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SOME MEASURES FOR INCREASING THE ENDURANCE OF OPEN-HEARTH FURNACES AND IMPROVING THEIR UTILIZATION

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The entirely unsatisfactory endurance level of smelting furnaces at the present time is a bottleneck in the open-hearth process. For this reason, scientific research work on the discovery of reserves in the steel smelting industry must give some priority to study on increasing the endurance of open-hearth furnaces, particularly with respect to roof, front walls, and the top rows of checkered brickwork of regenerators. All of these short-life elements are generally carried out in dinas brick, distinguished among all forms of fire-brick by its low refractory quality and thermal stability. Since dinas has found wide use heretofore in high-temperature open-hearth furnaces, this problem demands study both as to theory and practice.

The average hot surface temperature of a dinas roof during a heat is generally about 50° below the melting point of the dinas. In practice, however, there are often local increases in roof temperature up to 1710° or even 1750°; i.e., equal to and exceeding the refractoriness. In such a case, the temperature of the torch in the furnace may exceed the refractoriness of dinas by as much as 200-250°.

Under such unsafe temperature conditions, the dinas roof requires protection against burn-out by automatic regulation of its temperature, as was realized at one plant which, in efforts to improve roof durability of open-hearth furnaces, succeeded in increasing the number of heats for 185-t furnaces from 120 to 230-260.

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Good results in numerous experiments for studying industrial effectiveness of automatic regulation of air and fuel feeding in respect to changes in temperature of the furnace roof proved the expediency of converting all open-hearth furnaces to automatic regulation of heating for eliminating burn-out of the roof.

But not only high temperature and direct burn-out are causes of insufficient endurance of dinas brick in the roofs of open-hearth furnaces. Dinas in furnace ports is exposed to temperatures of the order of 1500-1650° which are lower than its refractoriness, and dinas bricks in the checker-work of regenerators are subject to the action of still lower temperatures, of the order of 1200°-1450. However, dinas also wears out rapidly in these parts of a furnace. It is noticed that the wear of dinas brick is especially intensive at points where there is a vortex or a reversal of gas flow. Dinas roof wears out not only in portions nearest the flame torch but mainly on both sides of the flame, i.e. at points of vortex turbulent motion in a gas flow.

This indicates that, in addition to high temperature, internal and external slag erosion of dinas have a significant effect on its wear. Fluxing is the result of interaction of silica with basic and amphoteric oxides included partially in the dinas itself and chiefly in the gas atmosphere of a furnace. Approximate composition of the oxide mixture which fluxes a dinas roof is as follows: 85-88% $FeO + Fe_2O_3$, 2.5-3% Al_2O_3, 5.5-6% $CaO + MgO$, 2% MnO.

Slag deposits in ports have the approximate composition: 55-92% $FeO + Fe_2O_3$, 5.5-25% $CaO + MgO$, 1.5-2% MnO. Thus, dinas in open-hearth furnaces is subject to fluxing with dusts, 85-95% of which are oxides of iron, calcium and magnesium, i.e., most active fluxes of basic character.

What is the effect of these fluxes on the melting point of dinas?

The phase diagram of the $FeO-SiO_2$ system shows that ferrous oxide is a most active flux lowering the refractoriness of dinas from 1710 to 1200° and even lower. Therefore, dinas brick may melt under the fluxing effect of basic oxides even at the temperatures of checker-work in regenerators. The furnace roof melts in the process of fluxing dinas with iron oxides, at 1530-1570°, i.e., at temperatures about 450° below the temperature of the flame.

The vortex motion of gases along side walls, near end walls and the damwall between slag chambers and regenerator brickwork intensifies the wear of dinas due to systematic accumulation of basic fluxing dust in these places.

For decreasing harmful swirling under roof, it seems expedient to investigate the effectiveness of installing two and more nozzles on each side of a furnace instead of one. This measure may secure more uniform wear of the roof and eliminate combustion processes outside of the working space of the furnace. It is also desirable to test a modified design of gas flues, making them smoothly sloping for decreasing vortex and eliminating a direct impact of the gases against end walls. In some open-hearth furnaces of old design, it is advisable to enlarge regenerators and slag chambers, equipping them with deflector-curtains for better settling of dust. Problems of hydrodynamics, highly significant for improving the endurance of open-hearth furnaces, are the subject of another investigation, hardly within the scope of this report.

In addition to screening and briquetting dust out of iron ore to decrease the amount of harmful iron oxides in gases, the specification of open-hearth ores for steel smelting must be defined more precisely. The present specification merely requires ore coarseness not less than 70% of 10-25 mm, without indicating the permissible dust content which, therefore, may reach 30%.

The removal of dust from such materials as dolomite and lime must be used as an effective and economically expedient measure for preventing the penetration of extremely active fluxing oxides of calcium and magnesium into regenerators and slag chambers. Additional expenses and losses in the process of screening and suction of dust out of these materials are entirely justified since the major portion of this dust with high basic properties, getting into slag chambers and regenerators, not only represents a total loss but also intensifies deterioration of the dinas refractories in these parts of the furnace. For the same purpose, an investigation has to be conducted to develope and test special devices for the purifying separation of gases in slag chambers.

Decreasing the dust content in ore, dolomite and lime, and the purifying separation of gases, beneficent to regenerator checkerwork and slag chambers -- only insignificantly decrease the wear of the furnace roof, since iron oxides, which erode roof dinas, are formed due to the oxidation of iron, inevitably evaporated during the melting procedure at the high temperatures of the open-hearth process.

To efficiently increase the endurance of basic open-hearth furnaces, it is necessary to eliminate the major cause of their intensive wear -- slag erosion of refractory materials with dust of the furnace gas atmosphere.

Investigations at a number of plants revealed substantial nonuniformity of wear in the horizontal cross-section of regenerators. More uniform wear of checkerworks must be achieved since it increases their life and improves thermal performance of the furnace. For this purpose, it is necessary to continue and develop systematic investigations of this essential problem by the photographing and physicochemical studying of the condition, wear, and slag clogging of checkerwork after stopping the furnaces for repair. Topographic study of the exterior and operational surfaces of checkerworks is necessary in respect to the character of their wear and to distribution, composition and temperature of exhaust gases. Studying the problems of hydrodynamics of furnace gases on special models is also desirable.

Since fluxing oxides in furnace gases are almost entirely basic, dinas, an acid material intensively eroded by basic oxides, must be replaced in the most eroding parts of furnaces by basic refractories which react less intensively with the basic dust of the furnace gas atmosphere.

In addition to sufficient refractoriness and increased endurance against basic oxides, these refractory materials must also possess a sufficiently high resistance to the effects of temperature changes. Comparative data on basic refractory materials and dinas are presented in Table 1.

This table shows that heat-resistant magnesite has the highest refractoriness and softening point. A main roof made of high-quality heat-resistant magnesite withstands 1100-1200 heats, i.e. 5-6 times longer than dinas roof. However these data, published in technical literature, must be experimentally substantiated because they are possibly exaggerated to a certain extent. Chromomagnesite brick,

Table 1

Most Essential Properties of Basic Refractory Materials and Dinas

Essential Properties	Dinas	Magnesite Refractories		Chromagnesite Refractories		Dolomite Refractories		Chromite
		Ordinary	Heat-Resistant	Ordinary	Heat-Resistant	Chromite	Water-Resistant	
Content of Basic Components	94-96% SiO_2	92-94% MgO	80-84% MnO 5-12% Al_2O_3 6% Al_2O_3	50% MgO 20% Cr_2O_3 6% Al_2O_3	52-70% MgO 9-16% Cr_2O_3 5-10% Al_2O_3	75% Dolomite 20% Chromite 5% Quartzite	30% MgO 46% CaO 16% SiO_2	30-42% Cr_2O_3 25-30% MgO 16-22% Fe_2O_3
Refractoriness, °C	1710	2000	2200-2300	1900	1900	1950	1770-1780	1900
Softening Point under Load of 2 kg/sq cm, °C	1650	1500-1600	1600-1650	1450-1520	1470-1550	1520-1600	1550-1600	1500-1650
Thermal Stability, Number of Temperature Changes	1-3	3-6	Not less than 50	3-8	40-80	2-8	3-8	15-20
Volume Weight, q/cu cm	2.36-2.39	2.6-2.7	2.8-3.0	2.85	2.75-2.80	2.8	2.8-2.9	3.0-3.20
Endurance in the Roof of Open-Hearth Furnaces, Heats	average 200-250	-	-	-	300-500	-	-	-
Endurance in the End Walls, Heats	60	greater th ordinary magnesite	Greater than ordinary magnesite	-	350	370	-	-
Endurance in the Middle of A Back Wall at Slag Level	-	Order of 700	-	-	-	Close to magnesite		

in spite of its lower heat-resistance and softening point, serves two and even three times longer than dinas brick. Heat-resistant chromomagnesite brick was used for the end walls of the vertical channels in one open-hearth furnace. These walls endured 300 melts without repair, compared with 40-50 heats for dinas walls. In addition, chromomagnesite brick in end walls considerably improves the operation of slag chambers, decreasing the amount of slag; whereas dinas walls, being more susceptible to erosion by furnace dust, cause slag accumulation in the chambers at a higher rate.

The process of emptying the slag chambers requires a great deal of labor. Therefore, mechanization of the slag removing operation is very essential. Up to the present, slag was removed by hand, having been broken into chunks by the use of explosives. Recently, the slag-removal operation has been considerably facilitated. Sections of channel iron with flanges in an upward position are placed on the bottom of the slag chamber in a direction perpendicular to the longitudinal axis of the furnace. An iron plate with an area equal to the bottom of the chamber is placed on steel balls which roll along channels. The plate is covered with refractory brick and false walls are erected on the plate up to a height a little lower than the top edges of the slag chamber. When a furnace campaign is interrupted for repair work, the plate together with false walls and slag is pulled with a cable into a pit, constructed next to the slag chamber at the level of the chamber itself, from which the slag is removed by a crane. Thus, removal of slag takes 4-5 hours instead 2-3 days. This measure decreased the repair period from 5-6 to 3-3.5 days.

In one case the operation of open-hearth furnaces was hampered by intensive contamination of checkers. Draft was insufficient for passage of gases through the clogged and fused brickworks. Toward the end of the campaign, heat periods were prolonged 1.5-2 times above normal.

Vertical and horizontal holes were made in the walls of the regenerators, and the checkers blown out with compressed air. This removed a considerable amount of fluxing dust consisting basically of iron oxides, which (dust) was reducing considerably the softening and fusing points of the dinas checkers.

This measure increased the number of heats from 250 to 300 and, what is more important, shortened the heat periods at the end of a furnace campaign. In addition, the checkers are presently in comparatively good condition, which substantially facilitates and accelerates their replacement.

Improvement of the endurance of open-hearth furnaces was also attained by establishing and maintaining optimum thermal conditions of heats. Experiments were conducted in a number of open-hearth shops to obtain maximum acceleration of heats, highest fuel conservation, and an increase in the number of heats without repair. Furnaces were automatized and well equipped with instruments. They had automatic reversing of valves, furnace pressure regulator, indicators and recorders of mazut consumption and air consumption for compressor and blowers, automatic regulation of air and mazut consumption, indicator and recorder of mazut preheating temperature and exhaust gas temperature, etc. Table 2 gives an example of the thermal conditions of an open-hearth furnace in respect to various periods of campaign and heat.

Table 2

Operational Conditions of the Open-Hearth Furnace Using Mazut as Fuel

Indexes	Charging Period	Melting Period	Boiling Period	Average for a Heat
Campaign up to 120 Heats				
Feed of Mazut, Kg/hr	1,700	1,450	1,000	1,450
Feed of Blowing Air, cu m/hr	23,800	19,600	12,400	-
Campaign from 120 to 220 Heats				
Feed of Mazut, Kg/hr	1,700	1,450	1,100	1,420
Feed of Blowing Air, cu m/hr	22,400	19,000	14,300	-
Campaign over 220 Heats				
Feed of Mazut, Kg/hr	1,600	1,700	1,150	1,390
Feed of Blowing Air, cu m/hr	22,400	19,000	14,300	-
Cycle of Valve Reversal, min.	14-12	12-10	10-8	-
Pressure in the Combustion Chamber of the Furnace				
During Campaign to 120 Heats, mm of Water Column	2	1.5	1.7	-
During Campaign of 120-220 Heats mm of Water Column	2.5	1.7	2.0	-
During Campaign Over 220 Heats, mm of Water Column	3.0	2.0	2.5	-
Heating Range for Checkers	1050-1150	1100-1250	1150-1250	-

Heat-resistant magnesite is still not used on a sufficient scale in steelmaking practice. This refractory material, made of fused or sintered magnesia on spinel binder, in addition to its high refractoriness and thermal stability, also reveals the highest resistance against the fluxing action of iron and other basic oxides present in the furnace atmosphere.

Magnesium oxide forms with ferric oxide a single chemical compound - magnesioferrite $MgO \cdot Fe_2O_3$ which enters into solid solution with magnesia. Both magnesioferrite and its solid solution possess high refractory quality; even with a 70% content of ferric oxide in this material, its melting point drops only to 1900°, while the melting point of dinas with the same concentration of oxides goes down to 1200°. Magnesia may absorb an amount of ferric oxide greater than its own weight without melting, under the conditions of the open-hearth process. It also forms high-refractory solid solutions with ferrous oxide.

Heat-resistant chromomagnesite, having lower refractoriness and thermal stability, has also a lower resistance to slag erosion. Theoretically, chromomagnesite has no advantages over magnesite, and the perference for it in open-hearth furnaces may be explained merely by the practical possibilities for adequate supply.

Chromite as a component of chromomagnesite refractories is highly unstable with respect to ferric oxide and reducing gases. It is known that exchange and migration of iron and magnesium oxides simultaneously with the oxidation of ferrous oxide occur in a solid solution of chrome spinel. This increases volume and destroys brick containing grains of spinel. Having a sufficiently high refractory quality, this brick does not melt under ordinary conditions of open-hearth furnace operation, but is subject partially to shearing at high temperatures. Owing to the presence of magnesia in this material, absorption of ferric oxide temporarily prevents quick deterioration of the chromite grains. Upon saturation of magnesia, ferric oxide destroys the chromite grains, considerably decreasing the endurance of chromomagnesite.

As a rule, the life of a chromomagnesite roof amounts only to half the service time of a roof lined with magnesite. Magnesite therefore is recommended for the main roofs of open-hearth furnaces.

Due to the greater specific weight and thermal expansion of basic refractories, roofs made of these materials must be of the suspension type. Magnesite bricks have to be elastically suspended, being enclosed in steel casings or interlayered with steel plates.

Satisfactory performance of suspended basic roofs was corroborated by using them for a number of years in large copper-smelting reverberatory furnaces, the operational temperature of which reaches 1600°, i.e., only 50° lower than the average temperature of the dinas roofs of open-hearth furnaces.

In spite of such shortcomings as heavy weight and increased cost, basic roofs have substantial advantages: namely, possibility for considerable acceleration of melting and for increasing furnace productive capacity; prolonged endurance of furnace and decreased idle time for repair works; increased basicity of molten slags and more precise control of their composition; lower specific consumption of refractory materials and, to a certain extent, fuel, due to a decrease in the number and length of shutdowns for repairing; considerable facilitation of cleaning slag pockets; and the possibility for effective utilization of new steelmaking technology based on the application of oxygen. Some published data demonstrate that, with the replacement of a dinas roof by a basic roof, the period of a heat in a 180-t furnace is decreased by one hour, furnace productivity is higher by 14.2 %, yield of steel increases by 1.5-t per hour, production of steel for the entire campaign increases by 5000 t, roof life is three and more times longer, and specific consumption of refractory materials drops by 90%. All these achievements may and must compensate for the considerably higher cost of the roof.

There are some other examples. For instance, a 35-ton furnace operating on mazut increased production more than twice after replacing the dinas roof with a basic roof; a 50-ton furnace heated with generator gas produced 215 tons daily, decreasing fuel consumption by 10% and the use of refractories by 60%. These data are far from being conclusive. Some plants obtained considerably better operational results for furnaces with basic roofs.

As for dolomite refractories they are still not sufficiently heat-resistant and may not be recommended as roof materials of high endurance. But they are entirely acceptable as a basic material of bricks for ports, rear and front walls and regenerator checkers, replacing the more expensive magnesite, chromomagnesite and high-alumina bricks. Substitution of dolomite refractories for magnesite ones in these parts of the furnace, in addition to decreasing furnace cost, releases magnesite for developing heat-resistant refractories for main roofs. However, a comparative technical-economic investigation must be conducted under industrial conditions for the final and correct solution of this problem. Such an investigation would take into account the possibilities for supplying the metallurgical industry with the required materials both now and later. From this viewpoint, construction of the entire upper part of a furnace out of heat-resistant chromomagnesite material, as has been repeatedly suggested, is not substantiated economically or theoretically. On the contrary, it is desirable to promote maximum use of the inexpensive dolomite refractories for all parts of furnaces except the main roofs, which require heat-resistant magnesite materials.

In conclusion, it should be noted that, in spite of the presence in the Soviet Union of the world's richest deposits of various refractory raw materials, the manufacture of basic and especially of heat-resistant refractory products is still below the proper level; and mass supply of these products to the steelmaking industry is unsatisfactory.

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