DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY ROPAR

RUPNAGAR-140001, INDIA

IIT Ropar

THERMO FLUIDS (ME303) LABORATORY REPORT

For Experiment:
Drop Impact (4B)

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Project Title

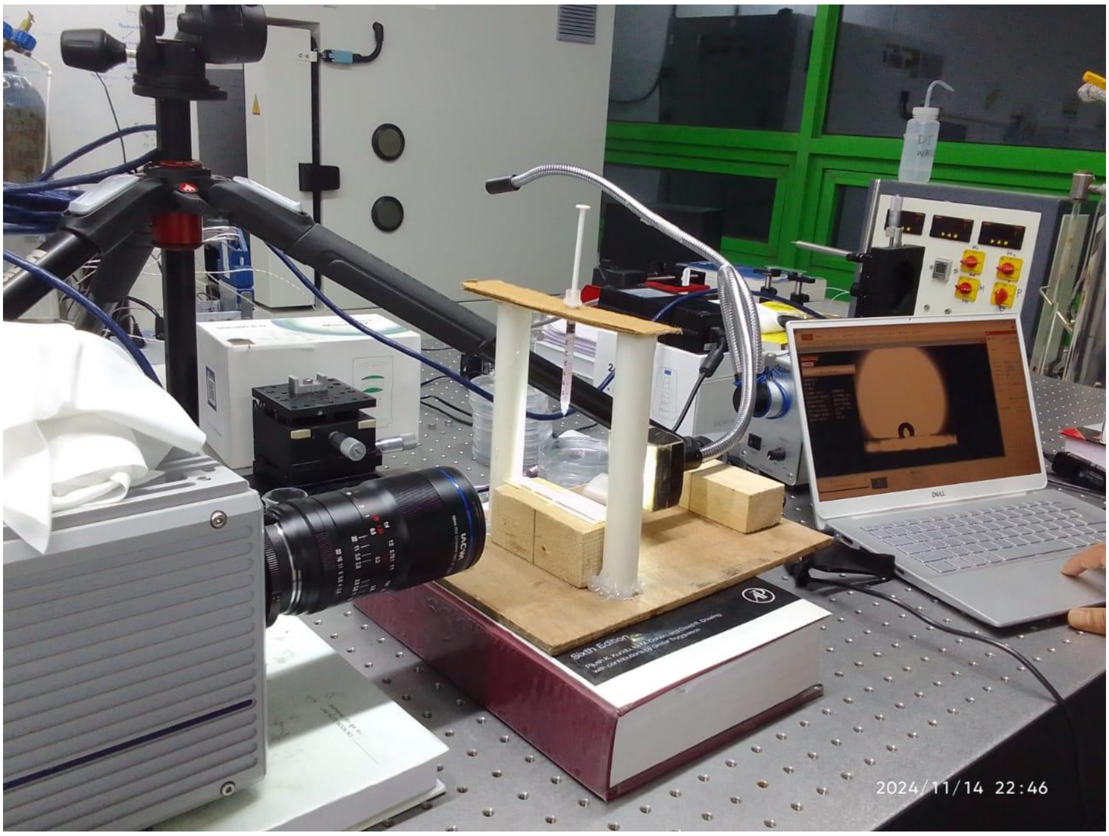
Record the behaviour of a water drop as it impacts three solid surfaces and find the nature of the solid surface in terms of its affinity to water

Introduction

In this project, we investigate the dynamic behaviour of a water drop as it impacts three distinct solid surfaces. By observing and recording the water drop's interaction, such as spreading, bouncing, or recoiling, we can assess each surface's wettability and affinity for water. This behaviour provides insight into the surface characteristics, such as hydrophobicity or hydrophilicity, which affect the contact angle and water adhesion. Understanding these interactions is essential in fields like material science and fluid dynamics, where surface properties significantly influence fluid behaviour.

Apparatus and material required

1. Syringe
2. **Superhydrophobic material**
   Rust-Oleum Never-Wet Multi-Surface Superhydrophobic Coating
   Composition:
   Silicone/Fluoropolymer Compounds, Hydrophobic Nanoparticles, Binders/Carriers, Solvents/Propellants
   The coating combines low-surface-energy compounds with micro-textures that trap air, creating a contact angle over 150° for extreme water repulsiveness.
3. **Hydrophobic material – Teflon tape**
4. **Hydrophilic material** – **glass**
5. High speed camera
6. LED Light
7. Diffuser – trace paper
8. Experimental setup



Theory

- **Introduction to Surface Affinity and Wettability**

When a water droplet impacts a solid surface, its behavior reveals key information about the surface's wettability, which is an indicator of how much the surface attracts or repels water. Wettability is commonly quantified by the **contact angle**—the angle at the junction of the liquid, vapor, and solid phases. This angle helps classify surfaces as:

- **Hydrophilic**: Contact angle < 90°, indicating a high affinity for water.
- **Hydrophobic**: Contact angle > 90°, indicating a low affinity for water.
- **Superhydrophobic**: Contact angle > 150°, showing extreme water repulsiveness.

The contact angle depends on factors like surface energy, roughness, and chemical composition, with smoother and high-surface-energy surfaces generally exhibiting lower contact angles and rough or chemically modified surfaces often exhibiting higher contact angles.

- **Surface Energy and Surface Tension**

Surface energy is the energy required to create a new surface and is closely related to wettability. High-surface-energy materials like metals are often hydrophilic, while low-surface-energy materials like polymers tend to be hydrophobic.
Surface tension is the cohesive force between liquid molecules at the surface. This force drives a water droplet to minimize its surface area and maintain a spherical shape in the absence of external forces. When the droplet contacts a solid, the interaction between surface tension and adhesive forces determines whether the droplet will spread or maintain its shape on the surface.

- **Droplet Morphology and Deformation Stages**

When a water droplet impacts a solid surface, it goes through several distinct morphological changes. These changes reveal a lot about the surface's wetting properties, as well as the balance between inertia, surface tension, and adhesion forces.
Stage 1: Contact and Initial Spreading
Upon making contact with the solid surface, the droplet begins to spread outward due to its inertia, driven by the kinetic energy of impact. The degree of initial spreading is influenced by:

- **Impact Velocity**: Higher velocities increase inertia, leading to more rapid and extensive spreading.
- **Surface Properties**: On a hydrophilic surface, the water droplet's contact angle is low, allowing the droplet to spread out more. Conversely, on a hydrophobic or superhydrophobic surface, the droplet initially spreads less because of a higher contact angle and resistance to wetting.

Stage 2: Maximal Spreading
After the initial spreading phase, the droplet reaches a maximum diameter, known as the **maximal spreading diameter**. At this point, the forces are balanced between:

- **Inertia**, which still pushes the liquid outward, and
- **Surface Tension**, which tries to retract the liquid back toward a more compact shape.

For surfaces with high affinity for water (hydrophilic), the droplet tends to remain in a flattened shape at maximal spread, creating a larger contact area with the surface. This prolonged maximal spread is due to the strong adhesive forces between the water molecules and the solid surface. On hydrophobic surfaces, however, this spread is less pronounced, and the drop quickly begins to retract due to weaker adhesive forces and stronger surface tension, which tries to minimize the droplet's contact with the surface.
The **spreading factor** (ratio of maximal spread diameter to initial diameter) can be used to quantify the degree of spreading. This factor is larger for hydrophilic surfaces and smaller for hydrophobic ones.

Stage 3: Recoil or Rebound
After reaching maximal spread, the droplet either recoils or rebounds, depending on the surface properties:

- **Recoil**: On mildly hydrophobic surfaces, the droplet retracts inward as surface tension becomes the dominant force, pulling the liquid back to minimize its surface area. The droplet may oscillate slightly before stabilizing in an equilibrium shape.
- **Rebound**: On superhydrophobic surfaces, the adhesive forces between the droplet and the solid surface are so minimal that the droplet can completely lift off from the surface after recoil, rebounding back into the air. This occurs because the droplet retains enough energy from the impact to overcome any minor adhesive forces, resulting in a "self-cleaning" effect seen in nature on surfaces like lotus leaves.

Rebound Height and Energy: The height to which a droplet rebounds depends on its residual kinetic energy after impact and the lack of adhesion to the surface. For highly hydrophobic surfaces, nearly all of the droplet's kinetic energy is conserved, leading to a high rebound. In contrast, for less hydrophobic or hydrophilic surfaces, energy dissipation occurs through adhesion and spreading, leading to a reduced or non-existent rebound.

Importance of Droplet Morphology Stages in Surface Characterization
The stages of droplet impact and deformation provide valuable information about the wettability and adhesion characteristics of the surface:

- **Maximal spreading** reveals the wettability level, with greater spreading indicating hydrophilicity.

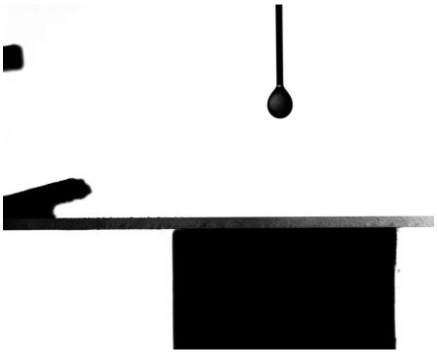
- **Recoil and rebound** behaviours highlight adhesion properties, with strong adhesion preventing rebound and low adhesion promoting it.

STEPS WE FOLLOWED

1. First of all, we made the experimental setup using wood and pipe in workshop lab.
2. Then we fit syringe on it.
3. Next, we fixed smart phone camera and phone torch opposite to each other and position of syringe was in between both of these.
4. Then we made the drop to fall from syringe and recorded this in camera.
5. We did this for three surfaces – hydrophilic, hydrophobic, superhydrophobic.
6. Then we measured the contact angle of the drops on all three surfaces by Image J software.
7. The results from phone camera were not very precise.
8. So, we repeated all this experiment in lab with experimental setup and high-speed camera for recording drop impact.
9. Then we again measured the contact angle of drop on all three surfaces by Image J software.

Experiment done by high-speed camera

Hydrophilic Material



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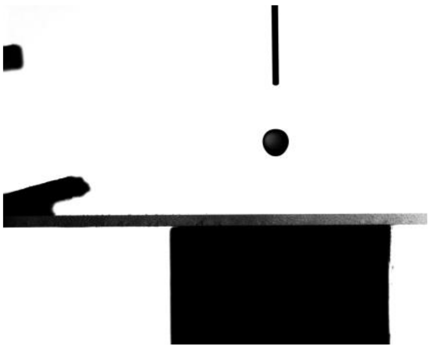

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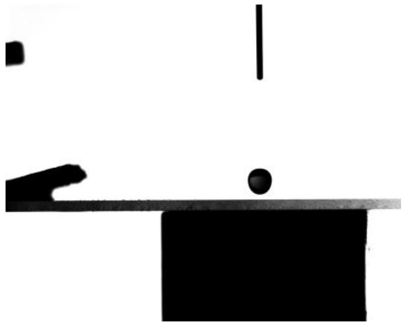

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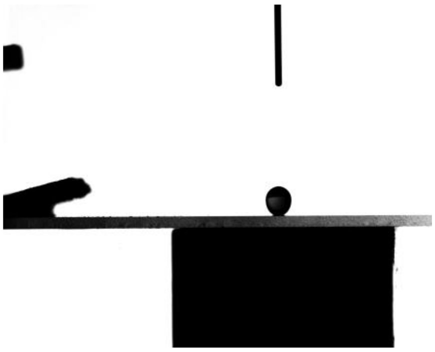

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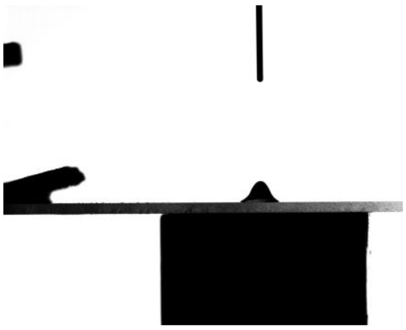

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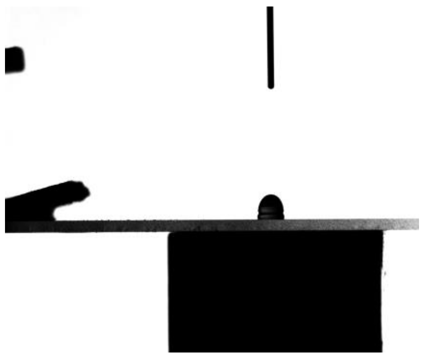

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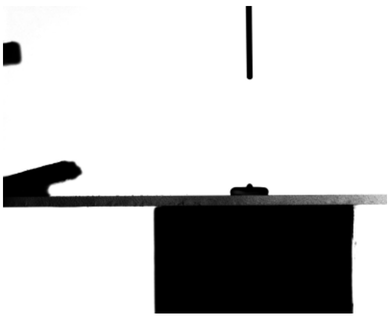

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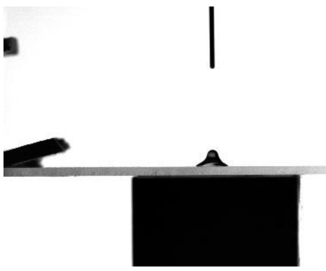

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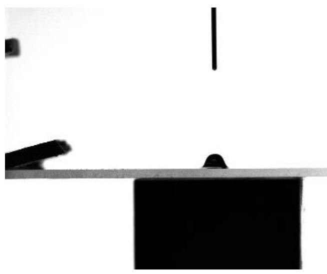

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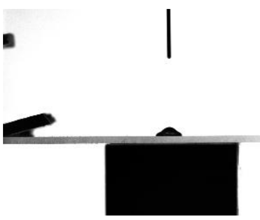

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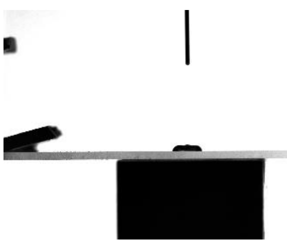
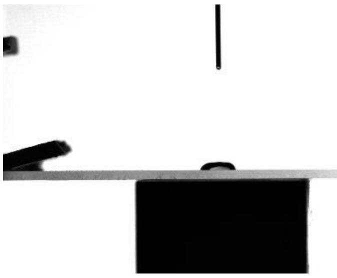
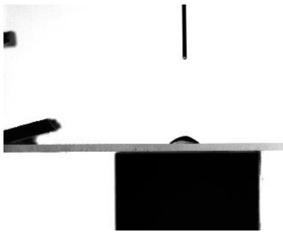


12 

13 

Hydrophobic material

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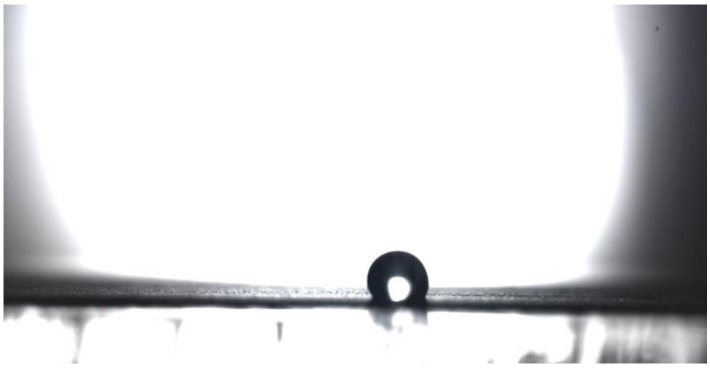

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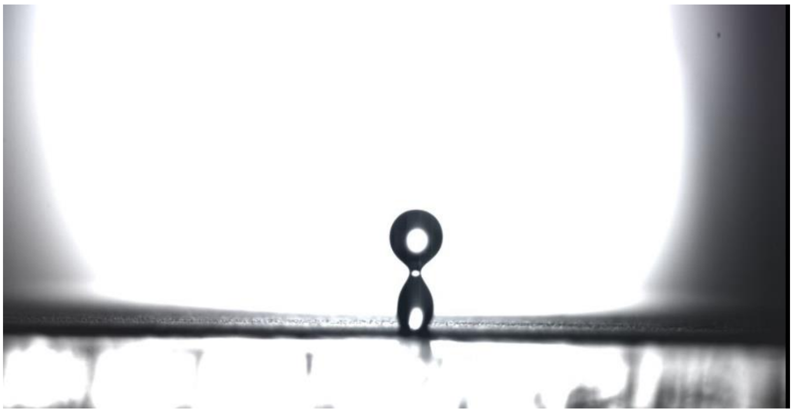
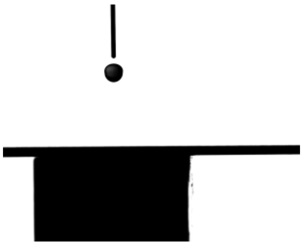


4.

Superhydrophobic Material



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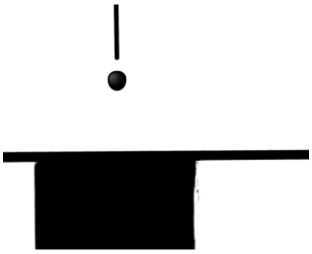

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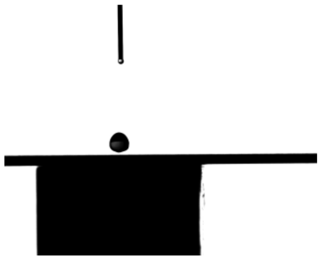

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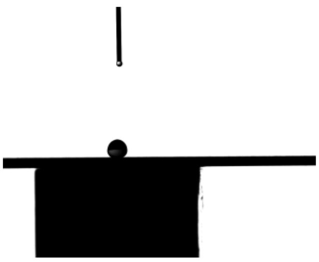

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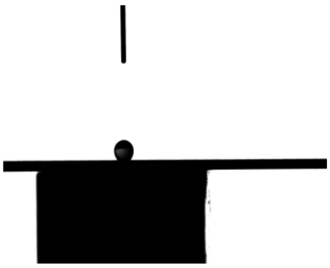

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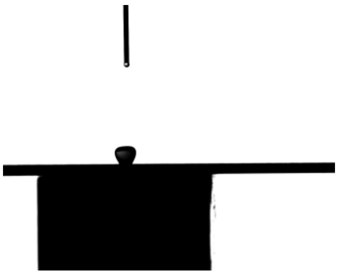

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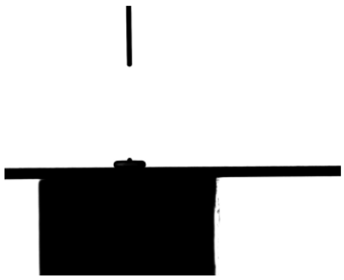

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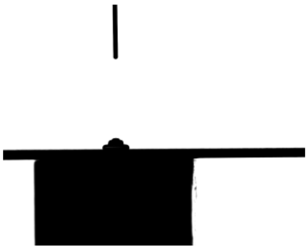

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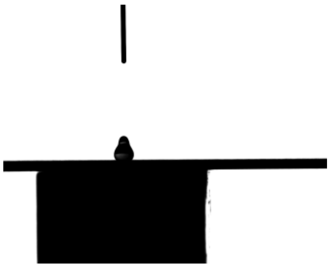

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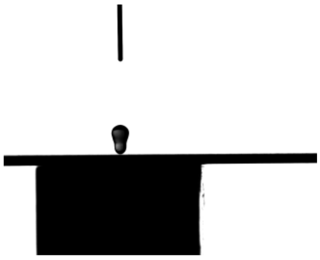

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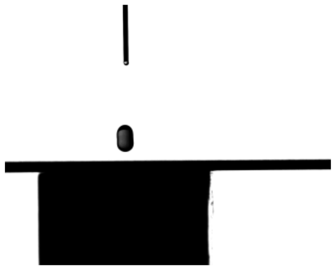

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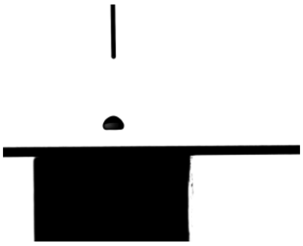

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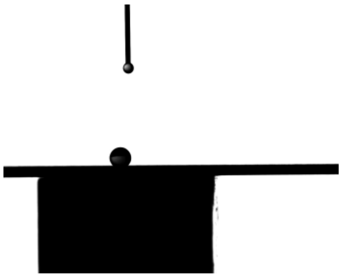

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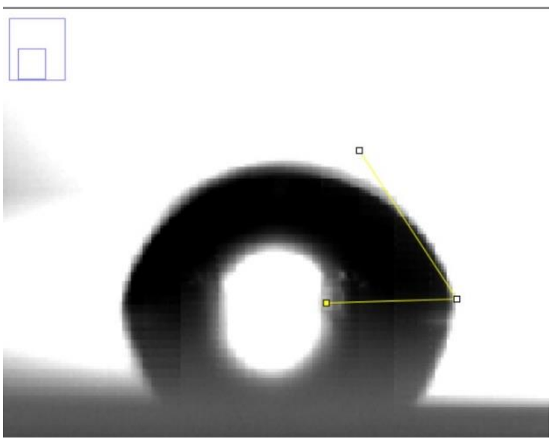
Measurement of Contact angle

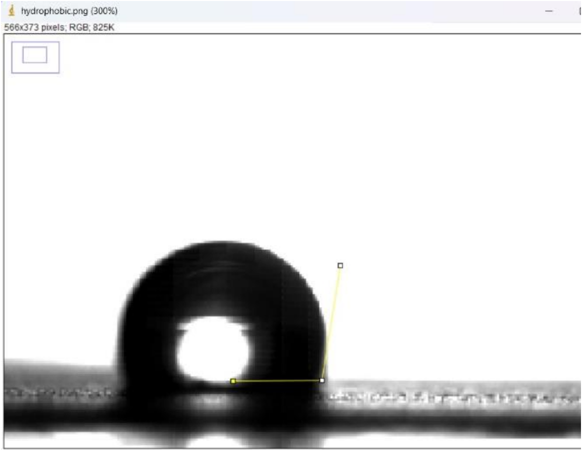


Contact angle

By smart phone camera - 47.16525

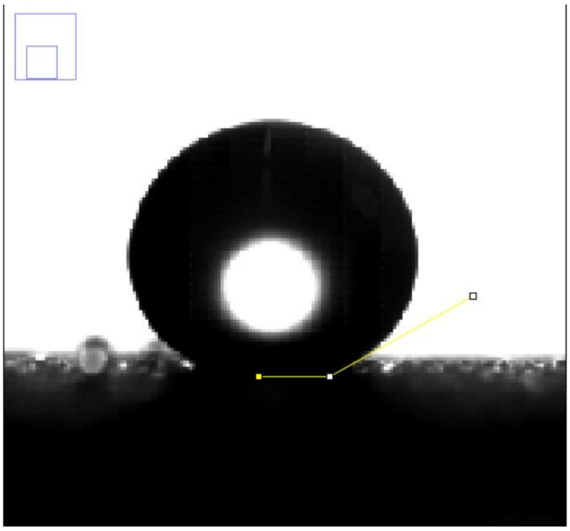
By high-speed camera - 58.622

Hydrophilic material



Contact angle
By smart phone camera – 99.64
By high-speed camera – 110.56

Hydrophobic material



Contact angle
By smart phone camera – 147.70275
By high-speed camera – 150.981

Superhydrophobic material

Conclusions

In this study, we examined the impact dynamics of a water droplet on three different surfaces: hydrophilic, hydrophobic, and superhydrophobic. By analysing the droplet's behaviour—such as spreading, recoiling, and rebounding—across these surfaces, we were able to characterize each surface's wettability and affinity for water. Our observations confirm that hydrophilic surfaces promote extensive spreading with minimal recoil due to strong adhesive forces, while hydrophobic and superhydrophobic surfaces exhibit limited spreading and significant rebound, with superhydrophobic surfaces demonstrating the highest contact angles and nearly complete water repulsiveness. This investigation provides valuable insights into surface interactions with liquids, which are crucial for applications in fields like material science, coating technology, and fluid dynamics.