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Innovatory Technology of Direct Steel Alloying and Ways of its Development

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ABSTRACT. The technology of direct alloying of steel envisages aluminium reduction of the alloying element from aluminothermic special briquettes, making use of the liquid steel heat. In order to diminish the anticipatory oxidation of reduced aluminium and vain melting loss the introduction of the more active reducing component than aluminium, i.e. of free carbon-forming organic compound – molasses – into a briquette is proposed. A mathematical model of the process of heat transfer from liquid steel to briquette has been developed and the optimization of technological parameters and the automation control system is presented. *© 2011 Bull. Georg. Natl. Acad. Sci.*

Key words: *steel, briquette of direct alloying, mathematical model, control system.*

1. Introduction. The production of high-quality steel is impossible without using special ferroalloys and multicomponent alloying compositions. For the moment the process of steel treatment by ferroalloys and alloying compositions takes place while tapping the liquid steel into receiving ladles. The mentioned process is related to the technological processes of out-of-furnace oxidation and alloying of liquid steel.

The out-of-furnace oxidation and alloying of liquid steel require the use of high-quality (low-phosphoric) ferroalloys and alloying compositions, which for their part call for necessary employment of high-quality concentrates in the process of production of the latter. And this leads to the cost rise of oxidative and alloying additions, to the non-rational use of natural resources and to the rise of cost price of products. When using such an active oxidative-alloying ore substitute as manganese, the problem becomes more involved due to the superfractionation of concentrate(0-5 mm) because it is impossible to employ it with useful effect in the production of ferroalloys and alloying compositions without their amalgamation (briquetting or agglomeration), which has a negative effect on the cost price of the final product. The mentioned problem is particularly urgent in Georgia because the high-quality oxide-type concentrates of Chiatura ore deposit are on the whole finely dispersed.

The analysis of the ways capable of solving this problem shows that in practice the innovatory and highly effective way consists in the so-called making of alluminothermic special briquettes for direct alloying of steel; the essence of the matter is related to the initiation of exothermal chemical reaction of manganese reduction in briquettes, making use of the heat of liquid steel. In such a case the process of receipt and dissolution of metallic manganese from manganese oxides (or carbonates) takes place directly in steel receiving ladles, i.e. simultaneous oxidation, desulphuration and alloying of liquid steel go without expensive ferroalloys or alloying compositions (Fig. 1). Such a process of steel treatment is known as direct alloying [1].

As shown in Fig.2, in the case of direct alloying the useful use of manganese or the index of transition in the

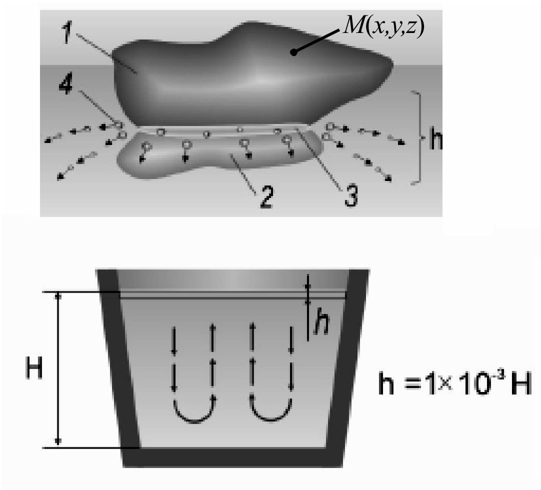

Fig. 1. Schematic pattern of the process of out-of-furnace direct alloying of steel.
1 – oxidic phase of reducing alloying element; 2 – reducer (aluminium); 3 – zone of exothermal reaction in the briquette; 4 – drops of reduced metallic element; *h* – zone of reduction and deposition of alloying element from briquettes to ladles; *H* – filling level of ladle by treating liquid steel.

liquid steel compared to ferroalloys is by 20% higher, it rises from 75 to 95%. As regards the passage of phosphorus, it is identical in both cases. Thus, under conditions of direct alloying a bounded composition of phosphorus in steel is ensured by increased quantity of manganese even in case of assimilation. This makes it possible to use comparatively poor carbonate ores, whereas the use of ferroalloy received from the same carbonate ore for the out-of-furnace alloying of steel is relatively low-efficient from the point of view of the quality as well as from the economic point of view.

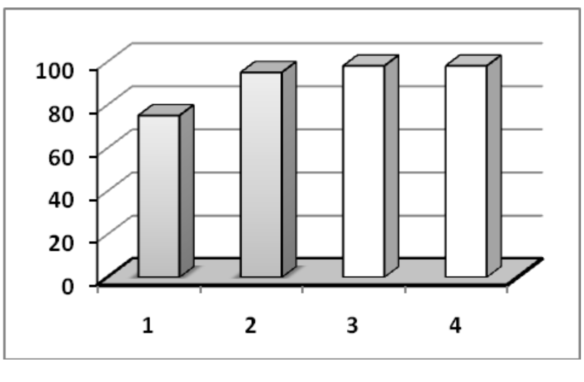

Fig. 2. Balance of phosphorus and manganese in steel in the case of direct alloying and alloying by ferroalloys.
1 – passage of manganese to steel while alloying by feroalloys (75%); 2 – passage of manganese to steel in the case of direct alloying (95%); 3,4 – passage of phosphorus to steel (98%).

In our case a full removal (dehydration) of manganese concentrate or hydroscopic water of ore (0.5%H_2O), the dissociation of oxides and carbonates and the reaction of reduction-oxidation take place on the aluminothermal briquette of manganese concentrate as a result of thermal effect of newly discharged liquid steel, namely:

dehydration:

$$MnOOH \times H_2O \xrightarrow{(60\text{–}150)^\circ C} MnOOH \xrightarrow{(150\text{–}600)^\circ C}$$

$$Mn_2O_3 \xrightarrow{(920\text{–}1060)^\circ C} Mn_3O_4$$

decarburization:

$$3MnCO_3 \xrightarrow{(400\text{–}600)^\circ C} Mn_3O_4 + O + CO_2 \xrightarrow{(1100\text{–}1250)^\circ C} MnO$$

manganese oxide reducton:

oxidation of reducer:

$$2[Al]+3[O]=Al_2O_3$$

formation of eutectic:

$$(Al_2O_3)+3(MnO)=3(MnO \cdot Al_2O_3)$$

manganese reduction:

$$3(MnO \cdot Al_2O_3)+2[Al]=3[Mn]+2(Al_2O_3)$$

Production approbation of the technology of direct alloying has been conducted in converting and electric-furnace (melting) shops in the largest metallurgical enterprises of the Commonwealth of Independent States [2-4].

The brands of carbon, low-alloyed and alloyed steel with the content of manganese from 0.5% to 12% have been melted. The same results have been obtained when alloying by other elements (chrome, vanadium, nickel, molybdenum etc.).

From the above-mentioned considerations the advantages of steel direct alloying may be stated as follows:

1. The exclusion of the necessity of producing ferroalloys from finely dispersed high-quality concentrates results in the economy of power and natural resources on the one hand, and in considerable decrease of harmful impact on the environment, on the other.

2. In direct alloying of steel the use of manganese concentrate or aluminothermal briquette as a primary material reduces the cost price of the ready-made product, because using this technique the total cost of manganese passing into steel is always lower than the cost of equivalent manganese passing from ferroalloy.

3. The technology of direct alloying of steel may be implemented in any steel-making plant without substantial reconstruction of the existing equipment.

Analysis of shortcomings of the technology of direct alloying. Along with the above-mentioned advantages, it should be noted that the practice of employment of briquettes for direct alloying has shortcomings that consist in the following: the reducer and the reducing material pass into the active state not simultaneously but the former anticipates the latter (clearly aluminum is the first to melt), thus, the reducer may suffer unforeseen losses. The first of the above-mentioned chemical reactions – that of aluminum oxidation – is an indication of this.

The experience of many investigators shows that under production conditions, while melting different alloys, the main factor hindering stable highly effective realization of the technology of direct alloying consists in the stochastic process – great difference in the output parameters of various meltings, namely: instability of the initial temperature of steel, variability of ladles' filling level, instability of physical and chemical indices accompanying slag, etc. Accordingly, it is necessary to have an individual approach to each melting, the latter requires to make use of individual choice of technological parameters participating in the process of direct alloying and this for its part calls for the synthesis of the diagnostics process and automation-control system.

Sometimes one of the main shortcomings consists in a great difference between the density of briquettes (2700-3500kg/m^3) and the density of liquid alloy (6500-7000kg/m^3). This problem becomes particularly urgent when it is necessary to alloy steel by such refractory elements as vanadium, niobium, tungsten. In such a case the quantity of heat liberated from briquettes by metallothermal reducing reactions lags behind the convective heat transfer from ferriferrous slag layers to surface medium (i.e. heat balance is disturbed). This calls for the use of additional production operations (e.g. mixing, surface heating). The rational way of solving the problem consists in prediction and control of functional parameters, making more urgent the problem of development of the analytical prediction and automation-control system of the process.

Ways of development of the technology of direct alloying. Systems analysis of the ways of eradication of shortcomings has revealed the following:

1. To diminish the oxidation of reducing aluminium and related losses, we must introduce into the briquette for direct alloying, together with aluminium, another more active, but for the initial conditions of thermal effect on the briquette, passivated carbon-forming reducer. In such a case during the period of bringing the briquette to the reheat and softening temperature, actually up to the melting point of aluminium (660±20°C), the passivated carbonforming component additionally introduced into the briquette, e.g. – the interaction of free carbon and hydrogen, liberated in consequence of dissociation of organic waste of sugar-making (molasses), with oxygen forms carbonic acid and steam, thereby the oxidation of aluminium is excluded and it stays in its initial free metallic condition, i.e. the first two of the three stages of manganese oxide reduction to manganese are excluded. Thus, there is a real possibility to raise the process efficacy.

Furthermore, due to gas evolved in the liquid bath, namely – in the slag-metallic separating layer, in consequence of the initiation of boiling effect, even distribution of the alloying element liberated from the briquette in the whole volume of treated alloy becomes possible. This is a positive factor for raising the efficiency of the process of direct alloying.

2. The second way to improve the technology of direct alloying of steel consists in effective diagnostics of the process and complex automation.

The main criteria of diagnostics of the process of direct alloying of steel is heat transfer from the liquid steel to the briquette. To this end a mathematical model (1) has been developed describing the change of temperature gradient in the volume of the briquette with such approximation that an averaged spheroidal radius R(mm) is taken for the geometric parameter of the segment briquette. The initial temperature in the briquette volume is taken to be uniform and equal to the ambient temperature. But after thermic action the temperature in the layers $M(x,y,z)$ of the (Fig.1) briquette is a function of the time t (sec) passed from the moment of the briquette installation into liquid steel and of its initial dimensions, i.e. of the average radius R(mm).

In the mathematical model u is the temperature at point $M(x,y,z)$ of the briquette at a given moment of time t, u_0 - the initial temperature of liquid steel; a - heat conduction of briquette dependng upon materials' properties and varieties used for direct alloying; and r – variable of the briquette average radius.

$$\begin{cases} \dfrac{\partial u}{\partial t} = a^2\left(\dfrac{\partial^2 u}{\partial r^2} + \dfrac{1}{r}\dfrac{\partial u}{\partial r}\right), \\ u\big|_{t=0} = u_0,\ 0 \le r \le R, \\ u\big|_{r=R} = f_i(t). \end{cases} \tag{1}$$

Effective control of initial temperature of liquid steel is sufficient for the mathematical model to be used in practice. Actually, while tapping steel, proceeding from the steady-state superheat temperature, such initial temperature shoud be selected for the briquettes at which the melt would ensure a minimum heat time of assimilation of the element to be introduced into steel, avoiding thereby the appearance of briquettes' melts on the surface as well as unwanted expenses.

Proceeding from the stated problem a structural model has been developed and proposed for the diagnostics and automation control system of the process of direct alloying (Fig.3).

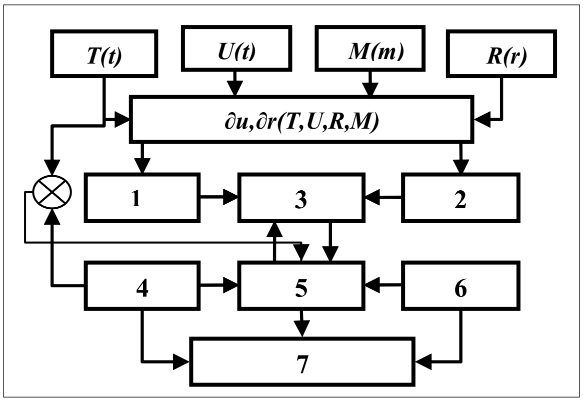

Fig. 3. Structural model of diagnostics and automation control system of the steel direct alloying process.

Unit $T(t)$ is a monitor link of the initial temperature of liquid melting; $U(t)$ – monitor unit of briquettes' initial temperature; $R(r)$ – monitor unit of briquettes' granulometric composition; $M(m)$ – monitor unit of liquid melt mass; $\partial u, \partial r\left(T, U, R, M\right)$ – diagnostic unit, defining the gradient and the rational initial temperature of briquettes; 1 – system for ensurance of the briquettes' given fractional composition; 2 – system of thermal treatment of briquettes; 3 – system of feed of briquettes; 4 – link of volumetric control of the treated melting temperature; 5 – technological system of liquid melt treatment; 6 – control of slag and metal's chemical composition; 7 – technological system of melting casting preparation.

Unit 4 transmits the informatiom on volumetric temperature of treating alloys and on its changes to the comparison unit where the information received from unit T((f/t)) about initial temperature of liquid alloy is registered. The signal of temperature changes of the alloy is transmitted to the technological system of treatment 5 of liquid melt, which interacts with the system of briquettes' feed 3. As a result, in case of need the mentioned signal in Unit 3 initiates the feed rate of briquettes and the temperature correction.

For its part, the unit of control 6 of chemical composition of slag and metal transmits information on the results of the technological process of direct alloying to the system of treatment 5 of liquid melt which forms a current (new) reference signal for the system of briquettes' feed 3, carries out the current adjustment of briquettes' feed process on the basis of initial conditions and specifications of steel and in case of need (unforeseen drop of steel temperature, deviations from chemical compositions etc.) stops their feed. After the termination of treatment process the alloyed metal with given temperature and chemical composition is fed for casting to the technological system 7 to prepare the metal.

Thus, the realization of the proposed novelties will promote eradication of shortcomings that still characterise one of the most progressive and innovatory technologies of direct alloying in ferrous metallurgy. Implementation of the proposed technical approaches will make it possible to raise the efficiency of direct alloying technology as well as to broaden the scale of its employment, this being a rather attractive fact from the point of view of raising the power efficiency of the field.

მეტალურგია

ფოლადის პირდაპირი ლეგირების ინოვაციური ტექნოლოგია და მისი სრულყოფის შესაძლებლობები

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ფოლადის პირდაპირი ლეგირების ტექნოლოგია ითვალისწინებს თხევადი ფოლადის სითბოს გამოყენებით მალეგირებელი ელემენტის ალუმინით აღდგენას ალუმინოთერმული ბრიკეტებიდან. ტრადიციული

ტექნოლოგიისაგან განსხვავებით, მოცემულ შემთხვევაში (მანგანუმის მაგალითზე) ადგილი აქვს მანგანუმის ოქსიდებიდან (ან კარბონატებიდან) მანგანუმის აღდგენისა და გახსნის პროცესს უშუალოდ ფოლადსამსხმელო ციცხვებში. შესაბამისად, თხევადი ფოლადის განჟანგვა-განგოგირდებისა და ლეგირებისათვის გამოირიცხება ძვირადღირებული ფეროშენადნობის ან ლიგატურების გამოყენება.

ალმდგენელი ალუმინის წინმსწრები ჟანგვისა და ფუჭი ამოწვის შემცირებისათვის შემოთავაზებულია ბრიკეტში ალუმინზე აქტიური ალმდგენელი კომპონენტის, კერძოდ, თავისუფალი ნახშირბადის წარმომქმნელი ორგანული ნაერთის - მელასის შეყვანა. ამასთან, ფოლადის პირდაპირი ლეგირების მართვისათვის შემუშავებულია როგორც თხევადი ფოლადიდან ბრიკეტზე სითბოგადაცემის პროცესის მათემატიკური მოდელი, ასევე, ტექნოლოგიური პარამეტრების ოპტიმიზაციისა და მართვის ავტომატიზებული სისტემა, რომელიც ახორციელებს აღნიშნული პარამეტრების ოპერატიულ კონტროლს და წინასწარგანსაზღვრული პირობებიდან გამომდინარე, აწარმოებს ბრიკეტების მოწოდების რეჟიმების რეგულირებას. შემოთავაზებული ნოვაციები წარმოშობს ფოლადის პირდაპირი ლეგირების ტექნოლოგიის ეფექტიანობის ამაღლების ახალ შესაძლებლობებს.

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