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ASSESSMENT OF SURFACE DEFECTS IN THE CONTINUOUSLY CAST STEEL

ABSTRACT:
The development of continuous casting to produce semi-finished products is now so far advanced that almost any grade of steel can be continuously cast, and in the most appropriate cross section for further shaping. High quality finished products can only be produced by using defect free slabs, blooms or billet. The removal of defects is either performed selectively by removing the specific defect. This paper, based on industrial research, refers to the possibility of defining and cataloguing the surface defects specific to the semi-finished products continuously cast, in order to discover the generating source and to take the proper measures to prevent and remedy them where appropriate. The industrial experiments were carried out over several months in a steel company, period when we searched the number and type of defects detected at the reception of the studied metallic material.

KEYWORDS:
steel, continuous casting, surface defects

INTRODUCTION

The continuous casting process, both in the technological aspect as well as on the plant parameters, was and remained a basic concern of all the specialists in the major steel-making companies. The world energy crises, the consumers' quality demands, the need to adjust prices to the market demand, were the main factors that stimulated the technological development and generalization of the continuous casting process in the last 60-70 years.

It is noticeable that our country showed the same trend, so that in 2000 the cast steel production represented 73.1% of the total steel production, noting that the total steel production in Romania has fallen sharply in recent years. The results of experiments, mostly applied in practice, are regularly presented at various international events, which constitute a solid data basis for documentation, implicitly leading to an increased efficiency of research in this field.

Concerns in the development of continuous casting technology, either theoretically or through industrial experiments, refers to the possibility of defining and cataloguing the surface defects specific to the continuously cast semi-finished products, in order to discover the generating source and to take the proper measures to prevent and remedy them where appropriate.

EXPERIMENTAL STUDY

The industrial experiments were carried out over several months in a steel company, period when we searched the steel quality level in continuously cast semi-finished products, determined by the number and type of defects detected at the reception of the metallic material we had studied. In Fig. 1, we presented the continuous casting installation of the company where the researches were conducted.

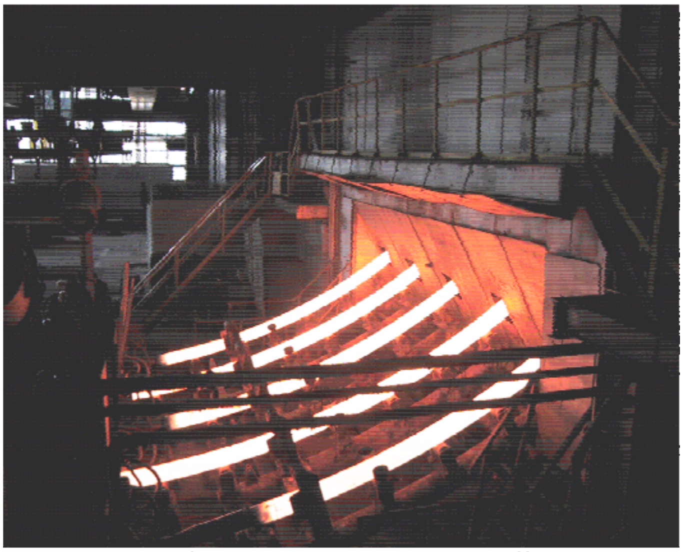

Fig. 1. The continuous casting installation

The steel is cast from the ladle into a tundish, which ensures a controlled flow in moulds, of appropriate form, water cooled. To prevent the sticking of the solidified crust, the mould oscillates in the casting direction with a higher speed than the casting speed, and into the mould is added a powdery lubricant. The mould is the essential technological component of the caster, which determines the shape of the profile cross section, realising the liquid-solid phase transformation, by a sudden and directed cooling, at the vertical casting into a water cooled double walled metallic cavity. At one strand, the cooling water flow differs from one dimension to another, its value ranging between 60-65 m^3h (at the mould for ϕ180 mm) and 110-125 m^3h (at the mould for bloom - 240 x 270 mm).

The strands are extracted and further cooled by using a direct water jet system. The purpose of the secondary cooling is to continue the cooling of the profile after leaving the mould, and to hurry the complete solidification of the cross section of the semi-finished product. The cooling in this area is achieved by direct pressure water spray, through nozzles, so that water is able to pass through the steam layer formed by evaporation, and to ensure the continuous and permanent contact with the metal. The sprinkling must ensure the adequate cooling afferent to a constant temperature drop, from the mould exit to the end of the secondary cooling zone.

The solidification of steel in the mould is achieved by the formation of crusts, whose thickness increases due to water splashing of the profile in the secondary cooling zone. The profile further extracted and straightened by passing through the drawing-straightening stands. The dummy bar *is separated from* the end *of the cast metal billet.*

The billet (completely solidified) is cut at predetermined lengths (5-8 m), with the flame cutting machine. The cut billets (blooms) are further moved on the roller table to the stoppers, from where they are taken over by transverse conveyors and carried on the cooling beds.

For the study, we selected only the heats used to cast steel billets Ø250 mm and Ø270 mm, respectively. For a more complete analysis, we took into account all the steel grades (carbon steel, low alloy steel, alloy steel) used to produce these two types of steel billets. The steel that is going to be continuously cast is primarily intended to obtain semi-finished products for tubes (Ø180 mm, Ø250 mm, Ø270 mm and Ø310 mm) and bloom (240 x 270 mm), for subsequent re-rolling. The share of continuously cast bloom of the total continuously cast steel is 50-60%, the balance being billets to be sent to another company (Fig. 2).

In terms of type, the steel that is going to be continuously cast is included in the following categories: general purpose steel, high quality carbon steel, low alloy steel and alloy steel, represented in Fig. 3.

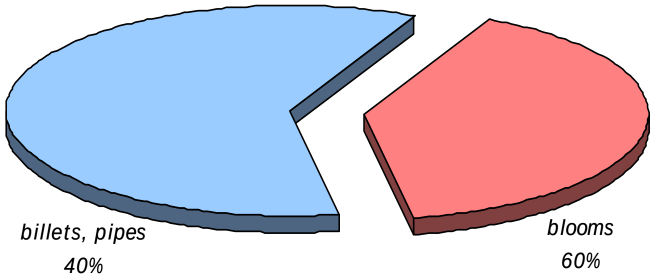

Fig. 2. Share of continuously cast bloom

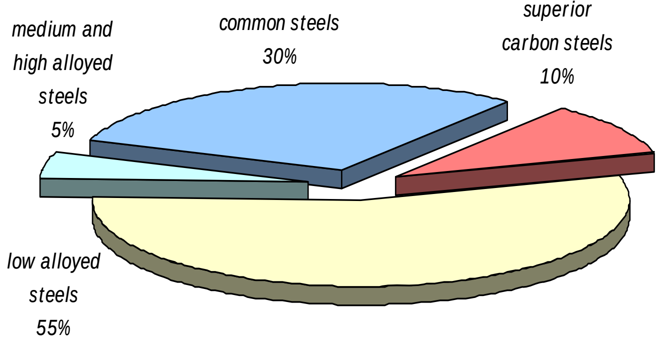

Fig. 3. Share of continuously cast general purpose steel, high quality carbon steel, low alloy steel and alloy steel

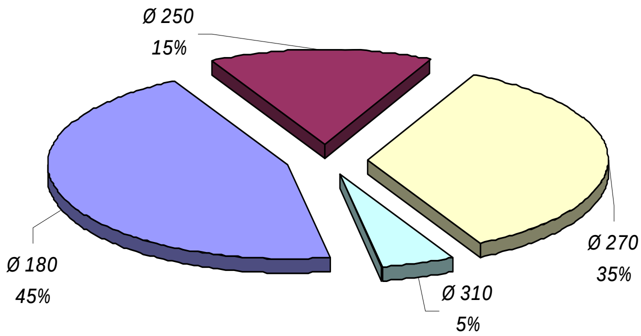

Fig. 4. Share of types & sizes

The data were taken from a batch of 55 hears of different steel grades, from which the Ø250 mm and Ø270 mm types were continuously cast. Currently, the types and sizes continuously cast (for billets) are: Ø180 mm, Ø250 mm, Ø270 mm and Ø310 mm, noting that Ø150 mm is not cast anymore because, from the quality point of view, a more competent product is cast now, which results through rolling at the Heavy Profiles Rolling Mill of the company. The share of types and sizes, calculated for the last 3 years, is presented in Fig. 4. The share of Ø310 mm billets is very low, because this size is continuously cast since September 2007, being still under the testing phase. The share of sizes and steel grades for billets differs from one month to another, depending on the beneficiaries' requirements.

The defects of material at the steel continuous casting appear during the solidification and cooling of the continuously cast semi-finished product, often leading to significant metal loss. To prevent such losses, the purpose of metallurgical technologies and constructive solutions is to find the causes of their occurrence, prevention and removal.

According to the literature, the defect can be defined as any deviation from the appearance, form, size, macrostructure or chemical properties provided in the technical standards or other normative documents in force. Defects are detected at the billets reception, by checking their surface quality on the inspection beds, or by checking the macrostructure of the test samples.

A defect is not always the result of a single case. Often, the defect is the result of multiple interacting causes, depending on a variable number of parameters. Similar defects, as "appearance", may have one or more different causes, and apparently different defects may have one or more common causes. Therefore, there are often found several defects on the same billet. The defects arising from the steel continuous casting can be classified as follows: surface defects, internal defects, form defects, mechanical defects and deviations from the prescribed chemical composition of steel.

RESULTS AND DISCUSSIONS

The share of the bloom, continuously cast in the company, represents approx 45-60%, the balance being billets for another company. The material defects at the steel continuous casting appear during the solidification and cooling of the continuously cast semi-finished products, often leading to important material losses. To prevent these losses, the purpose of metallurgical technologies and constructive solutions is to detect the causes of occurrence, prevention and removal.

According to the literature, we can define the "defect" as any deviation from the appearance, form, size, macrostructure and chemical properties provided in standards or other legal technical documents in force. The defects are found at the reception of billets, through visual inspection of their surface (on the inspection beds), or by checking the macrostructure of the test samples. A defect is not always the consequence of a unique cause. Many times, the defect is the result of the interaction of many causes that depend on a variable number of parameters.

Similar defects, as "appearance", may have one or more different causes, and apparently different defects may have one or more common causes. That is why several types of defects are often found on the same billet.

The cracks are openings found on the billet surface, with variable length and depth, which sometimes extend on the entire billet, on a strand or even on the full heat. The cracks are not always straight; they are sometimes interrupted and further continued in zigzag. Taking into account the direction on which they are formed, the cracks can be longitudinal, transverse or star types.

- Longitudinal cracks (Fig. 5). They form in the direction of extracting the strand from the mould (the bar that presents this type of defect is integrally rejected). They appear due to:
  - the unevenly removal of the heat in the mould and, therefore, the uneven increase of the strand crust, causing transverse tensions that lead to the strand cracking if the crust is not strong enough (uneven primary cooling);
  - turbulent flow of metal and a meniscus level variation in the mould;
  - secondary cooling too intense or uneven;
  - unequal, advanced wear of the mould that leads to a different thermal conductivity coefficient;
  - high casting temperature (failure to obtain the required ΔT);
  - great strand extraction speed;
  - inappropriate behaviour of the casting powder.

Fig. 5. Longitudinal cracks

- Transverse cracks (Fig. 6) - are rarely seen in round profiles they appear due to the tensions on the longitudinal direction of strand. If they are not deep, they are grinded (deviations within the permissible prescribed limits for diameter and ovality). The causes that give rise to transverse cracks are:
  - the thermal stresses due to the uneven solidification of the crust and the additional stress due to turbulent flow in the meniscus;
  - meniscus level variation;
  - depth of oscillation mark, presence on the bottom of the oscillation mark of segregations which cool more slowly and weaken the austenitic grain boundaries;
  - friction of the strand in the mould (at higher casting speeds, the melt flow between the mould wall and crust decreases, the edge friction increases with the viscosity of the powder used) or in the cylinder segments.

Fig. 6. Transverse cracks

- Star cracks (Fig. 7) and those caused by fragility at high temperatures – are very fine, being visible only on scale free surfaces. For removing the defect, the surfaces are locally grinded (if the cracks are not too deep).

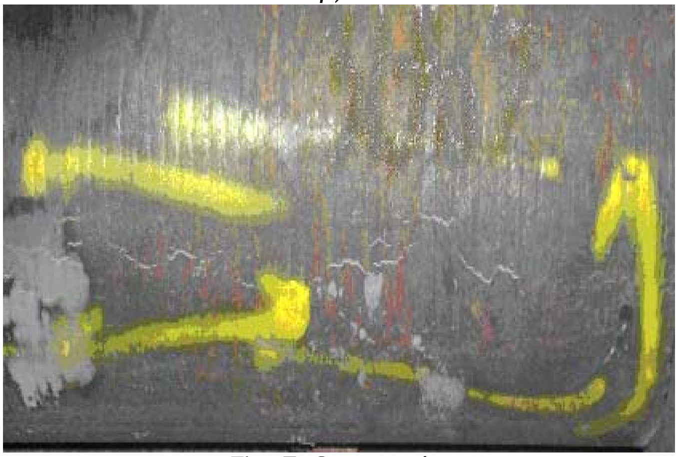

Fig. 7. Star cracks

The causes that give rise to star cracks are the intense local cooling, which induce local tensions, and the presence of copper at the austenitic grain limit. Some measures to be taken to remedy the star cracks are:

- the correct adjustment of the spray nozzle holes and the right correlation between the spray flow and the casting speed (automatic flow control);
- providing a uniform layer (film) of melted casting powder between the strand and the mould;
- the cooling of the strand with a moderate intensity when it leaves the mould, to avoid the increase of the thermal stress and the development of cracks.

- Depressions are local deformations of the continuous cast strand surface, which can develop either in the strand drawing direction (longitudinal depressions) or along the oscillation mark (transverse depressions). Generally, the longitudinal depressions appear at the round billets made of peritectic carbon steel and have the appearance of shallow ditches oriented along the strand drawing direction. Sometimes, this defect is accompanied by the slag resulted from the powder used in the mould, being known as slag band.
- The longitudinal depressions (Fig. 8) occur due to uneven heat transfer in the mould, which caused due to:

- the unequal development of the marginal crust;
- the steel level fluctuation in the mould and a too large quantity of melted flux, located in the space between the mould wall and the strand;
- the turbulent steel flow at the sub-meniscus level;
- the uneven and advanced wear of the mould, which results in a different coefficient of thermal conductivity.

They can be remedied by a slight, uniform and continuous cooling of the strand in the mould, by centring the casting jet in the mould; by controlling the fluctuations of the steel level in the mould, possibly using a mould with parabolic taper; by using a powder lubricant with suitable viscosity and melting rate; by minimizing the turbulence and surface agitation, optimizing the position of the input nozzle and its support; and by checking, before or after use, of the degree and uniformity of the mould wear.

Fig. 8. Longitudinal depressions

- The transverse depressions (Fig. 9) are formed in the transverse direction and may cyclically occur in relation to the strand length. The width of the depressions may cover some oscillation marks, and the depth can reach several mm. The peritectic steels with low Carbon percent and high percent of Manganese and the stainless steels are sensitive to the formation of this type of defect, due to the much larger contractions occurred during solidification.

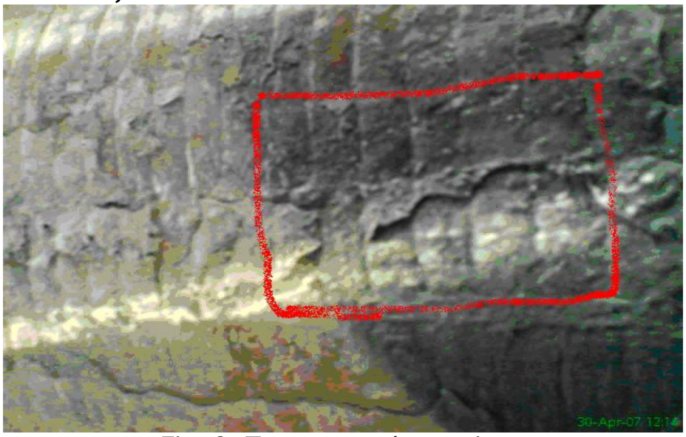

Fig. 9. Transverse depressions

The depressions precede the occurrence of the longitudinal shrinkage cracks and the marginal internal cracks (subcutaneous). The material that presents this type of defect is locally and cyclically grinded, to check the presence of subcutaneous fissures. The macro sample is taken.

The transverse depressions can be caused by the steel level fluctuation in the mould, by the too large quantity of melted flux, located in the space between the mould wall and the strand, and by the turbulent steel flow at the sub-meniscus level. They can be remedied by controlling the steel level fluctuation in the mould, by using a mould with parabolic taper, by using a powder lubricant with suitable viscosity and melting rate, by minimizing the turbulence and surface agitation, optimizing the position of the input nozzle and its support.

- □ Blowholes (Fig. 10) are cavities in the outer surface or in the subcutaneous zone of the billet, located at few tenths of millimetres from the stand surface. They have a diameter of 3 mm and a length (depth) that can reach up to 25 mm. Usually, they contain CO, relatively low H_2 and Ar, and they are often associated with inclusions.

Fig. 10. Blowholes

If they are superficial and/or few, they are grinded (not to exceed the allowed dimensional tolerance after grinding). They are caused by:

- insufficient steel deoxidation (presence of gases: hydrogen, nitrogen, oxygen);
- humidity of the casting powder;
- quality of the casting powder (% carbon, viscosity, basicity) - quantity and uniformity of its distribution;
- variation of the steel level in the mould, existence of moisture in the refractory lining of the tundish;
- the presence of argon entered in the mould during the injection of argon for filling the nozzle.

The measures to be taken to remedy these defects could be:

- sufficient deoxidation of steel by using dry materials and additives, protection of ladle and tundish;
- use of dry casting powder (and preheated, if possible);
- possibly choosing a casting powder compatible with the steel grade, temperature and casting speed (and, of course, a good correlation between the casting power quantity and the casting speed);
- controlling the steel level fluctuations in the mould, to prevent the steel to flow over the casting powder and to embed it, controlling the nozzle immersion depth, use of nozzles free of defects;
- avoiding the high casting temperatures;
- maintaining the argon debit below the critical value, to avoid the capture of argon bubbles by the meniscus and the development of slag foaming around the nozzle.

- □ Interruptions in the physical continuity of the casting (Fig. 11). This defect is caused by a short interruption of the casting process, and it can be removed by shortening the bar that contains it. This defect occurs due to sudden changes in casting speed, caused by the variations of steel temperature in the tundish, by the variations of steel level in the mould, or by the variations of casting mode. The main remedial measure is to maintain a constant casting speed, by providing a narrow range of temperature variation in the tundish, by maintaining the steel level in the tundish within the prescribed limits and by using the casting automatic mode.

Fig. 11. Interruption in the physical continuity of the casting

- □ Shrinkage cavity (Fig. 12) represents a gap of material, visible in the cross section at the end of a bar. It can be removed by cutting the end of the bar, and the defective portion is rejected. The causes that produce this defect are: high casting temperature, high extraction speed and intense secondary cooling.

Fig. 12. Shrinkage cavity

The measures taken to remedy this type of defect are:

- maintaining the ΔT within the established limits;
- a good correlation between the casting speed, ΔT and the cooling regime;
- reduction of the casting speed, reduction of the cooling intensity, maintaining the water flow at the established minimum limit.

Analysing the factors that cause the occurrence of the defects in the continuous cast billets, it results that the maximum share is firstly represented by the casting parameters or, on the other hand, by the steel chemical composition and degree of purity. To meet *the required chemical composition and degree of purity, a large number of technological factors must be synchronized during the entire continuous casting, of which the most important are:*

- *Steel chemical composition and degree of purity. As it is one of the main factors (it determines the drawing speed of the semi-finished product and prevents the occurrence of defects), the chemical composition of the steel that is going to be continuously cast should comply with the Euro norms updated for each steel grade, the chemical elements of the component ranging within specific limits prescribed by these standards in force. So, the Sulphur and Phosphorus contents shall be very low, being required to ensure a content of Sulphur < 0.015-0.020% (i.e. a value of the ratio Mn/S > 25-30), a content of Phosphorus between 0.020-0.025% and maximum 0.03% content of Copper.*

In the same time, the sum of these four elements must not exceed 0.067%, the observance of these restrictions leading to the reduction as much as possible of the tendency of fissure formation. In case of carbon, the values should be kept within very narrow limits and closer to the lower permissible limit for the respective steel grade. It is also required an advanced deoxidation of the steel with silicon, and the limitation of the aluminium content in steel (max. 0.007%), in order to prevent the deposition of Al_2O_3 inclusions in the hole of the casting funnel (where the steel enters in the protection tube) to avoid its obstruction and the occurrence of shrinkage micro-cavities in the continuous cast steel profiles.

An advanced degree of purity with low content of oxide inclusions in steel is obtained if the steel is deoxidised with aluminium during the treatment in the casting ladle, if we ensure all the required conditions to increase the buoyancy of the solid Al_2O_3 and to protect de liquid steel jet.

Following deoxidation with aluminium, it results inclusions of Al_2O_3 with higher draught capacity, i.e. with higher possibility to be retained in the slag created during the secondary metallurgy treatment, or in the tundish. The maximum size of non-metallic inclusions that remained in the liquid steel is determined by the time spent by the steel in the tundish, i.e. by the casting speed. A high level of steel in the tundish favours the flotation of these inclusions.

Of particular importance, in ensuring an adequate quality of the continuously cast semi-finished products, is the casting temperature, which normally should be as low as possible, because higher temperatures lead to the formation of columnar crystals (thus contributing to the trend of fissure formation), while low temperatures lead to a crystalline structure (more favourable in terms of metallurgy) due to the more extended globular zone.

However, a too low steel casting temperature can cause a transition to a pasty state that causes the clogging of the tubes, especially when starting the casting process. Therefore, the required temperature levels must be individually determined for the various groups of steel grades and, where possible, to establish the casting temperature for each heat.

We have to mention that the casting temperature should be with maximum 40-60°C higher than the liquidus temperature, because a higher overheating favours the occurrence of longitudinal cracks. We will also consider the temperature and the condition of the refractory lining of the ladle and tundish.

The experimental researches and the statistical calculations showed that the drawing speed decreases with increasing the section of the semi-finished product. Choosing a high drawing speed leads to the shortening of the casting duration and increasing of the installation productivity, but also to the decreasing of the marginal crust thickness and to the increasing of the mould height and the liquid steel cone length. To avoid these disadvantages, the cooling intensity should be increased, which would also facilitate the reduction of the transcrystallization zone. On the other hand, too much cooling intensity can cause the occurrence of internal fissures.

CONCLUSION

In conclusion, temperature control and adjustment is required in the mould. The main method to reduce the overheating consists of the introduction of consumable coolers. The value of the drawing speed must be equal to the speed of filling, and it is established in correlation with the diameter of the circle inscribed in the section of the semi-finished product, the height of the mould, the desired thickness of the marginal crust and the casting duration.

The experimental research and the statistical calculations showed that choosing a high drawing speed leads to the shortening of the casting duration (thus increasing the plant productivity), to the reduction of the marginal crust thickness, to the increase of mould height and to the increase of liquid steel cone length. To avoid these disadvantages, the cooling intensity should be increased, which would favour the reduction of the trans-crystallization zone. On the other hand, a too high cooling intensity may lead to the occurrence of internal fissures.

Moreover, from industrial experiments it was seen that the most frequent defects are the fissures (cracks), followed by the casting blowholes. Therefore, to obtain high quality and competitive semi-finished products, it is required to pay a special attention, during the entire manufacturing flow of billets (from liquid steel to the treatment in the ladle), to the steel protection against oxidation (before entering the mould), application of an optimum continuous casting technology (monitoring the steel behaviour in tundish and mould), and an appropriate arrangement of the continuously cast billets on the cooling beds, to prevent the bending of the steel bar under its own weight.

Also, the caster construction should meet certain technological requirements. To establish the optimum casting technology, we have to correlate all the factors that influence the physical-chemical-

metallurgical processes that occur at the interfaces mould-slag-liquid steel which, of course, have a great influence on the quality of the continuously cast steel.

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