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RESULTS OF BOILING HEAT TRANSFER TESTS ON LASER TREATED COPPER FIN

Abstract: *The paper presents the test results of boiling heat transfer of distilled water on a copper fin under atmospheric pressure. The surface of the fin has been modified with the laser and grooves have been produced along the fin's length. It has been determined that such a modification of the heater surface can results in elevated heat transfer coefficient. The value of this coefficient has been almost three times higher in comparison to the smooth reference surface.*
Key words: *boiling heat transfer, laser treatment.*

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РЕЗУЛЬТАТ ТЕПЛОПЕРЕДАЧІ ПРИ КИПІННІ НА МІДНИХ РЕБРИСТИХ НАГРІВАЧАХ, ЩО ОБРОБЛЕНІ ЛАЗЕРНИМ ОПРОМІНЮВАННЯМ

У статті представлені результати випробувань тепловіддачі при кипінні дистильованої води на мідних ребристих нагрівачах при атмосферному тиску. Поверхня ребер була змінена лазерним опромінюванням. Було встановлено, що така модифікація поверхні нагрівача може призводити до підвищення коефіцієнта теплопередачі. Значення цього коефіцієнта було майже в три рази вище у порівнянні з гладкою поверхнею.
Ключові слова: теплообмін при кипінні, лазерна обробка.

Introduction

Boiling is a very efficient heat transfer mode. It is characterized by significant values of the heat transfer coefficient and considerable heat fluxes can be dissipated at low temperature differences. However, technologies to further increase the heat fluxes are still searched for. One of the augmentation methods is the surface treatment. A number of different techniques are used – for example rough surfaces or the application of microstructures on heat exchangers. In the latter case a considerable increase in the heat flux is possible. For example Wondra and Stephan [1] investigated boiling of FC – 72 on surfaces with micro pin fins attached to a copper surface. The diameters of pores were 3.5 μm and 3.9 μm. The height of the produced structure was 45 μm and 32 μm, respectively. The authors found that heat flux dissipated from such a treated surface was even 7.1 times higher than for the smooth surface without such a coating. Similarly, other forms of surface treatment – such as oxidation – can improve heat transfer during boiling. Hong et al. [2] tested oxidised elements which proved to increase the heat transfer coefficient by 1.5 – 1.75 times for water boiling and up to 1.5 times for R – 11 boiling in comparison with the reference surface (without oxidation). Chang and You [3] experimentally analysed boiling heat transfer of FC-72 on surfaces with porous layers that consisted of solid particles joined together with epoxy. Aluminium, copper, diamond and silver powders were used of particle diameters ranging from 1 μm to 50 μm. The application of such microstructures resulted in increased heat flux even by ca. 330 % in relation to the smooth surface. These methods are common and involve the application of an additional coating on the surface, however, sometimes the exchanger is subjected to different treatment. Foe example Nimkar et al. [4] tested boiling of FC – 72 dielectric liquid on a surface with pyramidal shaped cavities of the size 40 μm square mouth and 240 μm square base etched in silicon base. Other solutions of microstructure production are possible such as the application of meshes or rough surfaces.

The application of laser treatment is not commonly discussed in literature. Hwang and Moran [5] focused their paper on the enhancement of boiling heat transfer from electronic components by the application of laser-drilled holes 3–15 μm in mouth diameter. Orzechowski [6] investigated the modification of the surfaces of copper and aluminium fins by laser and its effect on boiling heat transfer. The heat flux reported for a laser treated surface was even about 3 times higher in comparison to the smooth surface. In another work Orzechowski [7] analysed water boiling on laser treated surface with the additional coating of a copper fibrous structure of 85% porosity and reported an intensification of heat transfer.

A shortage of experimental data of boiling on laser treated surfaces requires to conduct tests in this area in order to expend the knowledge and enable to properly design such heat exchangers for example for possible industrial applications.

Material and method

The laser treatment was performed with the aid of the 6,5 kW TRUMPH laser system. The power supplied was ca. 800 W. The narrow grooves were created in this way of ca. 1 mm depth along the length of the copper fin some 2 mm apart from each other. In this method a surface extension is possible to obtain. Moreover, nucleation sites are produced within the grooves. Both these factors should have a positive impact on the boiling process.

The tests have been performed with the use of a long – wave thermovision camera basing on the method described in detail by Orzechowski [7]. The analysed fin is immersed in the boiling liquid on one side (here laser treatment was done on the sample) and on the other it is observed with the infrared system. Heat is supplied to the base of the fin, so the temperature gradient is created along the length. First, the temperature distribution should be recorded as presented in Figure 1.

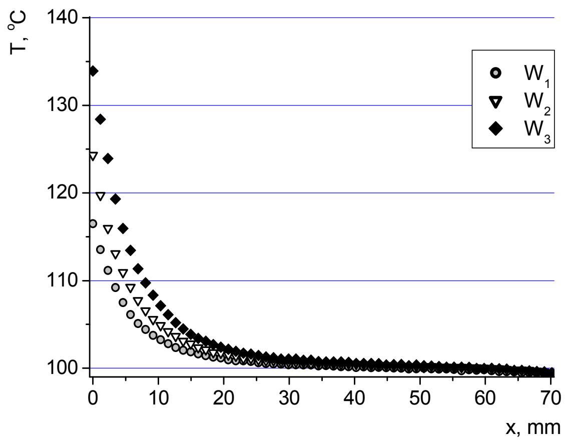

Fig. 1. Temperature distribution on the fin with laser treated surface for three values of power (W) supplied to the heater

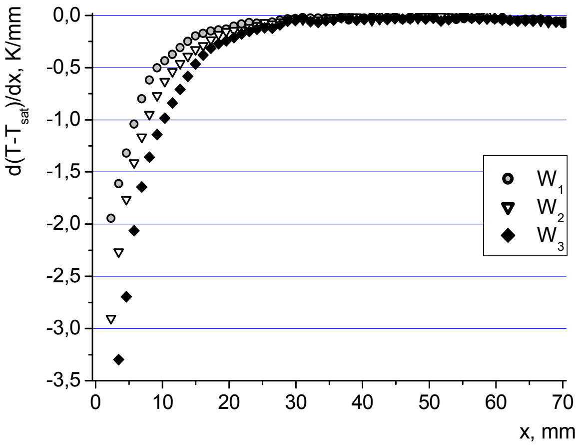

Fig. 2. Gradient of temperature difference for three values of power (W) supplied to the heater

Then the numerical differentiation is needed in order to determine the values of the first derivative of the difference between the surface temperature and the saturation temperature (Fig. 2). As can be seen in this figure the laser treated surface is efficient in dissipating heat because within a short distance from the base of the fin the derivative approaches zero.

The methodology presented in [7] enables to determine the boiling curve as a function of the heat transfer coefficient and the difference between the surface temperature and the saturation temperature. It is done based on the linear fitting of the experimental data (Fig. 3) and determination of constants assuming an exponential dependence of the heat transfer coefficient. It is worth noting that regardless of the power level the experimental points are located along one line with a very high R^2 value of 0.99.

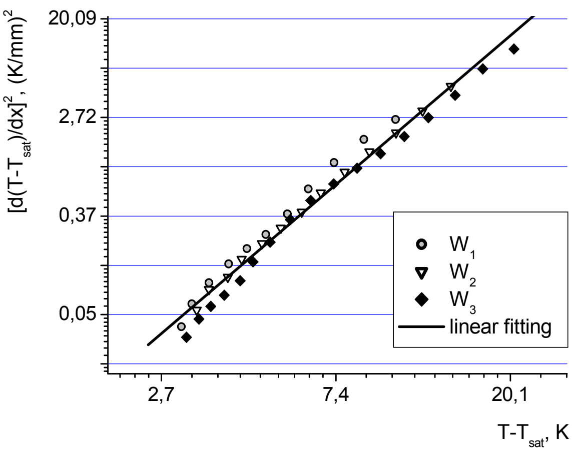

Fig. 3. Linear fitting of the experimental data

Boiling heat transfer test results

The method described in [7] enables to determine the boiling heat transfer performance of the analysed sample in form of the boiling curve based on the parameters obtained through the linear fitting. Figure 4 presents the dependence of heat flux vs. temperature difference of the wall and the saturation temperature (called 'superheat').

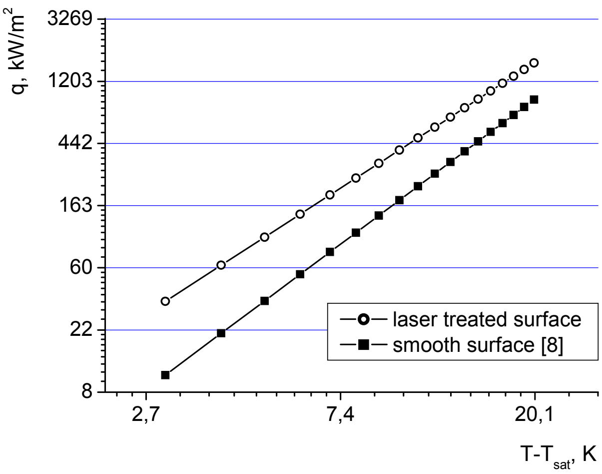

Fig. 4. Boiling curves for the laser treated surface and the smooth surface

It is clearly visible that the heat flux values of the laser treated surface are higher in comparison to the smooth surface results. This effect is more pronounced in the region of small temperature differences and diminishes as the superheat becomes higher. It might be related to an increased number of nucleation sites (locations where vapour bubbles are produced) available on the sample modified with the laser. Table 1 shows the obtained enhancement as the ratio of the heat flux of the laser treated surface and the smooth reference surface for selected values of the temperature difference (from 4 to 20 K).

Table 1

Heat transfer enhancement ratio

$T-T_{sat}$, K	4	8	12	16	20
q_{laser}/q_{smooth}	2,99	2,40	2,12	1,93	1,80

Conclusions

The application of the laser treatment is an effective method that can result in increased heat fluxes for the same superheat value. Boiling heat transfer performance has been improved in comparison to the smooth surface (without any modification) especially for small temperature differences. Here the heat flux has been ca. 3 times higher. It could be linked with a higher number of nucleation sites available for vapour production on the surface modified with laser. Further tests in this field could provide more data on the enhancement of boiling on such treated surfaces. However, one of the problems related to the use of laser on copper is a possible beam reflection and different heater materials might need to be used.

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ШЛЯХИ ПІДВИЩЕННЯ ТОЧНОСТІ РОЗВ'ЯЗКІВ ЗВОРОТНИХ ЗАДАЧ

В статті показано зв'язок числа обумовленості матриць і відносної та абсолютної похибок розв'язку зворотних задач, що описуються лінійними моделями. Обґрунтовано застосування методу найменших квадратів для покращення стійкості і підвищення точності розв'язків. Запропоновано метод забезпечення стійкості розв'язків, що базується на залученні додаткової інформації шляхом збільшення кількості вимірювань вихідних параметрів лінійної моделі. Розроблено спосіб і статистичний алгоритм забезпечення заданої точності розв'язку погано обумовлених систем лінійних алгебраїчних рівнянь.

Ключові слова: зворотні задачі, стійкість, лінійна модель, похибки, погана обумовленість

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WAYS TO IMPROVE THE ACCURACY SOLUTION OF INVERSE PROBLEMS

Abstract - The paper shows the relationship among the conditionality of matrices and the relative and absolute errors in solution of inverse problems described by linear models. Application of the method of least squares to enhance stability and improve the accuracy of solutions. The method of stability of solutions is based on attracting additional information by increasing the number of measurement outputs of the linear model. A method and a statistical algorithm to ensure the desired accuracy of solution poorly conditioned systems of linear algebraic equations.

Keywords: inverse problems, stability, linear model, errors, ill-conditioning

Вступ

Значна частина задач проектування, виробництва структурно-складних технічних виробів і