

CORROSION RESISTANCE OF STRUCTURE MATERIALS IN LEAD COOLANT WITH REFERENCE TO REACTOR INSTALLATION BREST-OD-300

A. ROUSSANOV, V. TROYANOV, G. JACHMENEV, A. DEMISHONKOV

STATE SCIENTIFIC CENTER OF RUSSIAN FEDERATION (SSC RF)
INSTITUTE FOR PHYSICS AND POWER ENGINEERING (IPPE)
OBNINSK, RUSSIAN FEDERATION

Abstract

Systematic researches for lead coolant have been performed from the beginning of 1990s within the framework of development of activities on the BREST-OD-300 reactor installation. The main type of corrosion damages in lead and lead-bismuth coolant is the local dissolution of structure materials (steels) and their components and then in those structure materials and components. The main results for ensuring high corrosion-erosive stability of materials in heavy metal coolant are given by the application of silicon-containing steels, the passivation oxygen, and the application of additional corrosion barrier as oxide films on the surface of structure elements. Various researches of corrosion behaviors of steels in lead coolant based on those results are under way. The experience gained so far allows to forecast the absence of corrosion damages of steels in lead-bismuth coolant up to 620 °C on the basis of tens thousand hours that was proved by successful experience of reactor installation activities. The obtained results from the test at higher temperature showed a good fuel-cladding compatibility.

The significant amount of experimental data of corrosion resistance of structure materials in heavy liquid metal coolant (Pb, Bi, eutectic Pb–Bi alloy), including the data of foreign sources obtained before the mid of 1960s, are adduced in the scientific literature. These data demonstrate, that the main type of corrosion damages in liquid Pb, Bi and Pb–Bi is the dissolution in them of structure materials (steels) and their components. The kinetic features of process of dissolution can be of different nature. For example, in some cases the dissolution is localized on boundaries of grains, causing inter-crystal infiltration of liquid metal (Pb, Pb-Bi) into steel.

The corrosion resistance study of structure materials in liquid Pb, Bi and Pb–Bi are systematically carried out in the Institute for Physics and Power Engineering (IPPE), Russia since the mid of 1950s. There was created and started up the unique complex of the experimental installations, including convection ampoules, loops, also non-isothermal circulating loops with forced circulation of coolant and reactor loops.

The basic varied parameters, on which the researches were carried out:

- Component and impurity composition of steels, the types of melting, influence of heat treatment of steels, condition and types of treatment of surfaces of steels and their weld joints;
- Type, structure and technology of protective antirust coats of steels. Such technologies, as alitizing, chromizing, nitriding, molibdenizing, oxidizing, and also lot of other kinds and types of coatings, including coatings created directly in liquid metal due to applying of dissoluble inhibitors were studied;
- The influence of temperature, and also gradient of temperature on liquid metal loop;
- The influence of coolant flow, conditions and flow regimes, especially of reactor core;
- Long-lived resource characteristics on parameter of corrosion resistance;
- The influence of stresses, thermocircles and vibrations.

The systematic researches for lead coolant were carried out from the beginning of 1990s, within the framework of development of activities on reactor installation BREST.

The main and the most dangerous kind of corrosion damages of materials both in Pb–Bi and in Pb coolants is the local corrosion of a material appearing as the separate corrosion–erosive centres (pittings). Local through corrosion damages of structure elements may appear at temperatures higher than 550°C after some hundreds hours under following conditions: unbalance of alloying and impurity elements in steel, poor quality of metal, absence of the control of quality of coolant, non–optimal coolant flow regimes. The typical corrosion rates in such cases are valued by values 2.55 mm/year.

The principle solutions ensuring high corrosion resistance of structure materials in heavy liquid metal coolant, were found by using of oxygen dissolved in coolant.

It was shown, as a result of long–term researches, that the corrosion resistance of structure materials in Pb and Pb–Bi essentially depends on concentration of oxygen, dissolved in liquid metal. At a definite level of concentration of dissolved oxygen the development of corrosion processes is locked due to protective oxide film formed on a surface of steel. At high temperatures an indispensable condition of blocking of corrosion processes is the presence of silicon in steel as additional alloyed element. The contents of silicon in steels used for heavy liquid metal coolant, are varied in limits from 1 up to 3.5% depending on application of steel.

Key role in solution of a problem of hyper–thermal corrosion resistance of materials was also played by developing and operational using of preliminary protective coatings on steels. These coatings are put on a surface of the most important structure elements of a reactor installation (fuel rod claddings, steam generators) at finishing stages of technological factory process of manufacturing of the suitable workpieces. The additional barriers on internal surfaces of liquid metal loop are formed also directly in coolant when reactor installation is prepared to operation (modes of running–in).

The best results on preliminary oxidizing of structure elements in a mode of factory cycle of their manufacturing were obtained by using of environments with low partial pressure of oxygen: Pb–Bi–O, H₂O + H₂ and CO₂. The applying of such technologies allows, first of all, to avoid kinetically critical stage of preliminary passivation process of the unsheltered reactor installation steels for the most important installation elements, and allows essentially to extend range of a permissible decrease of concentration of oxygen in coolant.

Thus, main factors ensuring high corrosion–erosive stability of materials in heavy liquid metal coolant (Pb, Pb–Bi) are:

- Application of silicon–containing steels;
- Passivation of oxygen, regime application for coolant;
- Application of additional corrosion barriers as oxide films formed on a surface of structure elements during modes of running–in.

The gained experience allows with confidence to forecast absence of corrosion damages of steels in Pb–Bi coolant up to temperature 620°C on the basis of tens thousand hours, that is proved by successful experience of reactor installations activities.

As a result of the carried out recently researches of corrosion behavior of steels in lead coolant with rather high contents of oxygen was shown, that in temperature range 550 – 650°C on the basis of tests during 8500 hours the liquid metal corrosion of core materials of BREST reactor installation was also not watched. The tests were carried out near to high passivation boundary of ferrite–martensite 12%Cr–Si steel of the EP823 type, i.e., in

range $4 \times 10^{-5} - 1 \times 10^{-6}$ mass% of oxygen dissolved in lead. At the same time, as was established as a result of these tests, protective oxide layers formed on steel are not optimal on their thickness. The researches for refinement of boundaries of passivation modes of activities of materials of BREST reactor installation are organized and carried out in IPPE.

The high reserve of corrosion resistance of steel EP823 was proved by last researches of fuel-cladding compatibility. The obtained results of research of compatibility of fuel rod materials (cladding of EP823 steel, lead contact heat-transfer layer, uranium mononitride fuel), tested at temperatures 650°C and 700°C during 9400 hours, were shown:

- The products of corrosion interaction and their thermal transfer on altitude of fuel rod were not revealed;
- There were not revealed infiltration of lead inside of a cladding, formation of corrosion centres on EP823 steel;
- The mechanical properties of fuel rod claddings were not changed as a result of a contact to a lead heat-transfer layer.