

Article

Locally Freezing Control via Superhydrophobic Patterns on Hydrophilic Substrates

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Abstract: Ice accumulation on cold surfaces presents significant operational and safety challenges in various fields such as power transmission, aviation, and polar marine transportation. This study investigates the effectiveness of selectively applied superhydrophobic patterns on hydrophilic substrates to locally control freezing behaviors. The freezing dynamics of water droplets impacting surfaces with hybrid wettability patterns were investigated experimentally under cold conditions. The results demonstrate that superhydrophobic surfaces significantly reduce the freezing rate due to decreased contact time and the contact region. By selectively placing superhydrophobic patterns on hydrophilic surfaces, the location of ice formation could be effectively manipulated. The use of multiple superhydrophobic stripes was found to segment the impacting droplets into several parts, implying the ability to selectively avoid ice accumulation at specific areas. Furthermore, experiments identified critical temperature thresholds at which the effectiveness of superhydrophobic stripes diminishes. When the temperature of the substrate is higher than -25°C , the superhydrophobic stripes can sufficiently divide an impacting droplet leaving no ice at the superhydrophobic region. In the tested temperature range between -25°C and -40°C , the ice coverage ratio at the superhydrophobic region increases as temperature decreases, with a maximum value of $25.6 \pm 2.33\%$ at -40°C . Superhydrophobic patterns also exhibited improved deicing efficiency during melting processes, highlighting their potential for robust ice management applications.



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Keywords: superhydrophobic patterns; droplet; anti-icing

1. Introduction

Ice formation is a common natural phenomenon, and the resulting ice accumulation on facilities such as power lines [1], aircraft [2], and marine structures operating in polar regions [3] has drawn significant attention. Specifically, sea spray and rainfall contribute to ice accretion on vessels and marine equipment, particularly in low-temperature environments. Such ice accumulation can critically diminish hydrostatic restoring moments, potentially leading to capsizing or structural damage under severe conditions [4,5]. To address the challenges of ice formation, extensive research efforts have been undertaken. Current strategies for anti-icing and deicing of marine equipment encompass both traditional active methods, including manual ice removal and electrical heating systems, and passive techniques, such as chemical anti-icing coatings and air or oil film isolation [5].

Recent advancements in this field have introduced novel anti-icing technologies, such as improved coatings, innovative materials, and microwave heating, which are increasingly being adopted for vessel and marine equipment applications [6].

With the development of preparation methods of superhydrophobic surfaces, they have been used widely in marine engineering [7]. Droplets impacting superhydrophobic surfaces exhibit bouncing behavior, significantly reducing their contact time and area compared to hydrophilic surfaces, consequently minimizing heat transfer and prolonging icing duration [8,9]. Thus, superhydrophobic surfaces effectively contribute to anti-icing capabilities. Numerous studies have explored droplet impact dynamics on varied surface types. Nguyen et al. [10] proposed a theoretical model accurately predicting icing times on aluminum surfaces, while Fang et al. [11] experimentally demonstrated that the ice formation from impacting droplets is dependent on both impact velocity and surface temperature.

Merlen et al. [12] theoretically analyzed and estimated the maximum spread diameter of the droplet impact on the superhydrophobic surface, and proposed an estimation formula for the maximum spread diameter. McDonald et al. [13] designed a kind of experimental method that could quantitatively measure the adhesion strength of ice on super-cooled surfaces. Jonathan et al. [14] found that nanostructured superhydrophobic surfaces have the ability to easily defrost. Gurumukhi et al. [15] tested the defrosting ability of a superhydrophobic stripe and elucidated the role of wettability gradients in defrosting. Adanur et al. [16] investigated three kinds of biphilic surfaces, which can control the droplets' movement, decrease the freezing temperature and delay the icing and beginning of nucleation. Alexander et al. [17] found that biphilic surfaces could change the number and size of impacting droplets, and delay the icing time at the same time. Additionally, Li et al. [18] reported asymmetric spreading behaviors of droplets on biphilic surfaces before achieving maximum diameter. Zou et al. [19] simulated the spreading behavior of droplets impacting on the chemically striped surface by CLSVOF method, and found that the stripe could split the droplet and enlarge the total length of the three-phase contact line, which could enhance the heat exchange rate. In their further work, Zou et al. [20] tested multiple stripes, and found that chemical stripe could increase the heat transfer by 45.51% at a temperature of 60 °C.

It should be noted that the freezing dynamics of a single water droplet impacting on a surface with hybrid wettability under cold conditions, as well as its anti-icing capacity, has rarely been investigated. However, systematic investigations into the ability of biphilic surface patterns to control the location of ice formation, facilitating rapid melting and thereby improving anti-icing effectiveness, are essential for advancing practical engineering applications. This study investigated the freezing behavior of droplets on hybrid surfaces composed of hydrophilic substrates and superhydrophobic patterns. The freezing dynamics following droplet impact were systematically examined, and the effectiveness of multiple superhydrophobic stripes in controlling ice formation locations was further evaluated. It reveals that employing multiple superhydrophobic stripes significantly improves anti-icing performance. Additionally, we explored the critical temperature limits at which superhydrophobic patterns lose their anti-icing effectiveness.

2. Materials and Methods

The experimental setup and the morphology of the frozen droplet on tested samples are depicted in Figure 1. The experiment was conducted in a transparent box made of acrylic shown in Figure 1a. Nitrogen gas was introduced as a protective atmosphere to avoid condensation. An aluminum block was cooled by dry ice to the desired temperature, atop which the tested samples were placed. When the block was cooled down to the desired temperature, we removed some dry ice to make sure the temperature did not

significantly change. A thermocouple was placed on top of the aluminum block to measure the temperature. The silicon wafers (99.99999%, Zhejiang China) had a thickness of 2 mm.

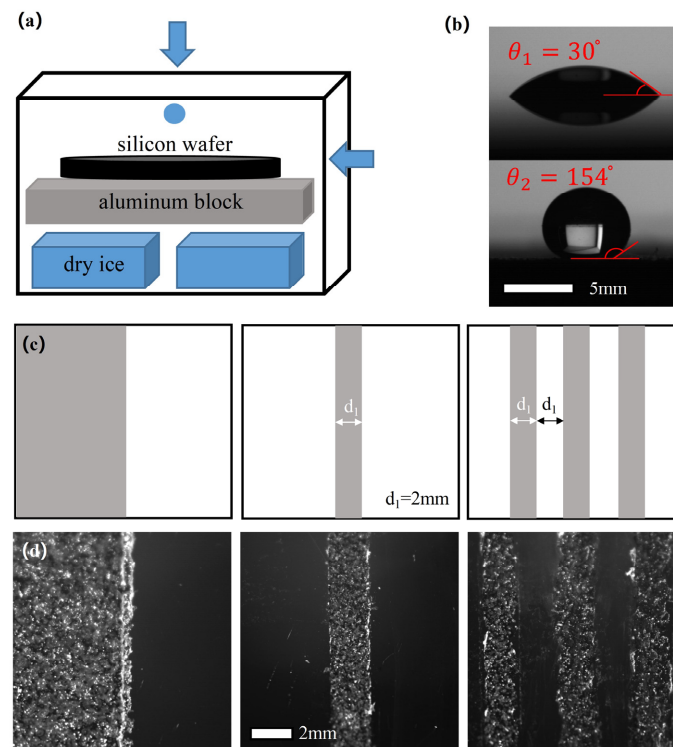


Figure 1. Experimental setup and morphology of a droplet on different samples at room temperature. (a) is the experimental setup where the arrows show the direction of camera. (b) shows the contact angles of a droplet on different surfaces. (c) is a schematic diagram of the tested samples, where the gray and white regions show the superhydrophobic and hydrophilic regions, respectively. (d) shows the fabricated samples with hybrid wettability.

A commercial superhydrophobic spray coating, NeverWet (Rust-Oleum 275619, NeverWet, LLC, Lancaster, PA, USA), was applied to make superhydrophobic patterns on a 2 mm-thick silicon wafer. The contact angle of a water droplet on the hydrophilic silicon surface was 30° (θ_1), and it is 154° (θ_2) at the region coated with the superhydrophobic coatings, with the sliding angle being 2° , as shown in Figure 1b. The contact angles were measured using a standard automated goniometer (Model 290, Ramé-Hart Inc., Succasunna, NJ, USA). The superhydrophobic patterns were spray coated on the hydrophilic silicon substrate using a shadow mask method. A silicon wafer was cleaned by ethyl alcohol and deionized water and dried by compressed air. Then, a plastic tape was put on the top. The desired patterns were cut on the tape followed by removing the tape at the unwanted region. Superhydrophobic coating was sprayed on the unprotected area using a spray gun. In the end, the remaining tape was peeled off the silicon wafer. The fabricated samples are schematically shown in Figure 1d.

During the freezing experiment, a droplet was released from a stainless-steel needle on top of the test sample. The diameter of the droplet before impact was $D_0 = 3.72$ mm, and the releasing height of droplet over the sample was kept constant at 5 cm, with the corresponding Weber number $We = \rho v^2 D_0 / \gamma = 50$, where ρ , v and γ are the density of water, velocity of the droplet, and air–water surface tension coefficient. The Weber number is a dimensionless parameter defined as the ratio of inertial forces to surface tension forces; in this study, higher Weber numbers show the droplets had greater impact velocities. The freezing process was recorded by a high-speed camera (Revealer, M120, HF Agile Device Co., Ltd.: Hefei, China) at 1000 frames per second (fps) with a resolution of

1024 × 768 pixels. The spreading diameter of the impacting droplet, d , is the instantaneous diameter of the droplet during spreading or recoiling process by the side view of the high-speed camera. The value of d was calculated via open software ImageJ (version 1.53k) manually. The ice coverage area was captured through the top view of the high-speed camera images and calculated via ImageJ manually.

3. Results and Discussion

3.1. Freezing Process of an Impacting Droplet on Substrate with Uniform Wettability

The freezing process of a droplet impacting on cold surfaces with different wettability is shown in Figure 2. When a droplet impacts on a cold hydrophilic surface at a temperature of $-15\text{ }^{\circ}\text{C}$, as shown in Figure 2a, it spreads rapidly to a maximum diameter, resulting in a large contact area between the droplet and the surface. As a result, the droplet freezes quickly due to the rapid heat transfer from droplet to substrate. However, when a droplet impacts on superhydrophobic surfaces at a temperature of $-15\text{ }^{\circ}\text{C}$, as shown in Figure 2b, it rebounds off the cold surface due to the surface's water repellency, leaving no ice on the substrate. The contact time of the droplet on the superhydrophobic substrate was only 21 ms. This shows that superhydrophobic surfaces can be used to avoid water attachment and ice formation in cold environments. It should be noted that the contact time of a droplet and the anti-icing capacity of superhydrophobic surfaces depend strongly on the surface micro/nanostructure and environmental temperature, as has been extensively studied in the prior literature [21–25]. In this work, we leverage the high water repellency of superhydrophobic patterns not to merely delay freezing, but to actively control the location of ice formation on hybrid surfaces. This pattern-induced segmentation of impacting droplets enables the spatial confinement of ice and represents a distinct mechanism to enhance anti-icing performance beyond what has been achieved with uniformly superhydrophobic surfaces.

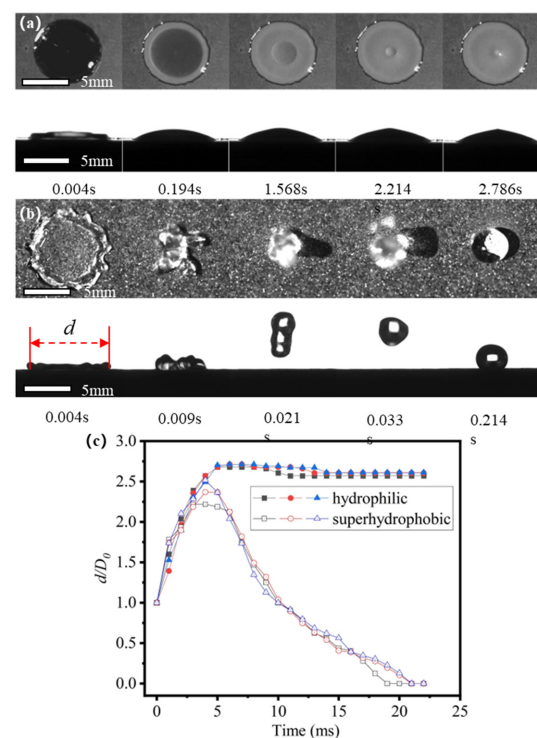


Figure 2. Freezing process of a droplet on the hydrophilic and bouncing process of a droplet on superhydrophobic surfaces. (a,b) are the impacting processes on the hydrophilic and superhydrophobic

surfaces at a low temperature, respectively. (c) are the normalized spreading diameters of the impacting droplet on the hydrophilic and superhydrophobic surfaces. The temperature is $-15\text{ }^{\circ}\text{C}$, and Weber number is 50. *d* in (b,c) is the transient spreading diameter, with the margin of error being $\pm 0.1\text{ mm}$.

3.2. Using Superhydrophobic Patterns on a Hydrophilic Substrate to Control the Freezing Behavior

Based on the ability of superhydrophobic surfaces to repel water, the freezing region could be controlled by selectively modifying the local wettability of the substrate. Figure 3 shows the freezing process of an impacting droplet on the hybrid surface, half of which is hydrophilic, and the remaining region being superhydrophobic. The temperature is $-25\text{ }^{\circ}\text{C}$, and the Weber number is 50. The landing position is at the edge between the hydrophilic and superhydrophobic region. Upon impact, droplets expand to their maximum diameter at both sides. Then, in the hydrophilic region, the droplet is pinned by the contact line, whereas in the superhydrophobic area, the droplet recoils to the other side. The underlying mechanism of directional motion comes from the surface tension difference between the hydrophilic and superhydrophobic regions. At the hydrophilic region, the cohesion force of solid substrate to the liquid is high enough to pin the three-phase contact line of the water droplet, as schematically shown in Figure 3c. At the superhydrophobic region, the solid substrate repels the liquid due to the low surface energy. Consequently, the net surface tension force is directed towards the hydrophilic side.

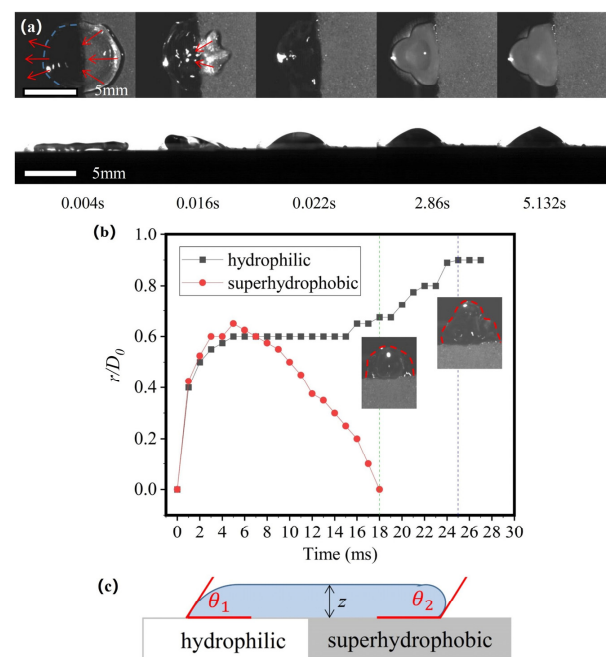


Figure 3. Freezing process of a droplet on a hybrid surface. (a) shows the top and side views of the freezing process. (b) is the normalized spreading radius in both the hydrophilic and superhydrophobic regions on the hybrid surface, where r is the droplet transient spreading radius, and the margin of error is $\pm 0.1\text{ mm}$. (c) is the schematic side view of a droplet on the half-hybrid surface. The temperature is $-25\text{ }^{\circ}\text{C}$ and Weber number is 50. The red arrows in (a) indicate the direction of pinning force of the substrate to the spreading droplet.

When a droplet impacts and spreads on the hybrid surface, as shown in Figure 3c, the curvature difference of the interface between the hydrophilic and superhydrophobic sides causes a difference in the Young Laplace pressure. Laplace pressure is defined as the curvature-induced pressure differential across a liquid interface. $\Delta P = \gamma(\frac{1}{R_1} + \frac{1}{R_2})$, where γ is the air–water surface tension coefficient, and R_1 , R_2 are the curvature radius of the deformed liquid surface.

Assuming the curvature of the three phase contact line is a circular arc for simplification, the Laplace pressure of the hydrophilic side is $\Delta P_1 = \frac{\gamma}{z}(1 - \cos \theta_1)$, and the Laplace pressure of the superhydrophobic side is $\Delta P_2 = \frac{\gamma}{z}(1 - \cos \theta_2)$, where z is the thickness of the spreading droplet [15]. The local curvature difference of the air–water interface caused by the different wettability results in the pressure gradient from the superhydrophobic side to the hydrophilic side

$$\Delta P = \Delta P_2 - \Delta P_1 = \frac{\gamma}{z}(\cos \theta_1 - \cos \theta_2) \quad (1)$$

That is the reason the droplet moves from the superhydrophobic pattern to the hydrophilic surface.

The freezing process of an impacting droplet can also be manipulated by a single superhydrophobic stripe. When a droplet impacts on the cold hydrophilic substrate with a single superhydrophobic stripe, as shown in Figure 4, the droplet spreads at both the hydrophilic and superhydrophobic area. After reaching the maximum spreading diameter, as shown in Figure 4a, the retraction behavior is different. More specifically, the three-phase contact is pinned at the hydrophilic area while rapidly receding at the superhydrophobic region. As a result, the droplet was cut into two segments by the superhydrophobic stripe and frozen in the hydrophilic region. Figure 4b shows that when the droplet is salt water, the superhydrophobic stripe could still divide it into two parts. This demonstrates its potential for application in marine environments. Figure 4c illustrates the spreading behavior of droplets impacting single superhydrophobic stripes when released from varying heights. The segmentation efficiency is observed to correlate with impact velocity: droplets released from greater heights attain higher velocities, leading to quicker segmenting, whereas low impact velocity results in incomplete segmentation.

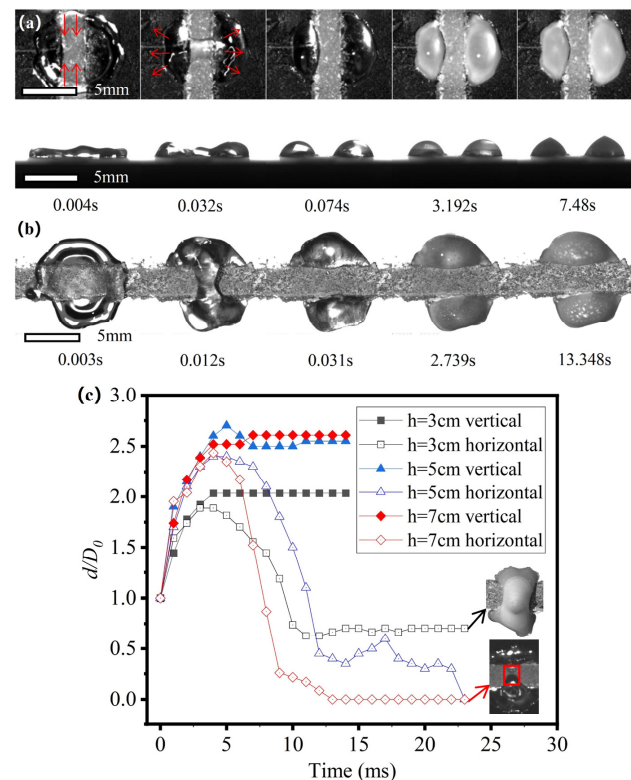


Figure 4. Freezing process of a droplet on a hybrid surface with single superhydrophobic stripe surrounded by hydrophilic regions. (a) shows the top and side views of the freezing process. (b) is the

top view of 3.5% salt water freezing process. (c) is the normalized spreading diameter in both the hydrophilic and superhydrophobic regions on the hybrid surface; the margin of error is ± 0.1 mm. Vertical means the direction which perpendicular to the strip, and the horizontal means the direction which parallel with the strip. The temperature is -25 °C, and Weber numbers of three heights are 30, 50, 70, respectively. The red arrows in (a) indicate the direction of pinning force of the substrate to the spreading droplet.

Therefore, one could use the superhydrophobic stripes to selectively cut the freezing droplet into several segments. Figure 5 illustrates the freezing process of an impacting droplet on a substitute with multiple superhydrophobic stripes. The droplet was divided into several tiny segments during the complicated impacting and Freezing process. Figure 5b presents the freezing morphology of three droplets that impact the hybrid region with slightly varied positions. The results shows that the presence of multiple stripes significantly enhances control over where ice forms, showcasing the potential of this approach in precise ice-management applications.

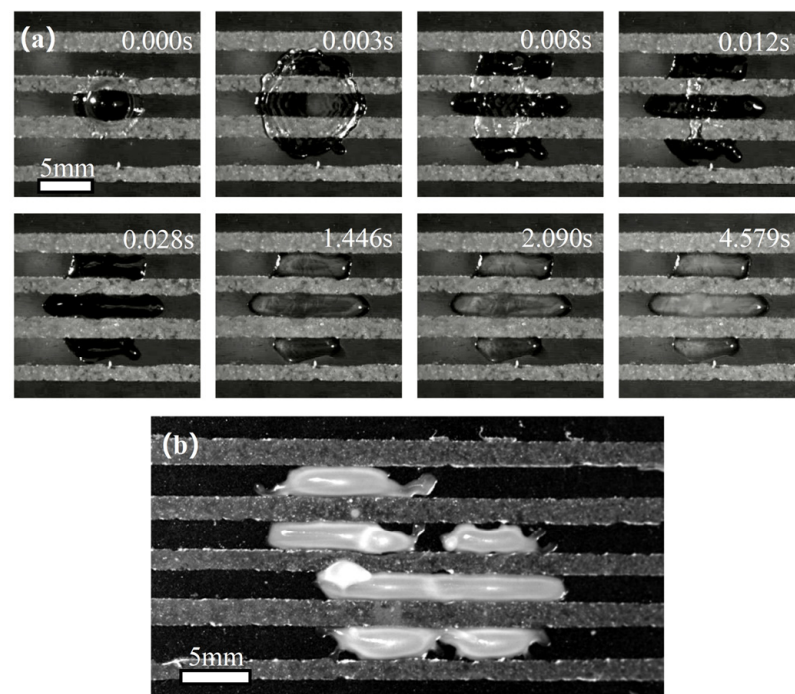


Figure 5. Freezing process of a droplet on a hybrid surface with multiple superhydrophobic stripes. (a) is the spreading process. (b) is the final ice accumulation of three droplets impacting on the hybrid surface. The temperature is -20 °C and Weber number is 70.

3.3. Failure of the Effect of the Hybrid Patterns on the Manipulation of the Freezing Process

The effect of temperature on the anti-icing capacity of the hybrid surfaces was investigated. At a lower-than-critical temperature of the hydrophilic surface, the effect of the superhydrophobicity on the freezing process fails (Figure 6a). More specifically, the superhydrophobic stripes can no longer effectively split the droplets into two distinct parts. This failure is attributed to the excessively low temperature of the hydrophilic surface, which is cold enough to accumulate ice to a degree that impedes the movement of droplets that would typically be influenced by the presence of superhydrophobic patterns. Consequently, some droplets on the stripes are unable to migrate to the hydrophilic surface, thereby expanding their contact area.

A series of experiments were performed on the sample with single superhydrophobic stripe. After impact, measurement of the “ice coverage ratio”, dividing the area of ice on the

superhydrophobic stripe by the spreading area of the impacting droplet, was investigated, as shown in Figure 6b. As the temperature decreases, the ice coverage ratio increases. For temperatures lower than $-35\text{ }^{\circ}\text{C}$, the ratio comes to $20.6 \pm 0.75\%$, and the stripe cannot segment droplets into two parts. When the temperature is $-40\text{ }^{\circ}\text{C}$, the ice coverage increases to $25.6 \pm 2.33\%$, and the superhydrophobic stripe is completely covered by the droplet.

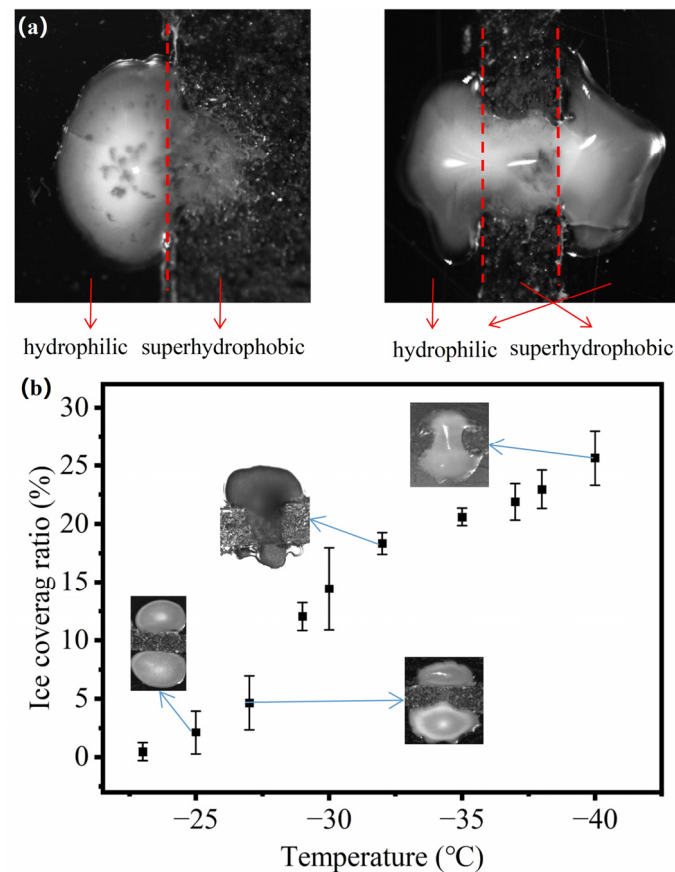


Figure 6. Ice coverage on the hybrid surfaces. (a) is the ice accumulation on two types of hybrid surfaces at temperature of $-40\text{ }^{\circ}\text{C}$. (b) is the ice coverage ratio on the hybrid surface with single superhydrophobic stripe under different temperatures. The error bars standards for standard deviations of at least 3 tests.

3.4. Enhancement of Deicing During the Melting Process on the Hybrid Surface

The hybrid patterns can enhance the deicing process during the melting process of ice on the cold substance. Figure 7 shows the melting process of a single iced droplet on the superhydrophobic surface and the hybrid substrate with multiple superhydrophobic stripes. The droplets were frozen under a $-25\text{ }^{\circ}\text{C}$ temperature and melted at a temperature of $60\text{ }^{\circ}\text{C}$. On a uniformly superhydrophobic surface, the ice typically maintains a nearly spherical shape with minimal contact area, which limits heat transfer and prolongs the melting process. In contrast, the hybrid surface induces partial spreading of the droplet, increasing the solid–liquid contact area and thereby accelerating thermal exchange during melting. Additionally, the segmentation effect introduced by the superhydrophobic stripes further facilitates efficient deicing by breaking the ice into smaller segments. The melted ice was split into several segments by the superhydrophobic stripes after melting, which suggests a practical strategy for directing the melting process in de-icing applications.

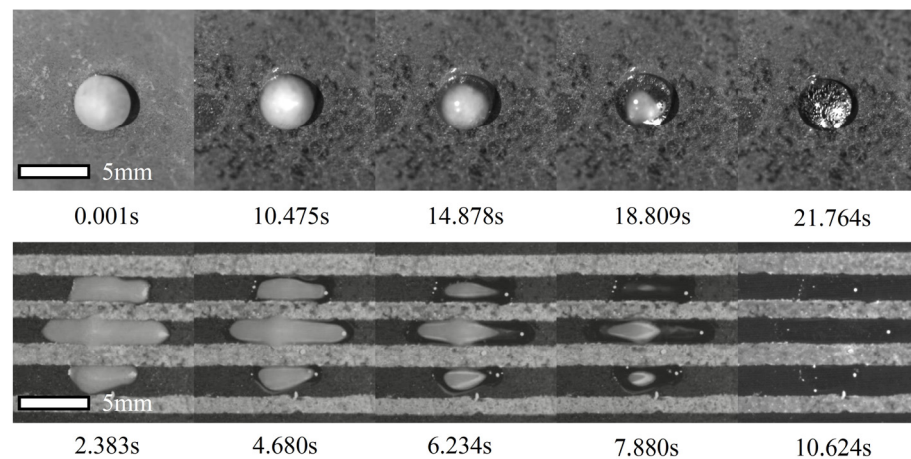


Figure 7. The melting process of ice on superhydrophobic surfaces and hybrid surfaces. The ice formed at temperature of -25°C and melts at 60°C .

4. Conclusions

This study systematically explores the use of superhydrophobic patterns on hydrophilic substrates for targeted ice formation control and enhanced anti-icing capabilities. The results demonstrate that superhydrophobic surfaces significantly delay freezing by minimizing droplet contact duration and area. Strategic integration of these patterns enables precise localization and segmentation of ice coverage region. However, their effectiveness diminishes markedly below a critical temperature threshold (approximately -25°C), becoming completely ineffective at -40°C . The hybrid patterned surfaces demonstrated superior melting efficiency compared to uniformly superhydrophobic surfaces, highlighting their potential for ice control applications; however, further investigation under realistic environmental conditions is necessary to evaluate their long-term robustness and practical suitability. This research clearly highlights the potential of hybrid wettability patterns as effective and precise solutions for anti-icing and deicing applications.

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Data Availability Statement: The data are available from the corresponding author upon reasonable request.

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References

1. Song, D.; Xu, C.; Song, B.; Pan, G.; Hu, H.; Choi, C.-H. Splitting an Impacting Droplet by a Superhydrophobic Wire. *Coatings* **2022**, *12*, 1866. [\[CrossRef\]](#)
2. Gent, R.W.; Dart, N.P.; Cansdale, J.T. Aircraft icing. *Philos. Trans. R. Soc. Lond. Ser. A-Math. Phys. Eng. Sci.* **2000**, *358*, 2873–2911. [\[CrossRef\]](#)
3. Zhang, Y.; Zhang, L.; Luo, G. Study on de-icing criterion of anti-icing coating and simulation analysis method of mechanical de-icing process for polar ship superstructure. *Ocean Eng.* **2023**, *288*, 115811. [\[CrossRef\]](#)
4. Mintu, S.; Molyneux, D. Ice accretion for ships and offshore structures. Part 1-State of the art review. *Ocean Eng.* **2022**, *258*, 111501. [\[CrossRef\]](#)

5. Shi, K.W.; Duan, X.L. A Review of Ice Protection Techniques for Structures in the Arctic and Offshore Harsh Environments. *J. Offshore Mech. Arct. Eng.-Trans. ASME* **2021**, *143*, 064502. [\[CrossRef\]](#)
6. Zhou, L.; Liu, R.; Yi, X. Research and development of anti-icing/deicing techniques for vessels: Review. *Ocean Eng.* **2022**, *260*, 112008. [\[CrossRef\]](#)
7. Fu, J.G.; Liao, X.G.; Ji, Y.L.; Mo, Y.Q.; Zhang, J.F. Research Progress on Preparation of Superhydrophobic Surface and Its Application in the Field of Marine Engineering. *J. Mar. Sci. Eng.* **2024**, *12*, 1741. [\[CrossRef\]](#)
8. Guo, C.; Liu, L.; Yang, R.; Lu, J.; Liu, S. Bouncing Regimes of Supercooled Water Droplets Impacting Superhydrophobic Surfaces with Controlled Temperature and Humidity. *Langmuir* **2023**, *39*, 10199–10208. [\[CrossRef\]](#)
9. Pan, Y.; Shi, K.; Duan, X.; Naterer, G.F. Experimental investigation of water droplet impact and freezing on micropatterned stainless steel surfaces with varying wettabilities. *Int. J. Heat Mass Transf.* **2019**, *129*, 953–964. [\[CrossRef\]](#)
10. Nguyen, V.-H.; Nguyen, B.D.; Pham, H.T.; Lam, S.S.; Vo, D.-V.N.; Shokouhimehr, M.; Vu, T.H.H.; Nguyen, T.-B.; Kim, S.Y.; Le, Q.V. Anti-icing performance on aluminum surfaces and proposed model for freezing time calculation. *Sci. Rep.* **2021**, *11*, 3641. [\[CrossRef\]](#)
11. Fang, W.-Z.; Zhu, F.; Tao, W.-Q.; Yang, C. How different freezing morphologies of impacting droplets form. *J. Colloid Interface Sci.* **2021**, *584*, 403–410. [\[CrossRef\]](#)
12. Merlen, A.; Brunet, P. Impact of Drops on Non-wetting Biomimetic Surfaces. *J. Bionic Eng.* **2009**, *6*, 330–334. [\[CrossRef\]](#)
13. McDonald, B.; Patel, P.; Zhao, B. Droplet freezing and ice adhesion strength measurement on super-cooled hydrophobic surfaces. *J. Adhes.* **2015**, *93*, 375–388. [\[CrossRef\]](#)
14. Boreyko, J.B.; Srijanto, B.R.; Nguyen, T.D.; Vega, C.; Fuentes-Cabrera, M.; Collier, C.P. Dynamic Defrosting on Nanostructured Superhydrophobic Surfaces. *Langmuir* **2013**, *29*, 9516–9524. [\[CrossRef\]](#)
15. Gurumukhi, Y.; Chavan, S.; Sett, S.; Boyina, K.; Ramesh, S.; Sokalski, P.; Fortelka, K.; Lira, M.; Park, D.; Chen, J.-Y.; et al. Dynamic Defrosting on Superhydrophobic and Bipilic Surfaces. *Matter* **2020**, *3*, 1178–1195. [\[CrossRef\]](#)
16. Adanur, B.; Cremaschi, L.; Harges, E. Effect of mixed hydrophilic and hydrophobic surface coatings on droplets freezing and subsequent frost growth during air forced convection channel flows. *Sci. Technol. Built Environ.* **2019**, *25*, 1302–1312. [\[CrossRef\]](#)
17. Van Dyke, A.S.; Collard, D.; Derby, M.M.; Betz, A.R. Droplet coalescence and freezing on hydrophilic, hydrophobic, and bipilic surfaces. *Appl. Phys. Lett.* **2015**, *107*, 141602. [\[CrossRef\]](#)
18. Li, X.; Wang, G.; Zhan, B.; Li, S.; Han, Z.; Liu, Y. A Novel Icephobic Strategy: The Fabrication of Biomimetic Coupling Micropatterns of Superwetting Surface. *Adv. Mater. Interfaces* **2019**, *6*, 1900864. [\[CrossRef\]](#)
19. Zou, L.; Wang, H.; Zhu, X.; Ding, Y.D.; Chen, R.; Liao, Q. Droplet splitting on chemically striped surface. *Colloids Surf. A-Physicochem. Eng. Asp.* **2018**, *537*, 139–148. [\[CrossRef\]](#)
20. Zou, L.; Wang, H.; Zhu, X.; Ding, Y.D.; Liao, Q. Chemically striped surface accelerate the droplet evaporation. *Colloids Surf. A-Physicochem. Eng. Asp.* **2021**, *612*, 125994. [\[CrossRef\]](#)
21. Cao, L.; Jones, A.K.; Sikka, V.K.; Wu, J.; Gao, D. Anti-Icing Superhydrophobic Coatings. *Langmuir* **2009**, *25*, 12444–12448. [\[CrossRef\]](#) [\[PubMed\]](#)
22. Cong, Q.; Qin, X.Z.; Chen, T.K.; Jin, J.F.; Liu, C.Z.; Wang, M.Q. Research Progress of Superhydrophobic Materials in the Field of Anti-/De-Icing and Their Preparation: A Review. *Materials* **2023**, *16*, 5151. [\[CrossRef\]](#) [\[PubMed\]](#)
23. Liu, Y.H.; Moevius, L.; Xu, X.P.; Qian, T.Z.; Yeomans, J.M.; Wang, Z.K. Pancake bouncing on superhydrophobic surfaces. *Nat. Phys.* **2014**, *10*, 515–519. [\[CrossRef\]](#) [\[PubMed\]](#)
24. Sarshar, M.A.; Song, D.; Swartz, C.; Lee, J.; Choi, C.H. Anti-Icing or Deicing: Icephobicities of Superhydrophobic Surfaces with Hierarchical Structures. *Langmuir* **2018**, *34*, 13821–13827. [\[CrossRef\]](#)
25. Song, D.; Liu, X.; Wang, X.; Du, X.X.; Hu, H.B. Experimental Investigation on the Droplet Stability of Superhydrophobic Mesh. *Coatings* **2023**, *13*, 756. [\[CrossRef\]](#)

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