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LOW CARBON STEEL MANUFACTURE IN EAF STEELMAKING SHOP

WYTWARZANIE STALI NISKOWĘGLOWYCH W STALOWNIACH ELEKTRYCZNYCH

Developed technology of low carbon steel grade manufacture foresees to use of potential of vacuum-oxygen decarbonization reaction without any additional oxygen enter (as gaseous as oxides) at ladle treatment. The guaranteed carbon content was lower than 0.01%. This as well as low amount of admixtures and alloying elements in steel provides high plastic properties of manufactured rod wire.
Keywords: EAF; semi product; low carbon steel; vacuum-oxygen decarbonization; thermodynamics; industrial experiments

Opracowane technologie wytwarzania nisko węglowych stali stwarzają możliwość zastosowania próżniowego odwęglania bez dodatkowego wprowadzania tlenu (w postaci gazowej lub tlenkowe). W uzyskanych w ten sposób stalach zawartość węgla jest niższa od wymaganej 0,01%. Zaobserwowano, że im mniejsza zawartość domieszek oraz dodatków stopowych w stali, tym lepsze właściwości plastyczne wytwarzanych prętów.

1. Introduction

Technology of low carbon steel rod wire manufacture was developed on the basis of thermodynamics calculations and industrial experiments (EAF-VD-LF) and extensive researches of metal quality (mechanical properties, amount and morphology of the non-metal inclusion).

Main technological complication of such metal manufacture is receive of low (less than 0.03 %) carbon content at output from EAF and in condition of ladle treatment with magnesia-carbon lining. Second problem is providing of dense structure of wire is made from metal with low content of silicon and manganese (less than 0.02 % and 0.12%, accordingly) and strong limited expense of aluminium (for the exception of clogging at pouring).

Developed technological process of low carbon steel manufacture includes: semi product melting in EAF from a scrap with part of cast-iron (or DRI etc for minimum content of Cr, Ni, Cu); partial deoxidation in ladle at steel output; metal decarbonization at vacuum treatment; final deoxidation and alloying of metal on ladle-furnace unit; continuous casting of steel with complete stream protection from the secondary oxidization.

2. Melting of low carbon semi product in EAF

The used EAF is a modern high-performance unit working with melting process intensification by blowing of oxygen, coke and natural gas through a few types of burning and tuyeres [1]. Oxygen blown in EAF is usually used for: controlled decarbonization; CO combustion in EAF working space; heating and scission of metal schicht by fuel burner usage; slag foaming due to CO bubbles generation [2]. After schicht melting, at high carbon content in melt, practically all oxygen goes to bath decarbonization, but on the last stages of oxidizing refining (<0.1%Ń) there is primary oxidation of iron. In low carbon (0.02-0.03%) melt the oxygen amount up to 90% will be expended on FeO formation, which high content in a slag results to reduce of lining service life.

For EAF semi product is proper for low carbon steel manufacture it was necessary to explore equipment possibility in purposes to produce minimal and to ground

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permissible maximal limit of carbon content it steel at output. The series of low carbon steel melts were made to that end. In spite of plenty of the carbonaceous materials blown in EAF for metal heating on all heats the low enough eventual carbon content (0.03-0.096%) as well as the high active oxygen content (1118-1799 ppm) and temperature (1653 – 1741 ˚C) were got.

The ratio of oxygen was expected to admixtures oxidization (difference between the common oxygen amount and stoichiometric one for coke and methane burning) was calculated (Fig. 1).

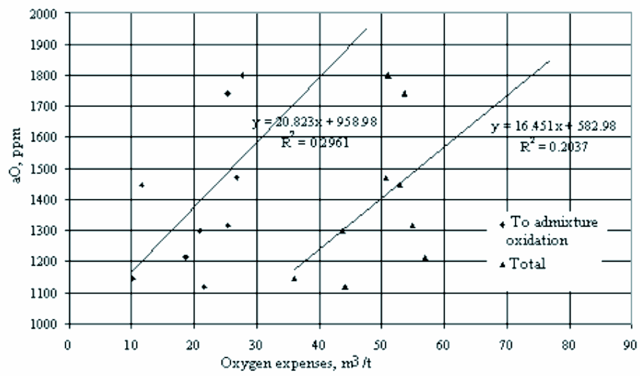

Fig. 1. The active oxygen content in metal in dependence from oxygen expense (common amount and its share for steel admixtures oxidation)

This shows the real possibility of active oxygen content (a_O) control in EAF semi product at output from EAF. Receipt of ever-higher a_O it is undesirable from point of iron losses, and also because of decline of lining firmness. However, it is necessary to take into account both initial carbon content in semi product and it further arrival.

Thus, for low carbon semi product receipt the a_O must provide the carbon remove from metal at vacuuming treatment to such values, that the further receipt (from electrodes at heating in LF, ladle lining and ferroalloys) will not exceed over of purpose carbon amount in steel. To this end the calculation of minimum necessary active oxygen amount for the receipt of carbon content in steel 0.005% at its various initial content (Fig. 2).

Comparison of necessary values of $a_O$upon calculation (80-1000 ppm) with its actual range in semi product at the output from EAF (458 – 1997 ppm, average - 1015 ppm on results the statistical analysis of commercial heats) shows that first one is sufficient, and sometimes, even surplus (from point decarbonization at further vacuum treatment). The calculation shows that amounts of active oxygen at metal output from EAF are enough for oxidation of initial carbon and its further receipt.

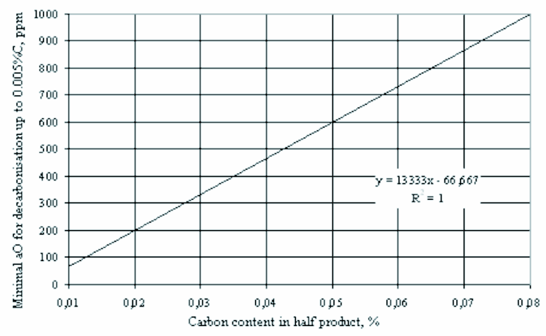

Fig. 2. Necessary level of active oxygen content in semi product for steel decarbonization to 0.005%

As is will be shown below, at following ladle treatment (VD and LF) of got semi product eventual carbon content in ready metal less than 0.01% was achieved even at initial carbon content up to 0.06 % and aO in EAF higher then 1100 ppm.

3. The vacuum treatment of semi product for low carbon steel manufacture

The calculation for ground of possible carbon content reduce at vacuum treatment and the experiments upon receipt of low carbon steel by the vacuum-oxygen decarbonization of initial semi product (without oxygen blowing at vacuum treatment).

Took into account that the temperature of outputted from EAF metal is substantially higher, then 1600°C, for which most literary sources gives the basic thermodynamics parameters of steel decarbonization reaction [3,4]. Therefore the equilibrium oxygen amount in a metal at 0.002-0.016% of carbon for the temperatures range of 1550-1750 ˚Ń was calculated (fig. 3).

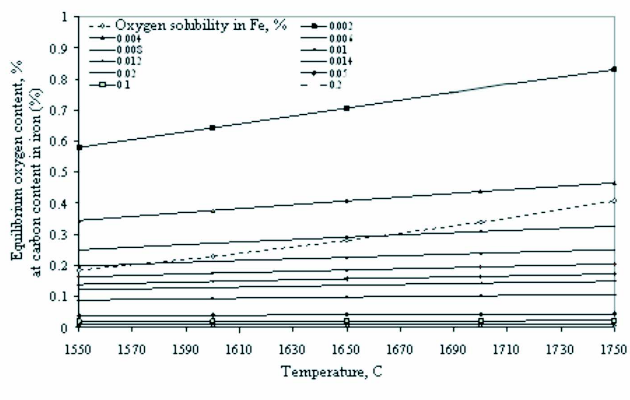

Fig. 3. Equilibrium oxygen content at various temperature and carbon content in a metal

At normal pressure the deoxidation ability of carbon at concentration higher then 0.08% exceeds such one for the manganese, but some below than for silicon (in those concentrations). The decompressing strengthens of deoxidation ability of carbon, thus temperature made substantial influence also. Temperature growth moves the equilibrium of the vacuum- decarbonization reaction. Therefore at identical elements content from temperatures 1600^{o}Ń and pressure below 100 mbar the carbon deoxidation ability becomes higher than ones of manganese and of silicon.

For target chemical composition (C – 0.01%, Mn – 0.12%, Si –0.02%) of steel and actual pressure in a vacuuming chamber to 100 mbar the equilibrium concentration of oxygen is also enough for predominating oxidization of carbon comparing to a manganese and silicon in all considered temperatures range.

In experimental heats the metal was partly deoxidized by aluminium addition in ladle during tapping from EAF before vacuum treatment. After that the metal was blowed by argon. At the same time the sampling was made as well as temperature and a_O was measured. During vacuum treatment of experimental heats any additives in ladle was not made. At decompressing and during all periods of treatment the melt was intensive "boils" that is explained by the running of reaction of vacuum-oxygen decarbonization of metal. The pressure at "deep vacuum" mode made 2-2.5 μbar. At further exposition of metal under a vacuum the process of decarbonization gradually slowed or even halted, that testifies to absence of one of elements – participants of reaction CO + ½ O_2 =CO. In our conditions the content of carbon is the limiting chain of this reaction besides its exact determination at low concentrations (less than 0.01%) is quite difficult, the changes of active oxygen was fixed. Calculated amount of CO extracted at vacuuming treatment made on the experimental heats from 36 to 86 m^3 that substantially exceeds the volume of argon blown on a metal stirring. Thus, the gas-metal interaction surface is considerably more developed at vacuum treatment of metal deoxidated partly only, that is pre-condition of quite full removal of admixture gases (nitrogen and hydrogen).

4. Ladle treatment of low carbon steel

At low carbon steels manufacture the one of the main tasks of treatment in LF device along with the carbon removal is metal desulphurization to the necessary level. The successful running of desulphurization process is provided by the fast formation of refining slag with optimum chemical compound. It is generally known the metal desulphurization under basic slags is arrived at oxygen content in a metal no more than 100 ppm and FeO content in a slag less 0.5%. Therefore, for determining of the terms providing intensive desulphurization of metal, on the experimental heats active oxygen content was controlled during ladle treatment.

Besides, deoxidation technology foresees the limited use of aluminium to avoid the clogging at pouring. High plasticity metal has not only low content of carbon (less than 0.01%) but also limitation in silicium (less than 0.02%). Naturally, low concentration of basic deoxidation agents claims promoted attention to oxygen content in steel. For final deoxidation of experimental heats the ferroalloys of calcium (SiCa and FeCa) were used because calcium possesses high affinity both to oxygen and to sulphur. Consequently, minimization of calcium ferroalloys consumption is possible at low amounts of active oxygen and sulphur in steel only.

It was taken into consideration for development of deoxidation techniques that at low silicium amount in a metal (less than 0.01%) its deoxidation ability [3] will be realized at active oxygen content more than 295 ppm only (Fig. 4).

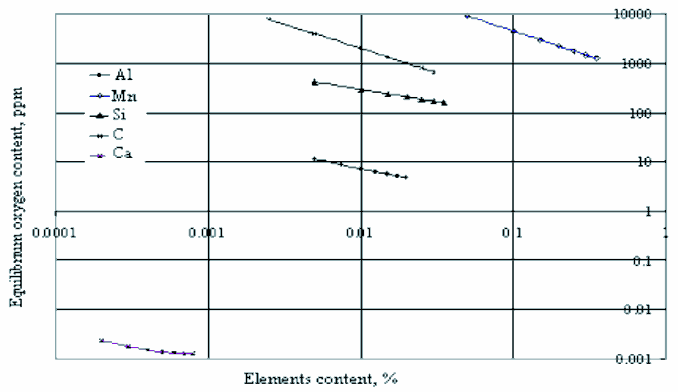

Fig. 4. Equilibrium concentration of oxygen at deoxidators concentrations inherent to low carbon steel grade

At the initial oxygen concentration less than 295 ppm the silicium is practically inactive and more strong deoxidators are needed (Al, Ca). Application of aluminium provides at content of dissolved part 0.005% the active oxygen content at the level of 11 ppm. The least equilibrium concentration of oxygen (less than 1 ppm) can be provided by application of calcium at dissolved calcium content in a metal in the interval 2-10 ppm. Fig. 5 shows the example of oxygen balance with the actual chronology of deoxidation agents' additions into a ladle.

It is shown that all pre-conditions for the successful desulphurization of steel was already achieved to the tenth minute of treatment. The pointed slag possesses high refining ability that gives sulphur content after LF less than 160 ppm at initial 56 ppm.

All heats were poured through magnesium lining tundish with channels diameter – 16.5 mm with complete protection of metal streams from the secondary oxidization. All got bar were rolled on rod wire by a diameter 5.5 mm.

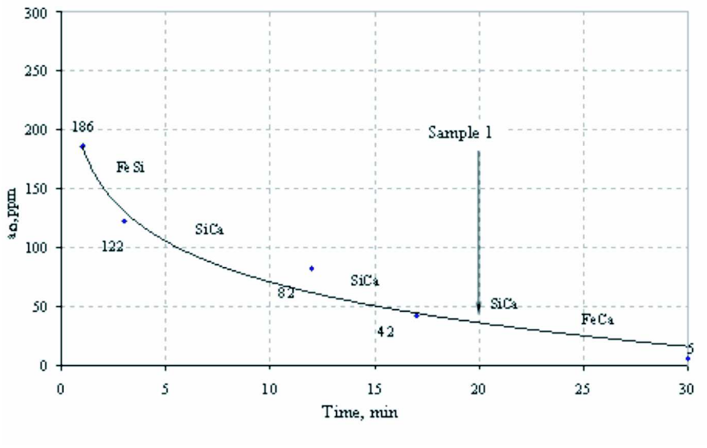

Fig. 5. a_O changes during ladle treatment of experimental heat

5. Experimental bar and rod wire structure and mechanical properties

The extensive researches of bar and rod wire structure and mechanical properties were executed. Microstructure of transversal sections of all explored rod wire samples by a diameter 5,5 mm from low carbon steel consists of practically clean ferrite with sections of tertiary cementite like evenly distributed fragments of net on grain boundaries (no more than a 1/6 perimeter of ferrite grains), separate point and small globular rashes. Size of actual grain and non-metal inclusion content conforms to requirements of low carbon produced unalloyed steels.

The axial liquation in all explored sections of rod wire of the experimental heats corresponded to the first class of standard row on EN 10016-1-1994. Determination of non-metal inclusion was made on ASTM E45 is shown that on non-metal inclusion content the low carbon steel fully satisfies to the standards requirements (to Ń4D grade). Metal micro hardness on the experimental heats made 93-109 units HV500. Mechanical properties of the received product: Rm – 320-354 MPa, Rp0.2 – 198-245MPa, Z – 84-85%, A5 – 42-44% and A10 – 33-36,%.

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Comparison of mechanical properties of the received metal with a known diagram of tensile strength – average lengthening for steel sheets in which production the low carbon compound most often used shows that they correspond to the level inherent of high-plastic IF-steels both on the received chemical compound an on properties. A structure and properties of the got metal provide drawability of rod wire to thin wires without the intermediate annealing, that considerably reduces processing costs. Application of such high-plastic rod wire allows us substantially to reduce the level of breakage during drawing.

6. Conclusion

The EAF semi product parameters (are suitable for low carbon steel manufacture with further vacuum treatment without the input of oxygen in any kind) are theoretically grounded and experimentally checked.

The optimum range of oxygen activity in a metal at output from EAF was determined. This value is most important because it provides the target content of carbon.

The achieved carbon content in ready metal makes 0.01%, that at low content of manganese (till 0.12%) and silicon (till 0.02%) provides a favorable microstructure and high plastic properties of produced rod wire.

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