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Influence of Fillers on Operational Properties of Heat-Resistant Composites on the Basis of Ground Slags and Clays

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Abstract

As a rule, composite materials, used for operation at high temperatures are multi-component systems, the most common components of which are a large-scale (or fine) filler and a binder. A binder often does not have high thermal stability. Therefore, in heat-resistant materials, a filler plays a special role, which is determined, in particular, by its type, dispersion and the degree of its material filling.

Keywords: heat-resistant composites, filler

1. Introduction

According to the obtained data the infilled slag-clay composites do not possess high thermal stability (6-8 cycles of water heat changes) with durability loss of 15-20% after calcination. In this regard, one of the research tasks was selection of an effective type of a filler and its content in a binder. A filler plays the role of a reinforcing component greatly enhancing the material's resistance at high temperatures [1, 2].

As for fillers and aggregates the authors tested conventional heat-resisting materials used in the refractory industry: broken chamotte bricks of various fractional compositions, chamotte sand Mgr=1,8, fine chamotte made from chamotte sand by grinding to get a specific surface of Ssp = 420 m^2/kg, technical alumina meeting the standard GOST 6912.1-93 with Ssp = 247 m^2/kg.

2. Materials and methods

In order to study the effect of a filler on changes of thermal-mechanical properties of a clay and slag binder the authors produced a series of samples on the basis of a clay and slag binder (CSB). CSB was produced from the Lipetsk fine granulated slag (Ssp = 320-350 m^2/kg) and the ground clay from the Issinskoe deposits in Penza region (Ssp = 500 m^2/kg). The content of the introduced filler varied in the range of 20-100% of the clay-slag binder's weight with 20% increments. The system was activated by the NaOH aqueous solution. The alkali content was 2% of the mixed binder's mass. The samples were prepared by pressing at the pressure of 20 MPa (mixture moisture-12%) and hardened under the air-humid conditions for 28 days.

The filler's effect on the strength in the dried state varies and depends on the type of the filler and degree of material filling.

The density of the dried up clay-slag samples with chamotte filler is within the limits of 1,85-2,1 g/cm^3, and the density of the structures with technical alumina - 1,56-1,65 g/cm^3.

The maximum durability indices are achieved through the introduction of fine chamotte in the amount of 60-80% of the binder's mass. The further increase of the fine chamotte content leads to the strength reduction. Chamotte sand weakens the structure of the clay-slag composite regardless of the filling degree: in the beginning, as the content of chamotte sand increases, the durability falls, and when its content in the system amounts 100% of the binder's mass, durability increases up to 54,4 MPa again. However, it remains lower than the durability of the unfilled clay-slag composite (60 MPa).

The introduction of broken chamotte bricks to the composite also affects the weakening depending on the filler's content. Among the fillers on the basis of broken chamotte bricks the lowest results in durability were displayed by fr. 0,3-0,6 mm, and the highest - by fr. 0,6-1,25 mm – up to 80 MPa.

High content of the technical alumina in the clay-slag material significantly reduces durability. Its strongest recession is observed at an increase of the alumina share over 40% of the binder's mass.

Thus, the fine chamotte with the content of 60-80% of the binder's mass and the broken chamotte bricks fr. 0,6-1,25 mm with the content 40-60% of the binder's mass are the most effective ones for durability improvement.

Broken chamotte bricks fr. 1,25-2,5 mm with the content in the system in the amount of 100% of the binder's mass appear to be of maximum efficiency in terms of thermal resistance improvement. In this case the heat resistance is at its maximum, which is over 70 cycles of water thermal cycling. Introduction of broken chamotte bricks fr. 0,6-1,25 mm and chamotte sand is less efficient, but with their 100% content the thermal resistance is in the range of 40-45 thermal cycles. A decrease in the grain size of broken chamotte bricks to less than 0,6 mm is inefficient as with any filler's content the thermal resistance of compositions doesn't change, as well as when fine chamotte is used.

The experiment findings have shown that the structure, containing an increased amount of coarse aggregate, is less vulnerable to thermal cycles collapsing.

With the application of broken chamotte bricks fr. 1,25-2,5 mm the samples had no large cracks even after 30 cycles of water thermal cycling.

The introduction of technical alumina into the clay-slag binder lowers the thermal resistance. The higher is the alumina content, the lower is the thermal resistance. Alumina is presented by γ-Al_2O_3 (40-76%) and α-Al_2O_3 (60-24%) and partially by β-alumina. Due to the fact that in alumina the transition of γ-Al_2O_3 into the α-form, which is bound to a significant change of volume, is not completed, this, probably is the reason why the rising temperature results in the inclusions' volume increase. It causes crack formation leading to structure weakening. In this regard, technical alumina was found to be an ineffective filler in the clay-slag binder.

The type of a filler makes a special effect on the change of durability after calcination. Some fillers do not reduce durability of samples after heating, and even promote its significant increase (up to 60% in certain cases). This effect is gained by the introduction of fine chamotte in the amount of over 60% of the binder's mass, chamotte sand (20-90% of the binder's mass) and broken chamotte bricks fr. 0,3-0,6 mm (20-80% of the binder's mass).

An increase of strength of the samples with charmotte fillers after calcination on the basis of CSB with chamotte fillers may be explained by binding of the free calcium oxide. This effect was studied on the portland cement concrete. According to the source [1], when heated up to 800°C the free calcium oxide in the cement stone is bound to a small degree; in the cement stone with chamotte addition, heated to 800°C, there is ≈60-90 % of the free CaO compared to the quantity that was in the sample, dried up at the temperature of 110°C. At the temperature of 800°C and higher the amount of the bound calcium oxide sharply increases. The cement stone heated to 1000°C contains ≈20-50%, and at 1200°C - less than 10% of the initial amount of the free calcium oxide. The experiment results processing enables to optimize the heat-resistant clay-slag structures. Apparently, the highest indices of operational properties can be received through using chamotte sand and broken chamotte bricks fr.1,25-2,5 mm as a filler (fig. 1, 2).

Fig. 1. displays that the best durability results can be achieved through the introduction of broken chamotte bricks fr. 1,25-2,5 mm in the amount of 60-80% of the binder's mass into the clay-slag binder.

In this case there may be provided the sufficiently high strength at compression – up to 50 MPa in the dried state, the high thermal resistance of 30 to 70 water thermal cycles with the loss of strength up to 50% after calcining. This composition could be recommended for use as the unloaded structures, due to the weakening indices being quite high, which complies with the state standard.

The introduction of chamotte sand to CSB in the amount of 80-100% of the binder's mass (fig. 2) will allow to use the received products as the loaded structures taking into account the influence of high temperatures. This result has been achieved due to high durability - over 50 MPa in the dried-up state, the high thermal resistance (40 cycles of water thermal cycling) with the loss in strength of 20% at most after calcination.

The comparison of the maximum strength values, its loss after calcination and the heat resistance allows to pre-select an area of the optimal degree of composition filling with chamotte fillers consisting of chamotte bricks (fig. 1, 2).

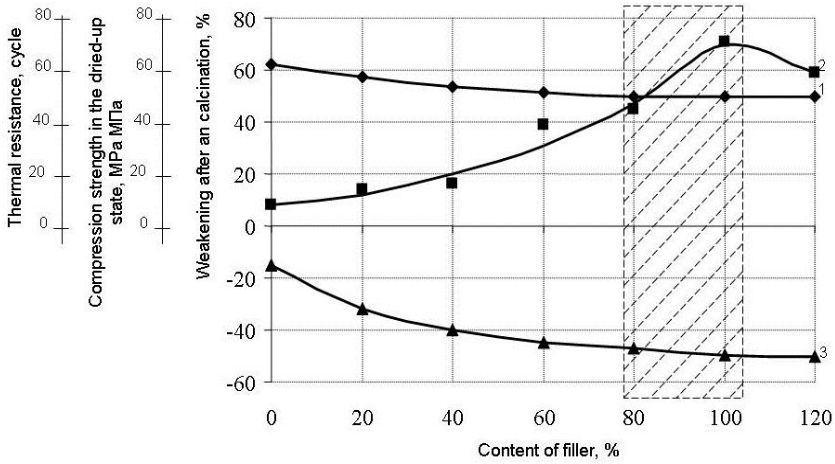

Figure 1: Optimization of the content of the heat-resistant material with the clay-slag binder consisting of broken chamotte bricks fr. 1,25-2,5 mm regarding its main operational properties.
1 - compression strength in the dried-up state, MPa
2 - thermal resistance, cycle
3 - weakening after calcination, %

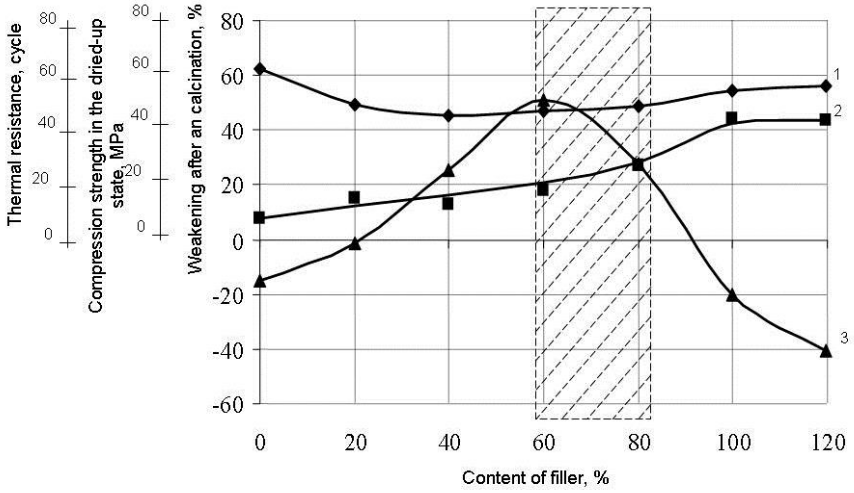

Figure 2: Optimization of the content of the heat-resistant material with the clay-slag binder consisting of chamotte sand fr. 0,14-2,5 mm regarding its main operational properties.
1 compression strength in the dried-up state, MPa
2 thermal resistance, cycle
3 weakening after calcination, %

Thus, in order to obtain the maximal durability there should be 60-80% of fine chamotte; 40-60% of broken chamotte bricks fr.0,6-1,25 mm. To ensure high thermal resistance when using broken chamotte bricks its content should be not less than 80%. The gain of strength during calcination is provided by fine chamotte and broken chamotte bricks fr. 1.25-2.5 mm with their contents, respectively, from 70 to 100% and from 20 to 90%. Apparently, optimization of the type and content of chamotte fillers must be carried out by means of mixes of various fractions: the system should include both fine chamotte and granular excipients.

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