PhD Open Days

Superhydrophobic and High-Temperature Resistant Coatings For Pool Boiling Regimes

PHD PROGRAM IN MECHANICAL ENGINEERING

José Pereira (sochapereira@tecnico.ulisboa.pt)

Extended Abstract

Introduction

This experimental work aimed to develop superhydrophobic coatings to be applied over AISI 304 stainless-steel foils, being high-temperature resistant and durable in pool boiling scenarios. For this purpose, the synthesis of the base materials of the coatings was based on the silylation of colloidal suspensions of diatomite with aminopropyltriethoxysilane (APTES) and perfluoroctyltrichlorosilane (PFOTS . For promoting a better adhesion of the coatings onto the substrate the resulting nanopowder was added to an epoxy resin binder solution composed of bisphenol A diglycidyl ether and tetraethylenepentamine (DGEBA/TEPA). After the dip or spray coating of the stainless-steel foil samples, those were post-cured, according to a well-defined temperature and permanency time in an oven to obtain smooth, homogeneous, and strong adherent coatings. It is worth mentioning that despite the large number of coatings reported in the literature, most of them cannot stand high temperatures or thermal stresses and loose their main wetting properties. Hence, the surfaces developed and tested in this work were devised to overcame such limitation.

Methodology

After preparing the surfaces, the wettability of the coatings was evaluated by contact angle measurement using the optical tensiometry technique (pendant drop method) with distilled water, as it is illustrated in Figure 1. The measurements were performed using the optical tensiometer *THETA* from *Attention*™. The main results of this measurement are summarized in Table 1.

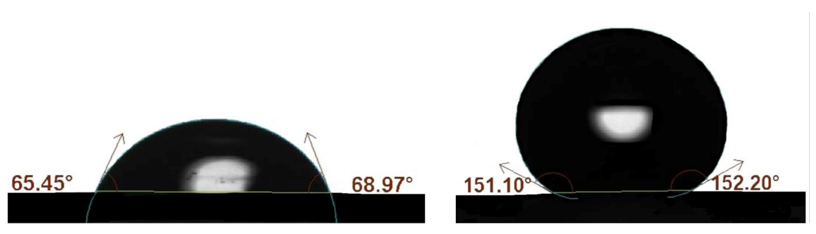

Figure 1 – Water contact angle measurements for the hydrophilic stainless-steel foil on the left and for the coating on the right

Then, the thermal performance of the coatings was evaluated under pool boiling conditions using an in-house developed protocol and set-up, which is schematically represented in Figure 2

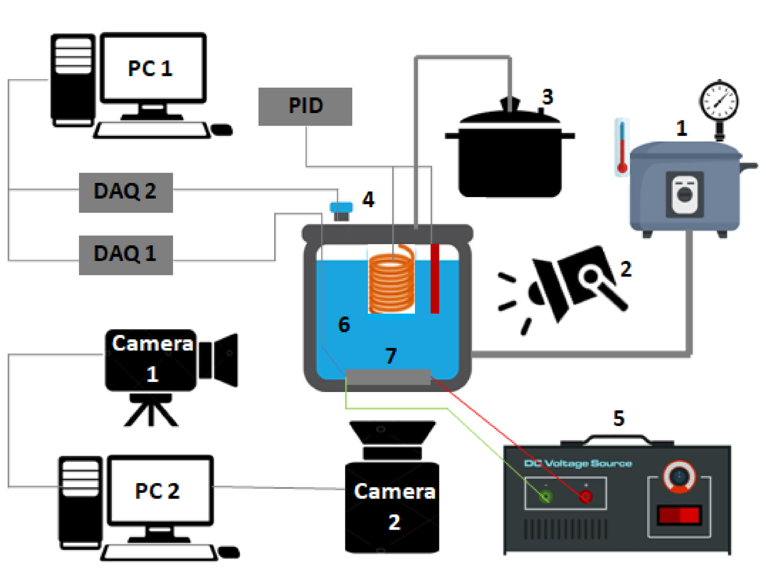

Figure 2 – Pool boiling set-up: 1 – Degassing station, 2 – Light Projector, 3 – Condensate container, 4 – Pressure sensor, 5 – DC voltage source, 6 – Tank, 7 – Sample holder

To test the effectiveness of the surfaces the bubble dynamics were studied by extensive post-processing of the images taken using a *Phantom v4.2* high-speed camera at 2,200 fps. Also, thermal images were taken using a *Onca MWIR-InSb-320* high-speed infrared thermographic camera. A typical obtained thermographic image is presented in Figure 5. The heat flux was imposed to the surface directly by DC current. The coating/substrate sets were tested by water jet resistance, adhesion, and abrasion essays, which apparatus can be seen in Figure 3.

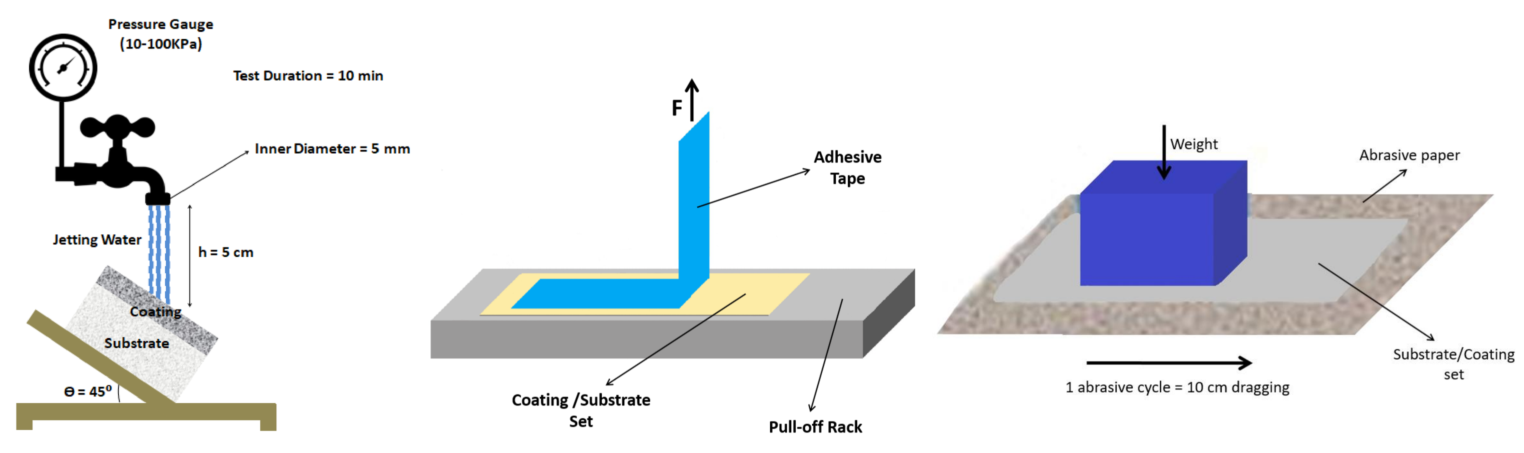

Figure 3 – Water jet resistance, adhesive strength and abrasive resistance in-house developed apparatus and protocols

Results and Discussion

The results of the evaluation of the wettability is summarized in Table 1**.**

Table 1 – Water contact angle for the diatomite-APTES-PFOTS-epoxy coatings at 25° C

Droplet Number	Left CA (°)	Right CA (°)	Average CA (°)	Droplet Volume (μl)
Av. ± St. Dev.	150.7 ± 4.5	150.5 ± 4.2	150.6 ± 4.0	5.4 ± 0.2

The results of the evaluation of the wettability vs pull off-cycles and wettability vs abrasive cycles are presented in the plots of Figure 4.

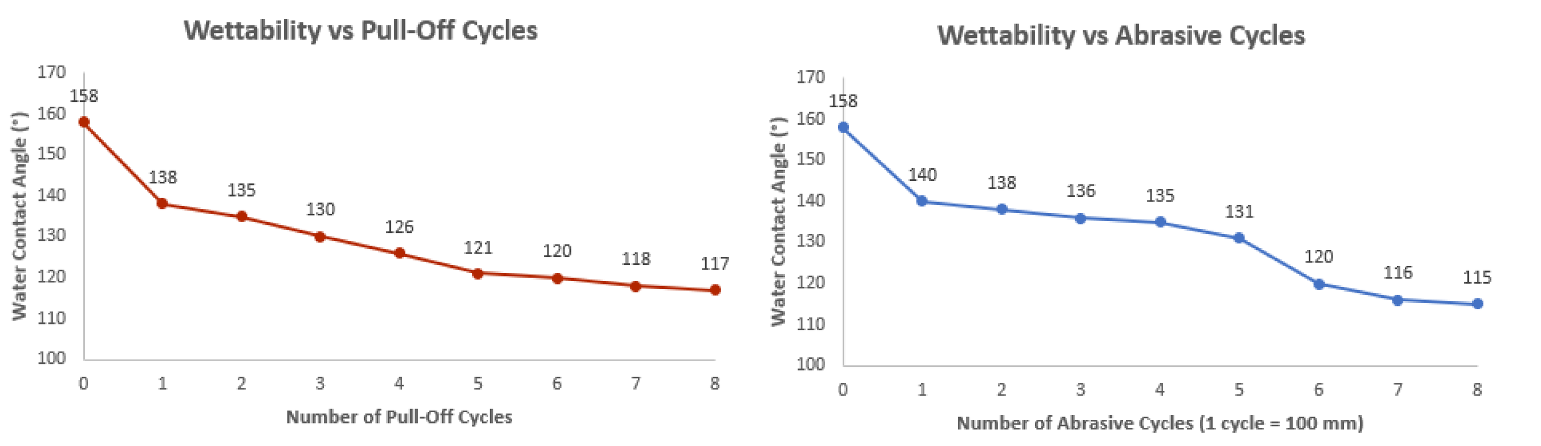

Figure 4 – Plots of wettability vs pull-off cycles and wettability vs abrasive cycles

The superhydrophobic coatings were applied in biphilic surfaces, i.e., hydrophilic surfaces with circular superhydrophobic regions. Different diameters of these regions were tested to evaluate their influence on the bubble dynamics and evaporation mass flux, which is given by Equation 1:

$$\frac{\dot{m}}{A_{SHF}} = 4 \times \frac{\rho_V \times f \times V_b}{\pi \times \emptyset^2} \qquad (1)$$

Where $\dot{m}$ is the evaporated mass per time unit, A_{SHF} is the area of the superhydrophobic region, ρ_V is the vapor density, f is the bubble departure frequency, V_b is the estimated bubble volume and φ is the diameter of the superhydrophobic region. The temperature distribution during the growth of the bubbles was also observed. It was also evaluated the influence of the distance between the superhydrophobic spots (pitch) on the same thermal parameters. There were identified and interpreted the regions and associated mechanisms of the convective heat transfer flow of the different biphilic arrangements by thermographic imaging. The results showed an enhanced pool boiling heat transfer rate and coefficient, which is given by Equation 2, and an overall improved thermal performance of the biphilic surfaces under the referred conditions.

$$h = \frac{q}{\Delta T_{SAT}} = \frac{q}{T_W - T_{SAT}} \qquad (2)$$

Where h is the heat transfer coefficient by convection expressed in $W/m^2.k$, q the surface heat flux, T_W the temperature of the wall and T_{SAT} the saturation temperature of the fluid.

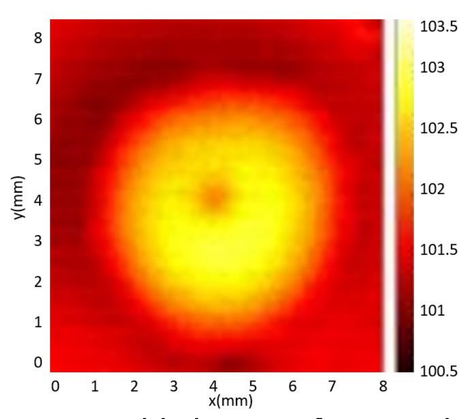

Figure 5 – Typical thermographic image of a superhydrophobic region

Prof. António Moreira
PhD Program in Mechanical Engineering

TÉCNICO LISBOA

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