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INVESTIGATION OF THE ULTIMATE STRENGTH OF PERICLASE-CARBON REFRACTORY MATERIALS AND ANALYSIS OF THEIR HIGH TEMPERATURE STRENGTH

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A setup for determining the ultimate strength of refractory materials in compression at high temperatures is examined. The value of the ultimate strength of periclase-carbon materials in compression in the temperature range 20 – 500°C are presented. The fracture process and strength are analyzed.

Key words: ultimate strength in compression, refractories, periclase-carbon materials, fracture, strength.

High-temperature plants are lined with refractory materials. In addition, the service life of many high-temperature plants is determined by the service life of the lining.

Optimization of the factors influencing the stability of the lining makes it possible to increase the working run of a plant several-fold. Even without changing the form of the refractory a significant result can be achieved by simply improving the operating conditions (temperature regimes).

Physical factors such as expansion and cracking arise in the case of thermal action on furnace lining. It becomes necessary to operate the plant continually without damaging the integrity of the lining in the working chamber and the technical-economic indices of the process.

To prevent the lining from being damaged by the stresses arising during heating it must be operated in a regime where stresses grow at a rate below their relaxation rate. It is important to calculate the values of the thermal stresses when calculating the rate of heating. The stress values calculated using computational relations are compared with the admissible values, and on this basis a conclusion is drawn concerning the rate of heating of the plant. The average heating rate of high-temperature plants is about 60 K/min [1].

The ultimate strength of the material is used in the calculations as the admissible value of the stresses arising with a change in the temperature field. Knowing the exact temperature dependence of the ultimate strength of the materials used it is possible to determine the maximum rate of heating of a plant (according to the conditions under which stresses arise).

The results of tests performed on carbon-containing refractories produced by 'Kombinat Magnezit' JSC are presented in [2]. The characteristics and the stability of the parts are indicated and it is noted that the refractories have a high resistance to thermal shearing in the presence of temperature fluctuations. It should be noted that the ultimate strength in compression (ranging from 19 to 61 MPa for different types of refractories) is presented only at temperature 20°C. Thus, the plant data do not show the dynamics of the change in this parameter as a function of temperature.

In the development of heating regimes for high-temperature plants the values of many parameters are constants, i.e., they are independent of temperature. For example, for calculations the specific heat capacity c, thermal conductivity λ and ultimate strength σ are often taken as constants. At the same time the value of the ultimate strength of a material in compression depends strongly on the temperature.

The temperature dependence of the ultimate strength of ceramic material used as lining is of great importance for the development of heating schedules for high-temperature plants.

A setup for measuring the elastic modulus and ultimate strength in compression, which is part of the IK-4 complex, is presented in [3]. This setup makes it possible to determine the strength in compression and the elastic modulus of molded materials and packed bodies. The ultimate strength and elastic modulus of fireclay refractory (ShB-5) are presented in this work. It is show that if at temperature 20°C the ultimate strength of a refractory material in compression is 20 MPa, then at 600°C the ultimate strength is 40 MPa. In addition, in the temperature interval 20 – 600°C the ultimate strength increases practically linearly, but after the maximum strength is reached at 600°C the value decreases to 5 MPa at 800°C.

A different picture is observed for dinas articles [4]. The ultimate strength in compression on heating decreases to

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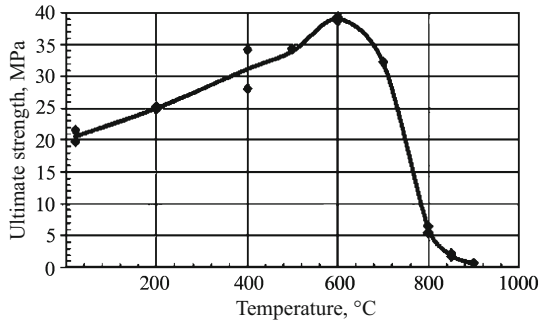

Fig. 1. Ultimate strength of a fireclay refractory (ShB-5) in compression versus temperature.

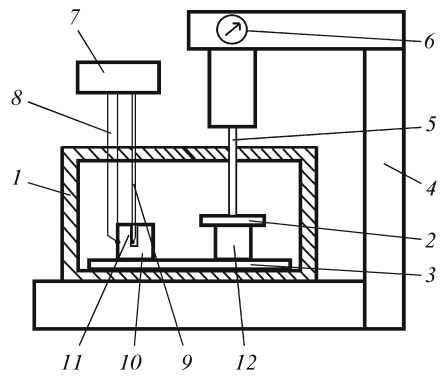

Fig. 2. Diagram of setup for performing thermomechanical tests on materials.

temperature 230 – 270°C, increases to 600°C and then decreases once again.

The authors of [5] present the dependence of the ultimate strength in compression at high temperatures for different refractory articles. The composition and thermophysical properties of the materials tested are not presented in [5]; this complicates the comparative analysis of the data obtained. The preliminary dependence presented for dinas refractories has extrema at temperatures other than those presented in [4]. The ultimate strength of magnesite refractories as a function of temperature tends to decrease evenly.

Since the thermomechanical properties of different types of refractories are different, when using refractories in high-temperature plants it is necessary to know such properties. For this reason the question of determining the temperature dependence of the ultimate strength for a particular refractory is pressing.

The problem of developing a method for determining the ultimate strength of materials at high temperature and finding the temperature dependence of the ultimate strength for periclase-carbon refractories was posed in this connection.

To solve this problem a procedure was developed and a setup was built to measure the ultimate strength of refractory materials at high temperatures [6].

A diagram of the setup for performing thermomechanical tests on materials is displayed in Fig. 2.

The ultimate strength in compression is measured as follows. Two identical samples in the form of a cylinder or rectangular parallelepiped are fabricated from the material being tested: control *1* and test *2* samples. A thermocouple *4*, whose hot junction is placed as close as possible to the geometric center (a channel *3* is drilled along the vertical axis up to half the height of the control sample), is placed in the control sample *1*. The thermocouple *5* for measuring the temperature on the surface of the control sample *1* is placed at any point on the lateral surface. The control sample *1* with secured thermocouples and the test sample *2* are placed inside the furnace *6* on the bottom plate *7*. Cylindrical samples are placed on any base, and samples in the form of a rectangular parallelepiped are place on any face.

The thermocouples are connected to a secondary instrument to measure the temperature — a summation device *8*, which shows the temperature t determined by the relation

$$t = \frac{t_1 + t_2}{2},$$

where t_1 and t_2 are, respectively, the indications of the thermocouple inside and on the surface of the control sample.

After the furnace *6* is switched on the temperature t which determines that the test temperature has been reached is followed. The temperature t is considered to be the test temperature.

After this temperature state is reached the test sample *2* is subjected to uniaxial stress by the press *9* by means of the forcing rod *10* on the top plate *11* up to fracture of the sample *2*. The load on the sample is determined from the force measuring setup *12*. The load must increase continually and uniformly at a rate ensuring that the sample fractures in 20 – 60 sec after the tests start.

The ultimate strength σ_c (N/m^2) of the test sample in compression is calculated from the relation

$$\sigma_c = \frac{P}{F},$$

where σ_c is the ultimate strength in compression, N/m^2; P is the largest load at which the sample fractures, N; and, F is the cross-sectional area of the sample, m^2.

When the ultimate strength is determined in compression the measurement accuracy is higher because the average temperature of the material and not the temperature near the mid-point of the surface of the sample is used as the testing temperature (unlike GOST R 50523–93). The setup for studying the temperature dependence of the ultimate strength in compression is shown in Fig. 3.

The test samples were periclase-carbon refractories with the composition MgO ≥ 80% and C ≥ 8%. The declared ultimate strength in compression equals 40 MPa (nameplate data from the manufacturer).

Fig. 3. Setup for measuring the temperature dependence of the ultimate strength in compression.

The ultimate strength was determined in the temperature range 20 – 500°C. The measurements are presented in Fig. 4.

The correlation coefficient of the relation presented was 0.966.

The temperature curve of the ultimate strength has the following tendencies: starting at temperature about 90°C the ultimate strength of the refractory increases to about 200°C, and then the value of the ultimate strength decreases evenly to 40 MPa (at about 400°C).

The temperature dependence of the stress in refractory materials is very complex, because not only reversible elastic deformations but only irreversible plastic deformations, which depend on the deformation time, occur.

The strength of refractories decreases with increasing temperature. This is due to an increase of the interatomic distances, weakening of interatomic bonds, the formation of a liquid phase and the appearance of plastic deformation. The formation of a liquid phase along crystal boundaries and between grains is the main factor responsible for the strength reduction in commercial refractories. As the liquid phase forms, the concentration of stresses in the material decreases and the mechanisms of deformation change from elastic to viscoplastic [7].

In this case the ultimate strength of the samples in the temperature range 150 – 300°C can be explained by a reduction of the total porosity at low temperatures with no chemical transformations.

The reduction of the ultimate strength on heating above 400°C is explained by onset of decomposition of magnesium hydrates, as a result of which cracks appear in the refractory and strength is lost.

The data obtained on the reduction of strength are confirmed in [8], where structural-phase changes occurred in magnesia refractories. Endo effects with extrema at 150 and

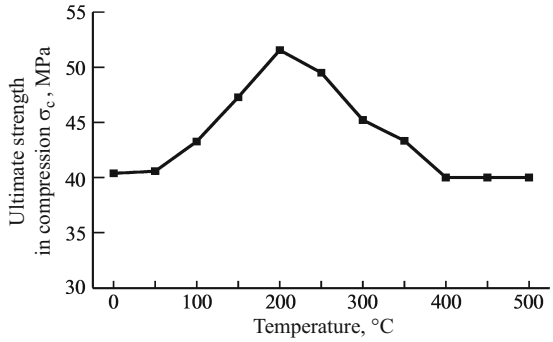

Fig. 4. Ultimate strength σ_c in compression versus temperature.

375°C were recorded on the DTA curve of periclase refractory. In addition, a distinct double endo effect due to mass loss at temperatures 550 and 615°C are recorded on the DTA curve. The first two endo effects were attributed to the removal of physically bound and crystallization water and the two high-temperature effects to dehydration of weakly crystallized magnesium hydrosilicates.

Our experimental data make it possible to talk about an increase in ultimate strength in compression in the temperature interval 150 – 300°C (to 20%) of the refractories studied, which gives an additional margin for increasing the rate of heating and decreasing the time and energy spent on the heating process.

The procedure and setup developed to determine the ultimate strength of materials at high temperatures make it possible to determine this thermophysical parameters with adequate accuracy.

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