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1Omsk State Technical University, 11, Mira ave., Omsk, 644050, Russia
2Siberian state road and highway university, 5/2, Mira ave., Omsk, 644080, Russia MODELLING OF DEFORMATION PROCESS FOR THE LAYER OF ELASTOVISCOPLASTIC MEDIA UNDER SURFACE ACTION OF PERIODIC FORCE OF ARBITRARY TYPE (IoP)

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THE CHEMICAL ENERGY UNIT PARTIAL OXIDATION REACTOR OPERATION SIMULATION MODELING (IoP)

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THE PROCEDURE FOR DETERMINING THE RESIDUAL LIFE OF HIGHTEMPERATURE AGGREGATES (IoP)

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ANALYSIS OF THE STRESS-DEFORMED CONDITION OF THE DISASSEMBLY PARABOLIC ANTENNA (IoP)

The procedure for determining the residual life of high-temperature aggregates

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Abstract. One of the main reasons for the withdrawal of high-temperature aggregates for repairs is the destruction of enclosing structures due to the occurrence of temperature stresses. A wide range of refractory materials used, a large number of product names, a difference in the operation of even the same aggregates makes it impossible to apply general principles for determining the residual resource of high-temperature aggregates, which is based, as a rule, on the determination of temperature stresses.

In the article there is suggested a technique based on the method of simulation modeling, allowing to estimate the remaining resource and reliability of the operating equipment. There are given data on the calculation of these indicators for a 25-ton steel-casting ladle. The values obtained make it possible to evaluate the rationality of the further operation of the high-temperature unit by the condition of reliability of the enclosing structures.

1. Introduction

The modern concept of "industrial security" is closely interconnected with the concepts: risk analysis, operability and reliability of equipment, as well as determining its residual resource. Determination of the reliability of the system as a whole is done by analyzing the reliability of its individual components. The analysis uses actual data on equipment operation in recent years. So, the authors [1] determine the reliability of the work of a complex of conveyor systems and robots based on the operation of robots. An analysis of the failure rate and the average time between failures leads to a calculation of reliability with the assumption of a constant frequency of failure. This allows you to consider options for replacing robots with the least reliability.

An important problem of reliability theory is the estimation of the parameters of the expected failure models. Evaluation can be based on data collected during operation. At the same time, the collected data array can incorrectly display the state of the aggregate for further data processing. In work [2] the application of the Bayes theorem for evaluative analyzes for competing risk systems is considered. For this distribution, a simulation is performed to check models and estimates and to study the effectiveness of estimates for a different sample size. Conclusions are given about the possibility of Bayes' theorem application for risk assessment.

The main problem in determining residual wear in such cases is the determination of the actual state of the constituent elements of the unit during its operation. Naturally, for a number of units, measuring the physical parameters of the elements in their operation is an impossible task at this stage in the development of technology. In other cases, the results will be characterized by the accuracy of the data obtained.

Let's consider definition of a residual resource of protecting constructions of high-temperature units. One of the main types of control of protecting constructions of high-temperature aggregates for determining their actual state is the thermal type of control. All methods of thermal control are based on the interaction of heated sections of protecting structures with sensors for measuring temperature or on the measurement of these temperatures by a non-contact method [3]. According to the temperature, the condition of the protecting structure is judged.

The presence of defective areas is determined by increasing the temperature at control points, which allows to judge the condition of the protecting structure and carry out repair work before the onset of emergency situations (for example, metal leaks for metallurgical machines).

These thermal control methods have significant drawbacks. First, there is no possibility of estimating the remaining resource. The use of these methods provides an assessment of the current wear of the enclosing structures without an analysis of previous processes and the subsequent development of the situation as a whole. It should be noted that when a critical value is reached, an assessment of the subsequent development of the situation is made - forecasting the emergency situation, but this is only at the final stages.

Secondly, the installation of temperature sensors in enclosing structures is a very undesirable process, as this breaks the integrity of part of its layer, and when thermal monitoring in metallurgical equipment there are limitations on the depth of installation of sensors.

2. Formulation of the problem

Thus, an important task is to obtain accurate data on the current state of the enclosing structure with minimal disruption of its integrity and use of this data to predict the residual resource.

3. Theory

The residual life of linings of a number of high-temperature aggregates, during which the thickness of the liner does not change (or there is a topography of wear of the enclosing structure during the working campaign of the unit), depends on a number of factors, and primarily on the value of the temperature stresses exceeding the permissible, their duration, and also on the lengths of compression and expansion zones in which the temperature stresses exceed the allowable ones.

The effect of other factors - the aggressive action of the environment, the quality of the materials used and the work performed, the level of vibration, etc., can be assumed constant for this unit under constant operating conditions. Let's consider high-temperature aggregates of periodic action, in which the work campaign consists of several cycles of heating enclosing structures.

The authors offer the following method of estimating the residual life of the enclosing structures of a high-temperature unit. The first step is to place the temperature sensors in the refractory layer, taking into account the limitation on the depth of installation of the sensors. The number of sensors and the distance from the inner surface are chosen on the basis of operational limitations related to the possibility of emergency situations (leakage, etc.). Also their number and location will affect the accuracy of calculations.

According to the technique stated in the article [4], the temperature fields in the enclosing structure can be determined.

The second stage is the arising stress σ by the formula:

$$\sigma = -\frac{\alpha \cdot \mathrm{E}}{1-\nu} \cdot (T_{av} - T_i) \qquad (1)$$

where α is the coefficient of thermal expansion, (1/°C);

T_{av} - is the average temperature of the refractory layer, °C;

T_i - temperature of the point at which the temperature stress is calculated, °C;

E - modulus of elasticity of material, MPa;

ν - Poisson's ratio.

We introduce two concepts: total compression rate ($N_{compr.}$) and total expansion rate ($N_{exp.}$). If the obtained value of the temperature stress σexp. or σcompr. exceeds the value of the tensile strength for a given type of refractory material, its value is taken into account in determining the corresponding total value, which is calculated as follows. Next, the step in time and coordinate for these conditions is determined.

To take into account the lengths of compression and expansion zones in which the temperature stresses exceed the allowable ones, we introduce a coefficient that considers these lengths. By the length of the compression zone we mean the distance between two neighboring points in which the stresses are determined, provided that the compression stresses in these two points exceed the allowable ones. That is to say, if the compressive stresses at a given step exceed the permissible values at three points, then z = 2. The formula for calculating the total compression criterion ($N_{compr.}$) at a given time step (for example, for a time of 1:40) would look like this:

$$N_{compr}^{1:40} = \sigma_{compr} \cdot (z+1), \tag{2}$$

where z is the number of compression zones in which the temperature stresses exceed the allowable ones.

A similar formula is used for tensile stresses. Next, we summarize all the obtained values of the summary indicators (separately for compression and expansion) for all time steps. This amount, when calculated for the whole work campaign of the unit, is the maximum total compression index ($\Sigma N_{compr.}$) and the maximum total expansion index (ΣN_{exp}). These totals take into account only the stresses exceeding the ultimate strength and leading to the destruction of the enclosing structures.

To introduce the residual resource criteria, we introduce the concept of total admissible indicators that will consider the stresses arising at the time and at points where, in reality, the stresses exceed the allowable values. Only when calculating the total allowable values, instead of real values of stresses, we substitute the strength values of the material. For example, at the time 0:40 a temperature stress of 113 MPa (with the strength value of 40 MPa) occurs at the point, which we consider for calculating the total index. To calculate the total allowable values, it is necessary to take into account the value of the stress at the same point at the same time, but at the value of 40 MPa.

If we divide the total values obtained by the total allowable values, we obtain a criterion of reliability for strength (for example, for compression):

$$k_{compr} = \frac{\Sigma N_{compr}}{\Sigma N_{compr}^{add}}, \tag{3}$$

In this case, the step in time and coordinate in the determination of stresses will determine the accuracy of the calculation of reliability criteria. To estimate the remaining resource, it is also necessary to calculate two arithmetic average values of the total indices for one cycle (for compression - $\Sigma N_{compr.av.}$, for expansion – $\Sigma N_{exp.av}$).

The resulting residual resource criteria will determine the residual resource for subsequent work campaigns of this unit under the unchanged operating conditions of the unit and the use of the same materials, layer thicknesses, etc. That is, after the next major repair, temperature measurement, calculation of temperature stresses ($\sigma_{exp.}$ and $\sigma_{compr.}$), total indicators and reliability criteria for strength are performed. The obligatory condition is the using in these calculations of the same step in time that was chosen to calculate the residual resource criteria.

After the first cycle of the unit operation, we have two values: $N_{compr.1}$ and $N_{exp.1}$. After the second and subsequent cycles, we add the existing total indicators with the newly obtained ones for the cycle n and obtain the total values after the cycle n ($\Sigma N_{compr.\ n}$ and $\Sigma N_{exp.\ n}$). At the same time, for each next cycle n we estimate the possibility of its accident-free operation by adding to the available sum $\Sigma N_{compr.n}$ and $\Sigma N_{exp.n}$ the values $\Sigma N_{compr.av}$ and $\Sigma N_{exp.av}$, respectively. If the obtained values are greater than the maximum total compression indices ($\Sigma N_{compr.}$) or the model total tensile indices ($\Sigma N_{exp.}$), then it is not rational to use the unit in the next cycle.

To determine the remaining life of the enclosing structures of the high-temperature unit, steel-pouring ladles with a capacity of 25 tons were chosen. The operation of these ladles is carried out at the enterprise PF LLP "Casting" (Pavlodar, Kazakhstan).

The cycle of the ladle operation is as follows: heating of its lining at the stand with a gas burner to the temperature of 950 - 1000 °C; discharge of the metal from the arc steel casting furnace into it; further processing on the installation ladle-furnace to the required chemical composition; transportation of the metal to the machine of continuous casting of blanks and discharge of the metal into the installation.

The ladle lining consists of four layers. The first layer (working), directly in contact with the molten metal, consists of refractory bricks 135 mm thick. The second layer - heat-insulating, is made of mullite-corundum ramming mass, 30 mm thick. The third layer is made of chamotte bricks of grade ShB-5 with the thickness of 65 mm and the last layer 4, in contact with the ladle cover, represents sheets of asbestos board 10 mm thick (Figure 1).

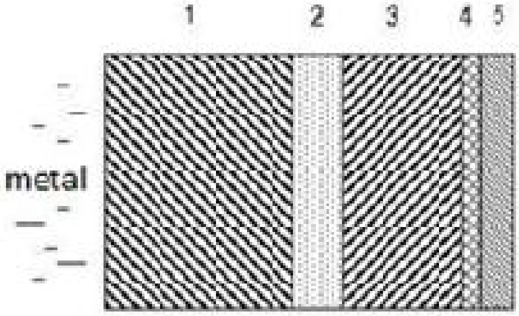

Figure 1.Lining of walls of a 25-ton steel-pouring ladle

The arising stresses will be considered only in the refractory layer, for which the compressive strength is 40 MPa; tensile strength: 25 MPa [5].

Analyzing the thermal processes in the lining of the steel-pouring ladle, we can say that the process that determines the resistance of the lining of the ladle will be heating it with gas on the stand. It is this process, controlled manually and based only on the experience of the personnel (there are no technical methods for controlling the surface temperatures of the lining), is individual for each cycle. Thus, the achievement of the final result in this process - the surface temperature of the lining 950 - 1000 °C - each time is carried out by similar, but different curves. The remaining processes: discharge of metal into a ladle, transporting it, etc. - practically identical in different cycles.

4. Results

To study the arising temperature stresses, measurements were made of the temperatures of the inner surface of the lining at two characteristic points: 2/3 of the height of the ladle – the level of the core of the torch (curve 1) and on the bottom (curve 2) (Fig. 2) [6].

It can be seen from these graphs that there are two points in time at which the surface temperature of the lining rises sharply. This corresponds to an increase in the fuel supply to the burner at the stand for heating the ladles. The withdrawal of the ladles for repair is carried out with a residual brick thickness of the refractory layer of at least 70 mm, while the ladle lifetime before the overhaul is 40 melts (or cycles).

Further, according to the equation (1), it is possible, by specifying the step in time and coordinate, to calculate the arising temperature stresses. After calculating the temperature stresses in the working layer of the lining, we obtain the following picture (Figure 3). There is a clear relationship between the temperature jumps (Figure 2) and the values of stresses that exceed the permissible values.

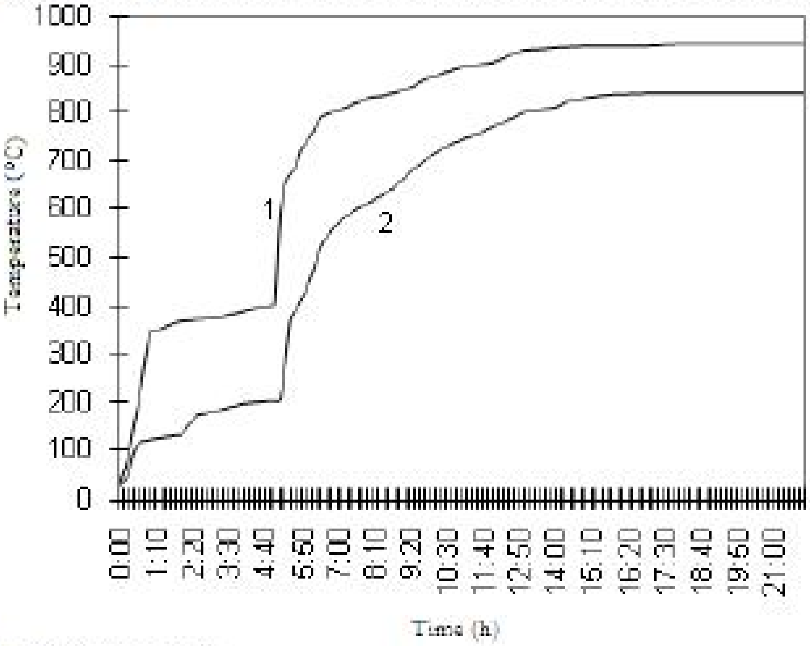

Figure 2. Internal Ladle Temperature

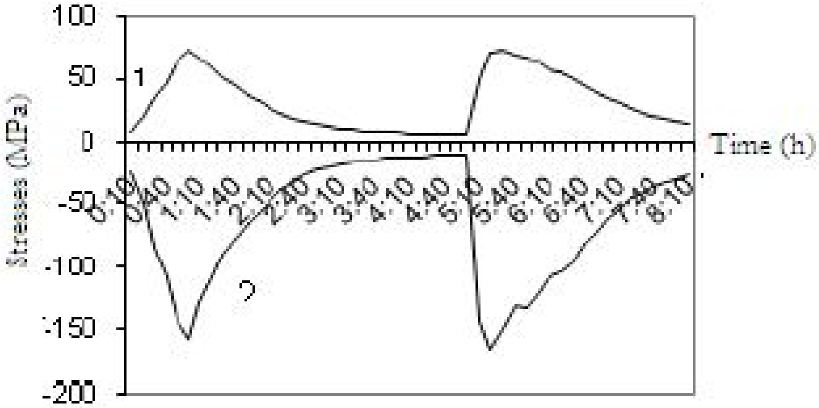

Figure 3.Stresses at the point of the level of the core of the torch on the outer (1) and inner (2) surfaces of the working layer of the lining

In the process of heating, two periods of time are allocated in graph 1 (Figure 3), the temperature stresses tension in which exceed the permissible: (0h 20m - 2h 10m, 5h 10m - 7h 30m); on the graph 2 (compressive stresses): (0h 30m - 0h 50m, 5h 20m - 8h 10m).

Now, having the values of the real temperature stresses that arise during the heating process of the lining of the steel-pouring ladle, taking into account the step in coordinate and time, it is possible to calculate the residual resource criteria. We give the following data: when determining the temperature stresses with a time step of 10 minutes and by breaking the thickness of the refractory layer of the liner into six sections, with the given heating curve, we obtain the values of the maximum total values for one cycle for compression – $\Sigma N_{compr.\ av} = 6951.215$; for the expansion $\Sigma N_{exp.\ av} = 8516.46$.

By taking the temperature readings for the working campaign of the steel-casting ladle in general (before the overhaul) for 40 cycles and calculating the total values, we obtain the following data: for compression $\Sigma N_{compr.} = 279883.314$; for the expansion $\Sigma N_{exp.} = 342826.321$. The calculated reliability criteria for strength are: for compression $k_{compr.} = 2.17$; for the expansion $k_{exp.} = 1.91$.

The criteria show the following: if during the operation of the unit the criterion for compressing $k_{comr.}$ and the criterion for expanding the $k_{exp.}$ exceed the values obtained, then the ladle must be taken out for repair (the thickness of the refractory layer is about 70 mm). If during the working campaign of the ladle $k > 1$, the operation of the ladle is performed with stresses exceeding the permissible limit, and if $k < 1$, then the resulting stresses do not exceed the strength limit of the materials used.

The residual resource n_{rem} (in quantities of smelting) can be estimated by the following formula:

$$n_{rem} = \frac{\Sigma N_{compr}}{\Sigma N_{comp.cd}} - n,$$

5. Discussion of results

The obtained results of the values of the total indices for compression and expansion allow calculating the residual resource at any time (after any cycle n) by comparing the values ($\Sigma N_{compr.\ n}$ and $\Sigma N_{exp.\ n}$) with the values of the total indices for compressive stresses ($\Sigma N_{compr.}$) or tensile stresses ($\Sigma N_{exp.}$), respectively.

The values obtained for the reliability criteria for strength show the limiting state of the criterion, beyond which the destruction of the liner will be critical for these operating conditions.

The main problem is to obtain data on the temperature fields of the refractory lining layer during the heating process. These data can be obtained in any accessible and technologically safe way and used to calculate the residual resource criteria. The methodology can be translated into a computer programming language and, when connected to a computer and temperature sensors can be used at workplaces of high-temperature unit operators.

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