On the Splashing Threshold of a Single Droplet Impacting onto Rough and Porous Surfaces

A. Gipperich*, A. N. Lembach, I. V. Roisman and C. Tropea
Institute of Fluid Mechanics and Aerodynamics, Center of Smart Interfaces
Technische Universität Darmstadt Petersenstr. 32, 64287 Darmstadt, Germany

Abstract

Drop impact onto rough and porous surfaces is found in manifold applications such as ink jet printing and irrigation. An experimental work is carried out in order to classify different splashing outcomes of water and isopropanol droplets impacting onto various structured and unstructured rough and porous surfaces. The roughness of the surfaces is characterized with internationally standardized horizontal and vertical statistical roughness parameters. An empirical relationship is developed to describe the splashing threshold on rough surfaces. Further differences in the splashing threshold of porous surfaces are presented.

Introduction

Manifold applications show the importance of drop impact onto solid surfaces. These reach from irrigation and pesticide spraying in agriculture and rain impacting on weather proof clothing to ink jet printing and high speed impact of water droplets in the last stages steam turbines.

Drop impact onto solid surfaces is studied since the late 19th century [1]. A classification of different impact outcomes is given in [2]. After the droplet hits the surface a thin liquid lamella starts to propagate along the surface. Depending on roughness of the surface, the liquid properties, drop diameter and impact velocity the advancing lamella may be disturbed leading to fragmentation of the droplet in some cases, denoted as splash. The splashing threshold, above which the drop splashes, is described as a combination of the Reynolds and Weber numbers. One of the most known splash parameters is the K number ($K = We^{1/2}Re^{1/4}$). Detailed studies on the effects of liquid properties, such as surface tension and viscosity are given in [3, 4] and where an alternative splash parameter is proposed.

The influence of surface roughness is addressed in [5, 6, 2]. So far often the average roughness R_a is scaled by the drop diameter before impact D. Empirical equations to describe the splashing threshold, depending on R_a/D, were proposed by [5, 7]. The threshold of [5] depends on the target material. No investigation on the splashing threshold of porous surfaces has been conducted up to date. The presented paper compares the splashing threshold of rough and porous targets. While R_a/D parameter as well as the K parameter were found to describe splashing in this study insufficiently a new measure of roughness slope to describe the splashing threshold is introduced.

Materials and Methods

Drop impact has been studied experimentally with a high speed video system. A syringe equipped with a commercial needle was used to produce a single droplet. After the drop detaches from the needle tip it is accelerated by gravity, passes a light barrier to trigger the high speed camera, and impacts onto a target. By varying the drop height different impact velocities were achieved. Used liquids were distilled water and isopropanol with drop size of $D_{H_2O} = 2.4$ mm and $D_{iso} = 1.7$ mm, respectively.

Six different target materials were used within the experiments (bronze, stainless steel, polyethylene, polytetrafluorethylene, glass and ceramic). Target properties varied in roughness, porosity and average pore diameter. The roughness is characterized by roughness amplitude and wavelength parameters defined in DIN EN ISO 4287. R_z is used to describe the maximum height of the profile and R_{Sm} is given by the mean width of the profile elements.

Results and Discussion

Figure 1 shows a sequence of images of a water droplet splashing during the lamella advance on a rough unstructured polyethylene surface. The lamella is significantly disturbed by the roughness. Instabilities develop in form of fingers when the lamella expands. In the last picture of the sequence it can be clearly seen that these fingers detach from the surface and break up into a large number of secondary droplets. Similar break up of the lamella was found for all investigated rough targets after detachment from the surface.

*Corresponding author: a_gipperich@gmx.de

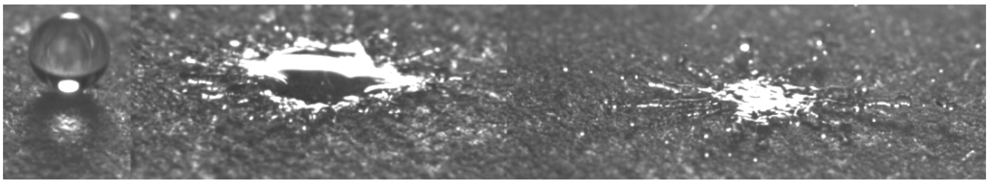

Figure 1. Prompt splash of a distilled water drop on a unstructured rough polyethylene surface (drop diameter: $D = 2.4\,mm$, impact velocity: $u = 3.1\,m/s$, $R_z = 103\,\mu m$, $R_{Sm} = 0.43\,mm$).

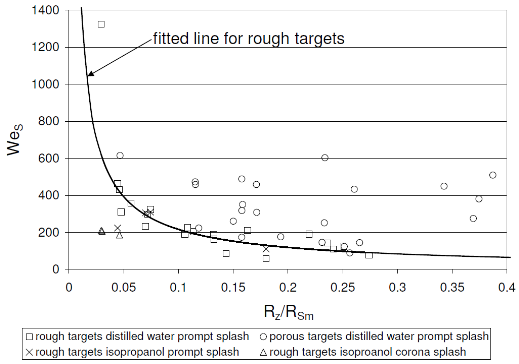

Figure 2. Weber number for the splashing threshold We_S vs. slope of the roughness elements R_z/R_{Sm}.

The degree of instability development is found to increase with increasing impact velocity and surface roughness. While for low impact velocities the expanding liquid lamella can follow all surface perturbations without being disturbed, the lamella detaches from the surface for higher impact velocities. This lamella detachement can be described by taking the ratio of the vertical and the horizontal roughness measure R_z/R_{Sm} which is a dimensionless measure of slope of the roughness elements. The droplet and fluid properties are summarised in the Weber number before drop impact: $We = (\rho u^2 D)/\sigma$, with ρ liquid density, u droplet velocity before impact and D initial drop diameter. The Weber number for the splashing threshold is denoted by We_S. No significant effects of liquid viscosity were found for the investigated liquids, because the lamella break up is dominated by inertia.

Figure 2 shows the obtained splash threshold value of the Weber number, We_S, as a function of R_z/R_{Sm}. The splashing threshold of the rough, non-porous targets can be described by a single line. Contrary to this the splashing threshold of porous targets is found to be equal or higher for all investigated targets compared to the rough targets. Influencing factors in the suppression of splash on porous targets are liquid penetration due to high porosity and pore size on the one hand and different roughness characteristics of porous targets compared to rough targets on the other hand.

Acknowledgement

The authors would like to thank Kibriye Sercan, Jami Winzer, Dr. Ludwig Weiler and Emil Aulbach, who were involved in the manufacture of the porous ceramic targets at the Institute of Materials Science at the Technical University of Darmstadt and Cécile Müller and Manuel Ludwig for their guidance during the roughness measurements at the Institute for Production Engineering and Forming Machines at the Technical University of Darmstadt.

References

[1] Worthington, A. M., *Proc. R. Soc. London* 25:261-271 (1876).
[2] Rioboo, R., Tropea, C., Marengo, M., *Atomization and Sprays* 11:155-165 (2001).
[3] Vander Wal, R. L., Berger, G. M., Mozes, S. D., *Experiments in Fluids* 40:53-59 (2006).
[4] Xu, L., *Physical Review E*, 75:056316 (2007).
[5] Range, K., Feuillebois, F., *Journal of Colloid and Interface Science* 203:16-30 (1998).
[6] Stow, C. D., Hadfield, M. G., *Proc. R. Soc. London. Series A Mathematical and Physical* 373:419-441 (1981).
[7] Trujillo, M. F., Mathews, W. S., Peters, J. E., *International Journal of Engine Research* 1:87-105 (2000).