IMPACT OF THIN NANOTECHNOLOGY COATINGS ON THE STRESS-STRAIN STATE OF THE CYLINDRICAL CLADDING MADE FROM ZR-BASED ALLOYS FOR NUCLEAR FUEL ELEMENTS

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Abstract. The actual problem about using the thin nanotechnology coatings for increasing operability of the cladding of nuclear fuel made from the Zr-based alloys is considered from the point of view the mechanical elastic interaction between the coating and the cladding. The mathematical model of thin coatings of the cylindrical cladding is presented in the form of especial boundary conditions for considering the equations of theory of elasticity, defining the stress-strain state of the cladding. It is shown, that thin coatings can decrease noticeably the stresses in the cladding made from the Zr-base alloys, widely used in fuel elements for nuclear reactors.

1. Introduction

Using thin nanotechnology coatings is one of the ways widely discussed to increase the operability of the cladding made from Zr-based alloys for fuel elements of nuclear reactors [1]. The main effects of application the thin coatings are connected both the properties of the coating materials as well as mechanical interacting between thick-walled and thin-walled structures, representing the cladding made commonly from the Zr-based alloys and its coatings respectively. The purpose of this research is to propose the mathematical model of mechanical interaction between the widely used cylindrical cladding from the Zr-based alloys and its thin coating made from the stainless steel as well as to estimate using this model the impact of the thin coatings on the stress-strain state of the cladding.

2. The stress-strain state of the cylindrical cladding considering with the thin coating

The cladding is commonly made from the Zr-based alloys as the cylinder with such length and ratio between the average diameter and the width of the wall, that the cladding can be considered as long and thick-walled. It can be assumed that the external impacting factors of the cladding are reduced to the internal pressure of the gases in the gap between the nuclear fuel pellets and the cladding and to the external pressure from the moving heat carrier. Considering these, the cladding is schematized as the long thick-walled axial-symmetric cylinder, like in the well-known plane problem of the theory of elasticity [2].

The thin coating of the cladding can be considered as the thin cylindrical shell, which is in the equilibrium under the radial stresses s_r from the cladding, the pressure p_a of the moving heat carrier and the circumferential forces N_t in the coating as it shown on fig. 1a. Displacements of the all point of the coating are equal to the radial displacement of the external surface of the cladding due to the thick of the coating is small. Thus, considering equilibrium of the segment of the coating (fig. 1a) with the Hooke's Law relation between the circumferential stress and strain, the radial stress on the external radius of the cladding is represented as the linear combination of the external pressure and of the radial displacement of the cladding; the multiplier at the radial displacement is depended on the Young's modulus of the material and the thick of the coating, as well as the external radius of the cladding. This representing of the radial stress on the external surface of the cladding must be considered as the boundary condition for equations of the theory of elasticity, defining the stress-strain state of the cladding. It is possible to find the analytical solutions for stresses and displacement in the cladding, considering the plane problem with this boundary condition [2], representing the model of mechanical interaction between the cladding and the coating.

3. Results for impact the thin coatings on the stress-strain state of the cladding

For researching the impact of thin nanotechnology coatings on the stress-strain state it is considered the cladding made from the Zr+1% Nb alloy with the different thick of the coatings from the stainless 18-10 type steel. The internal and external diameters of the cladding are 7,71 mm and 9,1mm respectively; the internal and external pressures are 10MPa and 16MPa; the Young's modulus of the materials of the cladding and the coating are 96GPa and 210GPa. This data are corresponded to the VVER-1000 type nuclear reactors, widely used in the Eastern-European countries. The results for the circumferential stresses and the radial displacements in the cladding corresponded to the different thick of the coatings are presented on the fig. 1b and on the fig. 1c. These results show that the thin coatings can decrease noticeably the stresses and displacements in the cladding, which is not contradict the known data about increasing the yield strength of the cladding with coatings comparing the cladding without coatings.

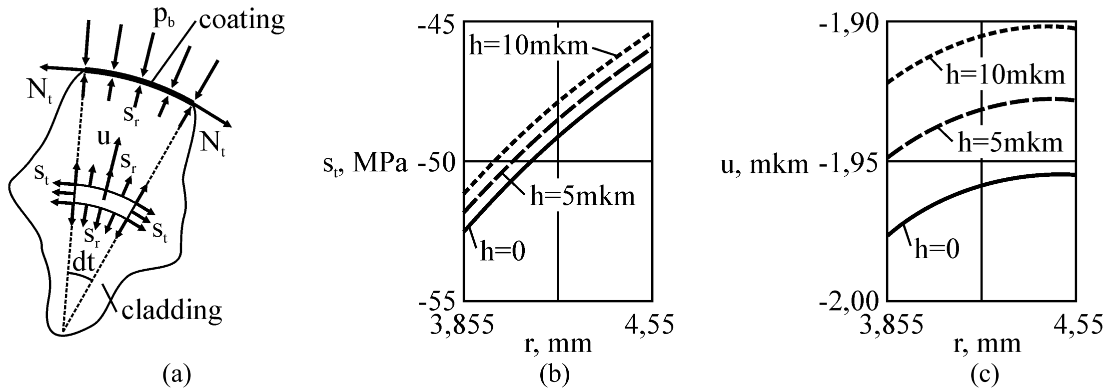

Fig.1. Schematizing of the cladding with the coating (a) as well as circumferential stresses (b) and radial displacements (c) in the cladding made from Zr-based alloy with different thick h of the coating made from the stainless 18-10 type steel

Results, presenting on the fig. 1b and fig. 1c for stresses and displacements in the cladding without the coating (h=0) are equal to well-known Lame's solution [2]. The boundary condition on the external surface of the cladding, representing the model of mechanical interacting between the cladding and the coating, reduces to well-known in the theory of elasticity boundary condition in the case of cladding with zero thick. Obtained and presented results are not contradicted with the known results [3] about impacting the coatings on the mechanical properties of the Zr-based alloy.

Conclusions

Obtained results demonstrate possibilities of noticeable impact of the thin nanotechnology coatings on the stress-strain state of the cylindrical cladding of fuel elements of nuclear reactors due to the specific of mechanical interacting between thick-walled and thin-walled structures. Using the thin nanotechnology coatings allows to noticeable decrease stresses, strains and displacements in the cylindrical claddings made from Zr-based alloys. At present, only particular results are well-known about the mechanical interactions between thick-walled and thin-walled structures. At the same time, it is necessary to fully solve the common fundamental problem about the mechanical interactions between thick-walled and thin-walled structures for realizing the all opportunities of the nanotechnology coatings on improving the cladding of fuel elements. Thus, it is necessary to develope the approaches for assessments the operability of the claddings of fuel elements considering with impact of the thin nanotechnology coatings for further widely industrial using of these coatings.

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