UDC 666.762.32:[669.18.046.5:621.746.32

IMPROVING THE STEEL LADLE LINING AT THE VOLZHSKII TUBE-MAKING PLANT JOINT-STOCK Co.

L. M. Aksel'rod,[1] Yu. S. Rodgol'ts,[1] A. A. Paivin,[1] V. V. Kazakov,[1] T. I. Toporkova,[1] and G. S. Rossikhina[1]

Translated from Novye Ogneupory, No. 5, pp. 80 – 83, May, 2003.

Routes towards improving the quality of refractory lining for steel ladles and choice of the refractory product configuration are described. Periclase-carbon refractories of the mini-key format based on a composite carbon binder are shown to be the best choice for the steel ladle lining. Conditions for efficient performance (lining for the liquid-metal jet impingement zone, replacement of the nested block by a monolithic one, development of optimum block composition etc.) are discussed.

In an electric furnace shop at the VTMP, 150-ton steel ladles have been put in service. The metal refining is carried out in a ladle furnace (100% heats, with argon blowing through a bottom tuyere; as needed, steel degassing in the ladle can be effected (using a VKR-type unit). The range of products includes low, medium, and high-carbon steels, also high-alloy steels (mostly tube steels). The tapping temperature is 1640 – 1670°C. Routinely, the number of heats per ladle per day was rather modest (1.9 – 2.5). In recent time, there has been a tendency towards increasing the number of heats per day, under conditions of the ever-increasing volume of production.

During the past four years, efforts were incessantly aimed at increasing the resistance of the refractory lining and thus making the production process more cost-effective (in terms of roubles per ton steel). The optimality criterion was assumed to be the equal refractoriness of the ladle components: bottom, walls, and slag zone.

Fruitful cooperation of metallurgists at the VTMP JSC and refractory engineers at the SRP, with occasional participation of specialists from the St. Petersburg Institute for Refractories JSC, in the development of steel ladle refractories has a many-years history. First, the high-alumina lining refractory was replaced with a periclase-carbon material, and the standard geometry of ladle components was retained using a screw-like pattern for the working (hot) layer of the lining. Simultaneously, studies were conducted concerned with choosing periclase-carbon refractories of adequate quality and improving design and pattern of the lining and shape of the refractory components.

P-format refractory components with a height tolerance of ± 0.5 mm were used to make a mortarless ring bricking. High-quality materials were produced at the SRP JSC using advanced technology and equipment (weighing batchers, sheltered conveyors, a computer-controlled mixer (Eirich), molding pressing equipment (Laeis) for shaping components in electronically controlled operation regimes, heating furnaces (275 – 290°C), raw material and final product quality control). The physicochemical characteristics of refractories for the lining of steel ladles are given in Table 1.

Therefore a new technology for periclase-carbon refractories using a composite bond (containing thermoplastic and thermoreactive binders) was proposed. Products containing a composite carbon binder (see Table 2) exhibit somewhat superior properties when compared with those containing conventional thermoreactive binders: the former exhibit a lower porosity and a higher strength and show a better reproducibility of properties when tested for certification. The longer service life for refractories based on a complex carbon binder was anticipated owing to structural improvements of the refractory, in particular, decreasing the average pore size and the percentage of intercommunicating pores. This should result in a lesser infiltration of corrosive components at the refractory – molten phase interface and in improved strength properties of the refractory, primarily, its bending strength [1].

Improving qualitative characteristics of oxide-carbon ladle refractories was in parallel with improving their configuration.

[1] St. Petersburg Institute for Refractories, St. Petersburg, Russia; Volzhskii Tube-Making Plant (VTMP) Joint-Stock Co., Volgograd Region, Russia; Semilukskii Refractory Plant (SRP) Joint-Stock Co., Semiluki, Voronezh Region, Russia.

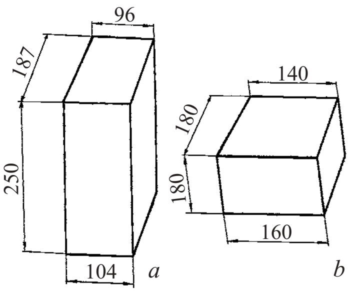

Fig. 1. Ladle lining components of format P (*a*) and mini-key (*b*): *a*) 4P8-grade product; *b*) 18/20-grade product.

Experience in the use of P-format refractories has revealed a number of shortcomings, primarily, the cracking in the slag zone; in the product (brick with a height of 250 mm), the crack typically runs horizontally in the middle portion of the brick. The crack seldom goes through the whole thickness of the hot layer of the lining (187 mm); however, after 15 – 20 heats, it looked much like the cracks in the vicinity of the joint. Currently, the products of mini-key format show a considerable potential for application in the field [2, 3]. Ladle products of P- and mini-key format are shown in Fig. 1.

Typically, the P-format components used are of 4P8-grade and 4P12-grade, with a hot-layer thickness of 187 mm. The mini-key format used are of 18/6-grade and 18/20-grade, with a hot-layer thickness of 180 mm. In both cases, the bricking is mortarless, of ring type.

The occurrence of horizontal cracks in a direction perpendicular to the hot surface was also noted by Japanese researchers in refractory components resembling the European P-format (of height 230 mm) [4]. Most likely, the cause for formation of these cracks is thermal shock, as follows from results calculated by a finite-difference method. The temperature profile in the lining was calculated for a temperature drop from 1600 to 1000°C at the hot surface within 6 min after the ladle was emptied.

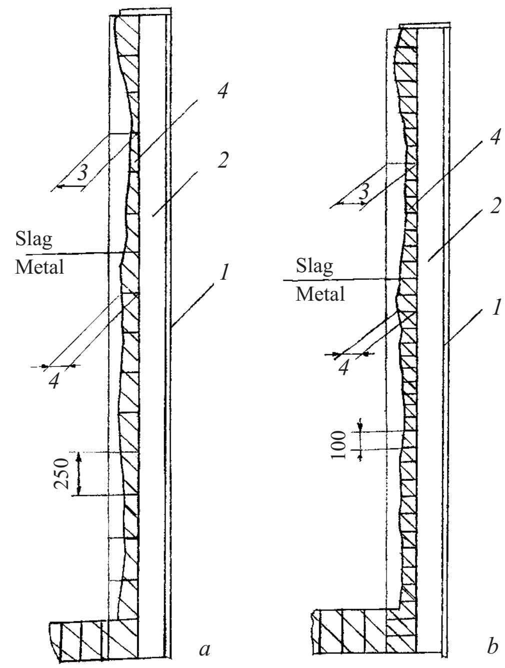

Fig. 2. Surface wear topography of the wall lining of a steel ladle: *a*) lined with P-format components; *b*) lined with mini-key format components; *1*) casing; *2*) control layer; *3*) hot layer (intact thickness; *4*) hot layer (residual thickness).

As was shown by numerical analysis, the rupture stress that concentrates at the center of the hot (working) surface of a refractory component with dimensions of 230 × 180 × 180 mm is 17% and 25% higher than that in components with dimensions of 145 × 145 × 180 mm and 145 × 145 × 230 mm, respectively.

The surface wear topography of steel ladles lined with refractory materials of different size is shown in Fig. 2. The

TABLE 1. Characterization of Periclase-Carbon Products

Property	Product tested*	
	PUKP-13	PUKS-7
Mass fraction, % (corrected for calcination):		
MgO	90.9 – 91.8 (> 90)	94.9 – 95.3 (> 91)
C	14.8 – 15.9 (13 – 17)	7.8 – 8.2 (7 – 10)
Open porosity, %:		
thermally treated	2.5 – 4.1 (< 8)	2.9 – 5.2 (< 8)
carbonized	12.0 – 12.2	11.7 – 13.0
Compressive strength, MPa:		
thermally treated	33.7 – 37.5 (> 30)	55.4 – 58.7 (> 30)
carbonized	20.0 – 28.0	24.5 – 30.0
Lining portion	Slag zone	Wall

* Data in brackets are rated values according to TU 1591-042-00188162–2001 Specifications; carbonization characteristics determined according to State Standard GOST 30771–2001.

TABLE 2. Characterization of Periclase-Carbon Products Using a Composite Carbon Binder

Property	Product tested	
	PUKP-13	PUKS-7
Mass fraction, % (corrected for calcination):		
MgO	90.4 – 91.5	94.7 – 95.4
C	14.8 – 15.6	7.9 – 8.5
Open porosity, %:		
thermally treated	2.5 – 3.1	2.2 – 2.7
carbonized	9.7 – 10.2	11.1 – 12.3
Compressive strength, MPa:		
thermally treated	36.3 – 38.2	58.0 – 62.0
carbonized	25.6 – 29.4	27.9 – 33.3
Lining portion	Slag zone	Wall

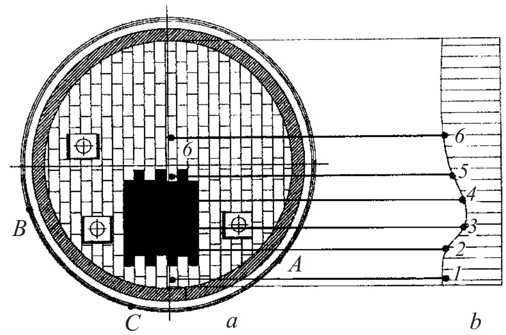

Fig. 3. Scheme for a refractory lining using periclase-carbon materials (*a*) and the wear profile of the lining for the bottom of a steel ladle (*b*): *A*, *B*, and *C* refer to the measurement zone of the residual hot lining thickness of a commissioned ladle; *1* – *6* refer to the measuring points.

measurements were made at sites with a high amount of wear, at points *A*, *B*, and *C*, that are found in the "impingement" zone of the ladle bottom (Fig. 3). To plot a curve corresponding to the residual refractory thickness, the least measurement values at the three points (a total of 9 to 12 measurements) in all the ladles inspected were taken into account; that is, for the residual thickness at these points varying from 45 to 90 mm, the residual brick thickness of 45 mm was used for the wear topography.

The in-service inspection of P-format components revealed a higher amount of wear at the edges of refractory components, especially in the slag zone. This effect may be due to the accelerated oxidation of carbon, either because of the leakage of air from the outside, or because of the decreased strength of refractory material in the edge zone (for example, because of the nonuniformly packed mixture in the mold). Finally, at the end of the ladle campaign, the amount of wear in the horizontal crack (along the horizontal joint) may reach 30 – 40 mm in depth, and in the vertical crack — 20 – 30 mm. Thus, for the residual thickness of the lining at the center of the brick 80 mm, the actual distance from the back face of the periclase-carbon brick is 40 – 50 mm.

In the mini-key format refractory brickwork, the amount of edge wear at the joints in the slag zone did not exceed 15 mm.

Averaged data on the ladle operational regimes (drying, start-up, normal service) are given in Table 3. During inspection, the ladle operation conditions (idle periods included) were under normal, routine control.

For ladles lined with mini-key format components, the service conditions were more stringent: most heats were treated by vacuum degassing (using a VKR unit), and the overall processing time was longer by 19%. These two factors resulted in an accelerated wear of the refractory material [2].

Special tests were conducted with the mini-key format refractories: in a number of ladles, the hot layer of the periclase-carbon lining in the slag zone was increased to a thickness of 200 mm. The effect was encouraging: the refractory lining durability increased by 14 – 18%; this technique may be especially advantageous for heats subjected to vacuum degassing.

The residual refractory thickness was found to be significantly larger in ladle walls lined with mini-key format components (see Fig. 2). An analysis of the ladle performance data as of 2002 revealed an improvement in the refractory lining durability, especially in the slag zone (by 14%). In the latter half of 2002, only mini-key format components were used for the ladle refractory lining at the VTMP electric furnace shop (EFS).

Another problem to be resolved was improving the refractory durability in the liquid-metal jet impingement zone. A scheme for the ladle bottom lining using periclase-carbon refractories is shown in Fig. 3*a*: the standard hot layer thickness was 250 mm; in the impingement zone, it was 300 mm (a typical refractory wear profile of the ladle bottom lining is shown in Fig. 3*b*).

Recommendations on the use of alumina-periclase-carbon refractories in the impingement zone have been proposed. In 2002, alumina-periclase refractories of APU-80 grade (according to TU 1591-001-00187027–2001 Specifications) available from the SRP JSC were tested for performance characteristics. The APU-80 refractory properties were: 80.1% Al_2O_3, 9.8% MgO, 8.0% carbon (mass fraction); open porosity and compressive strength of heat-treated components were 4.2 – 4.4% and 70.0 – 73.0 MPa, respectively. Preliminary test results showed the durability of APU-80 refractories to be 30% higher than that of

TABLE 3. Data on Thermal Stability, Operating Regimes, Performance Efficiency of Refractories for Steel Ladles

Product format	Ladle durability* (heats)	Heats treated by vacuum degassing*		Processing time			Refractory consumption rate per ton steel, %
		number	%	ladle furnace, h	continuous casting machine, min	ladle residence time*, min	
P	29.7	6.7	22.7	116	125	241	100.0
Mini-key	31.8	11.8	37.1	129	104	233	93.8

* Average value is given.

periclase-carbon refractories; currently, further tests are under way.

An issue of special concern was the use of nested bricks for the lining of the bottom blow tuyeres. Complications came from the specific design of the nested brick – slide gate assembly as well as from the ladle operational regime — 1.9 – 2.5 heats per ladle per shift. The first step was replacement of the prefabricated nested brick by a block made up from a low-cement castable (available from the SRP JSC). The tested components of grade SVN-1 and SVN-1T [5] showed a thermal resistance somewhat higher than that of prefabricated blocks; however, no final engineering solution yet has been found. Further work is clearly needed to improve thermal stability of refractory materials for nested bricks and their design. Another problem that requires prompt solution is the thermal stability of bottom blow tuyeres: replacement of the nested block in the ladle takes a rather long time, which may lead to complications with the blowing of shutdown tuyeres still fit for service.

Based on the results of testing of bottom blow tuyeres available from various manufacturers, both foreign and domestic, the conclusion was made that under the actual operating conditions at the VTMP, the best choice would be slit tuyeres from Plibrico Co. (the tuyere height is 450 mm). Currently, their thermal stability compares well with the thermal stability of the ladle bottom lining; however, this choice is not a final one considering that advanced refractory materials with still higher stability for the ladle bottom lining will certainly be developed in the near future.

REFERENCES

1. L. M. Aksel’rod, Yu. S. Rodgol’ts, T. I. Zolotareva, and T. E. Toporkova, “Periclase-carbon refractories using a composite binder,” *Novye Ogneupory*, No. 5, 14 – 18 (2002).
2. I. D. Kashcheev and E. E. Grishenkov (eds.), *Refractories and Their Applications. Refractories for Industrial Plants and Furnaces. Handbook. Vol. 2* [in Russian], Intermet Engineering, Moscow (2002).
3. T. Miwa, H. Mori, H. Fukushima, and M. Hyama, “Prolonging the life of hot metal ladles by refractory changes,” *Taikabutsu Overseas*, **19**(4), 35 – 39 (1999).
4. S. V. Éntin and N. M. Anzheurov, “New refractory products for industry,” *Novye Ogneupory*, No. 1, 77 – 80 (2002).