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Actual Technology of Steel Out-of-Furnace Treatment by Flux Cored Wire

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The issues of steel out-of-furnace treatment by flux cored wire with various fillers are considered at the present stage. Application of wires filled with analogues SK30 and SK40 (granular calcium + ferrosilicon) leads to considerable cost saving in the process of steel out-of-furnace treatment by calcium-containing wires. In addition, calcium recovery from a new wire type is more stable.

Keywords: STEEL, METAL PRODUCTS, OUT-OF-FURNACE TREATMENT, FLUX CORED WIRE, GRANULAR CALCIUM, SILICOCALCIUM, FERROSILICON, RECOVERY

Introduction

The world demand for products of iron & steel plants has dropped considerably and steelmaking has reduced for the last year in many industrially developed countries of the world because of the crisis. At this conjuncture, application of flux cored wire in the process of metal out-of-furnace treatment is rather important factor of competitive growth of made products, solving of the problem related to product expansion and maintenance of required quality of metal without considerable investment costs for Ukrainian iron & steel plants.

Application of flux cored wire with various fillers becomes the basic processing tool for steelmaking with minimum expenditures on ladle-furnace. The total technological level is rising due to possibility to control steelmaking process. 6-7 typrs of wire have been already used at several plants.

Results and Discussion

The new method of out-of-furnace treatment expands possibilities of complex technology. It allows utilizing such highly active reagents as calcium and complex modifying agent with rare-earth metals. Earlier, application of these reagents was extremely restricted because of low unstable recovery, which complicated reproduction of results.

Despite the wide development of out-of-furnace steel treatment by flux cored wire, there are a number of unresolved problems, significant differences in conditions of the same wire addition at the various iron & steel plants are observed (calcium recovery in different departments even within one metallurgical plant can differ in 1.5-2.0 times). At the same time, some special fine steelmaking processes can not be implemented without out-of-furnace treatment by flux cored wire with various fillers and their regulated feeding in the required ladled amount. Thus, addition of flux cored wire should be combined with all measures accomplished during out-of-furnace steel treatment in order to reach forecasted and reproduced results.

Therefore one of primary problems is still advancement of out-of-furnace steel treatment technique by flux cored wire, including melt preparation (molten steel should be prepared for inoculation and microalloying processes as much as possible, i.e. have a certain level of oxidation, purity in relation to nonmetallic inclusions, gases, temperature). Wire type and filler composition are selected depending on the purposes of treatment and required quality indicators and operating characteristics of finished product.

One of the major issues in using flux cored wires is selection and preparation of material, precise definition of basic element content in ferroalloy. When using flux cored wires filled with ferrotitanium 70 %, titanium recovery varied from 60 to 97 %. Further, it was found out that despite the total Ti content in ferroalloy more than 70 %, more than 10 % Ti was in the form of oxides and nitrides, which also led to pollution of steel and deterioration of metal products quality [1]. Therefore, it is necessary to consider both basic element content and content of N, O, Fe in requirements to material FeTi70. The similar situation was observed when using a wire with silicocalcium SK30. Under otherwise equal conditions, calcium recovery from one material was 2-3 times lower than in material by other manufacturers, despite the total Ca content in material more than 30 %. This points to the fact that significant amount of calcium in this material is in the form of oxides, which confirms necessity of careful control of materials and cooperation with reliable ferroalloy producers.

In current steelmaking practice, out-of-furnace treatment by calcium-containing flux cored wire is at the top position due to multivariable effect of calcium on physic-chemical condition of the melt, macro- and microstructure of billet, quality and properties of metal products and is an integral part of technology [2].

Wire filled with silicocalcium is the most widespread. At present, SK30 silicocalcium is the most widely used alloy for addition of calcium into steel in the world metallurgical practice. It is caused by following: such ratio of components in alloy (30 % Ca and 60 % Si) ensures an optimum combination of thermal-physical parameters affecting calcium recovery. It is necessary to mention that expenditures sharply grow and it becomes difficult to separate ferroalloy from slag when producing silicocalcium with Ca content more than 30 % , therefore all the world producers make only SK30 silicocalcium [1]. There is no such silicocalcium grade in State Standards and this material is not produced but obtained by mechanical merging of silicocalcium and metal calcium powders. Alloy is formed in the process of wire addition and necessary content of calcium is reached in ferroalloy when processing the liquid iron-carbon melt. Such wire is used at many plants (**Table 1**).

High efficiency of using SK40 is caused by the fact that alloy with Ca 40 % is formed in the process of flux cored wire addition into molten metal. A number of processes of interaction between Ca, free Si and their compounds (heating, dissolution, evaporation, dissociation, phase transformation, etc.) take place both inside of wire and in local place of filler interaction with the melt, which reduces temperature in reaction zone. The new type of wire filled with SK40 differs by increased content of Ca in running meter

Table 1. Technological parameters of using flux cored wire filled with SK40

No.	Plant	Wire diameter, mm	Inoculation equivalent coefficient according to test results	Increase of calcium recovery, % rel.
1	OJSC “Yenakiyevskiy Iron & Steel Works”	13	0.70	46.5
2	OJSC “Alchevsk Iron & Steel Works”	13	0.62	15.4
3	JSC “Donetsk Electrometallurgical Plant”	13	0.70	27.0
4	Production Association “Byelorussian Steel Works”			
	electric furnace shop-1	13	0.60	22.0
	electric furnace shop-2	14	0.55	35.0
5	JSC “Ural Steel”			
	ladle-furnace - 1a	15	0.62	19.7
	ladle-furnace - 2		0.60	23.7
6	JSCC “Moldova Steel Works”	13	0.75	10.0
7	JSC “Oskol Electrometallurgical Plant”	15	0.70	14.0
8	CJSC “Donetskstal Iron & Steel Works”	13	0.64	20.3
9	JSC “Taganrog Iron & Steel Plant”	13	0.70	–
10	JSC “Iron & Steel Integrated Works ”Azovstal”	13A	0.667	14.9

of wire and higher recovery of Ca by 15-30 % in comparison with silicocalcium SK30. That is why consumption of wire with SK40 is 1.4-1.6 times less than with SK30 in order to reach the target content of Ca in metal.

A set of conditions should be accomplished in order to reach such results [1], in particular – utilization of silicocalcium SK30 as charge component (with minimum amount of CaO and maximum Si free). As mentioned earlier, in silicocalcium SK30 at total content of Ca 30 %, some part of it can be in the form of oxides, which can be determined only by special phase analysis in specialized institutes. It leads to unstable recovery of Ca at out-of-furnace metal treatment by flux cored wire with filling SK30 and SK40. The authors have worked out new compositions of flux cored wires, analogues SK30 and SK40 filled with ferrosilicon and metal calcium to eliminate this factor, optimize calcium recovery and cost reduction while out-of-furnace treatment [3].

Ca-Si structural diagram is presented in **Figure 1**. It is obvious that alloy formed after addition of flux cored wire with FeSi65 and calcium metal (40 %) in molten metal has a melting temperature by 150 °C above than SK30. When producing such wire on a special line, stability of chemical composition of complex filler along the length of wire and also optimum conditions of dissolution and physic-chemical interaction of filler components are ensured. Comparative tests carried out at iron & steel plants ("Dneprospetsstal", “Oskol Electrometallurgical Plant”, “Byelorussian Steel Works”, “TAGMET”, etc.) confirmed high performance of new types of wire, and calcium recovery from new wire was more stable.

For steels with low content of silicon it is reasonable to use flux cored wire with A1Ca or FeCa. Application of aluminum-calcium wire allows combining processes of inoculation, microalloying and adjusting of Al content. The feature of such filler makeup is the low melting temperature of each component. The ratio of components is very important. In our opinion, the ratio between Ca and Al 40:60 mass % seems to be optimal unlike the ratio 60:40 % presented in work [5].

According to Ca-Al structural diagram, strong chemical compound $SaAl_2$ is formed, and as a result activity and pressure of Ca steams decrease and its evaporation temperature rises. The local increase of Al content in molten steel accelerates Ca dissolution, and Ca recovery increases.

Interesting results of aluminum-calcium wire application are summarized in work [6]. Aluminum-calcium flux cored wire was added into

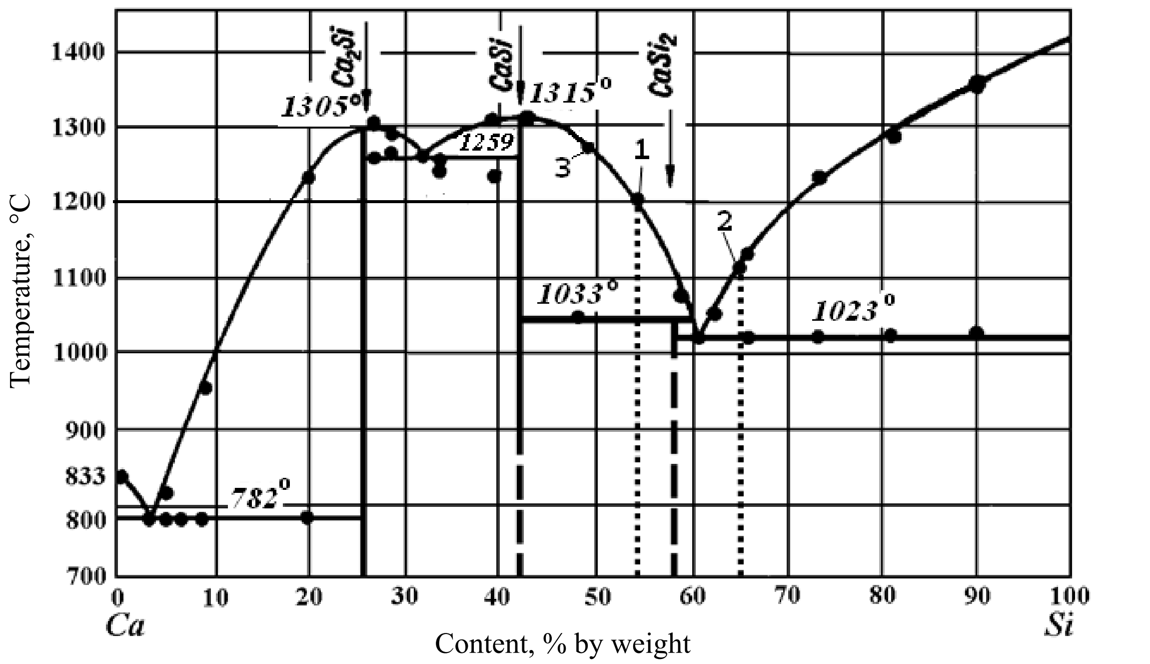

Figure 1. Structural diagram of Ca-Si: *1* - corresponds to mass ratio between Ca and Si in silicocalcium SK40 (SK30+calcium metal); *2* - corresponds to mass ratio between Ca and Si in silicocalcium SK30; *3* - corresponds to mass ratio between Ca and Si in SK40k (40 % calcium metal and 60 % FeSi65)

molten metal on ladle-furnace at the initial stage of treatment in order to study possibility of metal internal structure control and to provide necessary conditions of development of higher quality indicators of final metal products. Secondary aluminum was not used for intermediate product deoxidation when tapping from a steelmaking plant, and silicocalcium wire treatment was accomplished as usually at the final stage of treatment. Analysis of technological results showed that utilization of AlCa wire allowed lowering oxidation of metal and slag, which in turn predetermined reduced consumption of aluminum flux for slag deoxidation, increase in speed and extent of sulfur removal of metal, increase of Al and Ca recovery (from SiCa wire). According to authors [6], metallographic research showed that addition of oxidating-modifying AlCa rich alloy in metal at the early stage of treatment allows changing metal internal structure. But these results need further confirmation.

The new type of wire developed by authors and filled with metal (grained) calcium in thickened coating (0.6-0.7 mm) is of interest [7]. Commercial tests of this wire with diameter 13 mm in comparison with FeCa filled wire with similar Ca content revealed the following. Addition of new wire in melt is easier and featured by smaller gas evolution. It is confirmed by higher recovery of calcium 10-15 %.

Utilization of complex fillers (for example, containing mechanical mixture of metal calcium and high-basic molten refining mixture) allowing simultaneous microalloying, inoculation and metal refining, including removal of nonmetallic inclusions is an upcoming trend for all groups of steel grades.

Barium grain-refined steel has been of interest for last years. Out-of-furnace treatment of rail and wheel steel by flux cored wire filled with ferrosilicobarium was investigated at several plants. It is mentioned in work [8] that change of steel structure at Ba and Ca inoculation leads to change of microstructure and properties of metal during crystallization, which can be inherited after thermal strengthening. Addition of Ba in rail steel enhances plastic properties of metallic matrix and leads to more favorable kind of nonmetallic inclusions, which promotes increased durability of rails.

Strengthening of requirements to metal quality forces to advance calcium-containing (bearing) material treatment technology. When calcium is added to melt, appearance of deleterious inclusions is probable - solid aluminates of calcium and calcium sulfides along with high efficiency of its effect on metal properties. So, recent research [9] showed that the presence of such inclusions in tube steel impairs corrosion resistance of tubes and reduces their service. These corrosion-active nonmetallic inclusions are source of ballooning and pitting.

Investigation of emergency tube quality shows that mass fraction of chemical elements and mechanical characteristics completely correspond to specifications. The specified defects are revealed at corrosion testing and are considered as rejected sign. It is obvious that deleterious inclusions in such steels are inadmissible. This problem is solved when using complex modifying agents including calcium and rare-earth metals.

At present, steelmaking practice with raised demands to workability (with regulated content of sulfur) seems to be impossible without using calcium and sulfur-containing flux cored wires. Such steelmaking practice, as usually, provides initial sulfur removal from molten steel up to the content of sulfur 0.015-0.020 %, then calcium-containing wire treatment in two stages (the first for refining, the second for inoculation) and after that sulfur alloying of metal up to the target content. This practice ensures complete inoculation and globularization of nonmetallic inclusions prior to sulfur alloying of metal, which leads to considerable decrease of metal impurity by nonmetallic inclusions, reduction of surface defects amount, reduction of reject more than twice. Sulfur recovery is 75-85 %.

Niobium and vanadium out-of-furnace alloying of steel despite the high recovery of these elements from ferroalloys (85-93 %) is widely used. Recovery of basic elements is almost 100 % in flux cored wire. Economic efficiency is achieved at the expense of the specified content of elements and lowering of material consumption rates.

One of primary areas of current metallurgy is steel microalloying by chemically active elements affecting the formation of steel structure enhancing useful qualities. B is widely applied along with V, Nb, Ti, Mo in microalloying practice. And B content for various steel grades and purposes should be regulated strictly. This practice has been already used for a long time, for example, at Moldova and Byelorussian Steel Works, conditions of metal microalloying with boron with its residual content 0.001-0.008 % were developed on steels of different grades with various content of Mn, Si and C within 0.04 - 0.45 %. Positive effect of boron on physicmechanical and operating properties of rolled metal and rolled wire was proved. Stably high recovery of boron within 75.3-94.3 % depending on steel oxidation (α_o = 3-10 ppm) was gained.

Conclusions

Effect of new technology on metal quality, cost reduction at steelmaking and competitive growth of metal products when using flux cored wire has been proved at iron & steel plants by now. The flux cored wire has no restrictions regarding composition of fillers, and this is a great potential for this technology and its perspective.

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Современная технология внепечной обработки стали порошковой проволокой

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Рассмотрены вопросы внепечной обработки стали порошковыми проволоками с различными наполнителями на современном этапе. Показано, что использование проволок с наполнением аналогами СК30 и СК40 (кальций гранулированный + ферросилиций) приводит к значительному снижению затрат при внепечной обработке стали кальцийсодержащими проволоками, при этом усвоение кальция из нового вида проволоки носит более стабильный характер.