CONCLUSIONS

The wear of alumina—graphite immersion nozzles is greatly affected by the amount and type of fluxes in the composition of the slag-forming protective mixtures. In terms of the increasing corrosion capacity, fluxes are arranged as follows: calcium chloride, fluorspar, cryolite, sodium nitrate. With a content of more than 6-8% fluxes, the degree of wear sharply increases.

With a rise in the fabrication pressure and hence a reduction in the porosity, the resistance of the refractories increases.

In the contact zone for slag and refractory, penetration of slag into the refractory occurs, as well as oxidation of the carbon by active oxidizing agents (FeO, MnO), and the formation of fusible eutectics. The solution rate of refractory in slag melt increases with a change from a fixed specimen to a rotating one.

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DESTRUCTION MECHANISM OF BASIC REFRACTORIES IN FLAME FURNACE ROOFS

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Previously a study was made of the mechanism of destruction in aluminosilicate refractories as a function of the concentration of main oxide (Al_2O_3) [1], which clarified the chief properties determining the suitability of using them in roofs of flame kilns and furnaces. However, from comparative tests of aluminosilicate and basic refractories it was found that the latter have advantages [2] which indicates that they might be prospective materials for use in such sites.

To clarify the requirements of experimental work connected with improving the quality of basic refractories used for lining flame furnaces, the authors studied the destruction mechanism of magnesia—spinel products after they had been tested in the roof of a flame furnace.

The annular structure of the roof was made from MKhS and PShS articles, and included 22 rows from the water-cooled ring up to the seal of a plasmatron. Tests were made in conditions of a neutral atmosphere with a low concentration of smelter dust in the subroof region of the furnace. The most typical temperature of the working surface in the lining is in the center and periphery of the roof which was maintained during the entire campaign and is shown in Table 1.

Observations of the state of the working surface of the roof lining during operations showed that the main type of wear is cracking of the articles and their subsequent scaling in pieces measuring 25-50 mm. The external appearance of articles taken from the center and periphery of the roof after 61 heats is shown in Fig. 1.

TABLE 1. Temperature Schedule of the Working Surface of the Roof Lining from Experimental Refractories in a Flame Furnace during Melting

Lining section	Temp. at end of melting, °C	Temp. gradient across lining thickness (0-50 mm) in period of restoring thermal equilibrium	Temp. of lining during movement of the bath being charged, °C
Near plasmatron	1830—1850	9,4—10,5	850—750
At periphery of roof	1740—1760	8,5—9,3	700—600

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TABLE 2. Extent of Zones and Sizes of Periclase Crystals in Roof Articles after Service in a Flame Furnace

No. of specimen (see Fig. 1)	Zone	Extent of zone, mm	Size of periclase crystals, μm
1	Least-changed	Не опр.	80—100
	Transition	40—45	150—200
	Working	8—10	230—250
2	Least-changed	30—33	80—100
	Transition	55—60	120—250
	Working	10—12	300—350
3	Least-changed	25—27	80—100
	Transition	60—65	150—350
	Working	12—15	400—450
4	Least-changed	20—22	80—90
	Transition	65—70	120—300
	Working	12—15	450—500

All the articles taken after testing were sawn with a diamond wheel perpendicularly to the heating surface followed by polishing and grinding to make sections. The specimens were studied in reflected and transmitted light using immersion preparations and chemical etching with HF.

A typical feature of the extracted articles is the faintly expressed zoned structure compared with similar refractories from ordinary electric-arc furnaces [3, 4]. As shown by chemical analysis, this fact is linked to a large degree with the low input of fluxes from the melting region of the flame furnace.

Owing to the poorly expressed zonal structure, the zone boundaries were established by microscopic study on the basis of structural-phase features. As the boundary between the least-changed and transition zones, we selected a section showing marked enlargement in the periclase crystals, a reduction in porosity in the bond mass, and a sharp increase in the silicates concentration.

On the boundary with the working zone we noted the appearance of reaction ferrospinel, a sharp reduction in the amount of silicates and structural transformations connected with additional sintering, and selective growth of periclase crystals.

TABLE 3. Chemical Composition of Refractories PShS and MKhS after Service in the Roof of a Flame Furnace

Distance from working surface, mm	Weight parts of oxides, %						
	SiO_2	Fe_2O_3	CaO	MgO	Cr_2O_3	$Al_2O_3+TiO_2$	MnO
				Specimen No. 1			
3	2,68	7,80	1,82	66,73	13,74	4,15	2,79
9	3,90	5,61	2,14	68,46	14,47	4,15	1,29
18	3,04	6,08	3,46	68,74	13,74	4,09	
27	4,68	5,61	3,76	67,16	13,86	4,15	
36	6,48	5,22	5,27		Not determined		
45	6,76	5,03	5,44		»	»	
54	7,68	5,13	5,77		»	»	
				Specimen No. 2			
3	2,18	5,84	1,15	76,28	8,27	4,15	1,36
9	2,92	4,38	1,82	77,72	8,03	4,09	1,63
18	3,40	4,14	2,14	77,42	9,00	3,89	0,68
27	4,26	4,38	2,81	77,38	8,27	3,08	0,34
36	5,44	3,95	2,60		Not determined		
45	6,12	3,39	3,40		»	»	
54	7,29	3,95	4,75		»	»	
				Specimen No. 3			
3	0,93	7,80	1,42	66,53	14,36	6,63	3,13
9	3,47	5,97	3,14	66,81	15,96	4,56	0,59
18	3,10	6,34	3,07	66,68	15,92	4,29	0,77
27	4,55	6,34	2,51	67,55	14,87	4,43	0,10
36	5,28	5,80	3,74		Not determined		
45	6,20	4,94	5,10		»	»	
				Specimen No. 4			
3	2,92	7,80	1,77	71,09	9,07	4,45	3,15
9	3,91	4,87	1,65	77,44	7,74	3,50	1,21
18	5,21	4,14	1,82	79,08	6,92	3,23	
27	4,92	4,39	2,97	76,24	8,15	3,21	
36	5,05	3,71	2,91		Not determined		
45	5,68	3,48	4,25		»	»	

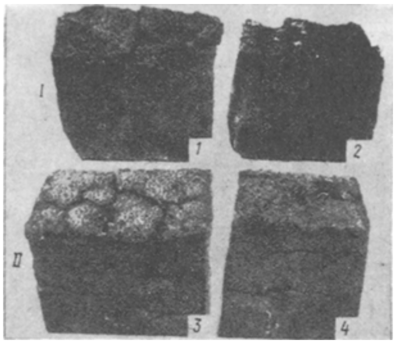

Fig. 1. External appearance of basic refractories from central (I) and peripheral (II) sections of the roof lining after 61 heats: 1, 3) articles PShS; 2, 4) MKhS.

Information on the developed zoned structures and dimensions of crystals of the main phases is given in Table 2. The zone formation increases from the plasmatron toward the periphery of the roof, although the temperature of operations diminishes in this direction (see Table 1).

The chemical and mineral compositions of the refractories across the zones are shown in Tables 3 and 4. The least-changed zones in phase composition are no different from the original articles. In the transition zones we identify two subzones of about the same extent "cold" contacting the least-changed zone, and "hot" contacting the working zone. In contrast to articles from other steel-melting units in the cold subzone of the articles from the lining of the flame furnace, we note the maximum amount of silicates, mainly easily fusible montichellite composition. Normally, in this subzone the amount of silicates is commensurate with their concentration in the original articles [4]. In the hot subzone the quantity of silicates diminishes by a factor of 1.5-2, and their composition alters in the direction of a sharp increase in forsterite content.

Unusual for the composition of working zones is the almost complete absence of silicates and ferrites of calcium, even directly on the working surface (not more than 1%). This reflects the low concentration of slag components in the furnace atmosphere.

The features of the microstructure of the zones are shown in Fig. 2.

The PShS refractory has microcracks in the least-changed zone, especially after service in the plasmatron. The nature of the cracks (narrow, horizontal orientation) indicates that they are probably formed as a result of the temperature gradient in the structure. These cracks are potential scaling horizontals. The thickness of such cracks is up to 0.08 mm.

In the transition zones of PShS articles the microcracking is reinforced. However, scale formation does not always occur since a significant part of the microcracks is filled with silicate melts (see Fig. 2b)

TABLE 4. Mineral Composition of MKhS and PShS Articles after Service in the Roof of a Flame Furnace

Minerals	Volume proportion of minerals in specimens across zones,* %											
	№ 1			№ 2			№ 3			№ 4		
	least-changed	transition†	working	least-changed	transition†	working	least-changed	transition†	working	least-changed	transition†	working
Periclase and secondary spinel (Mg, Fe) (Cr, Al, Fe)$_2$O$_4$	70	65/80	82	80	70/80	85	70	65/75	80	80	75/80	85
Residual chrome-spinel	15—17	14—16/8—10	3—4	10—12	10—12/10—12	7—8	16—18	15—17/12—15	8—10	10—12	10—12/10—12	4—5
Silicates	10—12	17—20/8—10	5—6	7—9	14—17/8—10	5—6	11—13	15—18/10—12	5—7	7—9	12—15/10—12	6—7
Including:												
forsterite	2—3	— /6—7	2—3	5—6	3—4/4—5	2—3	2—3	5—6 /4—5	1—2	5—6	4—5 /6—7	3—4
montichellite	8—9	17—20/2—3	2—3	2—3	11—13/4—5	2—3	7—8	10—12/6—7	3—4	2—3	8—10/4—5	2—3

*In working zones of specimens Nos. 1-4 there are 7-8, 2-3, 5-6, and 5-6% reaction ferrospinel, respectively.
† The numerator indicates the cold subzone, and the denominator — the hot.

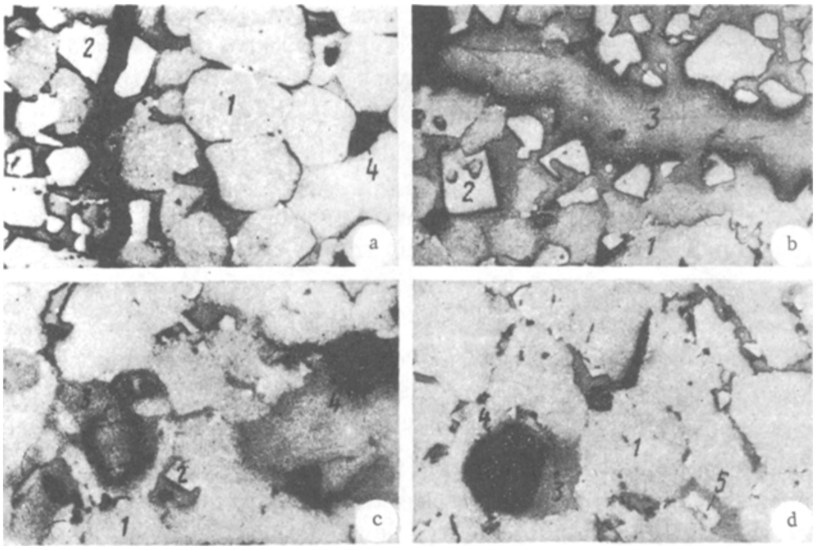

Fig. 2. Microstructure of specimen No. 1 after service in the furnace roof. a) Least-changed zone, b) transition zone, c) at a distance of 6 mm from the working surface, d) working zone. 1) Crystals of periclase with inclusions of secondary spinel, 2) residual chromite, 3) silicates, 4) pores, 5) reaction ferrospinel, × 100. Reflected light.

migrating from the hotter sections of the brick due to thermal flow. The silicate melt in these zones possesses a higher viscosity due to having temperatures close to the setting point; during cooling it, as it were, glues the cracked layer of the brick. This process is specific for the lining of flame furnaces and is due to the high heating of the working surface.

The negative role of silicates in the transition zones consists in reducing the high-temperature strength of the articles as a result of the separation of the periclase and chrome—spinel grains by the fusible monticellite melt.

The transition zones of the MKhS articles are also characterized by the higher macro- and microcracking. The cracks are partly filled with silicate. A distinctive feature is the tentative orientation of the cracks linking adjacent grains of chromite. As a result of the formation of a massive network of cracks, the refractory, as it were, is split into separate multifacets, i. e., volume fragments. This type of cracking in the transition zones is noted in conditions of sharp variation in temperature, and is useful since it suppresses local thermal stresses.

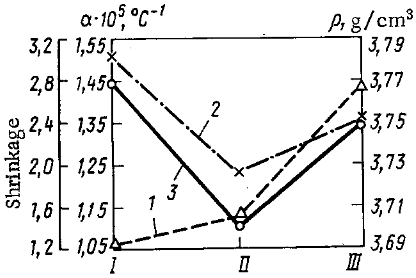

Fig. 3. Change in additional volume shrinkage (1), density ρ (2), and coefficient of linear thermal expansion α (3) over the zones of MKhS after service in flame furnace roof: I) hot subzone of transition zone plus working zone; II) cold subzone of transition zone; III) least-changed zone.

The working zones of the roof articles PShS and MKhS on the whole are identical and characterized by the formation of a developed crystalline growth of highly refractory phases — periclase and chrome–spinel (especially in MKhS); by the sharp reduction in the porosity as a result of additional sintering in connection with the mineralizing action of FeO, MnO, and the high-temperature action of plasma; and the small additional recrystallization of periclase (so much so that the crystals cannot grow out).

The chemicomineralogical and structural inversions in the refractory under the action of working conditions give rise to changes in the physicomechanical properties of the different zones (Fig. 3). The properties are determined on specimens measuring $10 \times 10 \times 55$ mm cut from the corresponding zones of MKhS articles after service.

The additional shrinkage of the zones during heating to 1800°C with a soak of 1.5 h is reduced in the direction from the cold to the hot part of the brick. The density is reduced in the cold subzone as a result of the increased concentration of fusible silicates and increases in the hot subzone and working zone on account of the content of iron oxides. Similarly, there is a change in the coefficient of thermal expansion of the zones.

Consequently, beside the temperature gradient, the formation of cracks in the refractory contributes, on the one hand, to additional sintering of the hotter part of the brick (usually in the limits of the hot subzone of the transition zone), and on the other hand, to stresses developing on the boundary of the zones as a result of the difference in their expansion coefficients.

In this connection on the boundaries of the hot and cold subzones of the transition zone, and also the transition and least-changed zones, the stresses due to the temperature gradient, and the internal stresses caused by the difference in α are summated and normally here we observe the formation of cracks, and moreover the scalings predominate (see Fig. 1).

This wear mechanism in the brick is typical of its service in the roof lining, but the rate of these processes in separate sections varies and diminishes from the center of the roof to the periphery. Additional destruction is also possible in the articles in the zone showing maximum accumulation of silicates when the local concentration of mechanical forces in the structure, with a certain noncorrespondence of the configuration of the roof and roof bricks, exceeds the high-temperature strength of the refractory in this zone.

CONCLUSIONS

The main form of wear in MKhS and PShS bricks in the roof of a flame furnace is the formation of cracks at a distance of 25-50 mm from the heating surface, located in a parallel plane, and their subsequent scaling. Scaling on the boundary of the zones occurs under the action of stresses due to the temperature gradient in the thickness of the brick, and internal stresses caused by direct difference in the coefficients of thermal expansion of these zones.

The advantage of MKhS bricks is the better adaptability of the structure to stresses in the presence of fragments (elementary volumes) which have a certain capability of independent displacement under thermal loading. In connection with this, the lining of the roof of flame furnaces should be made of magnesia–spinel refractories possessing the maximum possible thermal-shock resistance with a strength that is satisfactory for the service conditions.

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