ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

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RESEARCH OF CORROSION BEHAVIOUR OF STEAM GENERATOR TUBES FOR LEAD-COOLED POWER UNIT

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Introduction

For the reactor unit BREST-OD-300 vertical type steam generator (SG) designed. external surface of heat exchanger tubes (HET) is in contact with flowing liquid lead. Internal surface of HET is in contact with water-overheated steam environment of secondary circuit.

HET constructive material should be highly corrosion-resistant in the range of operating temperatures of 340-530 C at pressure 17 MPa (from secondary circuit) and at 550 C (as for primary circuit)

For this purpose, the new nitrogen, molybdenum, silicon containing austenitic stainless steel (grade EP302M) developed.

This choice is based on both experience of application of type EP302 stainless steel that is resistant to corrosion in lead coolant (when tested up to and previously obtained the positive test results of high-strength nitrogen-containing cold-deformed steels which are highly resistant to local types of corrosion in seawater and other chloride-containing environments.

Introduction

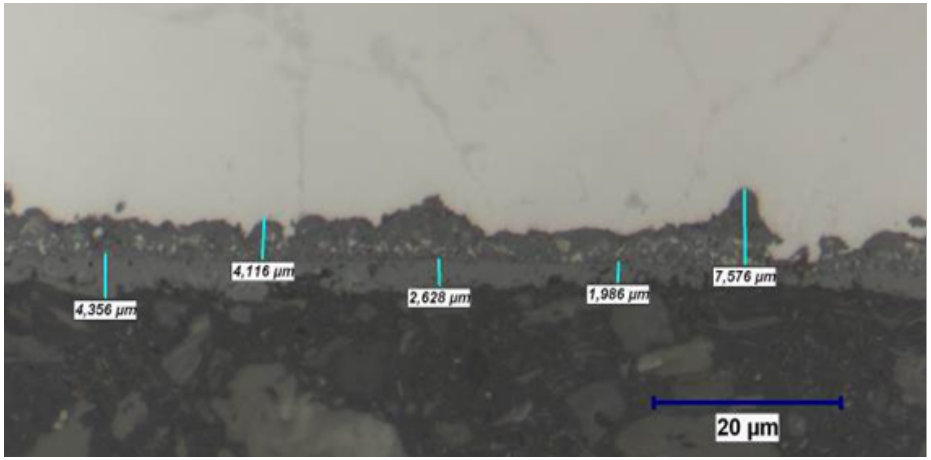
The following works were carried out:

- assessment of the rate of general corrosion, determination of the value of increase in corrosion according to the results of HET samples tests in liquid lead, water and superheated steam for using in strength calculations;

- assessment of effect of superheated steam and water environment on corrosion behavior of the model 'tube-tube sheet' joint of SG under static loading and low-cycle fatigue tests;

- assessment of the resistance of HET material microstructure sensitization and subsequent intergranular corrosion (IGC) susceptibility.

CORROSION RESISTANCE IN LIQUID LEAD

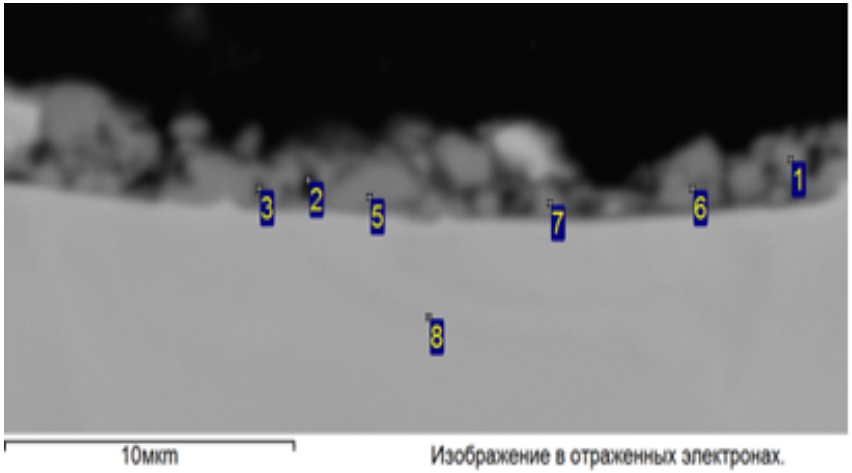


Oxide film formed on the surface of sample of grade EP302M steel. Tested in flowing lead at 550 C for 9000 hrs

Samples of HET trial part tested in non-isothermal test loop in flowing lead (0.5 m/s) at 550 C. Dissolved oxygen level maintained in base range.

It is revealed that two-layer oxide film formed (magnetite outer layer, chromium-rich spinel internal layer and some internal oxidation).

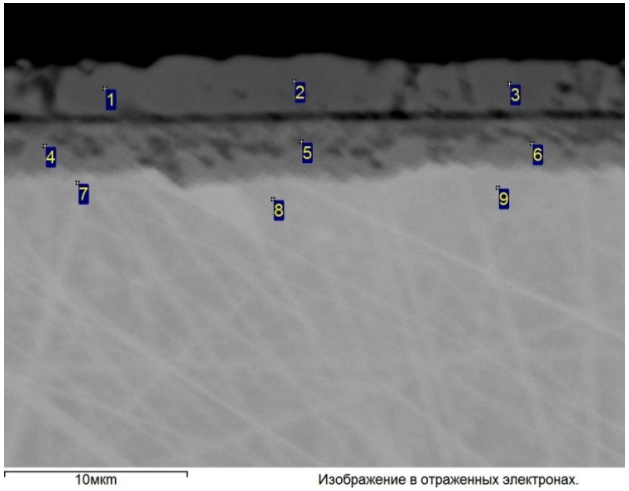
Oxidation mode has the fading character in time. Mechanical stress within designed range does not arise corrosion interaction.



Oxide film (REM image) formed on the surface of specimen of grade EP302M stainless steel. Tested in water at 350 C for 1000 hrs

According to the results of the elemental analysis, the oxide film (reference points 1-7,) consists mainly of iron oxides with a small addition of chromium and nickel oxides, with the weight fractions of iron, chromium and nickel averaging ~ 50%, ~ 15% and ~ 10%, respectively, and the thickness of the oxide film after 1000 h of testing not exceeding 4 μm.

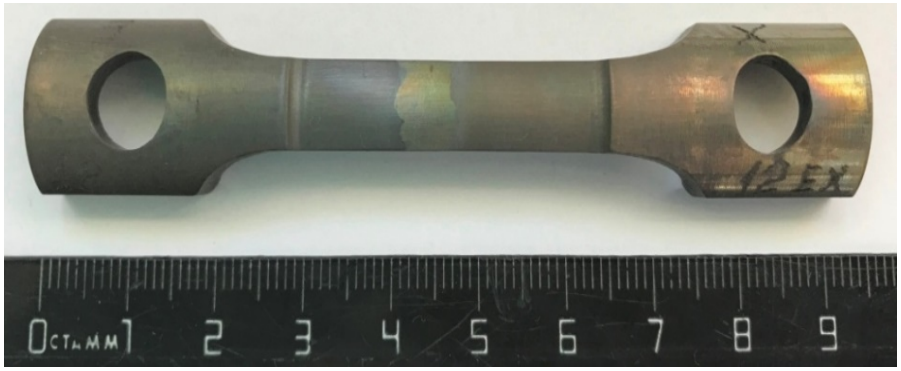
CORROSION RESISTANCE IN SUPERHEATED STEAM



Oxide film (REM image) formed on the surface of specimen of grade EP302M stainless steel. Tested in superheated steam at 525 C for 1000 hrs

Two-layer oxide film is formed on specimen surface. Its outer layer is iron oxide, which in stoichiometric composition corresponds to magnetite - Fe_3O_4 (points 1-3). The inner layer is a mixed spinel of complex composition (points 4-6), in which the mass fractions of chromium (Cr), iron (Fe) and nickel (Ni) are on average 27%, 22% and 19%, respectively, and the thickness of this oxide film after 1000 hours of testing averages 5 to 7 μm.

Testing of model weld joints for SG tube sheet in water and superheated steam



Sample of welded tube segment after static loading and subsequent low cycle fatigue tests in superheated steam at 505 C

- To perform weld joints of SG heat exchange tubes made of steel grade EP302M to tube sheet made of steel grade 321, 2 variants of welded joints are proposed: welding of tubes directly to tube sheet or welding of tubes through double austenitic plating over tube sheet.
- Corrosion-mechanical autoclave tests under static loading and low-cycle fatigue conditions are carried out in water and superheated steam media for experimentally validated choice of type of welded joint of ‘HET – tube sheet’. For this purpose, the samples of model welded joints made using different welding materials with and without double austenitic plating were tested

Testing of model weld joints for SG tube sheet in water and superheated steam

POCATOM

- Samples were tested during 2000 h in the model water and steam SG environments in the conditions of the static loading corresponding to tension 0.8 of yield strength (relatively to material grade 321 stainless steel). After 2000 hours of tests under static loading, tests were carried out for low-cycle fatigue with stress amplitude of 200 MPa, number of cycles of 102 @ frequency 0.1 Hz. Test conditions are selected basing on SG operation model in transient regime.
- According to the results of corrosion-mechanical tests, the metal of welded joints showed resistance to corrosion cracking both in model water and steam environments of SG both after static loading and cyclic loading.
- Visual and optical inspection of the sample surface (see figure 4) after testing has not revealed surface cracks and other defects. Oxide film formed on the samples surface that protected the metal from corrosion local corrosion damage.
- Selection of the type of the welded joint ‘HET - tube sheet’ for the SG will be made after completion of tests of model joints, including testing after additional heat treatment at temperature 550 C for simulating material aging (sensitization) during SG operation.

INTERGRANULAR CORROSION RESISTANCE

POCATOM

- Intergranular corrosion resistance of samples cut from the trial party of heat exchanger tubes estimated by electrochemical method of potentiokinetic reactivation (DL-EPR) according ISO 12732 for quantitative measurements and by using chemical method ASTM A-262 pr. E for qualitative assessment. The effect of samples aging at temperature 650 C and exposures up to 100 hrs as well as aging at 550 C for 7000 hrs on susceptibility to intergranular corrosion (sensitization) studied

- It was experimentally proved that EP302M stainless steel is resistant to intergranular corrosion both in the initial as-received conditions and after aging at a temperature of 650 C for 100 hrs and at temperature 550 C for 7000 hrs

THE MAIN RESULTS AND CONCLUSIONS

In the scope of work, the following results obtained:

- basing on the data of corrosion tests of grade EP302M stainless steel the calculated increases in corrosion to the wall thickness of heat exchange tubes are determined for the 30-year design life of the SG: in superheated steam at temperature 525 C - 0.1 mm; in water environment at temperature 350 C - 0.01 mm; in a liquid lead at temperature of 550 ºC - 0.1 mm (with controlled values of oxygen content ~ 10-6 mass (%));

- resistance to local corrosion damage (corrosion cracking and etc.) of a model welded-joint without surface cladding under static loading and low-cycle fatigue water and steam SG environments confirmed for samples without sensitizing heat treatment;

- resistance against intergranular corrosion of heat exchanger tubes in as-received condition and after aging under following regimes 650 C, 100 hrs and 550 C, 7000 hrs confirmed

THE MAIN RESULTS AND CONCLUSIONS

POCATOM

- An analysis of test data allows to conclude that grade EP302M stainless steel correctly proposed as the structural material for heat exchanger tubes. Corrosion and corrosion-mechanical properties allow providing reliable operation of the steam generator of BREST-OD-300 during the 30-year design life under conditions of sustainable compliance with the quality requirements of lead coolant and working environment from the side of the secondary circuit.
- In order to confirm the resource characteristics of heat exchanger tubes and reliable option of welded-joints ‘tube - tube sheet’ for steam generator, the following experimental studies are carried on:

- comparative evaluation of the corrosion behaviour of heat exchanger tubes with various finish processing of the inner surface (electrochemical polishing with different etching intensity, light annealing), issuing requirements to manufacturer;

THE MAIN RESULTS AND CONCLUSIONS

- comparative tests under static loading and low-cycle fatigue of model ‘tube - tube sheet’ welded-joints after long sensitizing heat treatment;
- evaluation of deviation of dissolved oxygen content in liquid lead on corrosion behaviour;
- influence of stress-strain state in the region of bending on corrosion behaviour of the material.

Thank you for attention!