REFRACTORY CONCRETE WITH PHOSPHATE BINDER
FOR HIGH-TEMPERATURE INDUCTION HEATERS

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Industrial induction heaters are lined with refractories in the shape of rings or segments set into the coils. The useful life of these heaters is three to six months [1].

The life of induction heating coils operating at temperatures up to 1300°C can be increased to three years by embedding them in concrete prepared with sodium silicate binder from Portland, alumina or high-lumina cement [2, pp. 88-92, 103-106]. Heaters operating at temperatures above 1500°C are embedded in a super-duty refractory concrete using an aluminophosphate binder and high-alumina or corundum filler.

The hardening of such a concrete gives rise to the formation of mono-, sesqui-, and diphosphates of aluminum [3, pp. 52-60]. On heating the ultimate product of the reaction of the acid with the alumina hydrate is aluminum orthophosphate $\text{Al}_2\text{O}_3 + \text{P}_2\text{O}_5 = 2\text{AlPO}_4$. This compound is a crystal-chemical analog of alumina and possesses no definitive melting point. At temperatures above 1300°C the $\text{P}_2\text{O}_5$ begins to be rapidly sublimated from the aluminum orthophosphate and the compound melts at the melting point of pure $\text{Al}_2\text{O}_3$ (2050°C) [3]. This is the source of the high refractoriness of concretes with aluminophosphate binder.

It is held that among aluminum phosphates the best binder properties are those of compounds with an $\text{Al}_2\text{O}_3 : \text{P}_2\text{O}_5$ ratio of 1:3 to 2:3. These are amorphous vitreous water-soluble substances which harden when mixed with an olivinlite or with tale or asbestos. The concrete is usually hardened by heating to about 280°C.

American workers have shown [5] that orthophosphoric acid is a stronger binder than aluminum phosphates. Compounds with phosphoric acid were found to have an ultimate bending strength of 280 kg/cm² as against only 84 kg/cm² with aluminum phosphate. The composition recommended for a concrete hardening at room temperature is as follows: 35.8% corundum of grain size 1.4-0.3 mm, 8% corundum of grain size 0.3-0.04 mm, 35.8% active alumina, 12.8% orthophosphoric acid (85%), and 7.8% water.

In their search for a concrete suitable for embedding induction heater coils the present writers found that concretes based on orthophosphoric acid with electrolytically produced corundum acquire full strength only after a heat treatment at 400-600°C. There is no electrical insulation for coils which will withstand such a temperature.

The hardening temperature was reduced by adding active substances to the composition which promote the formation of stable aluminophosphates at 250°C, e.g., 4% of fine-ground LT1 refractory clay and 18% fine-ground kyanite-sillimanite concentrate.

Trials with several concrete compositions yielded one which attained maximum strength after a heat treatment at 250°C and did not lose it as a result of moisture absorption (hydration of incompletely substituted aluminum phosphates) during a ten-day exposure to a humid medium. The optimum composition of this concrete is 50% high-alumina grog, 28% No. 6 electrolytically produced corundum, 4% fine-ground refractory clay, 18% fine-ground kyanite-sillimanite concentrate, and 20-23% (on 100%) orthophosphoric acid.

The refractoriness of this concrete is above 1700°C, the temperature of the onset of softening under a load of 2 kg/cm² is 1550°C, that for 4% compression 1620°C and for 40% compression 1660°C. The bulk weight of the concrete is 2.6 g/cm³ and shrinkage is 0.55% after heating to 800°C while after heating to

Fig. 1. Induction heater coil embedded in super-duty refractory concrete with phosphate binder.

Fig. 2. Hearth of induction-heated smelting furnace made of super-duty refractory concrete with phosphate binder.

1000°C no change occurs in the volume of the specimen. The thermal conductivity of the dry concrete is 1.3 kcal/(m·h·deg) and is not affected by the firing process.

The reaction giving insoluble aluminum phosphates was produced by continuing the heat treatment at 250°C for eight hours. The ultimate compression strength of the heat-treated concrete was found to be 400-500 kg/cm² and remained unaffected by storage in humid conditions. The concrete should not be heat-treated at a temperature below 250°C. Though of the required strength, such a concrete deteriorates owing to moisture absorption from the atmosphere. Too short a holding time at 250°C will also cause deterioration after ten days exposure in air. At a treatment temperature above 250°C the insulation of the heater coil embedded in the concrete is destroyed.

Laboratory tests were conducted with two copper tubes 32 mm in diameter and 260 mm in length embedded within a wooden mold in concrete with phosphate binder. They were first provided with electrical insulation.

The concrete was compacted in the mold by layerwise vibration. The specimens were at once placed into a drying chamber where they were subjected to heat treatment at 250°C for eight hours. After the treatment the insulation was found to be embrittled but its insulation properties were intact. When the heat treatment temperature was 300 and 400°C the insulation of the tubes was brittle, fragmented, and devoid of insulation properties.

In 1970 a plant producing electrothermal equipment embedded an induction heating coil, furnace hearth, and base in concrete for operation at 1800°C in the presence of fluorine (Figs. 1 and 2).

The inside diameter of the coil is 600 mm along the concrete, the outside diameter 800 mm, and height 600 mm, the turn spacing 10 mm, and the thickness of the inside layer of the concrete lining 15 mm.

The concrete was prepared from the following materials: high-alumina grog containing 66% Al₂O₃ with a grain size distribution of 15-20% 5-3 mm, 25-30% 3-2 mm, 30-40% 2-1 mm, and not more than 20% finer than 1 mm; No. 6 electrolytically produced corundum, and fine-ground LT1 Latnen refractory clay.

The kyanite-sillimanite concentrate used was a waste product from the Verkhne-Dneprovskii Metallurgical Plant and had a grain size distribution of 50% of 0.15-0.088 mm and 50% finer than 0.088 mm.

The orthophosphoric acid was proportioned into the prepared mixture in dilute form (density 1.579 g/cm³). The concrete was mixed in an S-742V mixer in the following sequence: weight-proportioning the components as calculated (for 100 kg concrete) to a precision of ±2%; thorough mixing of the fine-ground clay, kyanite-sillimanite concentrate and corundum with the high-alumina grog; adding the orthophosphoric acid and mixing to complete homogeneity.

Before the embedding process the coil tube was thoroughly cleansed of copper oxides, reduced to the required size, coated with K-47 lacquer, and dried in air at 25-30°C for six to eight hours. This operation was repeated three times after which the coil was coated with KO-911 enamel, dried first in air in