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New Approach to Drying High-Density Lining Materials

It was established that the basic mechanism of defect formation in lining at the drying stage is mechanical stress rupture resulting from high internal pressure developed during filtration of gaseous products of drying. Design principles of the drying process are suggested that help to obtain the maximum durability of lining with minimal time and energy consumption. Examples of implementation of the optimal drying technology are provided.

The issue of refractory lining repairs plays a critical role in steelmaking processes. Expenses on lining repairs significantly increase the cost price of steel and rolled steel. Therefore there exists a great demand for long life lining. Manufacturers of refractory lining try to meet this demand by designing and offering materials of complex composition which are generally characterized with considerably long life provided the appropriate drying technology is applied as well as the high-temperature heating and maintenance of temperature conditions during their operation [1, 2]. The cost of lining materials is rising, but the potentially obtainable lifetime is increasing even faster, which proves that use of more advanced materials is cost effective. However, many companies face various problems in practical application of the advanced filling lining materials: fissuring and delaminating of the refractory lining, rupture of its internal structure. This leads to a significant reduction in lining durability and prevents the expected performance of the expensive advanced lining materials.

As recently as 5–10 years ago it was considered that stricter observance of heat treatment schedules recommended by the manufacturers would be enough to obtain the design parameters of lining durability [3]. Various empirical solutions were offered [4]; however their application was far from securing the designed lifetime. We believe that the reason for this is lack of clear understanding of physical aspects of the drying processes as well as possible mechanisms of fracture initiation within the lining materials.

This explains the need for new approaches which would be more fundamental, on the one hand, and at the same time will be simple enough to implement and operate.

This paper is an attempt to outline the key problems inherent in this technology and try to offer possible solutions basing on extensive practical experience in developing technologies and equipment for drying and high-temperature heating of lining materials in metallurgy as well as the results obtained in numerical simulation of thermophysical processes in drying.

Numerical simulation of high-intensity drying processes of high-density lining materials

Refractory concretes used in lining of steel ladles are characterized with high density and low permeability to gases. Once the layer is formed the water content in the material can reach 10 %, the water being mainly mechanically bound. The original material is of extremely low tensile strength therefore intensive vapor generation in drying and the resulting high pressures lead to formation of ruptures in the solid layer which significantly reduces its durability.

Examples of simulation results are shown in Fig. 1 (some details of the simulation technique and the numerical results are given in [5]). With the permeability values typical of modern filling lining materials ($k \sim 10^{-14}...10^{-16}$ m^2) the peak values of internal pressure can reach several tens of atmospheres.

The results obtained show that in order to practically reach the durability parameters stated by the producers of these refractory materials it is not enough to simply decrease the rate of drying by empirical selection of the process variables. This approach results in longer drying time and over-consumption of energy and at the same time does not guarantee elimination of ruptures in the material.

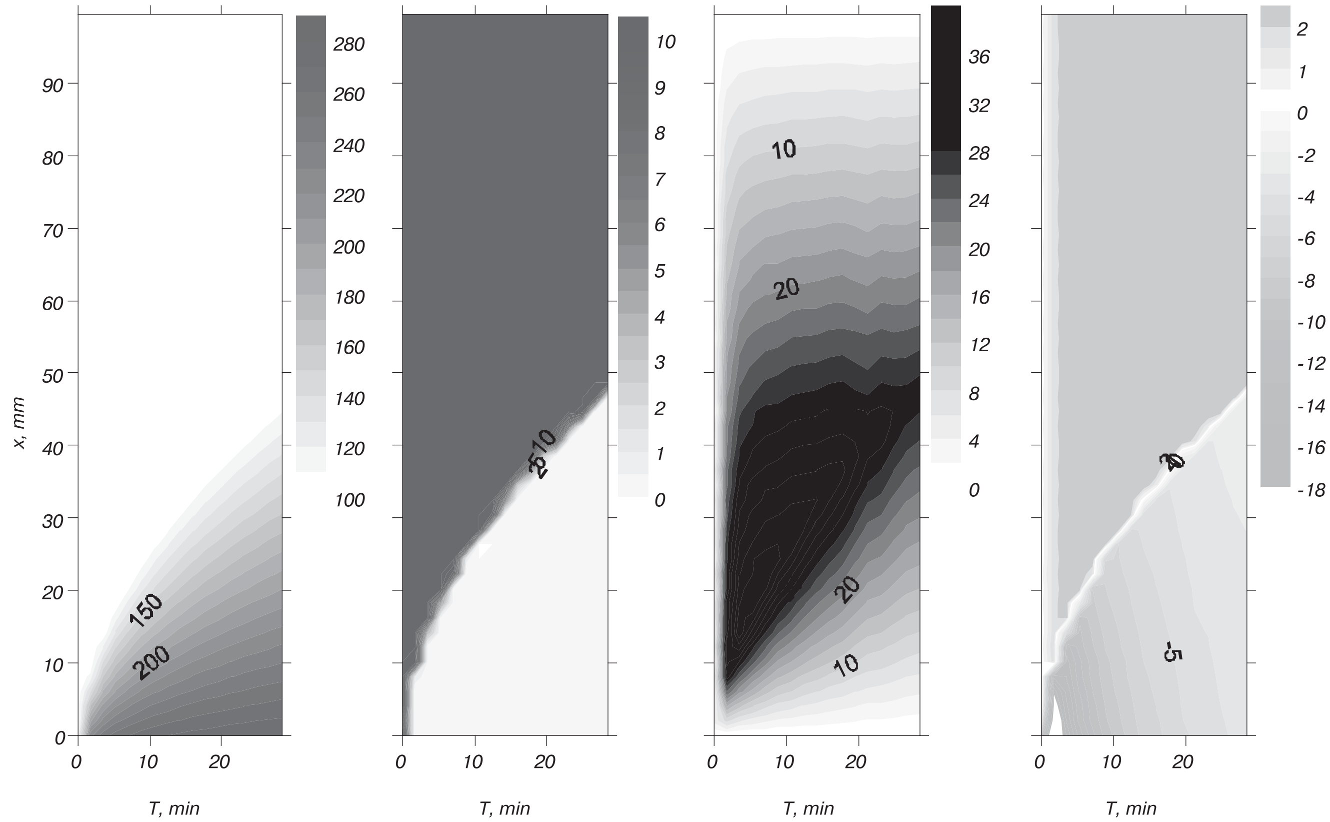
This problem can be solved only through consistent application of the systematic approach which will obligatory involve designing of the drying process parameters basing on mathematical modeling. This will require changes in the interaction patterns between manufacturers of the lining materials, producers of the drying equipment and end consumers.

Requirements to installations for drying of advanced high-density lining

There exists an objective contradiction in specification requirements for drying installations. For example, in accordance with the test data the thermal output of 200 kW is required for drying of a typical 100-ton steel ladle. At the same time the flame is so small in size that it is impossible to provide uniform heating of the whole inner surface of the ladle while uniformity in distribution of the heated gases and the heat transfer coefficient is of crucial importance to ensure high-quality drying.

Thus, to optimize the drying process and ladle heating with the flow of high-temperature combustion gases we need to create the optimal gas-dynamic field which would ensure the required temperature distribution pattern from the heat transfer medium and the heat transfer coefficient all over the inner surface of the lining.

Drying process with a significantly slow increase of the temperature ("soft drying" [4]) is considered to prevent formation of destructive internal stresses. However, this is not always the case: internal pressures with the magnitude of several atmospheres can develop when the drying front is already deep in the material layer.



a *b* *c* *d*

Fig. 1. Simulation of the drying process for a one-dimensional layer of porous material with one-side convection heating; *a* – temperature, °C; *b* – water content, by weight %; *c* – pressure, relative units; *d* – rate, mm/s; K = 10^{-10} m^2; heat transfer coefficient α = 200 W/m$^2\times$K; temperature of the heating medium 300°C.

That is why the law of temperature variation in the heat transfer medium (or any other parameter which is used for monitoring) has to be formulated so that to secure fulfillment of strength conditions at all the drying phases.

If we compare drying with the uniformly rising temperature rate of the heat transfer medium (10 °/h) and drying according to the optimal law which secures constant internal stresses, than the second option ensures minimal drying time and minimum fuel consumption. The fuel economy can be from 20 % to 50 % depending on the thickness of the material layer while the drying time can be reduced several folds.

In order to ensure uniform heating of the ladle inner surface at the required temperatures and heating rates it is necessary to use convective heat transfer achieved through intensive movement of the heat transfer medium of a comparatively low temperature. This is the most efficient method which combines uniformity of the heat transfer over the surface with low thermal gradients throughout the lining thickness.

The required flow of the heat transfer medium and the necessary law of control over the drying process are provided with a two-stage torch which burns fuel in the central channel and supplies air to dilute the combustion gases trough a side

a ***b*** ***c***

Fig. 2. Simulation of the drying process for a one-dimensional layer of porous material with one-side convection heating; *a* – temperature, °C; *b* – water content, by weight %; *c* – pressure, relative units; *d* – rate, mm/s; K =10^{-10} m^2; heat transfer coefficient α = 200 W/m$^2\times$K; temperature of the heating medium 300 °C.

channel. Thereby, high intensity of gas circulation in the ladle is provided irrespective of the thermal output. This enables creation of the optimal gas-dynamic field within the ladle and helps to design efficient drying schemes at all the process stages.

This technology has been implemented and verified in operation at different installations: vertical and horizontal, designed for steel ladles varying in capacity from 30 to 350 tons as well as for intermediate ladles of continuous-casting plants and hot-metal ladles (Fig. 2).

Conclusions

A method was developed for numerical simulation of the drying process as applied to lining materials for metallurgical ladles. This method enables designing of optimal control of the process in order to enhance the quality and durability of lining and to minimize energy and time consumption;

Introduction of this optimal drying technology allows to save 20–50 % of fuel and accelerate the drying process by several times as compared to conventional drying methods;

The main advantage of the optimal drying technology is enhancement of the lining durability up to the manufacturer-specified levels due to elimination of internal damage to the material.

REFERENCE

1. *Yansen Kh.*, REFRAFLEX – A Binding Agent for MGO-C Refractory Materials Based on Catalytically Activate Synthetic Resin; Non-Ferrous Metals, 2007, Vol.10, pp. 22-26 (in Russian).
2. *Egorov I.V., Zamyatin V.L., Anelkin N.I., Brilev S.B., Biryukov O.E.*, Results of CERALIT Solid-Cast Refractory Lining Operation in Heating Furnaces, Steel, 2008, Vol. 7, pp.77-79 (in Russian).
3. *Spirin V.A., Savin A.V., Chistyakov V.V., Sagan I., Dobshikov A., Belkov A.*, Control System for Installation of Drying and High-Temperature Heating of Steel-Teeming Ladles, Modern Technologies of Automation, Vol. 3, 2000, pp. 66-71 (in Russian).
4. *Lorenz V., Loktev A., Garten V., Bechmann D.*, MARECO Company on the Global Market of Equipment for Drying, Reheating and Thermal Conditioning of Metallurgical Ladles and Blast Furnace Chutes, New Refractory Materials, 2007, Vol. 12, pp. 19-27 (in Russian).
5. *Savin A.V., Nikolskiy V.E., Vokhmintsev D.V., Golubev V.O., Smirnov P.G.*, Drying of Advanced Lining Materials: Challenges and Solutions, Non-Ferrous Metals, 2010, presented for publication (in Russian).

Criterion estimation of severe plastic deformation efficiency from the position of their influence on the carbon steel structures evolution

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Currently there is practice of application ultra-fine grain (UFG) materials, including steel, in low-sized details (fittings, medical instruments, implants), low bulk commodities in research labs. But yet there are no manufacturing technologies for production of such materials which will allow to obtain a blank and to scale it up to the dimensions of half-finished product (sheet, rod). Besides, usage of steel with UFG structure is limited by poor knowledge of their mechanical and performance attributes.

We can't develop manufacturing process of producing hardware items of steel with UFG structure without solving problem of definition the structure and properties evolution in the course of deformation process. However, a very important part in the development of manufacturing process for shaping different material types including constructional steel with UFG structure is the limits of deformation ratio definition for concerned real process of producing finished product. These limits can be found in the course of research investigation about changes in the structure of work material after achievement it's yield value.

The results of metallographic examination show the change in interlamellar distance in pearlite structure of low and medium carbon steel grade C22E and C45E after equal channel angular extrusion (ECAE). Statistical analysis of the experimental data indicated that interlamellar distance in pearlite structure of steel grade C22E is 1.5–2-fold smaller then in steel grade C45E (Fig. 1). The interlamellar distance in pearlite structure of steel grade C22E changes from 0.27 to 0.18 micron and in the steel grade C45E from 0.58 to 0.24 micron after increasing the number of passes in the ECAE. The flakes of cementite at the expense of severe deformation in the pearlite structure are bending (Fig. 2 a), fractionizing (Fig. 2 b) and there is subsolution with the development of the supersaturated ferrite area (Fig. 2 c)

When increasing the number of passes in the ECAE process, we can observe the development of the ferrite frag-