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Study of heat transfer during boiling water on a modified surface obtained by microarc oxidation

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The paper presents an experimental study of heat transfer during pool boiling water on smooth and modified surfaces. The modification of the surface of the D16T alloy was carried out by applying a porous chemically stable coating using the micro-arc oxidation method, which ensures a high degree of adhesion to the substrate. Experiments have shown an increase in heat transfer during boiling on a coated surface compared to a smooth surface by an average of 30−50%.

Keywords: boiling, surface modification, micro-arc oxidation, heat transfer intensification.

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The overwhelming majority of current studies in the field of heat transfer during boiling are focused on the intensification of this process by means of modification of a heating surface [1–5]. A considerable number of different techniques of surface modification with their own advantages and disadvantages have been developed. Some of the widely used methods worthy of note are processing by deforming cutting, mesh and porous coatings, plasma coating, sintering of particles with a substrate, etching, etc.

Microarc oxidation (MAO) is one of the promising and little-studied methods for modifying a boiling surface. In the context of intensification of the heat exchange during boiling, MAO allows for the application of thin porous coatings with thicknesses and pore sizes ranging from several micrometers to several tens of micrometers to the surface of valve metals (aluminum, titanium, zirconium, etc.). The advantages of this method include a high degree of adhesion to the substrate, chemical stability, technological effectiveness and relatively low cost, and the capacity to apply coatings to surfaces with a complex geometry (e.g., to the inner surface of pipes or in hard-to-reach cavities). However, very few studies on heat transfer during boiling on surfaces modified by MAO have been published to date. The heat transfer on surfaces with an MAO coating was found to be intensified compared to the one on a smooth substrate during boiling of subcooled water [6] and nitrogen [7].

The aim of the present study is to examine the effect of surface modification by MAO on heat transfer during pool boiling of saturated water.

The key elements of the experimental setup used in the study are shown in the diagram in Fig. 1. The boiling surface was heated using the thermal wedge method. A copper block was heated by cartridge heater *3* with a maximum power of 350 W regulated by a laboratory autotransformer. To minimize heat leakage from the copper heating block to the environment, it was wrapped with a high-temperature thermal insulator (asbestos heat-resistant tape). Studied samples *5* 18 mm in diameter and 20 mm in height were made of aluminum alloy D16T and secured to the surface of the heating block with thermal paste. Four pre-calibrated chromel-copel thermocouples with a diameter of 0.2 mm (and a measurement accuracy of 0.5°C) were embedded in the studied sample and used to measure the heat flux density (q) and the temperature of the heat-transfer surface. They were positioned at a distance of 5 mm from each other on the sample axis. The upper thermocouple, which

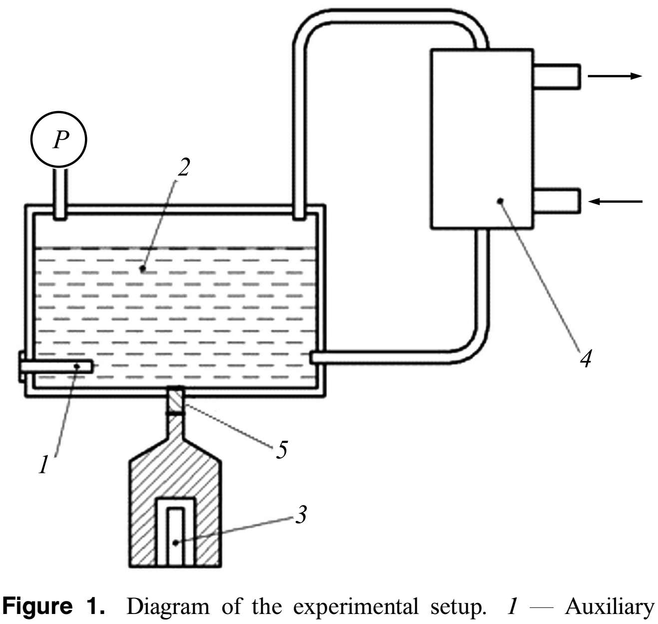

Figure 1. Diagram of the experimental setup. *1* — Auxiliary water heater, *2* — water tank, *3* — cartridge heater, *4* — vapor condenser, and *5* — studied sample.

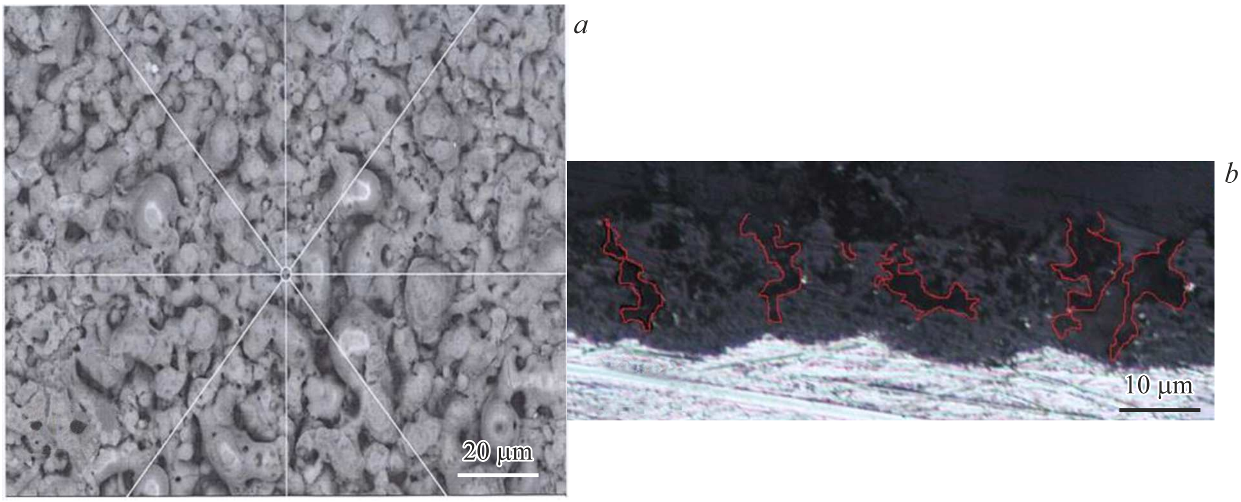

Figure 2. Scanning electron microscope images of the coating. *a* — Coating surface; *b* — cross section (pores are outlined).

provided the readings used to calculate the boiling surface temperature, was located at a distance of 0.5 mm from it. Thermocouple signals were processed by a Termodat-25M5 instrument with an automatic cold junction temperature compensation operated in the electronic recorder mode. The resulting plots of temperature variation with time recorded by each thermocouple were stored on a personal computer. The parameters of each thermal regime (experimental point) were determined after stabilization of the temperature values on all thermocouples. The approximate average holding time after changing the thermal load was 30 min.

Experiments were conducted with the use of distilled water under atmospheric pressure. Liquid was poured into a special stainless steel vented tank $100 \times 90 \times 70$ mm in size. Cartridge heater *1* (Fig. 1) was used to heat water to saturation temperature and maintain this temperature. Vapor produced in the process of boiling was condensed in a special coil-type heat exchanger *4* with a cold coolant (tap water).

The test sample made of alloy D16T was coated using the MAO method at the Gubkin Russian State University of Oil and Gas in accordance with the procedure outlined in [8]. Figure 2 shows the electron microscope images of the coating. The average coating thickness was 20 μm. Its cross section (Fig. 2, *b*) reveals vertical channels (pores) that are produced in the process of layer formation in specific MAO regimes. Pores of these shapes and sizes (from several micrometers to tens of micrometers) may serve as potential vaporization nuclei and improve the surface wettability.

Figure 3 presents the obtained experimental data in the form of boiling curves (dependences of q on the surface superheating relative to the saturation temperature (ΔT_{sat})). It can be seen that the application of an MAO coating to a smooth D16T alloy surface intensified the heat transfer by 30–50% on the average. The data on heat transfer intensification obtained by modifying the surface with microchannels [9] and with the application of a high-porosity coating [10] are also shown in Fig. 3 for comparison. These experiments yielded similar results.

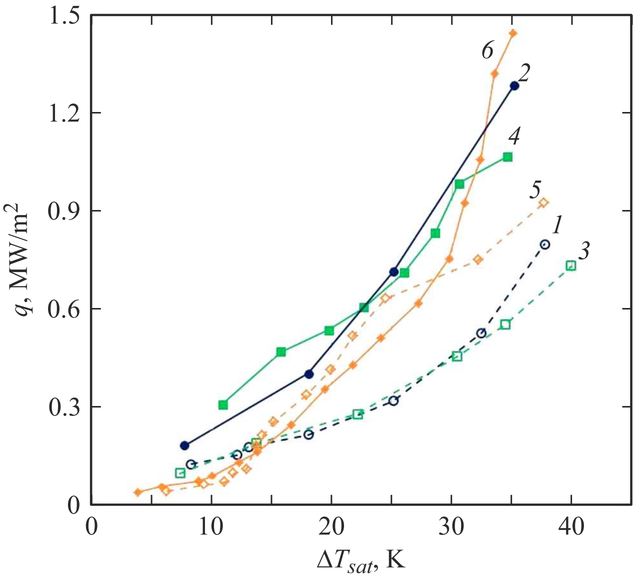

Figure 3. Boiling curves of water under atmospheric pressure: *1* — on a smooth D16T surface; *2* — on an MAO-coated D16T surface; *3* — on a smooth Si surface; *4* — on a surface of Si with microchannels with a cross section of $100 \times 100\,\mu$m; *5* — on a smooth copper surface; and *6* — on a copper surface with a porous coating (with a porosity of 94.4%). *1, 2* — Data obtained in the present study; *3, 4* — data from [9]; and *5, 6* — data from [10].

The obtained data are apparently related to the specifics of shape, size, and density of pores on the modified surface. These pores give rise to additional vaporization nuclei, the area of the heat-transfer surface increases, and capillary forces increasing the intensity of liquid suction are produced.

Thus, it was established experimentally that the heat transfer during pool boiling of saturated water on a surface with an MAO coating is intensified by an average of 30−50% compared to the heat transfer for a smooth D16T alloy surface. This fact and other advantages of the discussed method of surface modification (high degree of adhesion to the substrate, chemical stability, relatively low cost, etc.) indicate that microarc oxidation has potential for application for process intensification in cooling systems of various equipment utilizing liquid boiling.

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Conflict of interest

The authors declare that they have no conflict of interest.

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