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WORKING PROPERTIES AND USE OF REFRACTORIES IN INDUSTRIAL FURNACES

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The main reasons are considered that give rise to development of internal stresses in individual refractory components and a lining. The importance is noted of monitoring thermal expansion of a refractory during service, and also features of the behavior of monolithic linings on heating.

Refractory materials used in industrial furnaces and heating installations are subject to various forms of breakdown: fusion, deformation, cracks, separation, wear, chipping, etc. Under real conditions all of the factors listed operate, and therefore the choice of refractory material should be made after careful analysis of operating conditions for the heating unit and operation of the main factors that affect lining stability, and here consideration should be given to the production indices of furnaces operating under similar conditions.

In the majority of cases in studying the refractory characteristics of a standard brick specimens are cut from it for testing. The results obtained in this way determine with sufficient accuracy such properties as refractoriness, etc. At the same time these data are unsatisfactory for obtaining such properties as the magnitude of thermal stresses or thermal expansion, etc. This is connected with the fact that after laying individual bricks using a refractory mortar its physical properties as a whole will be markedly different from the properties of an individual object.

The amount of thermal expansion is the most important property of an individual brick. This index is evaluated from the results of tests by different methods:

measurement of the linear thermal expansion coefficient (LTEC). The results obtained are provided in the form of measuring the LTEC in relation to temperature;

determination of the temperature for the start of deformation under load. As a result of performing tests the maximum permissible operating temperature is established for the refractory material property. Here it should be noted that the amount of thermal expansion under load is normally less than linear thermal expansion;

evaluation of the amount of material creep. The ratio of the amount of deformation with respect to time is determined. In this case the overriding value is not the absolute amount of deformation, but the difference in deformation with respect to time;

determination of shrinkage with a reduction in temperature. In operating heating units under real conditions individual structural elements of a furnace are subjected to cooling both during furnace warm-up and also during termination of heating;

measurement of elasticity modulus values. The method consists of finding the relationship between the magnitude of load and the level of deformation. The index is taken as an absolute quantitative property, whereas a change in temperature for the start of deformation under load and material creep determine the relative level of deformation;

heat resistance testing determines the capacity of a material to resist internal thermal stresses that arise as a result of a temperature gradient without failing.

Thermal expansion properties determined for an individual brick should be used for calculating the behavior of a refractory lining as a whole.

These laboratory and industrial tests, in the course of which refractory resistance to a corrosive agent is determined, serve as the main choice of refractories. During furnace operation the lining gradually breaks down. Furnace lining resistance varies in relation to the type of furnace and it is an important economic index.

The theoretical possible maximum strength P_{theo} of a crystalline material is determined by the equation

$$P_{\text{theo}} = \sqrt{2E\gamma_1/a},$$

where E is Young's modulus; γ_1 is solid specific surface energy; a is lattice parameter. The approximation $\gamma_1 \approx 0.01Ea$

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is valid for refractory oxides, where $P_{\text{theo}} \approx E/10$. Taking $E \approx 105$ MPa, we find that $P_{\text{theo}} \approx 10^4$ MPa.

The difference between the theoretical and practical strength is explained by presence of numerous cracks and considerable stress concentration at the mouth of a crack. With an increase in load stress at a crack tip reaches the practical strength and the object breaks down. In this case the strength is:

$$P_{\max} = 2P_{\text{av}} \sqrt{\frac{l}{r}},$$

where $P_{\max}$ is the maximum stress at the crack tip; P_{av} is the average stress in the material; l is Griffiths crack length; r is crack radius of curvature.

The value of crack length is the same as crystal size, and r is equal to the size of crystal lattice atoms [$r \approx 0.1 - 0.4$ nm].

The refractory lining of industrial furnaces (melting and others) is normally made within a casing or framework. During thermal expansion of the refractory lining stresses arise that are transferred to the furnace casing. Here it is necessary to draw attention to the fact that the value of the LTEC only depends on bond forces between structural elements and it does not depend on the macro- and microstructure of objects. During lining failure the furnace framework also undergoes certain deformation.

One reason for failure of a refractory lining is insufficient monitoring of thermal expansion of the refractory lining. It reaches a considerable value when the mortar does not provide compensation for brick lining expansion or when a monolithic lining does not have expansion joints. For heating units, whose service life is determined by lining wear, such as converters, mixers, ladles, with correct fulfilment of expansion joints there is a marked increase in safety for lining failure and outflow of melt as a result of wear or local intense lining corrosion.

Apart from providing satisfactory jointing between individual refractory lining bricks, refractory mortars protect the lining surface from stress concentration under load. In designing a refractory lining it is necessary to select lining thickness precisely and with completion of the lining it should have uniform refractory mortar over the whole area of a brick in order to prevent stress concentration under load. Sine the refractory mortar is an element of a refractory lining it should fulfil the function of damping increasing stresses and redistribute expansion that occurs in individual lining bricks. Therefore determination of the strength properties of lining mortar with an increase in temperature is important in creating stable structures made of refractory materials.

In calculating thermal stresses in refractory materials it is not possible to derive a universal value for calculating furnace lining strength. It is desirable to calculate stresses that arise after installing a thermal insulating layer of a lining with a known ultimate strength in tension (compression) that absorbs thermal expansion of the refractory lining. This method facilitates furnace lining construction and its subsequent operation.

In view of expansion in the volume of the production of unmolded materials based on thixotropic mixes with low cement concretes there is extensive use in practice of monolithic linings. The advantages of these are primarily the absence of joints, more rapid assembly, high mechanization of the process, etc. in the new generation of concretes cement is partly or entirely replaced by additions of ultrafine materials whose typical size does not exceed 10 μm, including those that contain up to 1% of particles with a size of less than 0.1 μm whose fraction is up to 50% of the binder specific surface. In fact this class of particles within the composition of various unmolded mixes during laying of a lining forms a pore structure differing from that of molded objects. As a result of this assembly a finely porous, fine-capillary structure of monolithic concretes is formed. In spite of the low (5 – 6%) moisture content in this lining, its removal is difficult.

According to deformation theory for a thick-walled cylinder, for a monolithic lining of ideally elastic construction at the inner surface of a lining there is typically development of compressive stresses, whereas at the outer surface there will be tensile stresses. In this case it is important to provide total equilibrium between thermal expansion of the concrete used and a monolithic lining as a whole.

In this case lining material behavior is mainly determined by many factors, among which it is possible to separate the main ones:

- the density of component installation in a monolithic lining;
- conditions for removal of vapor from an evaporating component during heating;
- the dependence of material properties on temperature under plastic flow conditions;
- the effect of loading time, and also features o chemical reactions, setting (hardening) capacity, presence of transition to another physical state, etc.

Heat treatment of a monolithic lining requires observance of the necessary conditions, particularly for the temperature at its surface. Drying and heating of monolithic linings from a time and technical point of view are most complex processes in the course of lining preparation and subsequent operation.

There are simultaneously two processes with an increase in temperature for a monolithic lining: a reduction in surface tension and an increase in water vapor pressure in capillaries and pores, that in turn promotes an increase in surface tension. As a result of this water surface tension changes in relation to the process that prevails. With an increase in water temperature from 5 to 45°C surface tension decreases by a linear rule from 75.29 to 69.14 erg/cm^2 [2].

Depending on po re and capillary volume and their size, determined by cement composition and its preparation technology, these parameters will affect moisture removal, and as a consequence heat and mass transfer in a lining. Moisture evaporation from concrete occurs in the temperature range from 100 to 600°C since the pressure in capillaries and the transition temperature for water into steam depends on pore radius; the smaller pore radius in a monolithic lining, the higher the transition temperature for water into steam and steam pressure in capillaries. Since capillary pressure P_c, water surface tension σ and capillary radius r are connected according the Laplace by the expression $P_c = 2\sigma/r$, then pressure increases with a reduction in capillary radius. For example, with $r \approx 10^{-7}$ cm, pressure reaches 16.0 MPa. Therefore the total heat treatment time for a monolithic lining repeatedly exceeds normal lining drying duration. An attempt to accelerate heating causes an increase in steam pressure and it is the reason for "explosive" failure or monolithic lining delamination.

There are limits for the maximum rate of temperature drop for individual lining materials above which they are subject to thermal breakdown, K/min: graphite 500, chamotte (42% Al_2O_3) 5, high-alumina (85% Al_2O_3) 3 – 5, chromite-corundum 5; silicon carbide 30 – 50, cast iron 50, steel 100. thus, the collection of two processes during heating of a monolithic lining, i.e. "explosive" and thermal breakdown governs the temperature regime for heating a heating unit monolithic lining.

Correct selection of refractory materials, lining manufacture technology, analysis of possible reasons for lining failure taking account of structural features and processes that occur at high temperature, are important problems whose solution will make it possible to increase the operating life of heating unit linings.

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