Research wetting and Leidenfrost effects on structured surfaces in contact with water

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Abstract. The influence of micro- and nanostructured surfaces on the boiling characteristics is introduced. The working surfaces were obtained by processing the samples with a laser, plasma, electron, or ion beam. Some of the samples were preliminarily coated with nanocarbonic materials. The morphology and the contact angle of wetting during interaction with water were studied for surfaces. A description of the apparatus for investigating the Leidenfrost temperature is introduced.

1. Introduction
Technologies for modifying the working surfaces of process equipment elements are increasingly used for comprehensive solution of a wide range of problems in many fields of science and industry. Upon melting, evaporation, ablation and solidification of matter, micro- and nanostructures are formed on the surface of the material that significantly influence the parameters of the surface being treated by laser, plasma, ion and electron beams. As a result of the modification, the surface acquires some new physicochemical properties that were extrinsic earlier. It is also possible to use these technologies in order to achieve certain goals, for example, the regulation of hydrogen exchange on the surface of fuel tube envelopes of nuclear reactors.

2. Tailoring multiscale surfaces
A bank of working surfaces was obtained: 1.5-4 mm thick metal plates, treated with laser, plasma, electron and ion beams, pre-coated with nanomaterials. More than 20 samples were obtained. Some of the work surfaces are concomitant and were transferred for study after research on the following installations:
- plasma accelerator KSPU-T from SSC TRINITI. The KSPU-T unit is a single-stage coaxial high-current plasma accelerator. The energy released on the target is 0.5 ÷ 2.5 MJ/m2, the pulse duration is up to 0.6 ms, the ion energy is 0.1 ÷ 1.0 keV, and the plasma density at the target is 1022 ÷ 1023 m⁻³.
- the Kalmar accelerator, providing current I = 30 kA at an electron energy E = 0.3 MeV and current pulse duration at half-height τ = 10⁻⁷ s.

Working sections with a diameter of 30 mm were made from the samples after exposure. Photos of some typical working areas are shown in Fig. 1, 2, 3, description and processing characteristics are given in Table 1.

It is possible to observe unevenness of micro- and nanosize in the photos taken at different scales, which are potential centers of vaporization.
3. **Morphology and limiting wetting angle research**

The main objective of the research was to determine the parameters of the surface roughness and describe the structure, including the local melt zones. In order to obtain roughness parameters, the LEXT OLS4000 microscope was used. The contactless laser microscope Lext OLS4000 produces a precise automated surface roughness measurement regardless of the surface material characteristics and has a horizontal resolution of up to 120 nm, vertical - up to 10 nm. The total range of magnification, depending on the lenses used, varies from 50 to 17280 times. In the study of the roughness of the samples multiple automated measurements were made in at least 10 sample regions in different directions. Numerous measurement results are obtained, averaging for which is performed. For structures that have regular irregularities due to the processing features of the laser and electron beams, the results of measurements are obtained, both for regular irregularities and roughness parameters inside regular structures. The characteristics of some of the investigated surfaces are given in Table 1. The main characteristic values in the study are:
- Rc - the average height of the irregularity of the profile element. While passing in a certain direction in each of the analyzed regions, the microscope records the average value of the height of the irregularities from the low spot to the top. The minimum, maximum and average values are formed from the data obtained for regions.

- Ra - the arithmetic average deviation of the height of the irregularities from the average value. The microscope, as in the previous case, registers the average value in the direction of measurement for each individual region and forms the minimum, maximum and average values for regions.

As the results of roughness measurements show, the characteristic dimensions of the irregularities are 5-30 μm for most surfaces. For a number of surfaces local melt zones and deformations with unevenness values reaching 100 μm are observed. Characteristic irregularities are potential centers of steam formation for water and many freons at subatmospheric pressures.

Measurement of the static wetting angles for all samples using the KRUS DSA25 automated unit. The measurements for two initial droplet volumes were performed many times in different regions of surfaces. The averaged measurement results for some surfaces are presented in the application table. The measured data indicate that changes in the contact angle of surfaces wetting after surface treatment by beams are not mainly performed, even if there are metal melting zones and significant unevennesses. A noticeable change in the wetting contact angle in comparison with the untreated material is observed on some samples with surface strongly fused in the upward direction, a decrease in the value is observed for sample No. 6 of low-carbon steel treated with a laser. A decrease in the contact angle of wetting should lead to an earlier separation of the vapor bubbles, a shift in the Leidenfrost temperature to higher values, and an intensification of heat transfer during boiling [4]. An example of the obtained image for calculating the contact angle of wetting is shown in Fig. 4.

![Figure 4](image1.png)

**Figure 4.** A photograph of a drop on the surface of the sample when determining the contact angle of wetting

![Figure 5](image2.png)

**Figure 5.** Scanning of the surface of a sample made on a confocal microscope

Also, work is in progress to determine the Leidenfrost temperature for working surfaces and to study boiling in a large volume. Fig. 6 shows a diagram of the Leidenfrost temperature test apparatus.
Table 1. Sample research results.

| Sample number | Sample characteristics and method of treatment | Contact angle of wetting | Irregularity indices (μm): maximum, minimum and average value for 10 surface areas |
|---------------|-----------------------------------------------|--------------------------|--------------------------------------------------------------------------------|
|               |                                               | Before treatment | After treatment | \( R_a \) | \( R_c \) |
| 1             | Sample from copper, processed at the Kalmar unit, 0.1-0.5 MJ/m². | 83.6 | 82,8 | 3.256 | 13,34 |
|               |                                               |             | | 2.541 | 8,268 |
|               |                                               |             | | 3.11033 | 10,6874 |
| 2             | Sample from steel, processed at the KSPU-T unit, 1 MJ/m². | 82.1 | 82.6 | Far area 1: | 2.137 | 6.035 |
|               |                                               |             | | 0.920 | 4.6484 |
|               |                                               |             | | 1.3492 | 8.986 |
|               |                                               |             | | 0.7877 | 2.752 |
| 3             | Sample from aluminum, processed at the KSPU-T unit, 0.5 MJ/m². | 78.7 | 77.7 | Far area 1: | 29.983 | 51.628 |
|               |                                               |             | | 13.044 | 77.8974 |
|               |                                               |             | | 20.9195 | 77.8974 |
| 5             | Sample from aluminum, processed at the KSPU-T unit, 0.5 MJ/m². | 82.3 | 100.6 | Area 1: | 5.718 | 14.02 |
|               |                                               |             | | 2.50 | 8.364 |
|               |                                               |             | | 3.4326 | 10.809 |
|               |                                               |             | | Area 2 50x: | 8.278 | 31.656 |
|               |                                               |             | | 2.829 | 12.794 |
|               |                                               |             | | 5.3876 | 18.9919 |
| 7             | Sample from stainless steel, processed at the Kalmar unit, 3 shots 500 J, 100 ns. | 72.4 | 77.1 | Area 1: | 3.135 | 11.443 |
|               |                                               |             | | 1.674 | 3.271 |
|               |                                               |             | | 2.4213 | 8.3278 |
|               |                                               |             | | Area 2: | 2.431 | 17.144 |
|               |                                               |             | | 1.144 | 2.877 |
|               |                                               |             | | 1.7751 | 7.9203 |

**Notes:**
1. For sample 2 the results of the unevenness indices are presented for two areas: the region in the central part with the maximum treatment exposure and in the back, where the exposure and effect are less pronounced.
2. For sample 5 the results of the unevenness indices are presented for two regions with different survey rates of 50x 20x, respectively.
The Leidenfrost temperature is determined by the dynamics of evaporation of the drop. In the course of the experiment, the installation is heated to a certain surface temperature (it is selected experimentally) greater than the Leidenfrost temperature. The voltage on the heater is set in such a way that the surface temperature is reduced at a rate of about 0.5÷1 °C per minute. Periodically, a droplet of liquid of constant volume is placed on the work area with a special dispenser. The whole process is fixed to the video camera, with the help of the thermal imager fixed surface thermograms. Based on the received video, the droplet evaporation time is determined and correlates with the surface temperature, which is recorded using the software of the analog-to-digital converter. The Leidenfrost temperature characterizes the smallest heat flux and corresponds to the largest evaporation time of the liquid drop.

A fragment of the file with the results obtained is presented in Table 2.

### Table 2. Example of the results

| Time (s) | Temperature (°C) |
|----------|------------------|
| 38.3     | 205.6            |
| 38.2     | 204.5            |
| 50.9     | 203.8            |
| 49.0     | 202.5            |

4. **Appendices**

When modified by a laser, ion, plasma and electron beam treatment, the morphology of the material surface changes significantly - micro- and nanostructures are formed, which are potential centers of
boiling vaporization. On the surface of some samples, there is a significant change in the contact angle of wetting compared to the untreated surface, which can affect the shift of the Leidenfrost temperature, the shift in the boiling crisis, and the change in the heat exchange rate during boiling.

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