COMPUTER SIMULATIONS OF STATIC STRESS-STRAIN STATES FOR LONG-LENGTH PRESSURISED PIPES WITH EXTERNAL PROTECTIVE THIN NANOENGINEERED COATING UNDER NONUNIFORM TEMPERATURE FIELDS

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Abstract
Influence of nonhomogeneous temperature fields on the stress-strain state of the pressurized pipes is due to temperature dependencies of the structural material properties like Young's module, Poisson's ratio and linear expansion coefficient, so that the nonuniform temperature fields leads to the inhomogeneous of the material properties. It is proposed to use the differential equations formulated through the displacement and the stresses to consider the stress-strain state for axisymmetric long-length pipes with external protective thin nanoengineered coating taking into account the nonuniform temperature fields. The finite differences are used to make the computer simulations of the pipes with the external protective thin nanoengineered coating, and the cladding of nuclear fuel rods made from the Zr-based alloy with the thin protective coating made from the stainless steel is considered as the example. It is shown that consideration of structural material properties temperature dependencies can have the noticeable influence on the stress-strain-state estimations for the pressurized pipes with external protective thin nanoengineered coating under nonuniform temperature fields.

1. Introduction

The thin protective coatings are widely used for operability enhancing of different pressurised pipes including for the oil industry pipelines [1], for natural gas transportation pipelines [2], for steam boilers high-temperature pipes [3], for nuclear fuel claddings [4], as well as for other purposes. Effects of thin coating application is significant, so this idea has the further development, including through application of multilayers thin coatings [5], so that the researches about the pipes with thin protective coatings are in current interests at present, and a lot of existed scientific publications in this field confirm it.

The principal purpose of thin coating application for pressurized pipes is in corrosion protection of the main metal of the pipes from aggressive external mediums [6]. Different kinds of corrosion processes require developing of different protective coatings, so we have a lot of researches about the pipelines then coating to protect the particular kind of corrosion. The research [3] deals with the vanadium oxides induced high-temperature corrosion inherent for the steam boilers. The pipelines protective coatings to prevent the hydrogen embrittlement are considered in [7]. The specific corrosion processes of coated pipelines in soils taking into account of bacterial influencing are explored min [8]. At the same time, the protective coatings can be used to protect pipes not only from the corrosion, but also from other external influencing, including from the higher temperatures, like it is discussed in [9].

The implementation possibilities of thin coatings to protect the pipes are restricted by manufacturing capabilities and by the operability of such coatings under the pipes' exploitation conditions. In the research [10], the fabrication and behaviour investigation of new composite coating kinds for oils and gas pipelines are studied. The research [11] deals with studying about the manufacturing possibilities for making the internal coatings on the pipes. Possibilities of some manufacturing technology for making the nanocomposite coating with enhanced mechanical and corrosion protection are explored in [12]. Although, it is important to research influences of the manufacturing processes on the properties of pipes with thin protective coatings, but the principal difficulties are in anticipating these properties under the actual exploitation conditions of the pipes as the structural elements of complicated systems under influencing of different external factors. So, in the research [3], the corrosion processes from the vanadium oxide are considered taking into account a lot of different factors like the high temperature and the cyclic conditions. The crack safety of the cladding with the protective coating is considered in [13] with taking into account of the structural materials plastic behaviour. Protective thin coatings operability estimation is especially complicated for the claddings of nuclear fuel rods due to the specifics of the exploitation conditions in the cores of nuclear reactors, but this is principally required for design substantiation of the accident tolerant nuclear fuels [4]. The qualities of the coatings required to have the enhanced accident tolerant fuel claddings are researched in [14], and the performance of the nuclear reactor core loaded with such accident tolerance fuel is analysed in [15].

2. Computer simulations and discussing of the results

As the example, we will consider the pressurised pipe representing the nuclear fuel rod cladding made from the Zr-based alloy with the design similar to the well-known VVER-1000 nuclear reactor, but with the thin protective coating made from the stainless steel. The input data for the computer simulations will be following [16]:

$$a = 3{,}9 \text{ mm}, \quad b = 4{,}55 \text{ mm}, E_c = 177 \text{ GPa}, \quad \alpha_c = 17{,}5 \cdot 10^{-6} K^{-1}, \quad h_c = 10\ \mu m, \tag{1}$$

$$p_a = 10 \text{ MPa}, \quad p_b = 16 \text{ MPa}, \quad T_a = 340\ °C, \quad T_b = 300 \text{ °C}, \quad T_0 = 20\ °C. \tag{2}$$

We can see (fig.1), that the temperature dependency of the linear expansion coefficient for the Zr-based alloy has the complicated form, and to take it into account we will use the cubic splines to interpolate the known values.

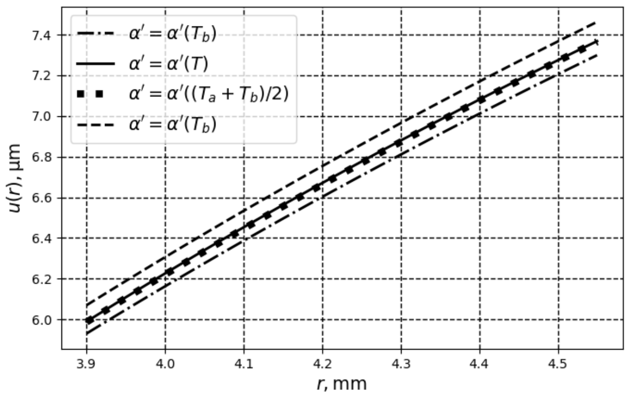

Fig.1. The radial displacements estimations

Conclusions

Due to the accomplished researches presenting in this article, the following conclusion can be formulated.

It is suitable to use the differential equations formulated through the displacement and the stresses to make the computer simulations of the static stress-strain states of the axisymmetric long-length pipes with external protective thin nanoengineered coating taking into account the nonuniform temperature fields. These differential equations can be numerically solved by using the finite differences, and it can be realised through the Python programming language to have the primary results.

The inhomogeneous of the material properties induced by the nonuniform temperature fields have noticeable influence on circumferential stresses leading, but it has no effects on the radial stresses and radial displacements of the pipes with the external thin protective coating. These regularities are shown for the particular example, and it is impossible to distribute them to all the cases, so that to have the reliable estimation for the stress-strain states in the pipes with the thin coatings, it is necessary to make the computer simulations for each particular case.

To have the reliable estimations of the stress-strain states in the pressurized pipes with thin protective nanoengineered coatings under exploitational conditions leading to nonuniform temperature fields, it is necessary to take into account the actual temperature dependencies of the structural materials properties, but not the different constant values estimating these properties on the average or others different senses.

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