International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 19 (2017) pp. 8824-8829

On Parameters of Normalized Different-Scale Relief Created on Brass Surfaces by Means of Laser

A.V. Ryzhenkov, M.R. Dasayev, O.V. Ryzhenkov, A.V. Kurshakov

National Research University MPEI, Krasnokazarmennaya Str.17, Moscow 111250, Russia.

Abstract

Over the last decade, many countries have been developing actively certain super-hydrophobic materials and coatings. The paper presents results of experimental studies of the influence produced by the laser radiation parameters on values of wetting and roll-off angles of the brass surface. A surface with contact angle of 141.6° and roll-off angle of 8.4° was obtained when laser beam passed along the surface with the linear speed of 300 mm/sec, at the frequency of 20 kHz. Analysis of the diagrams shows that the highest wetting angle values and the lowest roll-off angle values are achieved at the lowest travel speed of the laser beam, which leads to extending the relief formation period.

Keywords: Hydrophobic surface, coatings, hydrophobic resistance, surface texturing, laser

INTRODUCTION

Over the last decade, many countries have been developing actively certain super-hydrophobic materials and coatings. The reason is that hydrophobic surfaces have a number of unique characteristics and are used in order to reduce hydrophobic resistance, to intensify heat exchange processes, etc.

According to the modern classification, hydrophobic materials are those whose wetting angle lies within the range from 90 to 180°. Any surfaces having wetting angles over 120° are considered super-hydrophobic, and over 150° - ultra-hydrophobic.

Researchers are particularly interested in controlling wettability of surfaces due to its wide range of applications. For instance, hydrophobization of inner functional surfaces of heat supply pipelines and heat exchangers would allow for considerable reduction of energy consumption related to transportation of energy carriers, improving longevity of existing and new pipeline systems as well as extend their maintenance intervals. Lately, NRU 'MPEI' has carried out comprehensive studies of the influence that hydrophobization of metal surfaces can produce on their hydraulic characteristics [1-3]. Of particular interest are super-hydrophobic surfaces with contact angles over 120°; however, as shown in [4], a high wetting angle value as such will not guarantee good water-repellent behavior. There are a number of surfaces, from which liquid is not evacuated at high values of wetting angle. Therefore, apart from high wetting angle values of functional surfaces, one finds certain practical interest in low values of roll-off angle (below 10°), i.e., the tilt angle of a surface with relation to the horizontal plane that is necessary to make sure drops would be evacuated inadvertently from that surface.

Nowadays, surfaces with high wetting angle on various materials can be obtained by different methods, including plasma treatment, chemical and physical deposition as well as texturizing of surfaces using laser radiation [5-7]. Among these options, laser texturizing of different-scale normalized relief on functional surfaces is the most promising method due to potentially high production rates, low volume of waste and single-stage type of treatment.

MODIFICATION METHODOLOGY OF THE BRASS SURFACE USING LASER SYSTEMS

In order to texturize the multi-scaled harmonized relief using laser radiation, samples were made of L63 grade brass, size 30x30 mm and 1 mm thick.

The sample surface was modified using the laser machine FMark NS-FB-20 ('TsLT', LLC, Russia) based on fiber laser (Fig. 1). This laser machine uses an IR ytterbium laser, wave length – 1,064 nm, available pulse length variation range - from 4 to 200 nsec, available pulse frequency range – from 20 to 100 kHz, and the average laser radiation capacity at the output of the focusing system is minimum 22.4 W. Laser beam focusing on exposure surfaces is carried out using a two-axis deflecting system MS-II-10 (RAYLASE AG, Germany).

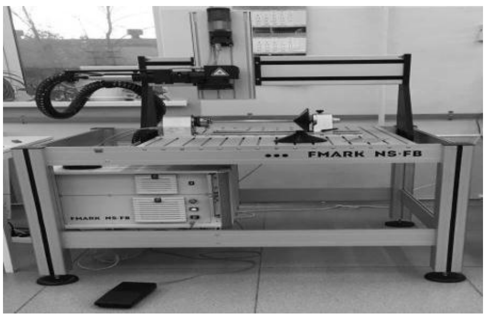
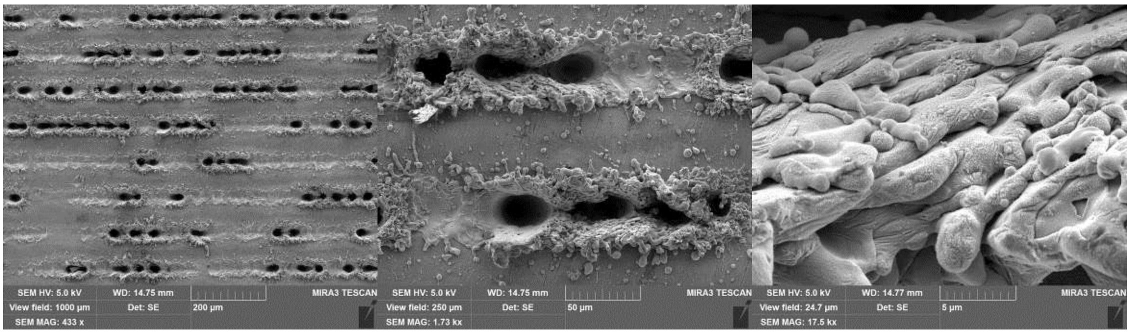


Figure 1: Machine FMark NS-FB-20.

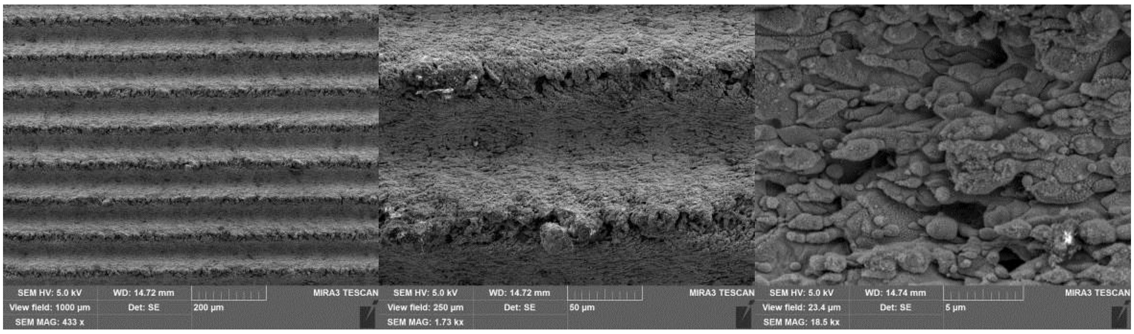
Modification process of the brass sample surface includes the following stages:

- preliminary preparation of sample surface (treatment with isopropyl alcohol, washing with distilled water, drying);
- mounting the sample on the coordinate table;
- laser beam focusing on the sample surface by means of a scanner;
- texturizing of normalized different-scale relief with preset geometry characteristics and laser radiation parameters.

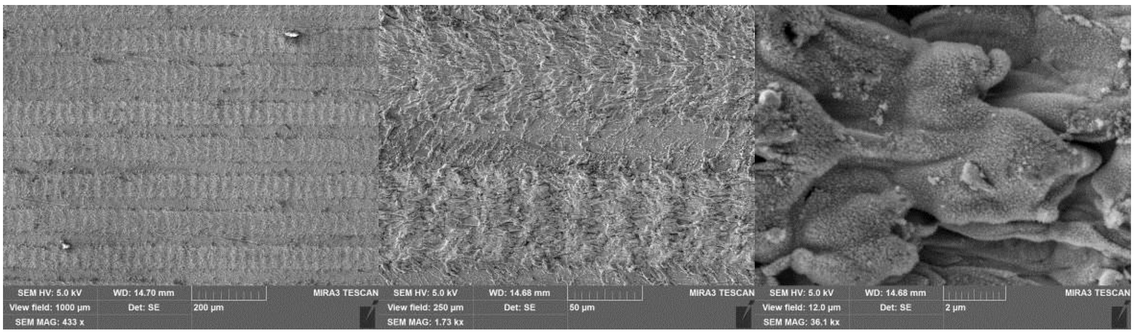
In this study, samples were exposed to laser pulses changing at the rate of 20 kHz, in the range from 20 до 100 kHz, while the linear travel seed of the beam varied in the range from 50 to 1,500 mm/sec. The resulting relief obtained under such processing parameters has the appearance of equidistant notches (Fig. 2).



a)



b)



c)

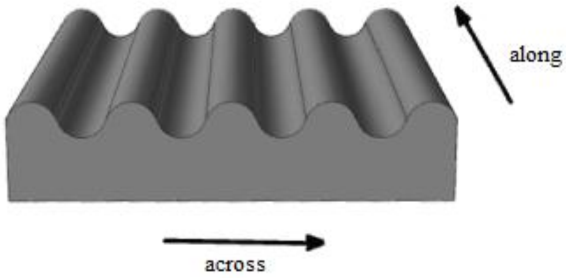
Figure 2: Images of modified brass surfaces using laser radiation under the following parameters:

a) scanning speed 100 мм/с, laser radiation frequency 90 kHz;

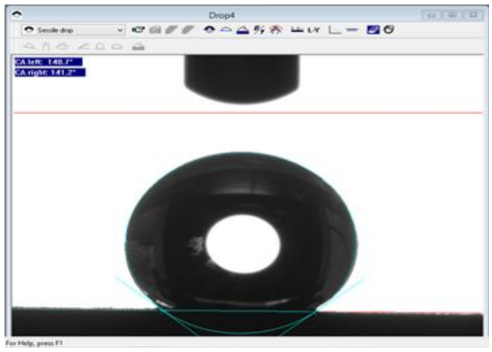
b) scanning speed 150 mm/sec, laser radiation frequency 20 kHz;

c) scanning speed 600 mm/sec, laser radiation frequency 20 kHz.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 19 (2017) pp. 8824-8829



(a)



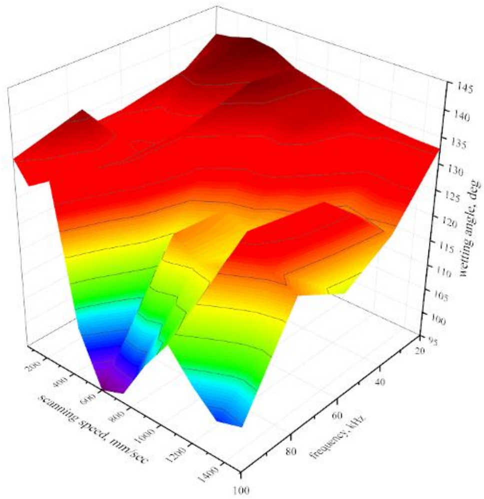
(b)

Figure 3: Travel direction of a drop of liquid with relation to the surface during measurements of roll-off angle (a); photograph of the measurement of wetting angles by means of the instrument OCA 20 (b).

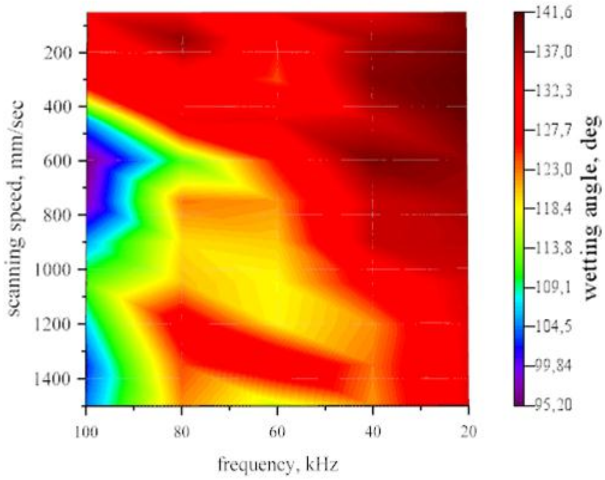
Limiting angles and roll-off angles were measured using the instrument OCA 20 (DataPhysics, Germany). In order to obtain the most accurate measurements, limiting angles were measured 6 times in different points of the modified surface, both across (3 points) and along the notches (3 points); afterwards, an average angle was determined, which was regarded as the final value (Fig. 3).

RESULTS AND DISCUSSION

As a result of a series of experiments with samples made of L63 grade brass, certain experimental data were obtained regarding the influence of the frequency and speed of liner travel of the laser beam on wetting ability of the sample surfaces (Fig. 4 & 5). When surface diagrams showing the influence of linear scanning speed and laser beam frequency on the roll-off angle (Fig. 5) were built for true contact between the drop and the modified surface (i.e., when the surface was turned 90° towards the horizon, the drop would not flow off the surface, the roll-off angle was assumed to be 90°.

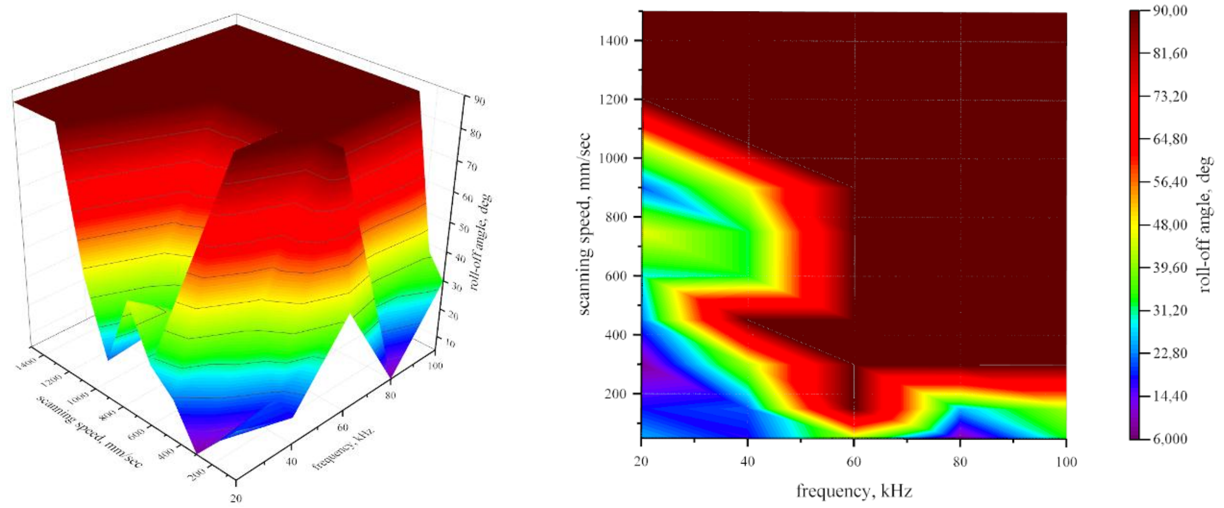


a)



b)

Figure 4: Surface diagram of the influence of linear scanning speed and laser beam frequency on the wetting angle (a) and its plane projection (b).



a) b)

Figure 5: Surface diagram of the influence of linear scanning speed and laser beam frequency on roll-off angle (a) and its plane projection (b).

The projection of the surface diagram of the influence of linear scanning speed and laser beam frequency on the wetting angle (Fig. 4) shows that values of contact angles exceed 130° under the following parameters of laser radiation:

– linear speed of the beam travel along the surface – from 50 to 1,000 mm/sec;

– pulse frequency – from 20 to 40 kHz.

In the highlighted area of the surface diagram, under the above parameters of laser radiation, certain peaks can be identified corresponding to the maximum wetting angles of the modified brass surface (Table 1):

Table 1: Influence of laser radiation parameters on wetting angle values

Parameters of laser radiation		Wetting angle, deg
Pulse frequency, kHz	Scanning speed, mm/sec	
20	50	139.9
20	150	140.3
20	300	141.6
20	450	140.9
40	300	139.3
40	600	139.9

As mentioned already, high wetting angle values do not identify low hydraulic resistance of a surface as liquid is flowing over it; to do that, measurements of wetting angle hysteresis H (1), are used. This hysteresis is the difference between values of advancing angle $\theta_{\text{нат}}$ and receding angle $\theta_{\text{от}}$ of the liquid on a tilted surface [8] (Fig. 6). Note that low values of hysteresis H indicate low values of roll-off angle.

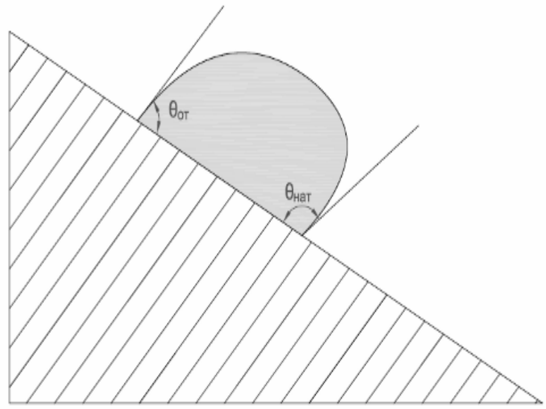


Figure 6: Diagram for determining of advancing angle $\theta_{\text{нат}}$ and receding angle $\theta_{\text{от}}$ of liquid drops on a tilted surface.

$$H = \theta_{\text{нат}} - \theta_{\text{от}} \qquad (1)$$

Roughness of the wetted surface causes deviations of measured angles, in contrast to angles on a smooth surface. We know that two different wetting modes are possible: homogeneous wetting (the Wenzel mode) [9], when the liquid contacts with the whole surface of the solid body and fills in completely any surface hollows (Fig. 7,a), and heterogeneous wetting (the Cassie-Baxter mode) [10], when surface irregularities capture some air, and drops contact with individual projections (Fig. 7,б).

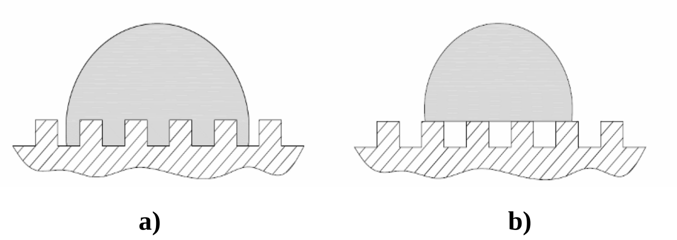


Figure 7: Homogeneous (a) and heterogeneous (b) wetting modes.

As early as in the first papers by Johnson and Dettre dedicated to studies of hysteresis on hydrophobic surfaces, it was mentioned that surface roughness affected advancing and receding contact angles [11]. The authors maintain that the hysteresis changes in a non-linear manner: initially, as roughness increases, the Wenzel mode takes place, and the hysteresis may reach as far as the critical value of the advancing contact angle, and then the hysteresis drops sharply down to values that are less than those on a smooth surface. This sharp changing of the hysteresis indicates a transition between the homogeneous wetting mode, when drops stick between surface projections, and the heterogeneous wetting (the Cassie-Baxter mode). Any further growth of surface roughness will lead to onsetting of the Wenzel mode, i.e., surface projections will act as obstacles for drops.

Fig. 2 shows that modification of brass surfaces under various parameters of laser radiation promotes creating surfaces with different-scale roughness. During joint analysis of the surface diagrams of influences produced by the laser radiation parameters on wetting abilities of modified surfaces (Fig. 4 & 5) one can see that high wetting angle values correspond to both low and high values of roll-off angle, and this, in turn, confirms the theory described in the studies of Johnson and Dettre.

As seen in the projection of surface diagrams the influence produced by linear scanning speeds and laser beam frequencies on roll-off angle, the smallest roll-off angles (below 10°) are found on surfaces of the samples that have been modified under the following parameters of laser radiation:

- linear speed of the beam travel along the surface – from 200 to 300 mm/sec;
- pulse frequency – 20 kHz.

By combining the discovered ranges of laser radiation for obtaining the highest wetting angle and the lowest roll-off angle, parameters were found that led to creating the brass surface with the best water repellent properties for various industrial applications, in order to reduce hydraulic resistance during transportation of liquid media.

The maximum contact angle of 141.6° (Fig. 8) was obtained after treatment with laser pulses of 20 kHz, and the linear speed of the beam travel was 300 mm/sec. The surface under study had the minimum roll-off angle (8.4°).

In the course of the studies it has been noted that

immediately after surface modification by laser beam, the

surfaces show hydrophilic properties during the first few days, and the maximum surface wetting angle is achieved as the samples are held for 10 days in the air, under standard atmospheric conditions.

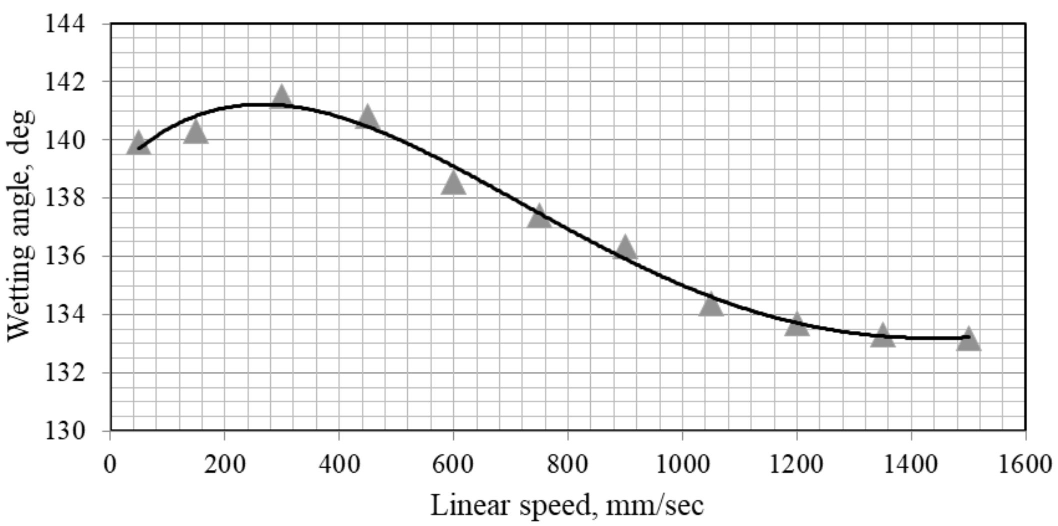


Figure 8: Correlation between the linear speed of the beam at the frequency 20 kHz and the wetting angle of the sample surface

CONCLUSION

The paper presents results of experimental studies discovering the influence produced by the laser radiation parameters on wetting parameters. It is observed that high wetting angle values will not guarantee good water-repellent properties. A surface with the best water-repellent properties (contact angle – 141.6°, roll-off angle – 8.4°) was obtained with the following parameters of laser radiation: linear travel speed of the laser beam along the surface – 300 mm/sec, and laser beam frequency – 20 kHz.

It has been discovered that the value of roll-off angle depends on the value of hysteresis, which, in turn, depends on geometry parameters of surface roughness. Low hysteresis values lead to low roll-off angles.

Analysis of the diagrams shows that the highest wetting angle values and the lowest roll-off angle values are achieved at the lowest travel speed of the laser beam, which leads to extending the relief formation period. Afterwards, this process is expected to be optimized in view of prospects of experimental industrial implementation.

ACKNOWLEDGEMENTS

The results have been obtained in the course of performance of the state assignment of the Ministry of Education and Science of Russia pursuant to Assignment No.13.9609.2017/8.9 'Development of innovative technical solutions for creation of a different-scale normalized relief on inner pipe surfaces to reduce hydraulic losses during transportation of liquid media'.

REFERENCES

[1] A.V. Ryzhenkov. On reduction of hydraulic resistance in oil pipelines. Neftyanoye Khozyaistvo, No. 11, pp. 136-139, 2015

[2] M.V. Lukin, A.V. Ryzhenkov, A.V. Kurshakov, O.V. Ryzhenkov and A.P. Karpunin. The results of the implementation of SAS technology for the renovation and life extension of district heating systems. Energy and Sustainability V, WIT Transaction on the Ecology and the Environment, Vol. 186, pp. 701-709, 2014.

[3] M.A. Morozov, A.V. Volkov, A.V. Ryzhenkov, A.G. Parygin and M.V. Lukin, A.V. Naumov. Calculation of pipeline systems taking into account hydrophobic properties of inner surfaces. Neftyanoye Khozyaistvo, No. 4, pp. 130-133, 2016

[4] Kijlstra, J. Roughness and topology of ultra–hydrophobic surfaces. Colloids and Surfaces A: Physicochemical and Engineering Aspects, Vol. 206, Issue 1-3, pp. 521–529, 2002

[5] Y.Y. Yan and N. Gao, W. Barthlott, Mimicking natural superhydrophobic surfaces and grasping the wetting process: a review on recent progress in preparing superhydrophobic surfaces, Adv. Colloid Interface Sci., No. 169, pp. 80–105, 2011

[6] L.B.Boinovich and A.M.Yemelyanenko, 'Hydrophobic materials and coatings: creation principles, properties and applications. Uspekhi Khimii, No. 77(7), pp. 619-638, 2008

[7] Tuteja A., Choi W. and Ma M., et al. Designing superoleophobic surfaces. Science, Vol. 318, pp. 1618–1622, 2007

[8] B. Krasovitski, Drops down the hill: theoretical study of roll-off angles and the hysteresis range on a tilted plane. Langmuir, Vol. 21, Issue 9, pp. 3881–3885, 2004

[9] R.N. Wenzel. Ind. Eng.Chem. Vol. 28, pp. 988-994, 1936

[10] A.B.D. Cassie and S. Baxter. Trans. Faradey Soc., No. 40, pp. 546-551, 1944

[11] Dettre, R. H. Contact Angle, Wettability and Adhesion. American Chemical Society, Vol. 43, pp. 136, 1963