Research on the influence of casting powders on the higher quality of continuous cast semi-finished parts

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Abstract. Pursuant of the modernization of steel elaboration and casting technologies, at present over 90% of the liquid steel undergoes continuous casting. The quality of the cast parts is influenced by: the casting temperature and rate, the flow rate of the cooling water and the characteristics of the casting powders. The research under consideration was done on a low manganese alloy steel X60QS elaborated in an EBT-type, 100 ton oven and cast on a 5-strand MCT casting machine. The paper gives the results of the research on the variation of the carbon, manganese and sulphur content per cast product for each casting strand and for each rod of the strand. The research managed to establish the causes that lead to deviations from the required chemical content for these elements, as well as the possibilities of eradicating them. The results are applicable in research and in practice.

1. Introduction
The extremely fast progress of steel continuous casting from the metallurgical point of view as well as in terms of installation construction allowed the widespread of this industrial process.

Alongside the interest in using this procedure more and more intensely, experts focus their attention on the improvement of the casting machines, the quality of the resulting semi-finished parts, as well as on allowing more and more steel grades to be processed on this flux [1], [9].

As to the construction of continuous casting machines, there have not been essential modifications lately, the type of construction in use being the one with crystallizer and a single-radius curved strand. In this domain, the preoccupations pertain particularly to the possibility of increasing the quantity of steel to be cast and to the increase of its quality [2], [5], [6].

The continuous casting installations, irrespective of the technological variant, (strip, vertical or curved) consist of the following parts: ladle, tundish, crystallizer, secondary cooling system, guiding and drawing system, cut off system and tilting system.

The ladle represents the connection element between the steelmaking furnace and the continuous casting machine proper, and it has to comply with a series of technological functions, among which the most important ones are: maintaining steel at a temperature that is as constant as possible; separation of most slag from the molten steel; metal should flow as smoothly as possible and at a constant casting flow rate. At the same time, the ladle has to be as safe as possible and the refractory lining must show high resilience [3], [4], [7].

The quality of the surface of continuous cast semi-finished parts is influenced, besides the technological factors, by the characteristics of the casting powders.
The casting powders used in steel continuous casting have a complex role, as they have to prevent steel re-oxidizing, while entrapping the non-metallic inclusions from the molten steel, grant thermal insulation and transfer, as well as the lubrication between the solidified steel crust and the crystallizer wall.

In order to meet all these requirements, the casting powders have to be analysed from the point of view of the following characteristics: fusibility, viscosity, superficial and interphase strain, the capacity of inclusion absorption.

These properties, in their turn, are, to a large extent, determined by the chemical and mineralogical content, by the grain-size distribution, the physical and chemical humidity of the powder, respectively of the casting powder slag.

On adding the casting powder into the crystallizer, it has to spread fast and evenly on the surface of the steel, covering it entirely. In this way, an insulating layer is formed, which considerably reduces the heat loss by radiation.

The casting powder should not burn or melt too fast on the surface of the molten steel, in order to avoid the formation of a thick layer of slag, but also on due time to form the appropriate lubrication of the crystallizer. As a result of the processes that take place on the surface of the metal bath, a relatively thin layer of liquid slag should be formed, capable of entrapping the non-metallic inclusions in the steel and, at the same time, to flow down over the metal meniscus, into the space between the strand and the crystallizer wall [8].

Moreover, the casting powder and the resulting slag should not carburize and impurify the steel and neither should they release toxic gases in the environment.

2. Industrial experiments. Data processing

Industrial experiments were carried out in a steel plant equipped with an 100-ton EBT-type electric oven, in-ladle LF and VD type 100-ton processing installations and an MTC 5-strand continuous casting machine. The experiments monitored and analysed the technological data of 21 charges of grade X60QS steel meant for making pipes to be used in the transport of hydrocarbons in an intensely corrosive environment. Table 1 shows the chemical content (the limits of variation and the allowed deviations) of the steel under study.

| C  | Mn   | Si | S max | P max | Cr rmax | Ni max | Mo   | Al |
|----|------|----|-------|-------|---------|--------|------|----|
| 0.09- | 1.35- | 0.20 | 0.003 | 0.015 | 0.20    | 0.20   | 0.05- | 0.020-|
| 0.12 | 1.45  | 0.30 |       |       |         |        | 0.08 | 0.060|

| Allowed deviations allowed per product |
|---------------------------------------|
| +0.01 | +0.10 | +0.05 | +0.002 | +0.02 | +0.05 | +0.05 | +0.003 |
| -0.02 | -0.05 | -0.05 |         |       |       |       | -0.003 |

The covering powder used in the tundish was GLUTIN T that has the following physical-chemical characteristics: grain size (<125µm), density (0.51g/dm³), melting point (1250-1350ºC), humidity <0.5%, free carbon 19%. The chemical content is shown in Table 2.

| SiO₂ | CaO | Al₂O₃ | MgO | Fe₂O₃ | Na₂O₃ | K₂O |
|------|-----|-------|-----|-------|-------|-----|
| 38.70 | 3.20 | 19.70 | 1.40 | 5.80  | 4.50  | 1.20|

The casting powder used in the crystallizer was ACCUTHERM ST 512 with the following physical-chemical characteristics: grain size (<125µm), density (0.83g/dm³), softening point (1050-
1110°C), melting point (1085-1145°C), flowing point (1095-1155°C), basicity CaO/SiO$_2$=0.7. Free carbon is 16.00%. The chemical content is shown in Table 3.

**Table 3. The chemical content of ACCUTHERM ST 512**

|       | SiO$_2$ | CaO  | Al$_2$O$_3$ | MgO  | Fe$_2$O$_3$ | Na$_2$O$_3$ | F     |
|-------|---------|------|-------------|------|-------------|-------------|-------|
| Values | 31.80   | 22.20| 10.70       | 2.60 | 2.60        | 3.40        | 3.60  |

The paper shows the results of the research on the variation of the carbon, manganese and sulphur contents per cast product, for each casting strand and each rod in the strand. From the quality perspective, the study focused on the homogeneity of the chemical content of the finished product, in order to avoid casting flaws. Temperature, casting rate and cooling water flow rate were also monitored.

All along the experiments, three sequences of 7 charges each were cast (therefore a total of 21 charges). The casting rate was recorded every 10 minutes. This was at the beginning of the 0.9m/min. casting, and then it oscillated between 1.5m/min. and 2.0m/min. Table 4 shows the values mentioned above for strand 1 of the first cast charge (almost similar values were also obtained for strands 2; 3; 4 and 5, respectively for the other charges).

**Table 4. Casting parameters**

| Time (min) | Casting rate (mmin$^{-1}$) | Temperature(°C) | Water flow rate in the crystallizer (lmin$^{-1}$) |
|------------|----------------------------|-----------------|-----------------------------------------------|
| 0          | 0.9                        | 1586            | 4.1                                           |
| 10         | 1.7                        | 1585            | 4.5                                           |
| 20         | 1.7                        | 1585            | 4.6                                           |
| 30         | 1.7                        | 1576            | 4.7                                           |
| 40         | 1.7                        | 1570            | 4.7                                           |
| 50         | 1.8                        | 1564            | 4.8                                           |

During the research, the lowest temperature in the tundish was 1539 °C and the highest 1595°C. The highest value of water flow rate in the crystallizer was 5.5l/min. on all the 5 strands.

Water pressure in the crystallizer was 9.8 bar on average, and on secondary cooling it was ranging between 8.6 and 10.4 bar.

The analysis of the resulting data shows that the technological parameters varied within normal limits, so that, from this point of view, the casting process was correct and no negative influences on the quality of the semi-finished parts were noticed.

The covering powder used in the tundish was Glutin T, as follows: on the first charge of each sequence the powder addition was of 80kg, and for the other charges of the sequence, it was of 70kg. There were no technological deviations in any charge.

The crystallizer was lubricated with Accutherm ST 512 casting powder. Six sacks were used for each charge.

The lubrication process took place accordingly, with the exception of bars 1 of each strand and sequence (more exactly, C, Mn and S did not range within the limits of the chemical content).

This aspect was not noticed with the other rods; herein after is given the variation of C, Mn and S (including the supplementary restrictions imposed by the beneficiary) for rod 3/strand 1 of each charge. The data were technologically analysed and processed in EXCEL and are shown in Figure 1-3.
The steel was continuously cast into rods having a diameter of 310mm, 5 bars /strand, 25 bars/charge, 175 bars/sequence, respectively 525 bars on the 3 sequences (21 charges). Graphics are given for rod 3 of strand 1 in each charge.

The analysis of the three graphs shows that there are no significant variations in terms of content.

From the point of view of its chemical content, grade X60QS steel is a low manganese alloy with a narrow variation range for the main elements in its content, particularly for carbon, and with a very low content in sulphur.

In terms of carbon content the upper limit was exceeded by 0,01%, which is an admissible deviation. As to the lower limit, it has not been reached.

With respect to manganese content, the upper limit was not reached, and the lower limit was attained by 3 charges, so the process of deoxidizing and manganese alloying can be considered very good.

As to sulphur, the upper limit was not exceeded, which means the desulphurization process went on very well (the result of processing with synthetic slag in the LF installation and with vacuum in the VD one).

The analysis of the data pertaining to the other elements in the chemical content proved that the elaboration-casting process went on very well.

For the first charge of the sequence, on each strand, the first bar showed significant differences of chemical content with respect to the three elements analysed above (C, Mn și S), both cross-sectionally (radially) and along the length. This variation of the chemical content appears along 1 m of the rod at most, from the beginning of the rod. In order to know the variation of the chemical content both radially and longitudinally, (disc shaped) samples were taken from the 1m. long rod (resulting from charge no. 1, strand 1) as follows:

- section 1 from the beginning of the rod;
- section 2 at 250mm from the first cut off;
- section 3 at 500mm from the first cut off;
- section 4 at 750mm from the first cut off;
- section 5 at 1000mm from the first cut off.

From each sample, 7 disc-shaped slices were collected in order to determine the chemical content at different points (a central one and the radius ones) according to the diagram given in Figure 4. The position of these points is similar for the other 4 samples, which allowed the analysis of the chemical content at various cross-sections of the rod. The resulting data were processed in EXCEL, the graphical representations being given in Figures 5-10.

![Figure 4](image)

**Figure 4.** The place where the disc-shaped samples were collected

![Figure 5](image)

**Figure 5.** The variation of the carbon content along the cross-section and length

![Figure 6](image)

**Figure 6.** The variation of the carbon content along the rod length and cross-section

![Figure 7](image)

**Figure 7.** The variation of the manganese content along the rod cross-section and length.

![Figure 8](image)

**Figure 8.** The variation of manganese content along the rod length and cross-section
Figure 9. The variation of the sulphur content along the rod cross-section and length

Figure 10. The variation of the sulphur content along the rod length and cross-section

Based on the graphical representations resulting from the processing of the experimental data and shown in Figure 5-10, a technological analysis is given herein after.

The carbon content. From the analysis of the data shown in Figure 5 and in Figure 6 one can notice that along a certain portion of the rod, corresponding to areas 3, 2, 1, 4 and 7 the carbon content is way above the accepted maximum (an important carburization), its diminishing starting with section 1, towards sections 2, 3, and 4, respectively, and ranging within the established limits in section 5.

With respect to areas 6, 9 and 8 steel carburization is significantly more reduced than in the area considered above and it has to be mentioned that its diminishing is maintained (as in the previous case) along the same direction, from section 1 to section 5. As to the central area (area 5), one can notice that, in this case, the variation of the carbon content along the rod under analysis was very low (from 0.141 to 0.118), so, practically, irrelevant. It is therefore to be noticed that in section 5, irrespective of the place of sampling, (1 – 9), the carbon content of the rods will range within the limits imposed by the beneficiary.

Steel carburization, respectively the variation of the carbon content along 1 m of the first cast rod, both cross-sectionally and longitudinally is determined by the casting powder, therefore there is an intake of casting powder (unmelted yet), as well as of viscous slag resulted from the melting of the lubrication powder in the first portions of cast steel.

According to the data given in Figure 4, by extension of the lateral surface of the rod (along 1 m), a lateral surface S1 would result from the reunion of the sides of areas 3, 2, 1, 4 and 7, and, in the same way, from areas 6, 9 and 8 would result surface S2; carburization is more intense on S1, and, in both cases, a lot more intense in the central area (area 5). In all three cases, along the direction from section 1 to section 5, the carbon content decreases (obviously, unevenly) so that the chemical content of the samples collected from these areas corresponds to the one requested by the beneficiary. The significant difference in terms of carbon content in the cross section must be caused, in our opinion, by the uneven spreading/distribution of the lubricant powder on the metal surface (which is explainable considering the level of the metal in the tundish at the beginning of the casting process).

The manganese content. Just like in the case of carbon, the analysis of the data given in Figure 7 and Figure 8 shows that there is a variation in the content of manganese both cross-sectionally and longitudinally. The content of manganese in the samples collected from sections 1, 2 and 3 is below the lower standard limit; for those in section 4, the content is over the lower limit, if we consider the acceptable technological deviation and, for all the samples in section 5, it is above the lower limit. It is to be noticed that the variations are smaller as compared to those of carbon, higher values being present in areas 3, 2, 1, 4 and 5 while in areas 6, 7, 8 and 9 they are even lower. It is obvious that, just like in the case of carbon, along the direction section 1 to section 5, the variations in manganese content diminish. We consider these variations to be caused by the segregation of manganese (–) in the first quantities of steel entering the crystallizer, as it has a temperature towards the lower limit of the
temperature interval recommended for casting. As the casting advances, the steel entering the crystallizer is hotter, which does not exclude a reaction of reduction of the manganese oxides from the lubricant slag by the carbon in the powder.

**The sulphur content.** As to the content in sulphur, again, just like in the case of carbon and manganese, it shows variations both cross-sectionally and longitudinally. It is worth mentioning that the content in sulphur was determined from the same samples used for carbon and manganese. The results are presented in Figure 9 and Figure 10. The analysis of the data given in these figures shows that the variations are higher in the samples from areas 1; 2; 3; and 4 as compared with those in the other areas (5; 6; 7; 8 and 9). Taking into consideration the variation of sulphur in these areas, it is possible that a re-sulphurization of steel should have taken place inside the crystallizer before the lubricating powder turned into slag.

To be noticed that supplementary samples (other than the ones mentioned before) were collected from the first steel rod, in order to determine the consistency of the chemical content along the rod, respectively in order to detect other anomalies as well. The samples were collected at every 0,5m and it was revealed that there is no redundancy of non-conformities related to the limits of the requested chemical content.

3. Conclusion
According to the information obtained on the elaboration – casting process flow and from the processing of the experimental data, the following conclusions can be drawn:

- from the technological point of view, the parameters of steel elaboration and casting have been observed (varying within the established limits), which led to the production high quality semi-finished parts by continuous casting;
- the problem related to the first rod of the sequence (on each strand) non-ranging within the limits of chemical content for C, Mn and S, both cross-sectionally and longitudinally, remained along 1m of the rod length for all the charges under study (if compared to section 1 of the first rod);
- the differences of chemical content related to the three elements under consideration can be taken as an anomaly generated at the beginning of the casting process by either too much powder (improper dosage) or by the wrong distribution of the powder in the crystallizer;
- the portion of deficient material is removed, which leads to a reduction of proper material (delivered);
- we consider that it is of interest to continue the researches in the sense of studying the evolution of the chemical content at more points on each section on the one hand and, on the other hand, establishing for the casting of 1 – 1.2 m rods the proper quantity of lubricating powder, eventually with a slightly different chemical content.

References
[1] Nica Ghe, Socalici A, Ardelean E and Heuțu T 2003 Tehnologies for improving the quality of steel, Mirton, Timişoara
[2] Drăgoi F 2012 Research on reducting the gas content of the steel treated on the technological and EBT-TC, PhD Thesis, University Politehnica Timişoara
[3] Heuțu T, Ardelean E, Socalici A and Popa E 2001 Experimență și rezultate cu privire la lubrefierea la interfața cristalizor – semifabricat turnat continuu, Analele Facultății de Inginerie Hunedoara III(1)
[4] Drăgoi F, Socalici A, Heuțu T and Ardelean E 2011 Industrial Research on the use of basic powdery waste in siderurgy, International U.A.B. – B.EN.A. conference environmetal engineering and sustainable development, Alba Iulia, Romania, May 26-27th, pp 302-303
[5] Puțan A 2013 Research on steel refining elaborated on the flow: electric arc furnace-ladle furnace-continuos casting, PhD Thesis, University Politehnica Timişoara
[6] Cârlan B A, Constantinescu D and Constantin N 2016 Study regarding the thermal properties of the iron oxides and their application in the process of the heat transfer from the furnace
hearth to the ingot, *Scientific Bulletin Series B-Chemistry And Materials Science* 78(4) 169-180

[7] Branescu E, Blajan A and Constantin N 2015 Experimental research on the characteristics of softening and melting of iron ores as significant factor of influence on gas permeability of blast furnace charge, *IOP Conf. Ser.: Mater. Sci. Eng.* 85 012006

[8] Hepuț T, Ardelean E, Socalici A and Popa E 2001 Experimentări și rezultate cu privire la lubrifierea la interfață cristalizor – semifabricat turnat continuu, *Analele Facultății de Inginerie Hunedoara* III(1)

[9] Ilca I, Hepuț T, Karsai E and Oargă N 1997 Research on the metal consumption with continuous casting, *Buletinul UPT* 42(26)