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IDENTIFICATION OF RELEVANT WORK PARAMETERS OF LADLE FURNACE WHILE MELTING THE HIGH DUCTILITY STEEL AND HIGH-CARBON STEEL

In the present paper, secondary metallurgical treatment in ladle furnace during smelting the high carbon steel and steel with improved ductility for cold-deforming, under industrial conditions were analyzed.

Common features of these steels are high requirements/strict standards imposed for their metallurgical purity; however they are especially exorbitant for improved ductility steels. In addition, it is widely used to specify alloying additives having significant weights– such as carbon and manganese - and explicitly restricted content of nitrogen requiring metal bath cover prior nitriding.

Keywords: ladle furnace, steel grade, high-carbon steels, high ductility steels

1. Steel production process conditions being subject of the research study

Production method of steel with improved ductility and high-carbon steel for cold deformation requires implementation of ladle furnace (ladle furnace, LF) in production line in almost every steelworks. This has to be a fully functional installation equipped, beside the heating system, with a device for: weighting and dispensing batch components and alloy additives, purging with gases while maintaining baths, measuring the temperature of bath, as well as for agitation of oxygen dissolved in bath and (Fe, Mn) O-oxides in the slag. Often it is required to encapsulate the ladle furnace, especially during the high-purity steel production.

Particular manufacturer of the steels being researched supplies to ladle furnace a liquid steel under standardized procedures for filling electric arc furnace with batch, standard procedures of smelting and refining, and also standard procedures of chute and deoxygenation and adding alloying additives during chute. Liquid steel delivered to ladle furnace is a metal differentiated according to temperature, phase and chemical structure– usually it is a low-carbon bath, slightly pre-deoxygenated, requiring crucial alloying additives, also in terms of the size, in order to characterized the required steel grade.

1.1. Steel grades being subjected to analysis

Steels for cold deformation, which means steels with improved ductility are used for making wire rods for screws. High-carbon steels are exploit for drawing or/and cold rolling – wire rods for wires. Examples of chemical compositions compared in Table 1 clearly show the required and at the same separate tasks that must be undertaken during production process of these grades of steels.

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TABLE 1

Example compositions of investigated steel grades

high carbon steel											
C	Mn	Si	P	S	Cr	Ni	Cu	Al całk.	N		
0.68	0.75	0.17								min.	
0.70	0.80	0.21	0.015	0.020	0.10	0.15	0.18	0.006	0.010	max.	
high ductility steel											
C	Mn	Si	P	S	Cr	Ni	Cu	Al całk.	Ti	B	N	
0.19	0.95							0.022	0.040	0.0020		min.
0.20	1.05	0.10	0.012	0.010	0.10	0.15	0.18	0.027	0.050	0.0030	0.010	max.

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Steels with increased ductility must be very carefully deoxygenated with implementation of non-metallic inclusion modification by using the alkaline earth metals. This process should precede the introduction of alloying additives with a component of high affinity for oxygen, and even more precise alloying micro-additives with high affinity for oxygen.

1.2. Implicit steel production processes

The requirement of metallurgical high-purity steel for cold deformation means satisfying the following problems:

- low or very low concentration of elements disqualifying the warp ductility, i.e., P, S, As, Cu, Sn and others,
- very low concentration of the oxygen dissolved and bounded – at the top - concentration of dissolved nitrogen,
- low or very low total oxygen concentration, which corresponds to a low content of non-metallic inclusions of very small dimensions and very good dispersion thereof,
- strong dispersion of intentionally induced precipitates generated by synthesis of micro-additives with carbon and/or nitrogen.

It could be easily indicated here that fulfilment of these requirements obliges the LF operators:

- to create - as fast as it is possible- refining, monophase synthetic slag with high sulphur capacity, to unable assimilation of removable non-metallic inclusions and reduced ability for gases transfer, and to tightly enclose the metal bath during argon purge,
- optimal execution of the sequence concerning additives: deoxidizer, carburizer, other carriers of alloying particles coordinated with optimal heating of the bath and the adequate intensity of argon purging of bath,
- modification of non-metallic inclusions of calcium or barium carriers, to such an extent as to obtain a full cover with particles of micro-additives, and to exclude the dross in the ladle process and during continuous steel casting.

The above mentioned actions could be implemented more or less successfully depending on the grade of the above listed steels. High-carbon steels will not require such forced care and insensitivity.

2. Relevant LF operating parameters during production of steels under the research study

Considerable simplification of LF procedures would have to be accompanied by standardization of the chemical composition of the molten metal which enters the process. It should be ensured that it will be provided without furnace and ladle slag after the chute process ended (slag collection); however, it should include synthetic $CaO\text{-}CaC_2\text{-}CaF_2$ slag. Shortfall of Al_2O_3 will originate from corundum inclusions of deoxidised bath. In addition alloying additives – not exposed to dross – provided during chute should essentially reduce such additives on ladle furnace, since they reduce the time of bath refining.

The current technical conditions provided by a manufacturer of these steels do not allow for such standardization. Therefore, during the period of industrial research the available ladle furnace station/unit needs to: be equipped with devices for variable bath purging with gases; performing bath temperature measurements; activity of oxygen dissolved in bath and the (Fe, Mn) O- oxides in slag measurements with appropriate active-meters.

2.1. Characteristics of the LF refining slag

Ladle furnace slag reaches the desired properties of refining in the case it is mainly constituted by components such as CaO, CaC_2, Al_2O_3 and CaF_2. Among other components – occurring in small quantities – total concentration of (Fe, Mn) O- oxides should be drastically reduced, so the % of (Fe, Mn) and O-oxides reaches the level < 1. Concentration of these oxides can be determined by using active-meter – the device available in Poland. In the beginning stage, the deoxidation process of the ladle slag by using granulated aluminium is required. Slag created in this manner should be fluid, homogeneous and monophase liquid. In case of excess liquidity, when the case slag unclenches in argon spout eye, the slag should be complemented with appropriate additive of dolomite lime. Refining property of such ladle slag can be easily assesses by decreasing sulphur concentration in well deoxygenated metal bath.

2.2. Optimal sequence for ladle metallurgy furnace additives

Melting process of steels, subject of the research study, requires substantial amount of alloying additives and carburizers with very moderate chemical affinity with oxygen. Their dissolution in the bath is a procedure endo-thermically corresponding to the weight of the additive. Effective dissolution of such additives can be accelerated by circulation caused by fairly intensive bath argon purging, which accentuates the size of a bath heat loss. These losses have to be compensated by means of arc heating, in which the power is limited by the ladle furnace transformer power. Optimal perform of this stage of the process is significant, and it is crucial to systematically heat metal bath without any super-cooling while stirring. This requires simulation calculations thanks to which it will be able to design a sequence of successive dissolution of alloying additives in a reasonable time. Introduction of additives with a high affinity for oxygen is conditioned by prior deep bath deoxidation. However, such deoxidation requires atmospheric oxygen flow cut-off – deoxidised refining slag tightly covers the surface of bath – in order to bound the vast majority of oxygen dissolved in the liquid steel by the introduced deoxidizer. Dissolution of injected deoxidizer into the bath – aluminium wire – and deoxygenation reaction are strictly exothermic processes, while the flotation of inclusions during bath moderate argon purging is a procedure with slightly endothermic nature. The efficient process of bath deoxygenation doesn't cool down the bath, so this process should be implemented in two stages, especially at the high oxidation of liquid steel after delivery to LF unit.

2.2.1 Intensity of argon purging to agitate the bath

Circular motion of the metal bath generated by the two-phase gas-metal column accelerates these processes, for which the stage of mass transport is an obstacle. The dependences which allow assessing the effect of circulation to its intensity are already known [1]. Description of LF and the process technologies contain the study [2], and the draft is shown in figure 1.

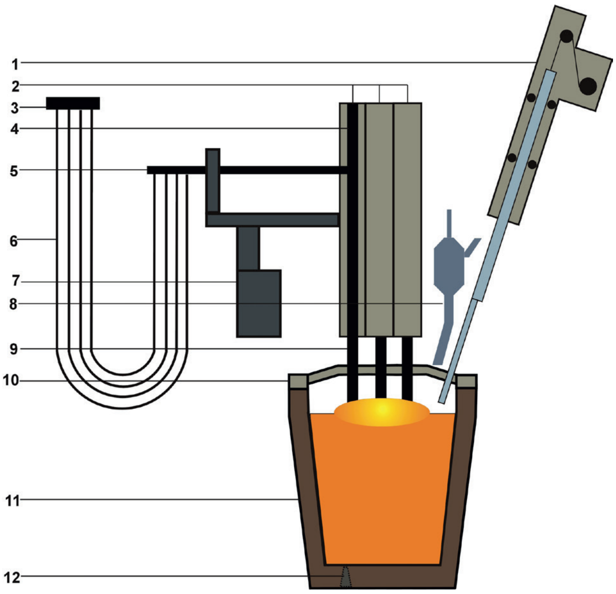

Fig. 1. Scheme of the ladle furncae (LF) station [1]. 1 – ladle, 2 – automatic temperature measuring and metal & slag sampling instrument, 3 – analyzer, 4 – LF operator's computer, 5 – Argon supply, 6 – ferroalloy reservoirs, 7 – automatic scales, 8 – charge chute

On the LF station, a series of refining procedures are carried out, after which the purified steel is chemically and thermally homogenized, adequately to the needs of the continuous casting of steel.

Closed workspace of the LF with a reduced air access, stable refractory lining of ladle, possibility of efficient bath heating, and the necessity for placing a number of particles into the metal make that the desired solution for stirring a bath is purging an inert gas into it, along with the effects implied by this action. Rational use of these effects was and still is causing the interest of contemporary science on phenomena associated with gas injection to the actual viscous liquids with high density.

Initially, the argon flow causes the bath premix, after which the temperature is measured and the sample of metal and slag is taken in order to determine their chemical composition. Besides the chemical composition and temperature, the concentration of the oxygen in the bath is monitored.

Monitoring the crucial parameters of the process allows the process operator the basis for rational utilization of the process stimuli in the time made available for him. In this context, the meaning of argon blowing into the molten metal is being revealed, and in particular the role of phenomena caused by gas injection.

2.3. Deoxidation and desulphurisation of steel baths in the LF

The process of deoxidation of the metal bath consists of two stages: oxygen scavenger chemical reaction with oxygen dissolved in the metal bath, hetero- or homogeneous nucleation phase of the resulting oxide, a volume increase of this phase up to non-metallic inclusion and the outflow of non-metallic inclusions from the bath together with their assimilation by the slag.

Reaching the state of deep bath deoxidation, indicated by measuring the concentration of oxygen being dissolved in the bath by using active oxygen injection meter, determines beginning of desulphurization of metal bath through extraction of sulphur into the refining slag. Efficiency of this process depends on the slag sulphur capacity, and its speed is conditioned on acceleration of the transport of sulphur to the border of the metal-slag breakpoint. By simulation of such process, the sulphur diffusion coefficient in the molten steel is replaced with the diffusivity of sulphur in metal.

However, bath deoxidation requires implementation of the remaining stages of the process. Nucleation of the inclusion phase ensures the energy dispersed during reaction of oxide creation, whereas increase in diffusion step or turbulent step depends on the excitation and movement of the bath caused by argon blowing. Also, removal of non-metallic inclusions by flotation occurs during the blowing bath with argon bubbles. The effectiveness of these processes is still intensely examined [3].

2.4. Modification of non-metallic inclusions and micro-additives in LF

Introduction of modifiers takes place through injecting a cored wire to the bath. Their mixing takes place during the bubble flow of argon in the bath. The modification consists mainly of non-metallic inclusions existing in the bath, most of which are corundum separations (group) or surface mounted other oxides and sulphides irregular separations of significant size. Without wetting by metal bath and as a result of deterioration in the secondary de-oxidation reaction with bath temperature decreasing, their trend to build clusters increases, which threaten the overgrowth of outflows during liquid steel flow. The modifier – element of extreme affinity for oxygen – reacts with existing inclusions changing their chemical and phase- composition until the newly formed, modified non-metallic inclusion will be molten. The efficiency of coalescing increases, as well as the flotation and assimilation of liquid non-metallic inclusions and this is the effect of the slag. Such implemented modification leads to a very efficient total deoxidation and achieving high purity steel [4].

The liquid steel state after the modifier is mixed guaranties almost lossless injection of alloying micro-additives with a very high affinity to oxygen of such element. Usually the introduction of an alkaline earth element as a modifier after deoxidation of melt covered with refining slag guarantees safe behaviour of "micro-additional" element to the end of continuous steel casting [5].

3. Summary

The research study carries out short analysis of required process conditions occurring in ladle furnace during increased ductility and high-carbon steel production intended for cold deformation. There were listed important industrial ladle furnace operation parameters during smelting the referred steel grades, indicating the potential range of changes in the modernization of smelting technology.

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