REFRACTORIES IN THE HANDS OF THE CONSUMER

SILICA CONCRETE ARTIFACTS FOR STEEL-TEEMING LADLES

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Refractory concretes are used extensively to line steel teeming ladles. The concrete linings are made by monolithic tamping [1-3] and casting [4] methods. Cherubim and Peach [5] give comparative results for the preparation of linings by different procedures.

The concretes used as the lining material are as follows: concrete with 95-99 % crystalline quartzite, 1-5% slag, and 16-18% slag (above 100%) water glass with a density of 1.3 g/cm³ [6]; concrete from quartzite with added clay [7, 8]; and silica concrete with a chemical binder [9, 10].

The advantage of a monolithic lining is that it is made by a mechanized procedure. However, the use of monolithic linings means that a sector for their preparation must be established in the casting bay of steel foundries; this is not always possible.

It is known [11] that concrete ladle artifacts, shaped in friction and hydraulic presses and with relatively low porosity and accurate dimensions, are in use.

This article gives the results of an investigation of the development of the procedure for making unroasted silica brick of enhanced porosity, and of the determination of the sites and conditions of its effective use in steel teeming ladles.†

The brick was prepared from natural silica filler, refractory clay, chromite, chemical binder, and strengthening additive.

Concrete masses of different compositions were subjected to laboratory tests (Table 1). The specimens were compacted at a pressure of 60 MPa and dried at 120°C. Their properties are listed in Table 2.

Concretes with filler B (masses Nos. 1 and 3) have a much higher linear increase at 1400°C than those with filler A (masses Nos. 2 and 4). The added clay retards silica regeneration; therefore masses containing clay exhibit less growth. Furthermore, the added clay reduces the refractoriness and strength of the concrete. Incorporation of chromite (masses Nos. 5 and 6) reduces the refractoriness and the softening point.

On the basis of laboratory investigations experimental batches of ladle brick — silica brick (S), silica with added clay (SC), and silica with added chromite (SCh) — have been manufactured at the Pervouralsk Dinas Works. The concrete masses were prepared in a concrete mixer. The artifacts were shaped in a KF-400 friction press with from three to five impacts. The artifacts met the requirements of All-Union State Standard (GOST) 5431-69 (grades 9, 12, 13, 16, and 18).

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Fig. 1. Thermal expansion of compacted silica concrete based on chemical binder: 1) during first heating; 1') during repeat heating; 2) during cooling.

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TABLE 1. Compositions of Concrete Masses

Initial material	Content of material in mass, %*					
	№ 1	№ 2	№ 3	№ 4	№ 5	№ 6
Silica filler						
A	—	90	—	100	—	—
B	90	—	100	—	90	80
Refractory clay	10	10	—	—	10	20 †

* Each mass contains 7-8% of chemical binder and 0.5% of strengthening additive (the optimal additive content was established on the basis of preliminary investigations) above 100%.

† The chromite content is indicated.

TABLE 2. Properties of Concrete Masses

Indices	Values of indices for masses					
	№ 1	№ 2	№ 3	№ 4	№ 5	№ 6
Compressive strength, MPa	5,9	5,5	16,0	17,5	18,7	22,0
Porosity, %	21,0	15,2	21,3	21,0	19,2	18,1
Softening point under a load of 0,2 MPa, °C:						
onset of softening	Not determined			1490	1380	1380
40% compression	"			1510	1400	1400
Linear increase during heating up to 1400°C, %	1,5	1,29	4,5-4,3	3,6	3,5	3,0
Refractoriness, °C	1690-1700	ot det.	1710	Not det.	1630-1650	1630
Apparent density, g/cm ³	2,07	2,17	2,05	2,16	2,21	2,33
Spalling resistance (1300°C-water), heating-cooling cycles	Not determined			2	2	1

TABLE 3. Wear of Bricks of Different Compositions in Steel Teeming Ladles

Bricks	Wear of brick, mm/melt, in courses		
	1-8	9-33	34-35
Silica:			
S grade	4,6	2,4	4,1
SC grade	8,2	4,3	3,25
SCh grade	10,0	—	7,0
Chamotte (roasted)*	4,9-7,8	2,7-5,3	1,9-3,1

*The wear in the slag belt (36-40th courses) is 4.1 mm/ melt.

Fig. 2. Change in modulus of elasticity E of compacted silica concrete based on chemical binder: 1) during heating; 2) during cooling.

TABLE 4. Properties of Artifacts

Indices	Values of indices of concretes subjected to heat treatment at $^{\circ}\text{C}$		
	110	800	1350 [†]
Open porosity, %	19,5	21,0	28,4
Apparent density, g/cm ³	2,08	2,05	1,64
Strength, MPa			
compression	40,7	39,6	12,8
flexural	6,91	4,31	1,94
tensile	1,72	1,58	0,20
Impact ductility, kJ/m ²	1,54	1,29	1,24
Wearability, mm	5,41	—	7,34
Softening point under a load of 0,2 MPa, $^{\circ}\text{C}$:			
onset of softening	1580 [‡]	Not det.	1560
40% compression	—	—	1570
40% compression	—	—	1570
Spalling resistance (1300 $^{\circ}\text{C}$ — air, heating-cooling cycles	5	1	2

*Refractoriness 1690–1710 $^{\circ}\text{C}$.

†The overall thermal expansion during heating to 1400 $^{\circ}\text{C}$ is 4.68%, the residual expansion is 3.59%; the linear expansion coefficient at 20–1400 $^{\circ}\text{C}$ is $1.52 \cdot 10^{-5}$, $^{\circ}\text{C}^{-1}$.

‡The softening point is indicated.

TABLE 5. Volume of Production of Silica Brick and Its Service Life

Indices	Value of indices for the year				
	1974	1975	1976	1977	9 months of 1978
Volume of production, 10 ³ tons	5,2	9,3	13,2	15,3	15,3
Durability, No. of melts*	17,5	18,1	22,5	24,3	26,8

*The durability of mullite-silica brick (mean for 1973) was 18.3 melts.

Fig. 3. Microstructure of transitional zone of silica brick left) in contact with mortar joint (right): 1) quartz; 2) metacristobalite (structureless); 3) glass; 4) cryptocrystalline substance with incipient crystallization of mullite; 5) pores. ($\times 80$). Reflected light.

The experimental concrete artifacts were tested at the Chelyabinsk and West Siberian Metallurgical Works in the linings of 130- and 140-ton steel teeming ladles. The S and SC bricks were used to lay the ladle walls over the entire height of the lining; the SCh bricks were used for the upper (30–38th courses) and lower (1st–8th courses) lining sectors. The procedures employed in these factories were used to lay the bricks and dry the linings.

The S bricks wore uniformly without formation of hollows in the lower and upper ladle sectors. The bricks in the upper ladle sector exhibited spallation. Penetration of slag into the body of the artifacts was not observed. Their increase in size during heating ensured closure of the vertical and horizontal joints throughout the ladle campaign. The lining was monolithic. Wear did not occur over the joints.

The SC brick exhibited heightened erosion wear along the horizontal joints in the lower sector of the ladle; in the upper sector (above the 22nd course), as in the case of S brick, we observed spallation and intense wear in the slag belt (36–38th courses).

The SCh brick in the upper sector of the ladle displayed uniform wear and no spallation; it was similar to high-alumina brick as regards rate of wear. Wear of this brick in the slag belt was higher. In the lower sector of the ladle its wear was twice as intense as that of S brick.

The rates of wear of the different types of brick are given in Table 3.

Preliminary tests showed that silica bricks of S grade underwent less wear in the factories than chamotte and high-alumina (based on chamotte from Arkalyk clay) artifacts. The wear of the SC and SCh artifacts is similar to that of chamotte brick in the upper sector of the ladle; in the lower sector it was greater.

We then made a detailed investigation of the properties of silica brick of S grade and its preparation procedure; we selected the conditions for drying ladles lined with this brick and determined the durability of

the artifacts in individual sectors of the lining. The properties of the artifacts are given in Table 4 and Figs. 1 and 2.

The final scheme of the lining of the 142-ton ladles in No. 1 shop of the West Siberian Metallurgical Works (WSMW) envisages the use of S brick and mullite-silica artifacts; the ladle bottoms and the lower 35 courses of the lining are laid with silica brick. Chamotte mortar is used in the laying of these bricks. The regime for drying the lining is as follows: heating from 20 to 200°C for 2 h, from 200 to 400°C for 3-4 h, from 400 to 500°C for 1-2 h, and residence at 500°C for 2 h.

Table 5 shows the amount of silica bricks manufactured and the durability of the lining. The saving obtained by use of silica brick was 815,000 rubles per annum.

The brick was investigated after service. Under the influence of high temperature, fused metal, and slag the brick acquires a zonal structure (Table 6).

The transitional zone of the brick is brownish, dense, and sintered; it differs from the least altered zone by the partial degeneration of the fine-grained component into metastable structureless cristobalite. The large grains of the filler are broken by a network of cracks into acute-angled fragments and are surrounded by metastable structureless cristobalite (Fig. 3). The material of the joint, 4-5 mm thick, consists of a cryptocrystalline substance with an overall refractive index $N = 1.560-1.570$, slightly altered quartz grains, and a colorless vitreous substance.

The working zone exhibits intense degeneration of quartz into large pseudomorphs of metastable structureless and flaky cristobalite (Fig. 4). In the gaps between the pseudomorphs we observe a colorless and brown vitreous substance with a refractive index of 1.590-1.640. As the working zone gets closer, skeletal crystallization of secondary cristobalite is observed. The thickness of the joint decreases to 1-2 mm; in the joint we observe perfect crystallization of mullite and the overall refractive index of the cryptocrystalline substance increases to 1.580-1.585.

On the brick surface we observe formation of a slag crust (1-1.5 mm thick) consisting of a brown vitreous substance with a refractive index of 1.600-1.640. Pointlike beads of metal are observed.

TABLE 6. Mineral Composition of Transitional and Working Zones of Brick after Service

Zone	Zone thickness, mm	Phase composition, %				
		Quartz	metacristobalite	secondary metacristobalite	cryptocrystalline and colorless vitreous substance	brown vitreous substance
Lower courses of lining						
Transitional Working	15—16	65—70	10—15	—	20—25	—
	20—21	3—8	55—65	5—6	10—15	10—20
Upper courses of lining						
Transitional Working:	40—50	75—85	5—10	—	10—15	—
	20—21	50—60	25—35	—	10—15	1
	7—8		65—75	8—10	—	15—25

* The petrographic investigations were performed by T. I. Boriskova.

Fig. 4. Microstructure of working zone of silica brick: 1) metastable flaky cristobalite; 2) glass; 3) secondary cristobalite. ($\times 80$). Reflected light.

On the basis of the foregoing, the character of wear of silica artifacts can be represented as follows. When heated to 600°C the large grains crack and highly viscous silica glass is formed in the binder. With a further increase in temperature the quartz is regenerated as the high-temperature modification and then passes completely into the glass, preventing penetration of metal and slag into the lining. As a result of the increase in size of the artifacts the working surface is self-compacted. In the upper sector of the ladle not all the quartz passes into the glass and we therefore observe spallation of the concrete over the weak distended zone.

CONCLUSIONS

The authors have investigated ladle artifacts of silica, silica-clay, and silica-chromite compositions based on a chemical binder. They have established that silica brick without additives exhibits less wear during service.

Brick manufacture has been organized at the Pervouralsk Dinas Works. The bricks are used to line 142-ton steel teeming ladles of the West Siberian Metallurgical Works. The durability of a lining made of silica brick (26.8 melts) was higher than that of a lining made of mullite-silica brick (18.3 melts).

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