Influence of aggregate type on thermal resistance and 4% load stress temperature of heat-resistant lime-slag concrete

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Abstract. A most promising development direction of heat-resistant concrete is the development of heat-resistant concretes based on lime-slag binder with highly-aluminous slag aggregates. One of the main process development directions of heat-resistant concrete for products with increased heat resistance is the lowering of the contents of expensive components: aggregates, binders, hardeners and powdered additives by various industrial wastes. Such replacement could significantly reduce the prime cost of heat-resistant concretes, and in some cases increase their operating temperature and durability. Based on experimental studies, efficient compositions of heat-resistant lime-slag concrete has been developed, based on chamotte, slag from aluminothermic ferrochromium and ferrotitanium process, with 1100-1300°C operating temperature.

1. Introduction
The most efficient heat-resistant concretes with high initial and residual strength, and high thermal resistance, are concretes based on liquid glass and lime-slag binder [1,2]. The operating temperature of such concretes is dependent upon the aggregate type [3,4]. The most thoroughly studied concretes based on lime-slag binder are concretes with blast-furnace slag or chamotte as binders [5]. However, such concretes have poor heat resistance properties. Heat-resistant concretes based on aggregates of aluminothermic process slags have low thermal resistance $T_2 = 5-10$, whereas those based on chamotte aggregate have high thermal resistance $T_2 = 15-20$ [6-9]. It allows an assumption, that heat-resistant lime-slag concretes based on mixed aggregate of aluminothermic process slags and chamotte could have optimum specifications: operating temperature and heat resistance.

In order to determine the influence of the consumption of ferrochromium slag (FCS), caustic soda NaOH and the aggregate type – chamotte, slag of aluminothermic smelting of ferrochromium (MCS), slag of aluminothermic smelting of ferrotitanium (FTS), as well as of aggregate mixtures on the basic physical and mechanical specifications of heat-resistant concrete, a full factorial experiment was conducted.

2. Experimental

2.1. Materials
For lime-slag heat-resistant concrete generation, the following materials were used:
• FCS from the process of OJSC “Chelyabinsk Electrometallurgical Integrated Iron and Steel Works”;
• MCS and FTS from the process of JSC “UK “RosSpetsSplav-Group MidUral” Kluchevsky Ferrous-Based Alloy Works;
• technical caustic soda, flake-grained, made by JSC “Bashkirian Soda Company”;
• refractory chamotte blocks of ШГР-28 code, by ООО “Mechel-Materials”;
• utility water.

The proportion of the aggregates chamotte and MCS (or FTS) was varying from 0:100 % to 100:0% with 50% (wt) pitch. The aggregate had been preliminarily sieved into 4 grain sizes 0-0,16; 0,16-0,63; 0,63-2 and 2-5 mm [10]. The proportion of the aggregates was selected for minimum density.

2.2. Sample preparations

During the selections of concrete compositions, the sealing compound and FCS quantities were varying, based on the stipulation of obtaining equal concrete-mix consistency. In order to maintain the equal consistency of the concrete mix while reducing the metering quantity of FCS, equivalent quantities of aggregate of 0-0,16 mm grain size were introduced.

For the assessment of the thermal resistance of lime-slag concretes sample cubicles were made with 7 cm edge length. For measurements of 4 % load stress temperature, sample cylinders were made with 36 mm dia., 50 mm height.

The hardening of the samples took place in a thermal treatment chamber without air circulation and without maintained constant humidity. The humidity inside the thermal treatment chamber was maintained by the quantity of water evaporating from the concrete mix surface poured in moulds. To reduce the humidity loss rate, the concrete mix surface in the moulds was covered with thermally resistant film [11,12]. The temperature rise rate within the range of 20-60°C was 20°C/h, whereas in the range of 60-120°C it was 15°C/h. The temperature value 120°C was selected for maximum strength gain. The isothermal exposure at 90°C was 5 hours, and 8 hours at 120°C. The thermal treatment was selected by experiment in the course of the study proper.

2.3. Statement of Method

The thermal resistance and the load stress temperature were determined based on the method of GOST 20910-90 “Heat-Resistant Concretes. Engineering Specifications”. To determine the 4 % load stress temperature, a strain was generated equal to 0,2 MPa – equivalent to medium density concretes of 1500 kg/m³ and in exceed thereof.

3. Results

3.1. Thermal resistance

Figure 1 shows dependences of the influence of the contents of NaOH, FCS vs aggregate type on the thermal resistance of heat-resistant lime-slag concretes.

The thermal resistance of a lime-slag concrete with chamotte aggregate is very high, reaching up to 82 cycles. If chamotte is replaced by MCS an abrupt decrease of thermal resistance is observed. A decrease of the thermal resistance in connection with the increase of the MCS share as chamotte replacement is the evidence of the increase of the difference of linear thermal expansion factors of the cement stone based on a lime-slag binder and of the aggregate, as well as that of the growth of the elasticity module of lime-slag concrete at increased higher-density particle contents.

An analysis of the obtained dependences demonstrates that the influences of FCS and NaOH quantities with mixed chamotte and FTS aggregate, and pure FTS aggregate are identical as to the increase or decrease of the physical and mechanical properties to similar dependences in mix compositions with MCS. The basic physical and mechanical properties of lime-slag concrete are also
significantly influenced not only by the quantity of the binder and the proportion of the components therein, but also by the aggregate type and the proportion of chamotte and FTS therein.

3.1. Heat resistance of heat-resistant lime-slag concretes with different aggregates

**Figure 1.** Dependence of the influence of the contents of NaOH, FCS on the thermal resistance of heat-resistant lime-slag concretes with different aggregates: a) 100 % chamotte; b) 50 chamotte : 50 MCS; c) 100 % MCS; d) 50 chamotte : 50 FTS; e) 100 % FTS.

3.2. 4 % load stress temperature

Figure 2 shows dependences of the influence of the contents of NaOH, FCS vs aggregate type on the 4% load stress temperature of heat-resistant lime-slag concretes.

The analysis of the results of the influence of NaOH and FCS quantities on the 4 % load stress temperature demonstrates, that the dependence is strictly linear, whereas it is inherent to any aggregate type. Increased quantities of FCS and NaOH lead to decreased 4 % load stress temperature values. Increased quantities of NaOH and FCS almost identically influence the 4 % load stress temperature, whereas an aggregate type change causes repeated phenomenon. Increased quantities of MCS and FTS
cause the 4%-load stress temperature to grow. The 4% load stress temperature at FTS aggregate is lower than the same at MCS aggregate but higher than the same at chamotte aggregate. The explanation of the phenomenon is that the quantities of refractory compounds in FTS are intermediate between chamotte and MCS.

Figure 2. Dependence of the influence of the contents of NaOH, FCS on the 4% load stress temperature of heat-resistant lime-slag concretes with different aggregates: a) 100% chamotte; b) 50 chamotte : 50 MCS; c) 100% MCS; d) 50 chamotte : 50 FTS; e) 100% FTS.

4. Conclusion
Based on theoretical and practical data, compositions of heat-resistant lime-slag concretes were selected, based on chamotte aggregates, slags of aluminothermic smelting of ferrochromium and ferrotitanium and mixtures thereof to determine their influence on the thermal resistance and the 4% load stress temperature.
Basic conclusions of the paper:

- Lime-slag concretes on chamotte basis feature higher thermal resistance values than those on FCS and FTS bases, however, the 4 % load stress temperature is significantly lower;
- Physical and mechanical specifications of lime-slag concretes based on a mixtures of chamotte and MCS or chamotte and FTS aggregates feature intermediate values between similar concrete specifications based on single aggregates;
- The 4 % load stress temperature of lime-slag concretes on FTS basis is lower than that of lime-slag concretes on MCS basis, whereas the heat resistance values feature a reverse tendency;
- By replacement of chamotte by aluminothermic process slags, the operating temperature of lime-slag concretes could be increased by 100-200°C;

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