Pool boiling heat transfer performance of the surface modified with laser

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Abstract. The paper deals the problem of pool boiling heat transfer on the surface produced by the modification with the laser beam. The laser enabled to produce grooves and roughness which have a positive impact on heat transfer. The distilled water and ethanol boiling performance of a horizontally located specimen is discussed and the test results are compared with the model of boiling heat transfer selected from the literature. The laser technique proved to be a valuable tool for producing surfaces that improve thermal performance during pool boiling.

Keywords: boiling, heat transfer, laser melting

1 Introduction

Both boiling and condensation provide the opportunity to exchange large heat fluxes, which is of interest due to the fact that modern technological devices require the dissipation of considerable heat loads. The further increase in heat transfer can be obtained with the modification of the surfaces.

Kaniowski and Pastuszko [1] focused their paper on the modification of the heater surface with specially prepared microchannels (of the depth 0.2 – 0.5 mm) and tested boiling of water. These authors found out that the maximum heat flux for a modified surface was about 2.5 times bigger in comparison to the heater without any grooved on its surface. During the testing, the mean diameters of the departing bubbles were determined with high speed camera and it was reported that the diameter rose and the frequency of departure fell with the increasing heat flux. A later paper by the same authors [2] contains data of FC – 72 boiling. Here the improvement of the modification of the heater was also evident. It was stated that heat transfer coefficient was more then five times the value of the surface with no grooves. The researchers also pointed out that many elements influence boiling performance such as surface roughness, wettability and etc. Maciejewska et al. [3] focused on the boiling enhancement in the flow mode in minichannels, however the concept of the phenomenon is consistent with the pool boiling mode. The modification of the heater surface with the lasers has been the subject of some papers already. Piasecka et al. [4] considered laser texturing assisted with vibrations as well as the electromachining technique as the means to intensify boiling. In [5] six samples were tested in water and ethanol pool boiling conditions. The specimens were produced in such a way that

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longitudal fins were developed. The authors claimed that the modification with the help of the laser beam was very efficient and the heat flux dissipated from such surfaces was a few times higher than from the reference surface. The grooved generated with the laser were up to 0.55 mm deep and up to 1.15 mm wide.

It needs to be noted that the enhancement of heat transfer can be very important for many areas of engineering such as the ventilation systems [6] and others [7 - 11].

Due to the significant possibilities offered by the laser modification, the present paper will be focused on the analysis of nucleate pool boiling on the sample produced with the laser beam.

2 Testing method and sample characteristics

Laser beam enables to produce various shapes on the surface. The present study deals with a specimen whose diameter is 3 cm. It was made by SPI G3.1 SP20P pulsed fiber laser at the set impulse frequency of 60 Hz and scanning velocity of 200 mm/s. Figure 1 shows examples of specimens generated with this technology.

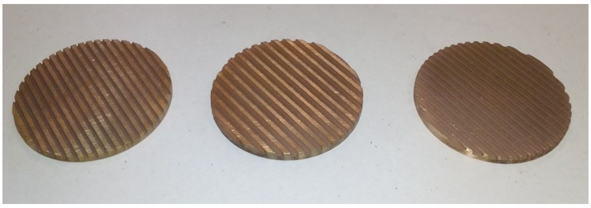

Fig. 1. Examples of specimens made with the laser.

The advantage of using the laser beam is the creation of the grooves (longitudal fins), which extend the surface available for heat exchange. However, the additional and very important aspect is the creation of the rough surface at the bottom (due to the thermal interaction with the metal). Roughness can also significantly increase the heat transfer during boiling due to the increased density of nucleation sites (locations where bubbles grow) on such a modified surface. Figure 2 presents the morphology of the surface at the bottom of the groove. It can be seen that it is not uniform and dips as well as hills are present (of the height up to 85 μm).

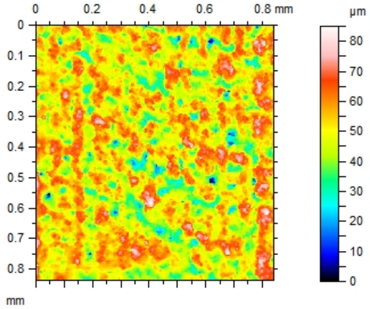

Fig. 2. Morphology of the surface subjected to laser (the bottom of the grooves of samples in Fig. 1).

The measurements of heat flux have been made on the stand, where the sample is located on top of the heater and attached horizontally through soldering. Above it the vessal with the liquid (water and ethanol) is located. The details of the testing method have been provided by the authors in [5].

3 Results and discussion

Apart from measurements of heat flux dissipated by the samples, the boiling performance investigations are also focused on the actual processes occurring on the specimens. This task is arranged with high speed digital cameras that can take pictures at very high frequencies. Figure 3 presents the photos of the fully developed nucleate boiling phenomenon of distilled water.

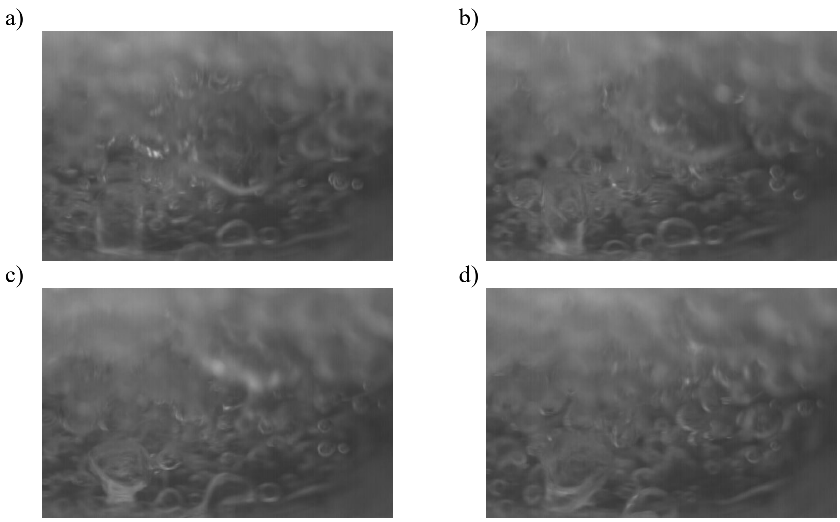

Fig. 3. Boiling of water on the horizontal sample: a) t = 0, b) t = 0.01 s, c) t = 0.02 s, d) t = 0.03 s.

Two laser - made samples were selected for comparison, they both had the same groove depth of 0.55 mm, but sample A had the groove width 0.60 mm, while sample B the groove width of 1.15 mm. Figure 3 shows the ratio of the heat flux dissipated from sample B to the heat flux from sample A (data adopted from [5]).

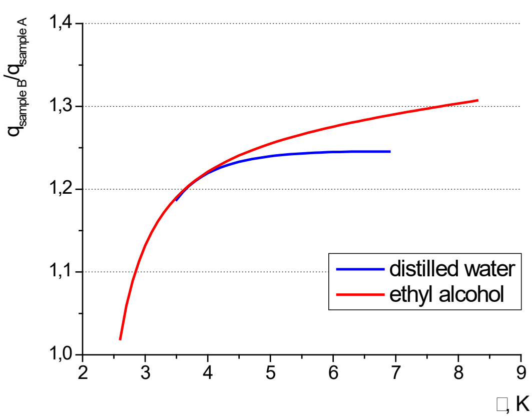

Fig. 4. Ratio of heat flux from selected laser treated samples.

As can be seen the performance of sample B is slightly better than sample A and very similar for both the boiling agents. The heat flux values of sample B become larger with increasing superheat (difference between the surface and saturation temperatures). This might be linked with the larger groove width of sample B and, thus, larger surface area of increased roughness.

The proper operation of phase – change heat exchangers and their design requires that the heat flux and general performance can be correctly calculated with the adequate correlations as well as models. For this aim, various methods are used in terms of modeling (as given, for instance in [12 – 14]). In the present paper, a simple model based on the conduction heat transfer, will be used to compare the experimental data with the calculated ones. This model was developed by Nishikava et al. [15]. The test results of samples A and B (adopted from the authors' work [5]) were compared with the results obtained with the application of the model [15] and it has been graphically shown in Figures 5 and 6.

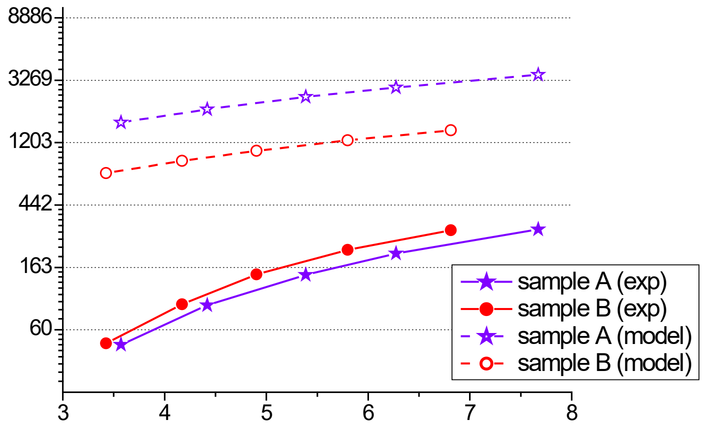

Fig. 5. Comparison of the experimental and model calculated data (water).

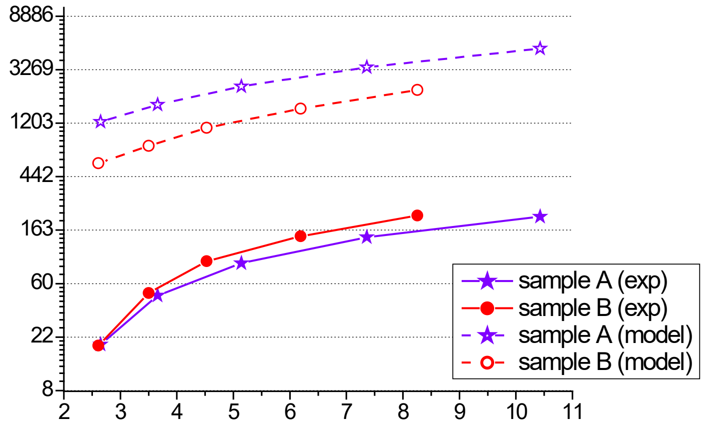

Fig. 6. Comparison of the experimental and model calculated data (ethanol).

Nishikava et al. [15] model is based on the concept of heat transfer conduction and does not take into account a complex process of bubbles' formation and departure. Thus, the results obtained with this model proved to be quite distant from the experimental data for both the samples and both the fluids (though it was especially visible for water). However, the general trend of heat flux increase with superheat has been maintained. It seems that this model should be used with caution for the analyses of surfaces modified with the laser beam.

An interesting feature is the fact that the experimental data are relatively close to each other for both the specimens, while the respective calculation results according to [15] are quite apart from each other. It indicates that the assuptions taken in the model about the large impact of conduction might not be true. However, more data is needed to be certain regarding the usability of the Nishikava et al. model in the assessment of heat transfer mechanisms on the laser treated heaters.

4 Summary and conclusions

The laser treatment technique can generate surfaces of modified morphological features. This has a large influence on thermal performance of specimens during nucleate boiling. The extension of the surface area, on which heat exchange occurs as well as the creation of roughness by the laser beam can lead to increased heat fluxes. The model by Nishikava et al. failed to provide correct calculation results that would match the experimental data. This can be caused by the mechanisms of boiling related to convection such as bubble and liquid movements and not solely conduction.

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