material is polished, given the condition that the billet is within the established dimensions of diameter and ovality after being polished.

One of the causes leading to this defect occurrence is determined either by the inadequate placing of the rollers in the stand or by clogging the lower drawing stand rollers in the scale. It may be possible the locking of the roller bearings of the thread drawing stands and there were other situations when the rollers had been turned partially (uncorrespondingly).

Figure 17. Dent of roller

The defect "roller pressing", shown in figure 18, is defined as a longitudinal cavity of the material because of the pressure exercised by the rollers.

The diameter and the ovality are controlled, the macro sample is taken and if the material has not got any internal defects and it is within the size limits, it can be delivered, but only after polishing the sharp edges of the cavity.

This defect appears because of the too high pressure in the hydraulic roll (on the stand).

The defect can be avoided by monitoring the pressures from the control cab in order to provide an optimal working pressure of the stands and by updating the hydraulic schedule of the station and by replacing the present distributors with other reliable ones.

Figure 18. Roller pressing

IV. CONCLUSION

A particular importance in granting the adequate quality of the continuous cast semi-finished products is represented by the casting temperature, which normally should be as low as possible, since it is well known that high casting temperatures lead to the formation of columnar crystals, which make for the formation of fissures.

Too low a casting temperature can turn steel into a paste state and clog the immersion tubes, particularly on starting the casting procedure. As a result, the needed temperature levels have to be individually determined for each group of steel grade and, when it is possible, the casting temperature of the charge should be determined.

We mention that the casting temperature has to be $40 \div 60^{o}C$ at most above the liquidus temperature, because overheating favors the appearance of longitudinal fissures. It is also to be considered the temperature and state of the refractory lining of the ladle and distributor.

The research we have carried out shows that the drawing rate decreases with the cross section of the semi-finished product. Choosing a higher drawing rate leads to cutting short the duration of the casting process, therefore to the increase of the installation productivity, but it also reduces the thickness of the crust, increases the height of the ladle, and it also increases the solidification cone of the liquid steel.

In order to avoid these disadvantages, the cooling intensity should be increased, which would favor the diminishing of the transcrystallization area. On the other hand, too high a cooling intensity may lead to the appearance of internal fissures.

It is necessary to control and adjust the temperature inside the ladle, the main method of reducing overheating consisting in the introduction of consumable coolers.

The value of the drawing rate has to be equal to the filling rate v_u and in correlation with the diameter of the circle inscribed in the cross section of the semi-finished product, with the height of the ladle, the thickness of the crust and the duration of the casting process.

The study has also shown that the most frequent flaws are fissures, followed by shrinkage caused by the casting process. In order to obtain more competitive semi-finished products, particular attention has to be paid all along the billet manufacturing flux, starting with steel elaboration, the secondary treatment in the ladle, its protection against oxidation up to the pouring into the ladle, the application of the optimal continuous casting technology (monitoring the steel behavior both inside the distributor and ladle) as well as the correct positioning of the continuous cast billets upon the cooling beds in order to avoid their bending under their own weight.

Also, the construction of the casting installation has to meet certain technological requirements and in order to establish the optimal casting technology it is necessary to correlate all the factors influencing the physical, chemical and metallurgical processes taking place at the interfaces ladle – slag – liquid steel and which, obviously, have a serious influence upon the quality of the continuous cast steel.

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