REFRACTORY CONCRETES OF A NEW GENERATION: RELATIONSHIP BETWEEN THEIR COMPOSITION, STRUCTURE, AND PROPERTIES

Yu. E. Pivinskii

The superior service properties of the recently developed refractory concretes (ceramic concretes (‘keramobetons’), low-cement refractory concretes (LCRC), or vibrocast thixotropic refractory bodies (VCTRB)) are ensured during the stages of planning and production by selecting all the raw materials and the composition of the concretes properly taking the service conditions into account. The refractory concretes are capillary-porous composite materials whose strength, deformability, thermal shock resistance, and resistance to melts have a regular relationship with the structure. The structure of a concrete owes, in turn, to its composition, the properties of the original components (the type of the binder, the additive, and the filler), the technological parameters maintained during its production, the conditions under which its subsequent setting (or drying) is carried out, and the regime of heating up to the service temperature.

Specific Features of the Structure. Refractory Concretes Containing Coarse (Lumpy) Fillers. In general, two main types of structures can be identified in the refractory concretes of the classes under study [1-4], viz., a microstructure showing the internal structure of the binder or the matrix phase and a macrostructure revealing the components of the binary system (the binder and the filler). Drawing an analogy from the classification of structural concretes [5], the concept of mesostructure can be used for the refractory concretes having a discontinuous granulometric composition [for example, with a fine (0.1-1.0 mm) and a coarse (5-10 mm) filler]. In the case of structural concretes, the term ‘mesostructure’ implies the structure of their cement-sand solution (mortar) [5]. In the given case [1-4], mesostructure means the structure of the system consisting of a binder and a fine filler. The macrostructure of the concrete is similar to its mesostructure.

The contact regions (boundaries) between the filler and the matrix (binder) play an extremely important role in the structure of the refractory concretes. The characteristics of these regions are determined to a large extent by the properties (in particular, the porosity) of the filler. The presence of a porous filler leads to the exchange of moisture between its grains and the shell of the binder [6, 7]. According to the schematic shown in Fig. 1, the layer of direct contacts between the filler and the binder is located at the center. A part of the binder enters the pores of the filler and is adsorbed ('accumulated' in analogy with the process of slip casting) at the surface of the filler 1 [8] to form a layer 2 whose thickness increases with increasing ‘active’ porosity of the filler [7, 8]. The grains of the porous filler that are surrounded by the monolithic contact layer intergrown with the contacting material appear as if they are fixed inside a dense and strong ring [6]. Owing to this, the bond strength attained across the interphase boundaries (interfaces) exceeds that obtained in the concretes containing dense (pore-free) fillers. In a number of cases, this leads to an increased strength of the concretes obtained using porous fillers. Thus, as was shown earlier [9], the strength of the binders (castings) based on the highly concentrated binder suspensions (HCBS) of the mullite system containing a porous chamotte high-alumina filler is higher than that obtained when using a filler having a similar size distribution but consisting of porefree electrocorundum.

The most important characteristics of the concretes include their pore structure [2, 7]. The concrete mixtures invariably contain some quantity (volume) of entrapped air that is initially adsorbed at the surface of the grains of the binder and the fillers and is not removed during mixing and vibratory molding. Usually, these pores have sizes ranging from 0.1 up to 1.5 mm. According to our previous studies [10], the content of the gas phase in the molding mixtures of the mullite—corundum ceramic concretes to 3-5%. It is assumed that the spherical gas inclusions have a favorable effect on the thermal shock resistance of the concrete due to their ability to localize (arrest) the developed cracks.
In the refractory concretes obtained using dense fillers, sedimentation-pores can form due to external and internal dehydration. During external dehydration, a part of the sealing water flows around the filler grains, moves upwards, and goes out and the remaining water accumulates under the filler grains and saturates the contact zone (internal dehydration). These pores have a size of 0.05-0.1 mm. They can have a negative effect on the service characteristics of the concretes.

We note that the parameters of the pore structure undergo significant changes during the course of drying and heating and, also, during their service. This was demonstrated on the low-cement refractory [11].

The granulometric composition of the refractory concretes is one of the most important factors having a significant effect on their structure.

When obtaining very large and thick-walled monolithic refractory linings, the concretes additionally containing a coarse-grained refractory filler can be quite promising. In the common concretes, the maximum grain size of the filler $D_{\text{max}}$ is in the 5-10 mm range [4]. On the other hand, in the concrete containing a coarse-grained filler having a discontinuous granulometric composition, $D_{\text{max}}$ can be $\geq 50-150$ mm, i.e., an order of magnitude higher. In conjunction with the other merits of the system, this makes it possible to increase the filler content of the concrete significantly (and to decrease, thereby, the cost) since the concrete mixture of a conventional composition moves freely into the gaps of the coarse-grained (lumpy) filler. The effectiveness of the refractory concretes under consideration has been established in several types of concretes, viz., the conventional refractory concretes [12], the ceramic concretes [7, p. 224], and the low-cement refractory concretes [13]. When preparing and repairing the bottom linings of steel-teeming ladles using a cast siliceous concrete based on a liquid glass binder, Siminov et al. [12] introduced lumps of the spent concrete having a size up to 300 mm (up to 40% of the total weight) into the binder system. In this case, the lumpy filler moves into the as-prepared concrete under its own weight (sometimes, it is forced in).

As a result of prior service, the pieces of the spent concrete assume a well developed zonal structure. In the layer of the freshly prepared concrete, their zonality is characterized by multidirectional orientation and does not coincide with the zonality of the concrete formed freshly parallel to the heating plane.

Introducing the filler in the form of lumps leads to a decreased growth of the concrete during the process of heating and to compression during the cooling process owing to the presence of transformed quartz in them. The lumps of the filler divide the layer of the as-prepared concrete into relatively small separate regions throughout the volume; even if cracks are developed in these regions, they would be localized in the gaps existing between the lumps. Besides this, the lumps of the spent concrete whose size exceeds the thickness of the working and the sintered zones (40-65 mm) reinforce the structural zones of the cast lining and hinder not only crack nucleation but also layering and falling-out of the upper layer of the concrete lining from an inverted ladle. Owing to this, it is possible not only to decrease the specific consumption of the refractories but also to improve the service life of the linings.

In order to obtain large-size monolithic linings, a ceramic concrete consisting of an ordinary ceramic concrete mixture and a ‘vibrosunk’ coarse (100-150 mm) refractory filler (scrap) was suggested. In a similar concrete that is called ‘ceramic stone concrete’ [7, p. 224], the supplementary coarse filler can fill up to 40-50 vol. %. This, in turn, decreases the consumption of HCBS and the moisture content of the concrete and, thereby, makes it possible to reduce the duration of the