

IMPROVING PRODUCTION TECHNOLOGY OF TUBE STEEL GRADES IN CONVERTER PROCESS

Received – Primljeno: 2015-12-24

Accepted – Prihvaćeno: 2016-04-25

Preliminary Note – Prethodno priopćenje

Nature of formation and evolution special features of nonmetallic inclusions during ladle refining of converter HSLA steels for pipelines have been studied. Nonmetallic inclusions of the CaO-Al₂O₃-MgO system, close to calcium monoaluminate CaO-Al₂O₃ with up to 5-6% of MgO, have been found as favorable from morphology point of view. These small inclusions nucleate on endogenous MgO substrates at sufficient high content of calcium in steel melt. Hot rolled plates can be rejected due to the coarse calcium bi- and hexa-aluminate inclusions (CaO·2Al₂O₃ and CaO·6Al₂O₃), usually containing exogenous MgO. These coarse inclusions form under calcium deficiency conditions, especially in the case of longtime steel holding in a ladle.

Key words: nonmetallic inclusions, tube steel, deoxidation, modification, strip

INTRODUCTION

Critical parameters and technological recommendations providing low level of nonmetallic inclusions in steel have been formulated: calcium/aluminum ratio used for steel deoxidation and modification was increased; interval between additions of calcium and aluminum was decreased; full time of refining was corrected; procedures for lowering of steel reoxidation during pouring were conducted. Twenty five heats were carried out according to recommendations and the specimens from 128 hot-rolled plates were investigated for evaluation of nonmetallic impurity rating of steel. Metallographic analysis revealed that 95% of finished plates had rate up to 2,0 according to GOST 1778-70 (Sh6 method) standard.

This work deals with studying nonmetallic inclusions which are formed in converter steel of the tube grades (22GYu, 10G2FB, 09GSF, etc.) in the course of secondary refining and pouring. The main objective of the studies consists in the developing the technology providing the impurity of the strip with nonmetallic inclusions no more than the second point in accordance with GOST 1778 – 70 [1].

EXPERIMENTAL PART Equipment and tools

In the work there were carried out studies of the metal obtained in the conditions of the Severstal JSC.

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The sections were made on the equipment for preparing samples of Buehler Ltd Company. Metallographic studies were carried out on the motorized microscopes of Nikon Epiphot TME and Zeiss Axiovert 200 MAT equipped with analyzers of the image Thixomet Pro. The micro-X-ray spectral analysis of inclusions (MXSA) was carried out on the electronic microscope of ZEISS SUPRA 55VP with the Inca (Oxford Instruments) attachment.

Thermodynamic modeling was carried out by means of the commercial software of FactSage with the use of the FSstel and FToxid [2] databases, as well as the original program developed at the Metallurgical Technologies chair of FSBOU VPO SpBPU for the description of forming endogenous nonmetallic inclusions when modifying steel with calcium. There were calculated the temperature dependences of the nonmetallic inclusions mass which were formed in the course of steel cooling and crystallization. There were considered chemical reactions of forming in liquid steel of all possible compounds within the Fe – Ca – Al – Si – Mn – S – O system.

The impurity assessment by nonmetallic inclusions of cast metal samples was made according to the ASTM E – 1245 - 03 standard.

The analysis of the obtained results showed that for all considered melts made by the basic factory technology there was observed the general tendency connected with increasing the impurity of metal nonmetallic inclusions in the course of continuous pouring. On average by the melts the level of steel impurity in the processing on the metal operational development installations (MODI), in the furnace ladle (FL) and the installation of steel vacuum processing (SVP) does not exceed 0,015 vol.%, in the course of continuous pouring this value can increase by 1,5 - 2,0 times and reach 0,03 vol. %.

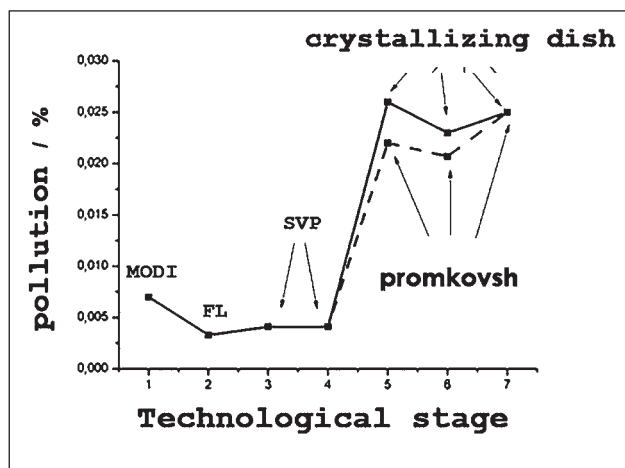


Figure 1 Changing the volume share of nonmetallic inclusions in the metal in the course of secondary refining and continuous pouring

In Figure 1 there is presented an example of changing the volume fraction of nonmetallic inclusions in the liquid metal in the course of secondary refining and pouring for one of the studied melts. In this case the volume fraction of inclusions by the end of secondary refining makes less than 0,005 vol. %, however in the course of continuous pouring it increases to 0,020 - 0,025 vol. %.

Thus, the efficiency of actions realized in the course of secondary refining which purpose is refinement of steel from nonmetallic inclusions can be considerably reduced owing to the developed processes of the secondary oxidation of steel in the course of continuous pouring.

RESULTS AND DISCUSSION

The impurity assessment by nonmetallic inclusions of samples of the hot-rolled sheet (strip) obtained from the metal of the studied melts was carried out using two various techniques: ASTM E – 1245 - 03 and GOST 1778 - 70. There was studied the phase structure of large lines of inclusions exceeding the second point in accordance with GOST 1778 - 70 which existence is one of the main causes of declining the quality of steel products and increasing the extent of sheets rejection.

As a rule, these large lines represent endogenous and exo-endogenous multiphase inclusions of the $\text{CaO} - \text{Al}_2\text{O}_3 - \text{MgO}$ system close in structure to hexa- ($\text{CaO} \cdot 6\text{Al}_2\text{O}_3$) and bialuminate of calcium ($\text{CaO} \cdot 2\text{Al}_2\text{O}_3$). MgO oxide of magnesium of the exogenous origin getting to the melt from lining of the ladle can be a part of such inclusions. The temperature of melting this group of inclusions exceeds the temperature of the liquid melt ($T_m > 1700$ °C), therefore there are formed refractory conglomerates with iron layers, subsequently when rolling transformed into fragile lines (Fig. 2).

In the metal structure there are also large lines, close in their structure to $12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$ which corresponds to the eutectic in the $\text{CaO} - \text{Al}_2\text{O}_3$ system [3]. At the temperatures of secondary refining ($T_m \approx 1360$ °C) such fus-

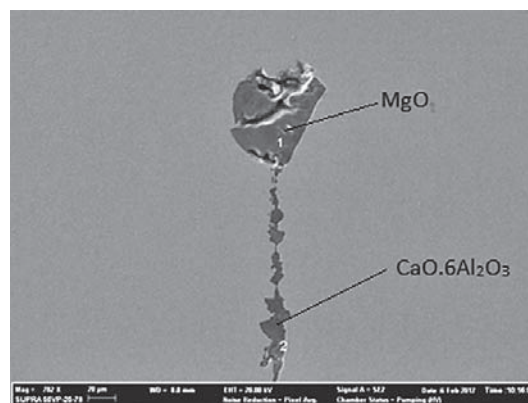


Figure 2 Refractory line inclusions found in the metal structure

ible inclusions are formed in the liquid state at the moment of introducing the calcium-containing modifier in the melt at considerable supersaturation of the metal with calcium. The formed endogenous slag drops easily coalesce, they are integrated and removed from liquid steel, however those particles which remain in steel, form large hardly deformed extended inclusions subsequently.

It was established that from the studied inclusions from the point of view of morphology the most optimum are compounds of the $\text{CaO} - \text{Al}_2\text{O}_3 - \text{MgO}$ system close in structure to monoaluminates of $\text{CaO} \cdot \text{Al}_2\text{O}_3$ calcium and MgO containing to 5-6 %. These inclusions of small size (6 - 8 microns) are formed in the liquid state, have a spherical form and under plastic processing their form is not practically subject to changes.

For the purpose of studying the evolution of the phase structure of nonmetallic inclusions in the course of secondary refining and pouring there was carried out MXSA of samples of the cast metal which were selected at all main stages of steel processing (after discharging from the converter, at the furnace-ladle set, before modifying with calcium, from the tundish and crystallizer in the course of continuous pouring). There were also studied the working surfaces of filtration partitions of tundishes and submersible glasses. The phase structure of the found inclusions was estimated taking into account the results of thermodynamic modeling [4].

We will consider how the structure of the nonmetallic inclusions which are formed in the course of secondary refining of liquid steel changes. After discharging steel from the oxygen converter with simultaneous introducing alloying materials and deoxidants (secondary aluminum and silicomanganese) there are formed nonmetallic inclusions of the $\text{Al}_2\text{O}_3 - \text{SiO}_2 - \text{FeO}$ system (corundum, hercynite, aluminosilicates). Small inclusions of corundum are formed at considerable supersaturation of the metal with oxygen and aluminum. A part of these inclusions is removed from steel in its processing at the metal operational development installation (MODI) due to low adhesion to the matrix melt, however a small amount of inclusions owing to their small sizes after all remains in steel by the time of its modifying.

After the melt modifying with calcium-containing materials (ferrocalcium or silicocalcium) in the metal there are formed nonmetallic inclusions of the following types: liquid oxide compounds of the $\text{CaO} - \text{Al}_2\text{O}_3 - \text{SiO}_2$ system; calcium bialuminates ($\text{CaO} \cdot 2\text{Al}_2\text{O}_3$); calcium sulfides presented both in the form of single nonmetallic inclusions and as a part of multiphase inclusions as the plating cover. Besides, in the metal there were found aluminosilicate inclusions and corundum which were present in the melt still before modifying. In the metal there often can be present exogenous particles of slag (globules in structure close to integumentary slag) and linings (large inclusions having MgO at the heart).

According to the results of thermodynamic modeling of the process of steel modifying with calcium the main equilibrium type of inclusions which are formed under specific temperature and concentration conditions, is calcium bialuminate $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$.

Owing to the fact that calcium introduced into the melt is not distributed in the ladle volume instantly and evenly, at different points of the melt there can be realized various ratios between the content of aluminum and calcium $[\text{Al}]/[\text{Ca}]$ that leads to forming nonmetallic inclusions of the most various structure in the conditions of the corresponding local balance. In particular, in the immediate area of introducing the modifier in the conditions of considerable supersaturation of the melt with calcium there are formed endogenous liquid inclusions close in structure to $12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$. Later on in the course of the flushing period (averaging purge) of secondary refining when reagents are distributed evenly, there takes place the gradual recrystallization of these inclusions which became nonequilibrium, therefore their average composition approaches the equilibrium composition of $(\text{CaO} \cdot 2\text{Al}_2\text{O}_3)$. Indeed, at this stage of secondary refining in the metal there were found multiphase nonmetallic inclusions having an intermediate structure consisting at modifying temperatures of the solid ($\text{Al}_2\text{O}_3 - \text{CaO} \cdot \text{Al}_2\text{O}_3$) and the liquid ($\text{CaO} - \text{Al}_2\text{O}_3 - \text{SiO}_2$) phases.

Studying deposits on filtration partitions of tundishes showed that the prevailing type of inclusions which are besieged on them are compounds the $\text{CaO} - \text{Al}_2\text{O}_3 - \text{MgO}$ system, in particular, of calcium bialuminate $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$ and magnesium spinel $\text{MgO} \cdot \text{Al}_2\text{O}_3$ that speaks of the significant role of lining when forming nonmetallic inclusions in the course of secondary refining [5].

The micro - X - ray spectral analysis of nonmetallic inclusions found in the metal samples which are selected from the tundish and crystallizer in the course of continuous pouring of steel permitted to record the gain of acute-corner small (0,5 - 2 mkm) nitride inclusions. As a rule, these inclusions are allocated on substrates of the oxide particles formed in steel at earlier stages (still before pouring).

In certain cases there was also revealed that on the surface the globular inclusions of the $\text{CaO} - \text{Al}_2\text{O}_3$ sys-

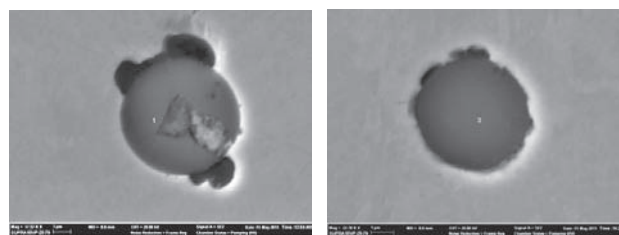


Figure 3 Multiphase inclusions revealed in the metal samples selected in the process of steel continuous pouring: the base (the light-grey component): calcium aluminates ($\text{CaO} - \text{Al}_2\text{O}_3$); the dark component on the aluminates surface is the $\text{FeO} - \text{Al}_2\text{O}_3$ system oxides

tem developed when modifying, there are formed oxides of the $\text{FeO} - \text{Al}_2\text{O}_3$ system (Figure 3).

The described phenomena can be a consequence of secondary oxidation of the liquid metal at continuous pouring.

The comparative analysis of technological parameters of the melts which are characterized by various morphology and number of nonmetallic inclusions permitted to reveal the critical parameters having the most significant impact on steel impurity.

The scheme of liquid steel deoxidation at the discharging from the converter is one of the key moments of the technology. According to the carried out studies and the results of thermodynamic modeling, the main type of inclusions which are formed at this stage are slag compounds of the $\text{Al}_2\text{O}_3 - \text{MnO} - \text{SiO}_2 - \text{FeO}$ system. Depending on the amount of introduced aluminum together with liquid inclusions there are also formed solid compounds of Al_2O_3 corundum and hercynite $\text{FeO} \cdot \text{Al}_2\text{O}_3$. The extent of hercynite removal from the melt is much lower owing to high adhesion to the melt. It should also be noted that the most hard-to-remove inclusions of $\text{FeO} \cdot \text{Al}_2\text{O}_3$ are formed in the conditions of deoxidation of the reoxidized metal with aluminum.

Within this work the following schemes of processing of metal at discharging from the converter were tested:

1. Without use of aluminum at discharging.
2. Using aluminum which quantity is reduced twice in comparison with the operating technology.
3. With preliminary deoxidation of metal manganese and silicon before aluminum introducing,
4. Using calcium carbide.

The final deoxidation of steel was carried out with aluminum according to two technological schemes:

- a) by the standard factory technique (without regulation of the needed time interval before calcium introduction);
- b) aluminum introduction was carried out no more than 10 minutes prior to calcium-containing materials introduction.

As a result there was regulated the quantity of the added aluminum and calcium for extra oven processing, corrected the intensity of purge with argon in continuous pouring, developed the restriction for the liquid steel stay in the ladle.

The best results for steel impurity with nonmetallic inclusions were shown by the experimental melts executed according to option 1a (without use of Al at discharging) and 3b (preliminary deoxidation of the metal before introducing Al at discharging, a short interval between introducing Al and Ca). The average impurity of the metal samples which were selected from the crystallizer made 0,0031 vol. % in option 1a and 0,0096 vol. % in option 3b that was much lower than the impurity obtained according the old technology.

Owing to the technological difficulties arising when using option 1a (restless metal, danger of modulations), it was decided to carry out a series of test melts of steel 22GYu by technology 3b. In three series there were made 25 test melts without deviations from the requirements of the working plan. On 128 continuously-cast blanks after plastic deformation there was defined steel impurity with nonmetallic inclusions. The results of the metallographic analysis showed that 95 % of the ready rolling has impurity no more than 2,0 points in accordance with GOST 1778-70 (Sh6 method). Thus, the proposed technology of secondary refining of tube steel grades provides the required level of the metal purity for nonmetallic inclusions.

CONCLUSIONS

According to the results of the work done there can be drawn the following main conclusions:

1. There was studied the evolution of nonmetallic inclusions forming in the secondary refining of the converter tube steel grades.

2. There were defined the critical parameters of the technology having the decisive effect on the metal impurity with nonmetallic inclusions.
3. There are formulated technological recommendations providing the strip impurity with nonmetallic inclusions of no more than the second point according to GOST 1778-70 (Sh6 method).

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Note: Responsible translator into English is N.M. Drak, KSTU, Karaganda, Kazakhstan