The Role of the Dynamic Contact Angle on Splashing

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This letter studies the behaviour of droplets splashing on various substrates, ranging from hydrophilic to super-hydrophobic substrates. In particular, we study the effects of the dynamic contact angle on splashing. The experimental approach uses high-speed imaging and image analysis to recover the apparent contact angle as a function of the spreading speed. Our results show that neither the Capillary number nor the splashing parameter are appropriate to characterise the splashing behaviour. However, the maximum dynamic advancing contact angle and the splashing ratio β adequately characterise the splashing behaviour. In this complementary material we report the liquid and substrate properties, and further experimental results.

I. COMPLEMENTARY MATERIAL

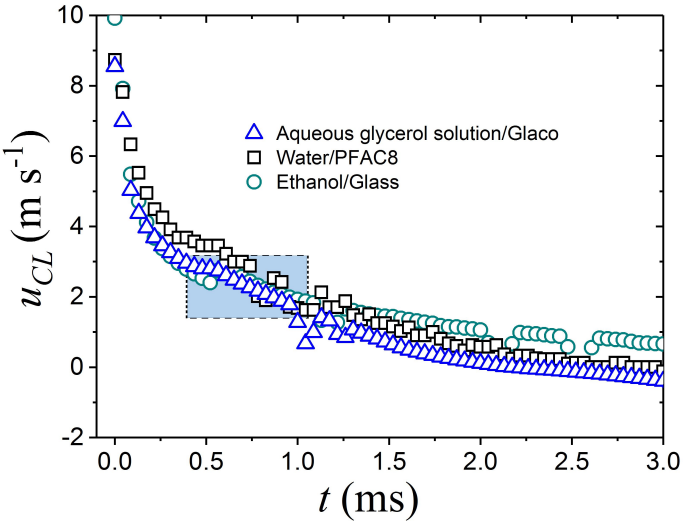

FIG. 1: Contact line speed for spreading droplets in terms of the time from impact. Here, the impact velocity for water and the aqueous solution droplets is of 1.34 m/s, while for the ethanol drop is of 0.98 m/s. The highlighted area shows the time domain where the lifting of the lamella occurs for splashing cases.

Our experiments were performed with three liquids, i.e. pure water, a 4.7 cP water and glycerol solution, and ethanol, and the following flat solid substrates: glass, mica, cast acrylic, polytetrafluoroethylene (PTFE/teflon), Glaco and Perfluorodecyl acrylates ($PFAC_6$ and $PFAC_8$) applied to glass. Liquid and substrate properties are presented in Tables I and II. Our experiments covered the ranges of $130 < \mathrm{We} < 811$, $69 < \mathrm{K} < 299$, and $0.027 < \mathrm{Ca} < 0.256$. Within these parameters, our experimental observation indicate that the lifting of the lamella and splashing occur in the range of 0.4 to 1.2 ms after impact. In the same time scale, for spreading droplets, contact line velocities are found in the range of 1.0 to 2.5 m/s, results are shown in Figure 1. Consequently, we expect wettability to be important in the timescale of hundreds of microseconds and at contact lines in the range of 1.0 to 2.5 m/s.

Figure 2 shows that ethanol drops impacting at U = 1.97 m/s (We=258) present no splashing on a glass substrate ($\theta_{max} = 87$) but splashing on a Glaco-covered substrate for an impacting speed of U = 1.89 m/s ($\theta_{max} = 98$). Figure 2 also shows that water impacting onto Glaco-coated surfaces at a speed of U = 2.09 m/s (We= 167, $\theta_{max} = 147$) splashes but when impacting $PFAC_8$ at U = 2.34 m/s (We=189, $\theta_{max} = 131$) no secondary drops are detached (fingering of the lamella but no splashing).

Past experiments with low-viscosity droplets impacting smooth solids have demonstrated that the wedge angle (α) approaches a value of 60 degrees at the time of splashing (t_{splash}) [1, 2]. Experiments and analyses demonstrate that the wedge angle, at the time of splashing, of an aqueous glycerol droplet impacting a glass substrate at U_0 = 3.68 m/s is $\alpha = 57 \pm 5$ degrees, Figure 3. This result is in agreement

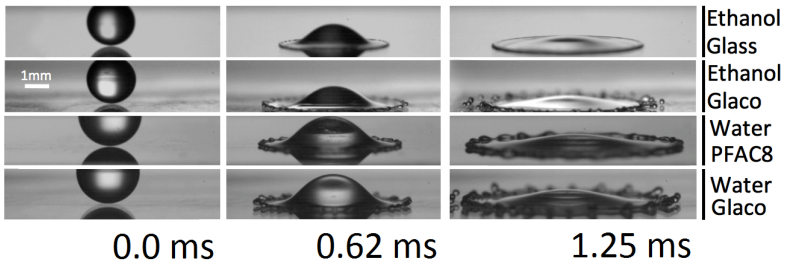

FIG. 2: Impact behaviour for ethanol and water droplets. Here, We = 258 for ethanol on glass and We = 250 on Glaco, We = 167 for water impacting on Glaco, and We = 189 for water on $PFAC_8$. Splashing is observed on Glaco, but no splashing is observed for ethanol on glass.

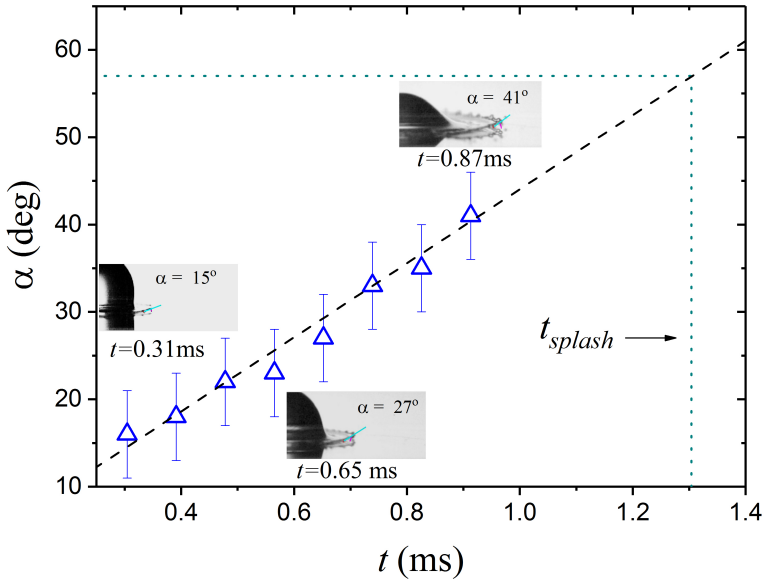

FIG. 3: Measured wedge angle (α) as a function of time for an aqueous glycerol droplet impacting glass at $U_0 = 3.68$ m/s. As seen, the wedge angle extrapolates to a value of $\alpha = 57 \pm 5$ at the splashing time (t_{splash}).

with both the value of 60 degrees obtained by Riboux and Gordillo in 2014 and with the value of 59 ± 8 obtained by de Goede et al. in 2018 [1, 2].

TABLE I: Equilibrium and Dynamic contact angles for the substrates used throughout the experiments. Unless shown, the error on the contact angle measurements is of 2 degrees.

Substrate	θ_s Water	θ_{max} Water	θ_s Ethanol	θ_{max} Ethanol	θ_s Glycerol & Water	θ_{max} Glycerol & Water
Glass	11	109	5 ± 4	87 ± 4	11	119
Mica	31	107	5 ± 4	87 ± 4	31	118
Acrylic	56	105	5 ± 4	87 ± 4	56	123
Teflon	93	113	5 ± 4	87 ± 4	93	127
$PFAC_6$	111	122	31	96	111	120
$PFAC_8$	120	131	56	100	120	126
Glaco	145	147	5 ± 4	98	145	147

[1] G. Riboux and J. M. Gordillo, Phys. Rev. Lett. **113**, 024507 (2014).
[2] T. C. de Goede, N. Laan, K. de Bruin, and D. Bonn, Langmuir **34**, 5163 (2018).

TABLE II: Fluid properties used throughout the experiments

Fluid	μ (mPa s)	σ (mN/m)	ρ (kg/m^3)
Ethanol	1.04	22.3	789
Water	0.98	70.8	998
Water & Glycerol	4.77	68.5	1,126