DOI 10.1007/s11148-020-00386-3
Refractories and Industrial Ceramics *Vol. 60, No. 5, January, 2020*

INVESTIGATION OF THE DEPENDENCE OF REFRACTORY THERMAL CONDUCTIVITY ON IMPREGNATION WITH A CORROSIVE MEDIUM

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Translated from *Novye Ogneupory*, No. 9, pp. 50 – 54, September, 2019.

Original article submitted July 14, 2019.

Features of impregnation a corrosive medium for the working layer of the lining of rotary kilns and casting ladles for ferroalloy production are considered, and results are provided for analysis of the impregnation thickness. The change in the thermal conductivity of refractories after service is investigated on the basis of a developed and patented method. It is found that the thermal conductivity of the refractory material of an industrial furnace lining working layer increases (by 5 – 12%) due to refractory impregnation by a corrosive medium.

Keywords: fireclay refractories, impregnation with corrosive media, rotary furnace lining, pouring ladle lining, refractory thermal conductivity.

Refractory materials used in high-temperature units are selected for each a particular case, and the properties of refractories will relate to their declared specification only with constant composition. In new refractories, installed in heating units, impurity components are arranged in the binder part of a charge (matrix) for which there is normally refractory chemical corrosion. In the ideal case complete absence of impurities within the refractory composition is desirable since even a small amount (for example 2 – 3%) considerably worsens the refractory properties, and in particular it reduces corrosion resistance [1]. Apart from impurities, added to refractory materials during their manufacture, during operation of a high-temperature unit there is possible impregnation of the lining by a corrosive medium. The porosity of a lining working layer, high temperature, and connected with it low viscosity of a corrosive melt, facilitate this process.

Apart from deterioration of firing properties and a reduction in corrosion resistance of refractory materials a change in their composition leads to a reduction in strength and deterioration of thermophysical properties (thermal conductivity, heat capacity, etc.). In a number of works [2, 3] the main reasons for lining breakdown are considered to be impregnation of refractories by melt and formation of zones with different chemical composition and structure. Avoidance of impregnation of refractory object by molten slag and metal provides an increase in lining life by a factor of 1.2 – 1.5. A nonuniform capillary structure of refractories facilitates penetration of a corrosive medium into a lining and formation of zones with different chemical and phase compositions, and structure. A consequence of zone formation is a change in the LTEC in different refractory zones and as a consequence thermal spalling over boundaries of zones with a change lining temperature in the course of a production process or transition from one standard heating unit operating regime to another [3].

Thermal conductivity (as a component part of thermal diffusivity) enters into the calculation scheme of determining thermal stresses that limit the rate of a heating unit warm-up. In this case better material thermal conductivity which makes it possible to conduct warm-up at a faster rate [4]. Undoubtedly an important factor in this is the depth of penetration of a lining working layer, i.e., the refractory layer thickness with a change thermal conductivity. If it is considered that the maximum thermal stresses arise at the boundary of a refractory layer (from the warm-up side) and decrease through the thickness of a lining, then it may be suggested that impregnation of a working layer even to an insignificant depth will affect the warm-up process.

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Fig. 1. Start of the calcination zone in a thermogram.

Fig. 2. Chamotte refractory impregnation from calcination zone.

Therefore, in order to model thermal operation of a lining of a high temperature unit taking account of the effect of operating conditions it is necessary to consider a change in refractory thermophysical properties during action upon it of a corrosive medium. The effect of refractory impregnation on thermal conductivity is considered in this article.

ROTARY FURNACE LINING

In considering the thermal operation of a rotary furnace (on the example of a sintering furnace) it should be noted that the degree of impregnation of chamotte refractory in a lining depends in the position of the furnace length, i.e., on the furnace zone within it is installed.

In the drying zone impregnation of a lining working layer is hardly observed as a result of low temperature. The level of the temperature of the working surface is determined by the fact that heat fed to this zone proceeds in moisture evaporation, which limits surface temperature to 600 – 800°C.

In a heat-sensor thermogram for the start of the calcination zone is related to the highest point of the housing temperature (in the 50 m region of a furnace) up to the start of the sintering zone, i.e., 30 – 40 m (Fig. 1). The significant length of the calcination zone is due to the high thermal demand for the limestone decomposition reaction, i.e., about 425 kcal/kg, and until the charge receives this amount of heat material sintering is impossible. Therefore, for the calcination zone the temperature is fixed, i.e., it is possible only to talk about over the length of the zone. In the calcination zone a process is observed reducing the lining service life, i.e., degeneration of refractory in the upper part of the zone due to impregnation of chamotte with charge components. The depth of penetration of chamotte refractory from the calcination zone is shown in Fig. 2. In order to realize the impregnation process it is necessary that the temperature of the inner lining surface of the sintering zone was not below 1100°C.

Analysis of damaged lining in this zone shows that impregnation of the working layer is not a defining factor for refractory life. The main wear of the working layer of a lining proceeds as a result of spalling of chamotte refractory due to unsatisfactory behavior of non-steady thermal regimes

Fig. 3. Calcination zone lining after rotary furnace service.

Fig. 4. Rotary furnace surface thermogram with zone of insignificant lining burn-through.

(start-ups and stoppages). Spalling of individual lining elements proceeds to a depth on average by 10 – 20 mm, and for a number of refractories (Fig. 3) an overall area to several square meters.

The working layer of a lining in the sintering zone is under more favorable conditions as a result of the fact that it is sealed by a layer of skull. The actual wear of the lining in this zone is observed either at its beginning or in the zone due to absence of a layer of skull. Chamotte is classified as a neutral (semi-acid, semi-basic) refractory material that gives rise to its high degree of resistance in an alkaline medium, for this zone there is also typically one of the dangerous regimes, i.e., i.e., so-called burn-through of a lining, which is a result of combined action of high temperature (>1700°C) and alkaline melt. During action of melt on a lining over several hours it is possible to burn it over the whole thickness. This also facilitates low chamotte resistance towards reducing reagents, which are formed by a coal dust flame. A thermogram for a furnace surface is shown in Fig. 4 with a zone of insignificant lining burn-up.

The lining of the cooling zone is worn quite rapidly for two reasons:

– sinter contains alkaline liquid phase that leads to chemical wear of the working layer of a lining. However, as a result of low temperature in the cooling zone (surface temperature up to 600°C) this process quite slowly;

– for one furnace rotation the working layer of a lining in the cooling zone is subject to thermal shock (sinter at a temperature of about 950°C then air at a temperature of 300°C), which gives rise to flaky spalling of refractory.

Therefore, the resistance of a rotary furnace lining is determined by two factors: thermal and chemical actions. Action of temperature in this case is a more important factor, determining the period between furnace repairs.

FERROALLOY PRODUCTION UNIT LINING

Analysis of the state of the working layer of the lining of ferroalloy furnaces shows that all surface in contact with melt are almost uniformly covered with a layer of skull. A significant service life of a lining of a ferroalloy furnace and its continuous operation are factors for which the effect of lining impregnation on thermophysical and strength properties for refractory is not marked.

Fig. 5. Pouring ladle lining after three melts: *1*) coated by solidified metal; *2*) coated by solidified slag.

The lining of different ladles for ferroalloy production is made from chamotte brick grade ShKU-32 with thermal conductivity of 0.8 W/(m·°C). A lining with an overall thickness of 130 mm consists of two layers, each of half a brick. The binder used is a mixture of sand with refractory clay and water.

It has been established that the surface of the working layer of a pouring ladle lining for ferroalloy production is partly covered with deposited metal. Part of the lining, located above the level of melt in a ladle, is partly coated with a slag deposit (Fig. 5). Results of analysis of the state of refractory elements of a lining during operation have shown that already after the first two melts impregnation of refractory by melt is observed visually. The depth of melt penetration for refractory specimens of the working layer of a pouring ladle lining after three melts comprises 15 – 20 mm (Fig. 6). However, this does not have a marked effect on the thermal operation of a ladle lining due to the insignificant duration of a ladle campaign, consisting (for the working layer of a lining) up to 5 – 7 days (up to 20 melts). Action of temperature is a defining factor for the life of the lining of different ladles for ferroalloy production.

CHANGE IN REFRACTORY THERMAL CONDUCTIVITY

Impregnation of refractory material by a corrosive medium leads to a change in both its mechanical and also thermophysical properties, in particular an increase in thermal conductivity due to changes in material structure and also due to impregnation of a layer in contact with a corrosive medium and its particles. This occurs as a result the fact that as a rule working medium thermal conductivity is higher than that of the refractory material. In view of the fact that thermal conductivity plays a significant role in developing

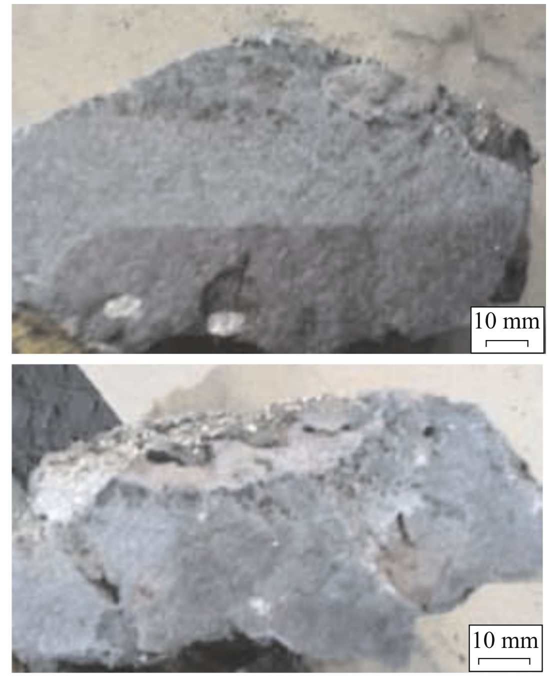

Fig. 6. Impregnation of refractory working layer for a pouring ladle lining after three melts.

warm-up curves for high-temperature units it is necessary to evaluate the change in refractory material thermal conductivity during use in high-temperature units.

Numerous methods have been developed in order to measure thermal conductivity; industry produces a number of instruments. In this case not all methods are suitable for determining refractory thermal conductivity with impregnation. With use of the method of a cylindrical probe, which is implemented in IPT-MG4 Zond thermal conductivity meter, it is not possible to obtain the data required. By means of the instrument it is possible to obtain local thermal conductivity for small areas, and in order to construct warm-up curves it is necessary to known the average thermal conductivity value for the whole refractory thickness.

In order to determine refractory thermal conductivity after partial service in a high-temperature unit (in order to take account of change in materials properties with consideration of impregnation) an experimental unit was created for measuring refractory material thermal conductivity at working temperatures. In order to improve measurement precision in the experimental unit two methods were combined: a regular regime method and a hot wire method. This is achieved by the fact a specimen is placed in a furnace within which it is heated uniformly. During heating instrument readings are recorded in order to calculate thermal conductivity by a method of a regular regime. For achievement of the required prescribed temperature level and a steady-state temperature field for a heated furnace space a voltage is fed to a heated wire and readings of the corresponding temperature are recorded [5]. This method is used to find values of thermal

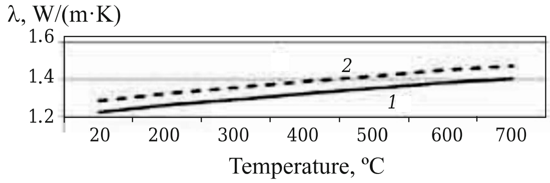

Fig. 7. Dependence of thermal conductivity λ of ShTsU chamotte refractory on temperature: *1*) ShTsU refractory before operation; *2*) ShTsU refractory after operation (8 months).

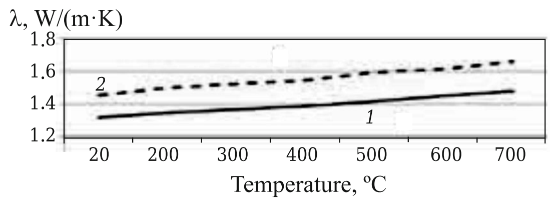

Fig. 8. Dependence of thermal conductivity λ of ShTsU chamotte refractory on temperature: *1*) ShTsU refractory before operation; *2*) ShTsU refractory after three ferrochrome melts.

conductivity of specimens selected from the working layer of a lining of different high-temperature units.

In order to study chamotte refractories (grade ShTsU) specimens were selected from the working layer of a sintering furnace lining during current repair (after 8 months of operation). The experimental data obtained before and after refractory operation are shown in Fig. 7. It is seen that after operation of ShTsU refractory within the working layer of a sintering furnace lining during 8 months their thermal conductivity increases by approximately 4 – 5%. In order to study ShKU chamotte refractories specimens were selected from the working layer of a lining of pouring ladles of ferroalloy production during intermediate repair after three ferrochrome melts. The data obtained (Fig. 8) show that after three ferrochrome melts ShKU refractory thermal conductivity increases by about 10 – 12%.

Therefore, it has been demonstrated by experiment that operating conditions for refractories within the working layer of a high-temperature unit significantly affect their thermal conductivity. An increase in thermal conductivity may reach 12% of its initial values. The values obtained make it possible to adjust the warm-up curve for high-temperature units. Apart from thermal conductivity lining warm-up rate significantly affects material strength since it is a defining factor for thermal stresses that arise. In this connection for subsequent studies it is necessary to obtain the dependence of refractory material strength in temperature.

Impregnation of refractory material with a corrosive medium may have a favorable effect on lining functioning. This occurs in the case when melt is deposited and forms a protective layer, i.e., a skull at the lining surface. Formation of a skull is typical for example for ferroalloy production furnaces within which water-cooled panels ate installed in order to form a skull on the working layer of a lining.

CONCLUSION

The following conclusions may be drawn on the basis of these studies:

– as a result of interaction of refractory working layer lining with molten metal there is a change in geometric parameters and thermophysical properties;

– impregnation of refractory by a corrosive medium (in industrial furnaces) leads to an increase in thermal conductivity both due to a change in structure and also due to impregnation of a layer in contact with a corrosive medium, and its particles. In order to evaluate the change in thermal conductivity of refractory materials during service in high-temperature units a patented method has been developed for determining material thermophysical properties and a measurement unit has been created based upon it.

Results of studying the change in refractory material thermal conductivity during service in high-temperature units have demonstrated that refractory thermal conductivity within the working layer of industrial furnaces increases (by 5 – 12%) as a result of impregnation of refractory by a corrosive medium.

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