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Supercooled drops: dynamics of impact, nucleation and solidification

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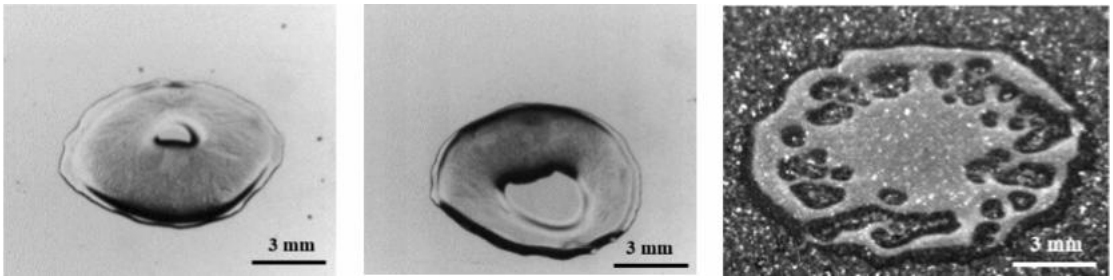

Fig. 1: Outcome of impact of a supercooled water drop on a polished aluminium target (left to right) with the air velocity 10 m/s and 20 m/s and on a rough substrate R6 with the air velocity 20 m/s.

The freezing of water droplets upon impact with cold surfaces is a common natural phenomenon with far-reaching effects on daily life, engineering, and the environment. For example, in aviation, aircraft passing through clouds with supercooled large droplets (SLD)—droplets over 50 µm in diameter—face the risk of ice buildup. This ice can form on wings, the fuselage, and engine inlets, posing significant safety concerns. However, the unique behavior of these droplets and the influence of their size on freezing dynamics remain poorly understood.

This study [1] investigates the impact of supercooled droplets on surfaces with varying roughness, observed using a high-speed optical system. Few examples are shown in Fig. 1. Experiments recorded how these droplets freeze when striking surfaces under different wind conditions. By analyzing both the fluid motion and freezing patterns, the research highlights how airflow and surface textures influence the freezing process.

When droplets hit and spread on surfaces, they create air bubbles that serve as effective nucleation sites. The faster the impact, the more bubbles are produced, leading to a higher nucleation rate. On rough surfaces, with features like ridges and grooves, bubbles are trapped more easily, further increasing nucleation rates. In contrast, smoother surfaces exhibit lower rates of bubble entrapment.

Over time, bubbles dissolve in water—a 20 µm bubble, for example, dissolves in about one second—resulting in a gradual decline in the nucleation rate. However, on polished, partially wettable surfaces, bubbles do not disappear during the receding phase. Instead, they are carried along by the contact line, persisting as active sites for ice nucleation.

Keywords: supercooled drops, nucleation, freezing delay, mushy material.

References:

[1] Ding, M., Hussong, J. and Roisman, I.V., 2025. Freezing of a Supercooled Water Drop after an Impact onto a Solid Wall. Cold Regions Science and Technology, 229, p.104359.