A NEW GENERATION STEEL FOR HEAT EXCHANGERS TUBES OF REACTORS DESIGN WITH LEAD COOLANT

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1 Work relevancy

The feasibility of creating new generation fast neutron reactors with heavy liquid-metal coolants is largely governed by the development of new structural materials. One of the most complex components of a newly developed innovative pilot and demonstration fast neutron reactor with lead coolant (BREST-OD-300) is the steam generator. The material of heat-exchange tubes shall have a sufficiently high corrosion resistance in the liquid lead coolant, which flows around the heat-exchange tube, as well as in a steam-water environment with high parameters, having an impact on the tube from the inside [1,2,3].

The additional difficulty is caused by the fact, that the heat-exchange tubes should have a big length (more than 30 m), because welding of the tube pieces is not allowed because of high reliability requirements. Up until now, the materials suitable for application in the above-mentioned conditions were non-existent. The well-known steel grades, which have high corrosion resistance in a liquid lead flow, such as 12Cr-Mo-W-Si-V-Nb (EP823) ferritic-martensitic steel and 15Cr-9Ni-3Si-Nb (EP302-Sh) austenitic steel, are not suitable because of several reasons. For example, EP823 steel does not have the required corrosion resistance in a steam-water environment. Its main advantage is the high radiation resistance together with the satisfactory corrosion resistance in a heavy liquid-metal coolant, and it is generally used in fuel claddings and other components of the reactor core. The EP302-Sh steel has high corrosion resistance in a liquid heavy-metal coolant flow, however, its resistance to local corrosion in steam-water environments which contain chlorides (hereafter – chlorine-containing environments) is insufficient.

In the reactor design, two-layer heat-exchange tubes were initially considered. The inner layer was intended to provide high corrosion resistance in the steam-water environment, and the outer layer – in the liquid lead flow. However, because of quite serious technological issues arising during the course of actual implementation of such heat-exchange tubes, and due to their high cost, this option was rejected.

It was decided to create a new grade of steel having a high corrosion resistance in the liquid lead flow along with a high resistance to local corrosion in the chlorine-containing environments, by means of targeted alloying the already known EP302-Sh austenitic chromium-nickel steel.

2 Development and performance verification of new steel

It is known, that the key role in corrosion resistance in liquid lead flow belongs to chromium and silicon, which effect the formation of a protective oxide film representing a barrier preventing penetration of the corrosive liquid lead to the metal with subsequent onset of the high-speed liquid-metal corrosion, causing damage to the structural material. Thus, the known stainless EP302-Sh chromium-nickel steel is alloyed with both chromium in an amount of 14-16 %, and silicon in an amount of 2.2-3.0 %. However, the presence of a significant amount of silicon (2.2-3 %) in the austenitic steel also has a negative effect on its characteristics. Specifically, during long-term temperature exposures, the austenite, which contains a significant amount of silicon, becomes unstable and vulnerable to breakdown due to precipitation of the excess phases (such as Ni_3Si, sigma phase, carbides, etc.). In turn, precipitation of these phases leads to deterioration of mechanical properties and susceptibility to the types of local corrosion in the chlorine-containing environment, such as pitting, stress corrosion cracking and crevice corrosion.

Based on the objective of creation of the new steel resistant to corrosion both in the lead flow and in the steam-water environment, the following principles of additional alloying of EP302-Sh steel were developed:

– reduction of carbon content in EP302M-Sh steel (in EP302-Sh steel, carbon content is 0.08-0.12 %) decreases the risk of intergranular corrosion (IGC), embrittlement after cold working and thermal ageing;

– addition of nitrogen increases stress-corrosion cracking stability of the austenite and increases steel strength with preservation of the high ductility;

– addition of molybdenum increases resistance to stress-corrosion cracking in the chlorine-containing environment;

– addition of vanadium stimulates the formation of fine nitride powders and improves the strength properties of the steel;

– addition of tungsten in regulates the content of ferritic phase and promotes an increase in the strength properties in the high temperature conditions;

– increase of the nickel content improves the austenite stability without decreasing the resistance in the lead coolant conditions;

– decrease of the upper limit of silicon content increases the austenite resistance to thermal exposure and creates preconditions for satisfactory weldability with the preservation of stability in the heavy liquid-metal coolant flow;

– increase of the upper limit of chromium content up to 20 % compensates for the silicon content decrease, contributing to the preservation of the high corrosion resistance in the lead flow and in the water-steam environment;

– introduction of boron minor additions (introduced based on calculations prior to steel casting and are not controlled) provides purification of the crystal boundaries, increases the processing ductility and the impact strength.

A series of laboratory melting of the new steel grades created based on the above alloying principles was performed. The manufactured specimens were used to test the new material properties including the resistance to local corrosion in the steam-water environment [5].

For the selected compositions of EP302M-Sh and EP302-Sh steels, an assessment of resistance of these materials to the intergranular and pitting corrosion was performed.

The **K** parameter characterizing a susceptibility to IGC during the standard testing (H_2SO_4+$CuSO_4$+Cu, 24 hours, 650 ^oC) is determined based on the content of the alloying and impurity elements [6]. If **K≤14,** then the steel is susceptible to IGC; if **14≤K≤16**, then the steel is slightly susceptible to IGC. The obtained parameter **K=13** for EP302-Sh steel is indicative of susceptibility of this steel to IGC, whereas for EP302M-Sh steel, the obtained parameter was **K=20.** Thus, EP302M-Sh steel has high resistance to IGC.

For the stainless steels, the pitting corrosion resistance is determined according to the **PRE** equivalent [7]. The **PRE** equivalent for EP302-Sh and EP302M-Sh steels was equal to **14** and **25.2**, respectively, which indicates a higher resistance (nearly twice as much) of EP302M-Sh steel to the pitting corrosion.

Specifications on EP302M-Sh steel were developed for tube shells and long tubes. For the first time in the domestic and foreign practices, a pilot batch of long tubes (up to 45 m) was fabricated.

3 Practical importance

The results of the development of the new steel with the improved properties as opposed to EP302-Sh steel, were as follows:

– impact strength of EP302M-Sh steel is 2-3 higher than that of EP302-Sh steel;

– yield point at a temperature of 550 ^oC is significantly higher than that of the standard stainless austenitic steels;

– long-term of EP302M-Sh steel is higher than that of EP302-Sh steel;

– long-term ageing at a temperature of 550-600 ^oC does not lead to a reduced resistance to the local corrosion in the chlorine-containing environments and its resistance is higher than that of EP302-Sh steel.

The obtained properties suggest that a new unique material for heat exchange tubes of fast neutron reactors with lead coolant has been developed.

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