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Can Biomimetic Superhydrophobic Surfaces Resist Underwater Biofouling?

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INTRODUCTION & AIM

Biomimetics draws inspiration from nature to solve human challenges, with superhydrophobic surfaces mimicking water-repellent properties. This study investigates the potential of biomimetic surfaces in resisting underwater biofouling.

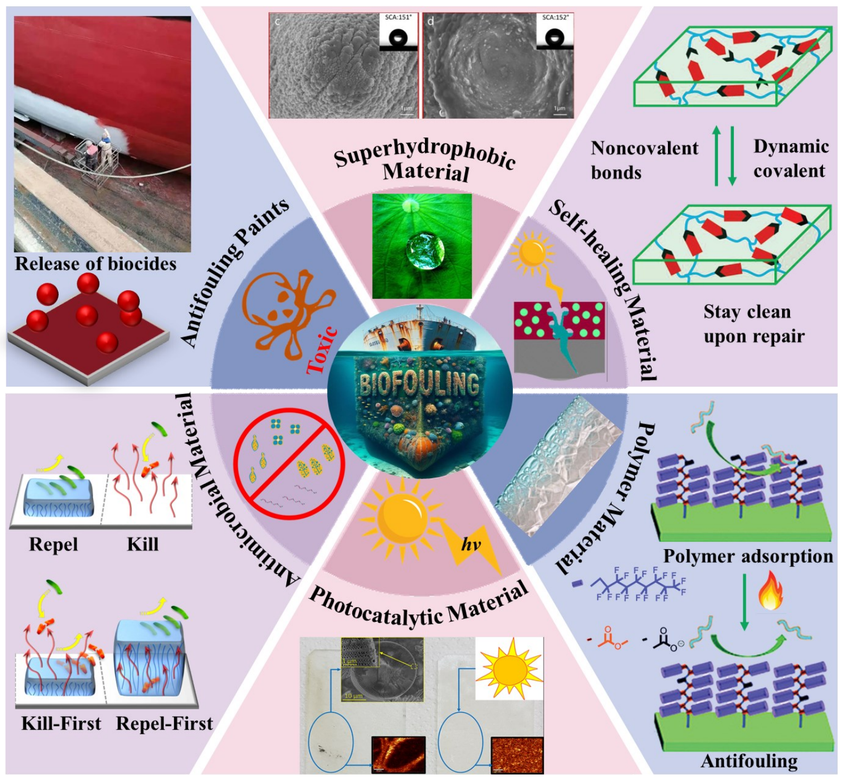

Figure 1. The classification of antifouling materials.

We aim to explore how biomimetic superhydrophobic surfaces can mitigate biofouling, a significant issue in marine industries. Through experimental analysis and theoretical modeling, we strive to design more efficient and sustainable anti-biofouling materials.

METHOD

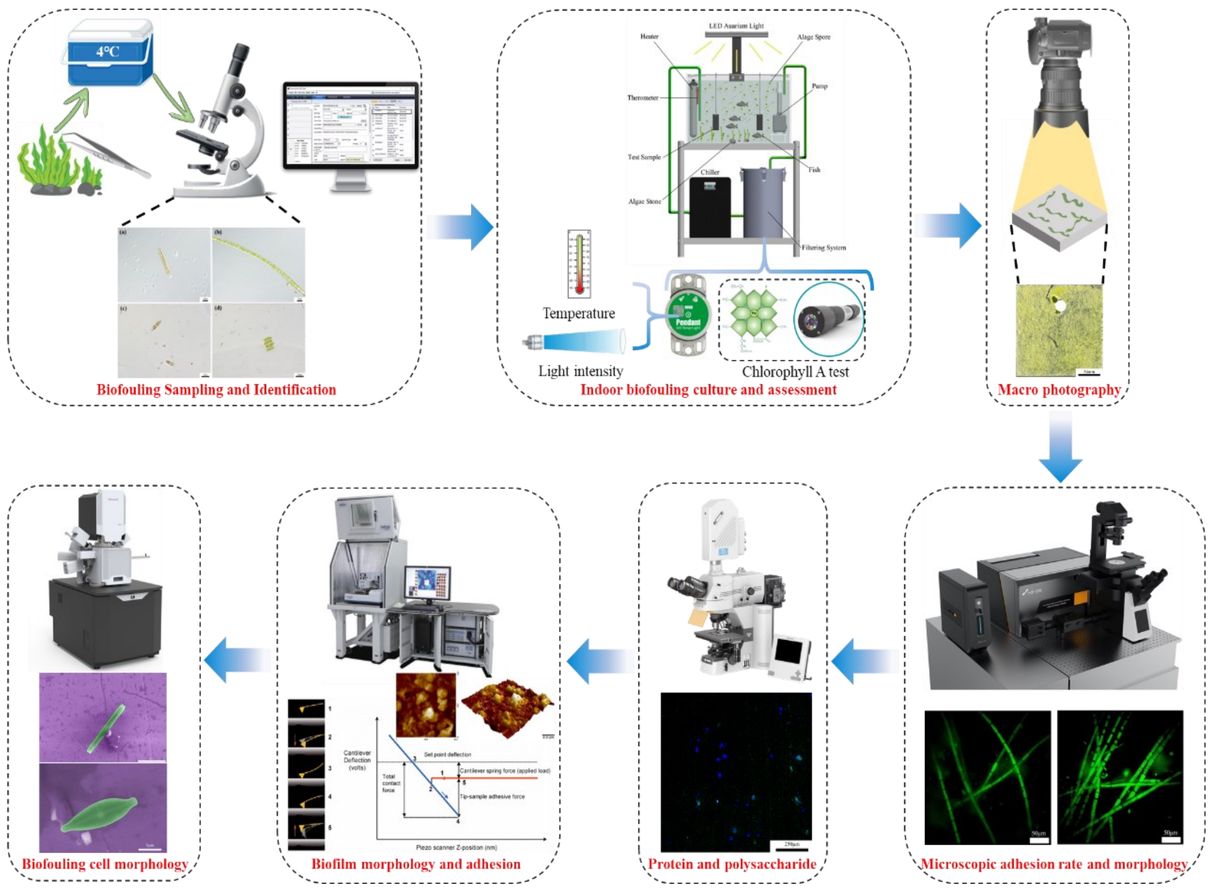

Figure 2. Schematic diagram of the process of assessing the resistance of materials to marine and freshwater biofouling. Biofouling Sampling and Identification (microscope); Indoor biofouling culture and assessment (cultivation box, chlorophyll A probe, and luxmeter); Macro photography (camera); Microscopic adhesion rate and morphology (his-sim); Protein and polysaccharide (CLSM); Biofilm morphology and adhesion (AFM); Biofouling cell morphology (SEM).

Eight steps has been established, incorporating findings from prior research and the investigations carried out by our team: 1) Sampling & Identification, including collection using cryopreservation tanks and initial characterization of freshwater biofouling samples using optical microscope; 2) Macro Photography, employing high-resolution digital single-lens reflex camera to capture the macroscopic state of microbial attachment on material surfaces; 3) Microfouling Observation, using high sensitivity structured illumination microscope (HIS-SiM) technology for microscopic observation of microfouling; 4) Protein & Polysaccharide Detection, utilizing CLSM along with specific staining techniques to identify proteins and polysaccharides within biofilms; 5) Biofilm Morphology, employing AFM for detailed observation of biofilm structures; 6) Biofilm Adhesive Force, also using AFM with force-distance curve measurement modes to assess the adhesion forces of biofilms on different material surfaces; 7) Biofouling Cell Morphology, utilizing SEM equipped with an energy-dispersive spectroscopy spectrometer to examine and analyze the morphological and chemical composition of biofouling cells; and 8) Artificial Intelligence, leveraging advanced data analytics and machine learning algorithms to synthesize data collected from the previous seven steps, for predicting the types of organisms that may attach, their rates of attachment, as well as estimating the expected service life of the material. As illustrated in Figures 6 and 7, these steps form a multi-layered, multi-dimensional evaluation system, aiming to provide an in-depth and comprehensive investigation into the antifouling capabilities of materials.

RESULTS & DISCUSSION

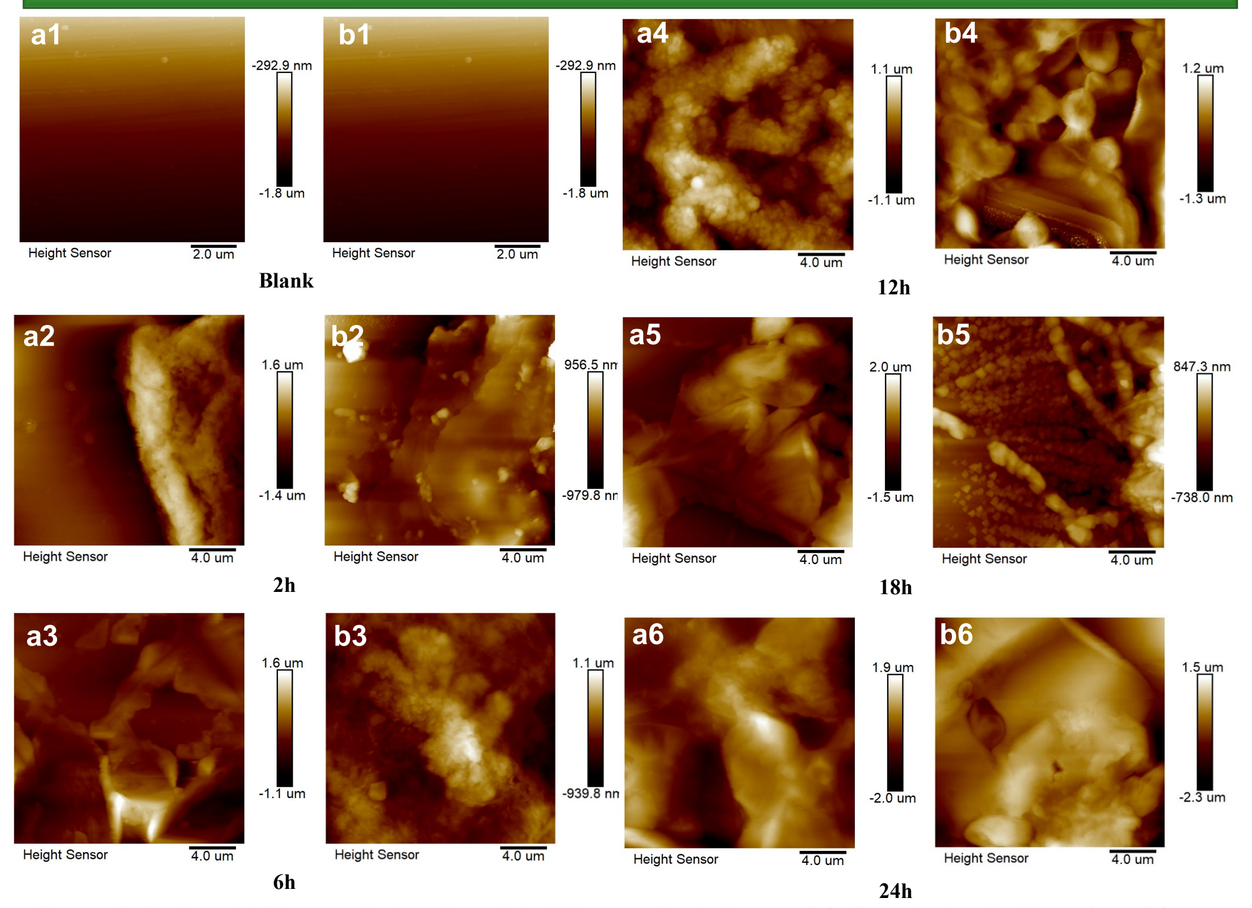

Figure 3. Surface biofilm morphology from 0 to 24 hours. Control group (a), Superhydrophobic surface (b).

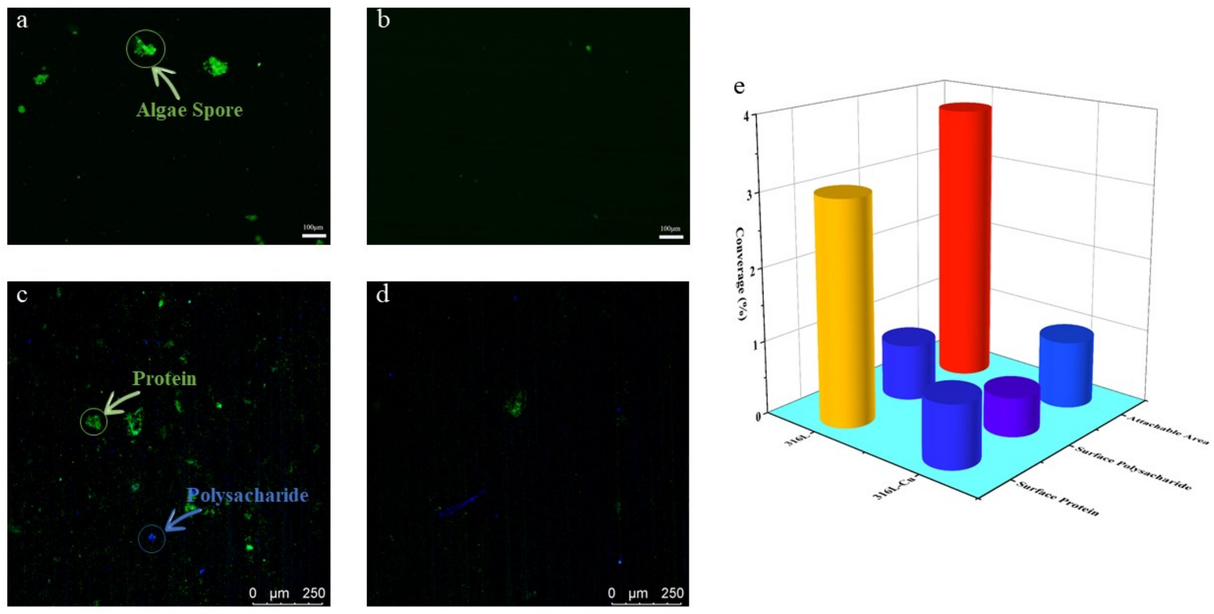

Figure 4. Fluorescence microscopy image of the control group surface (a), fluorescence microscopy image of the superhydrophobic surface (b), confocal laser scanning microscopy (CLSM) image of the control group surface (c), and CLSM image of the superhydrophobic surface (d), Quantification of protein, polysaccharide, and algal spore area fractions on the control and superhydrophobic surfaces (e).

Under static conditions, untreated and superhydrophobic surfaces showed similar biofilm characteristics. However, under dynamic conditions, untreated surfaces accumulated significantly more protein, polysaccharides, and algal spores compared to superhydrophobic surfaces. While the superhydrophobic surfaces did not alter initial biofilm attachment under static conditions, they demonstrated effective resistance to biofouling in dynamic environments. This resistance is attributed to their enhanced water repellency and reduced surface energy.

CONCLUSION

In conclusion, while laboratory tests demonstrated the promising hydrophobicity and chemical stability of biomimetic superhydrophobic surfaces created using femtosecond laser technology, extended testing in simulated marine and freshwater environments revealed limitations in their biofouling resistance capabilities. Despite initial effectiveness, the surfaces experienced a decline in performance over time due to the accumulation of biofouling agents and the dynamic nature of aquatic environments. These findings underscore the importance of considering real-world conditions in evaluating anti-fouling strategies and highlight the need for multidisciplinary approaches to enhance the durability and effectiveness of biomimetic superhydrophobic surfaces. Future research should focus on integrating superhydrophobic features with complementary anti-fouling technologies to develop more robust solutions for combating biofouling in marine and freshwater systems.

FUTURE WORK / REFERENCES

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