Dewetting of patterned surfaces

T. Cubaud, P. Jenffer and M. Fermigier
Laboratoire de Physique et Mécanique des Milieux Hétérogènes,
ESPCI, 10 rue Vauquelin, 75005 Paris, France

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Abstract

When a thin liquid layer is deposited on a partially wetting substrate, spontaneous dewetting can occur if the layer is smaller than the equilibrium thickness related to the contact angle. We study the influence of wettability defects, both isolated and interacting on the receding contact line.

1 Introduction

Removal of liquid films from solid surfaces either by dewetting or by drying is a phenomenon occurring in many industrial processes. Dewetting as well as wetting is influenced by the existence of defects on the solid surface. Wetting spots or roughness can pin the receding contact line and prevent the complete removal of the liquid film. The dynamics of dewetting on smooth solid and liquid surfaces is now well understood [1, 2] but so far there have been few dewetting experiments on patterned surfaces with a non uniform wettability [3]. We have investigated experimentally the influence of both isolated and interacting defects on a spontaneously receding contact line.

2 Experimental set-up

Thin layers of viscous liquids (polydimethylsiloxane oils) are spread on a glass surface by sweeping an horizontal blade a very small distance above the glass plate. By varying the distance between the blade and the glass surface we are able to prepare films of different initial thickness (100 to 600 microns). The glass plate is treated with a fluorocarbon surfactant (3M FC 725) to prepare a substrate with a very low surface energy (13 mN/m). Following the surface treatment, the polydimethylsiloxane oils do not wet the glass completely : the contact angles are respectively $\theta_a = 52^0$ (advancing) and $\theta_r = 40^0$ (receding). The corresponding equilibrium thickness e_0=2 l_c sin($\theta/2$) for a pancake of fluid is between 1.3 and 1.0 mm. Once the layer of liquid is spread over the entire glass plate (typical size 30 x 30 cm), we open a hole in the layer by blowing air on the free surface. Since the thickness of the liquid layer is smaller than the equilibrium thickness, the hole opens spontaneously. The edges of the liquid layer are held on the edges of the glass plate where the contact angle is smaller. The evolution of the liquid layer is recorded from above with a high resolution (4 million pixels) CCD camera. The digitized pictures are processed to extract the location of the receding contact line.

We first checked the dewetting speeds on smooth surfaces. The hole remains circular as it grows. During the first stage of dewetting the speed is constant and independent of the film thickness. As the fluid from the film is collected into a rim around the contact line, this rim grows. When the size of the rim exceeds the capillary length, it is flattened by gravity. As a result, the flow regime changes and the speed of dewetting decreases [2]. In most of our experiments, the hole is large enough so that we are in this gravity dominated regime, with a rim wider than the capillary length and of constant height.

3 Single defects

3.1 Deformation of the contact line

To investigate the influence of wettability defects on the dewetting process, we begin with isolated circular defects of varying size d. The defects are circular patches of polymeric ink (with $\theta_r = 15^0$) deposited on the fluorocarbon layer. When the receding contact line reaches the more wetting spot, it pins on the edge of the defect, it is distorted and if the defect is large enough, a drop of liquid is left on the defect, i.e. the dewetting process is not complete (figure 1).

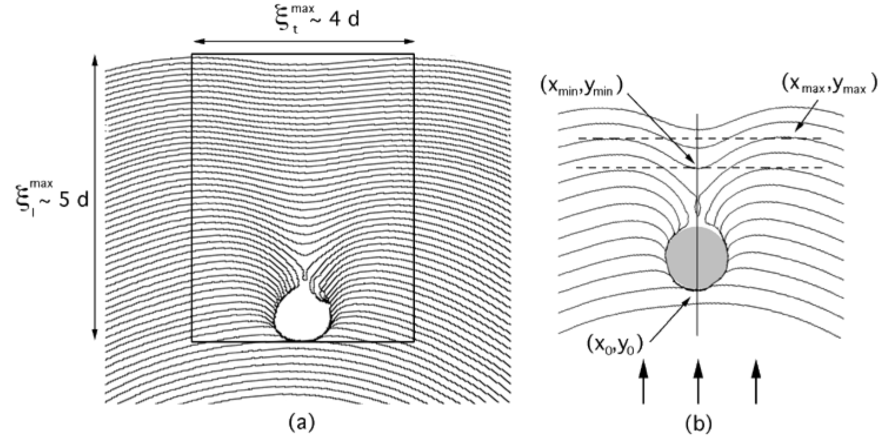


Figure 1: Shape of the contact line receding over a wetting defect, shown at different times. The contact line moves from bottom to top. A satellite drop is left behind the large defect. On the right construction of the tangents to the contact line to determine the amplitude of deformation. On the left, extent of the deformation sideways and behind the defect.

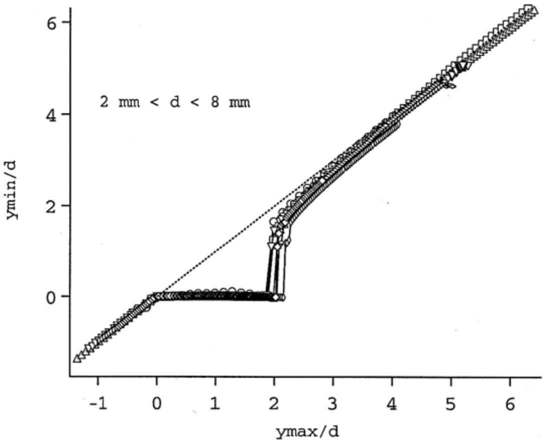


Figure 2: Amplitude of deformation of the contact for different defect sizes. The location of the rear of the contact line is plotted as a function of the position of the front of the contact line. Both positions are normalized by the defect size.

To quantify the deformation of the contact line, we measure the distance between the two tangents to the contact line which are normal to the direction of motion (figure 1). It can be seen that the deformation extends to several defect diameters on each side and that the deformation relaxes very slowly once the contact line moves away from the defect. We plot the position of the bottom tangent ymin as a function of the position of the top tangent ymax. When we normalize these positions by the defect size d, we see that all the data for defect sizes between 2 and 8 mm collapse on a single curve (figure 2). This means that the amplitude of deformation is proportional to the defect size. We found a similar behaviour in the dual case of non wetting defects in a forced wetting experiment [4]. The fact that the relation between defect size and contact line deformation is the same in the dual cases mentioned above is not obvious. The geometry of the meniscus is different (in the dewetting case there is a rim of liquid at behind the contact line) and the capillary numbers are generally different : in a spontaneous dewetting phenomenon the contact line speed is such that the viscous dissipation balances the gain in interfacial energy, whereas in our forced wetting experiments the speed and capillary numbers were very small.

3.2 Nucleation of a satellite droplet

In addition to the drop trapped on the wetting defect, a smaller drop can be left behind the contact line when a too long thread of liquid connects the trapped drop and the receding liquid layer (figure 3). The instability leading to the formation of the satellite droplet is similar to the Rayleigh-Plateau instability of a liquid thread connecting two drops, except that the liquid thread is here deposited on a solid substrate. Actually, the phenomenon in the present case is very close to the one seen when an isolated drop moves fast enough on a partiallly wetting surface [5]. The formation of the satellite droplet occurs only if the thread is sufficiently long, which requires a large defect (d > 3 mm corresponding to 2 l_c).

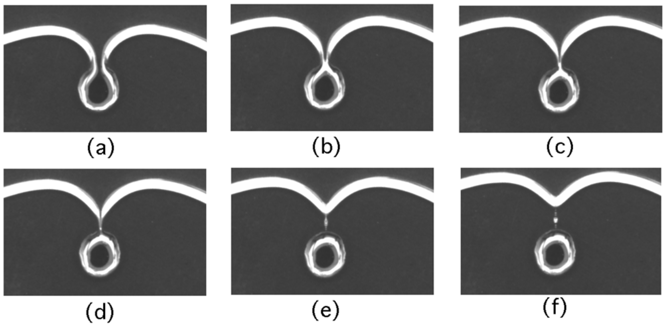
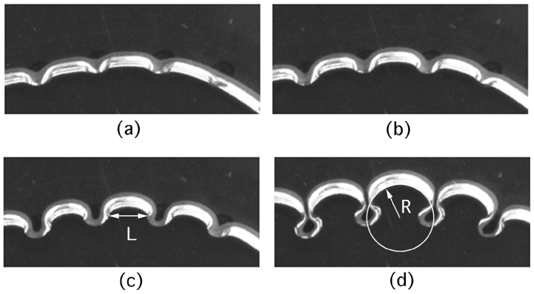


Figure 3: Nucleation of a satellite droplet behind the drop trapped on the defect. The contact line moves from bottom to top (image a to f).

4 Several circular defects

Since the deformation induced by a single defect extends over a distance larger than d, we expect an interaction between defects if they are close enough. An experiment with several circular defects with a constant spacing is shown on figure 4. The same experiment was done for different distances between the defects. One of the striking geometrical features of this experiment is that, once the contact line moves past the line joining the defects, its radius of curvature R in the plane is essentially constant. The shape of the line is quite different from the one observed in a corresponding (same defect size and spacing) forced wetting experiment, where the curvature of the contact line changes continuously.

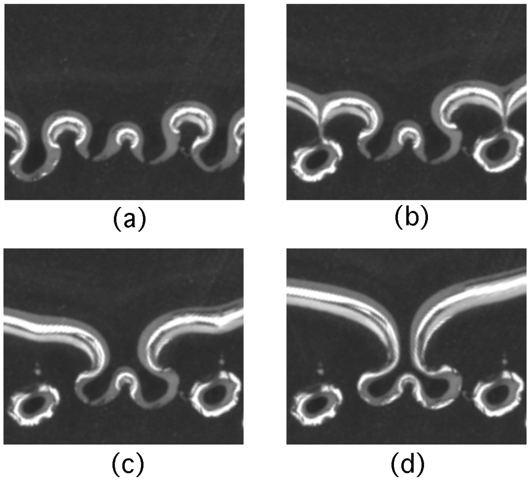
When a hole is opened in a liquid layer, there is a minimum radius Rc above which this hole can grow [6]. This critical radius is of the order of magnitude of the layer thickness. So we do not expect to see radii of curvature of the receding contact line smaller than Rc. This maximum curvature criterion is observed in some experiments where the contact line is trapped by defects which are too close to one another (figure 5).



(a) (b)

(c) (d)

Figure 4: Contact line receding over a line of wetting defects, seen from above. The white region is the meniscus. The contact line moves from bottom to top (image a to d).



(a) (b)

(c) (d)

Figure 5: Contact line receding over multiple defects. The line is trapped on the central defect because the local curvature is too small.

5 Acknowledgment

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6 References

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