Impact of hexadecane and water droplets on non-wetting surfaces

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Introduction

The impact of drops onto dry solid surfaces is a phenomenon involved in many industrial applications. Moreover, the investigation of the interaction of single drops with a surface [1] is a first step toward the understanding of more complex phenomena, such as the liquid spray impact, and the development of technologies such as droplet management in microsystems. The phenomenon of drop impact is strongly influenced by parameters related to the surface characteristics, among which one of the most important is the wettability. The wetting behavior of solid surfaces may be defined by the contact angle built by the liquid interface when it meets the solid surface. Advancing (θ_A) and receding (θ_R) contact angles are usually measured, respectively, by expanding and contracting sessile drops on a horizontal surface. Their difference $\Delta\theta = \theta_A - \theta_R$, named as contact angle hysteresis (CAH), provides an indication of the drop mobility (the lowest the $\Delta\theta$ value, the highest the drop mobility). In the last decade superhydrophobic surfaces (SHS) have attracted an increasing interest due to their remarkable self-cleaning and anti-sticking properties. Superhydrophobicity causes the water droplet to bead up on the surface instead of spreading on it. The standard conditions are $\theta_R > 135°$ and $\Delta\theta < 10°$ for superhydrophobicity, $\theta_A > 90°$ for hydrophobicity and $\theta_A < 90°$ for hydrophilicity. Nonetheless, a few papers [2][3][4] have shown how superhydrophobic surfaces might not necessarily lead to a total rebound of impinging water drops, especially above a given value of Weber number ($We = \rho v^2 D_0/\sigma$, where ρ is the density of the fluid [kg/m^3], v is its impact velocity [m/s], D is the droplet diameter [m] and σ is the surface tension [N/m]). Eventually impalement can occur, leading to the droplet deposition on the surface. In this sense a surface only hydrophobic, but smoother or with a different topology can be more effective in repelling liquids even for a large value of *We*. Furthermore, a new class of surfaces has emerged, namely amphiphobic surfaces, with the ability to repel liquids with different polarity and therefore also with low surface tension. Often superamphiphobic surfaces exhibit even larger values of static contact angles and CAH lower than 5°. To better understand the existence of a general criterion to predict the drop impact outcome, and the key parameters governing the drop-surface interaction, the normal impact of both water and hexadecane drops on solid dry surfaces with different wettability was observed using a high-speed camera. The present study establishes a relationship between drop impact outcomes and surface wettability, taking into account different parameters for both the liquid drop (impact velocity, surface tension, viscosity) and the solid surface (morphology and roughness, chemistry, wettability).

Material and methods

The wetting behavior of sandblasted aluminum foils before (TQ samples) and after the deposition of: i) organic-inorganic hybrid coatings (S samples), ii) infused hybrid coatings (SI samples), iii) grafting fatty acid treatment (LAU samples) and iv) grafting FAS (FAS samples) treatment was analyzed.

The surfaces were characterized in terms of wettability (see Figure 1), topography and roughness. SEM images of *S* and *SI* surfaces show a flower-like nanostructure made up of crossed, 200 nm long flakes and nanometric cavities. *LAU* and *FAS* samples display a terrace-like structure with sub-micrometric edges. On the sandblasted *TQ* surface taken as a reference, microabrasion by sand grains produced an irregular microstructure with asperities and cavities. Roughness data show the difference between coated (*S*, *SI*) and etched (*LAU*, *FAS*) samples: the former have lower average roughness but higher peaks. A comparison with the data obtained for a TQ surface led us to conclude that the hybrid nanostructured coating has a small influence on the micrometric roughness of S and SI, while the main contribution belongs to the microstructure provided by sandblasting. On LAU and FAS surfaces, etching provided a rougher structure, but with less pronounced asperities and cavities.

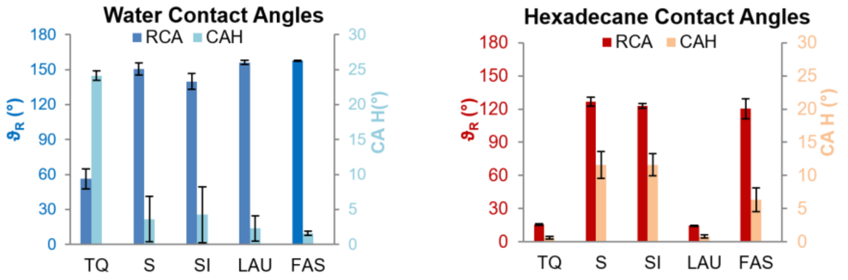


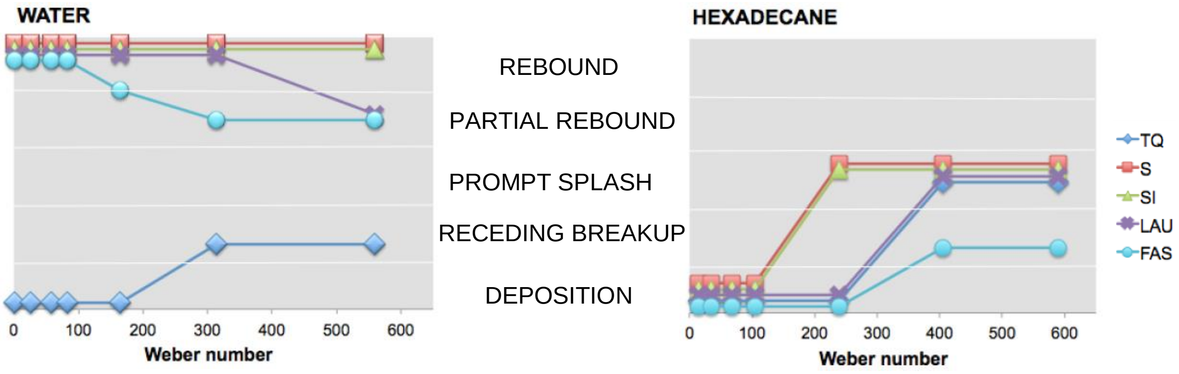
Figure 1. Average receding contact angles (θ_R) and contact angle hysteresis (CAH) with water (left) and hexadecane (right).

A typical experimental apparatus for drop impact studies was used [2]. Experimental conditions were the following: impact speed in the $0.05 < V < 4.2$ m/s range, drop diameter in the $1.5 < D_0 < 2.6$ mm range, Weber numbers in the $0.1 < We < 635$ range, and Ohnesorge number ($Oh = \mu/(\rho\sigma D_0)^{1/2}$, where μ is the liquid viscosity [Pa s]) in the $0.0023 < Oh < 0.0186$ range. Images of drop impacts were recorded using a high-speed camera (PCO 1200-HS) with typical frame rates of 1568 and 2477 fps and a pixel resolution of 31 μm/pixel.

Results and Discussion

In Table 1 the summary of all the outcomes of the drop impact tests is reported. Five main regimes stand out: complete rebound, partial rebound, prompt splash, receding breakup, deposition.

Table 1. Summary of the drop impact test outcome. In the table the mean values of each We interval are reported.



Generally, it is not possible to correlate in a straightforward manner the surface wettability with the drop impact outcomes. The Cassie-to-Wenzel transition (CWT) can be observed even on statically repellent surfaces (hexadecane drop impact on FAS surfaces). Moreover surface chemistry is relevant, as surfaces with identical morphology and wettability but different functional groups (eg. LAU and FAS) display different behavior on water drop impact. As far as the liquid properties are concerned, with increasing viscosity and lower fluid surface tension, the CWT shifts to smaller Weber numbers. In the case of hexadecane drops, the CWT threshold is so low that no rebound has been observed, even if the contact angles are well above the expected critical values obtained from previous works focusing on water drops [3]. Therefore a direct and important consequence is that the numerical simulations of drop interaction onto solid, dry surfaces with various wettabilities are not yet able to capture the final outcome of the impact, since the micro and nanoscale topology of the surfaces and even their chemical properties are still very difficult to be properly implemented in a DNS code.

References

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