Advancing Agriculture Sustainability in Rural Maine by Using PFAS-free Paper

THE UNIVERSITY OF MAINE Cooperative Extension

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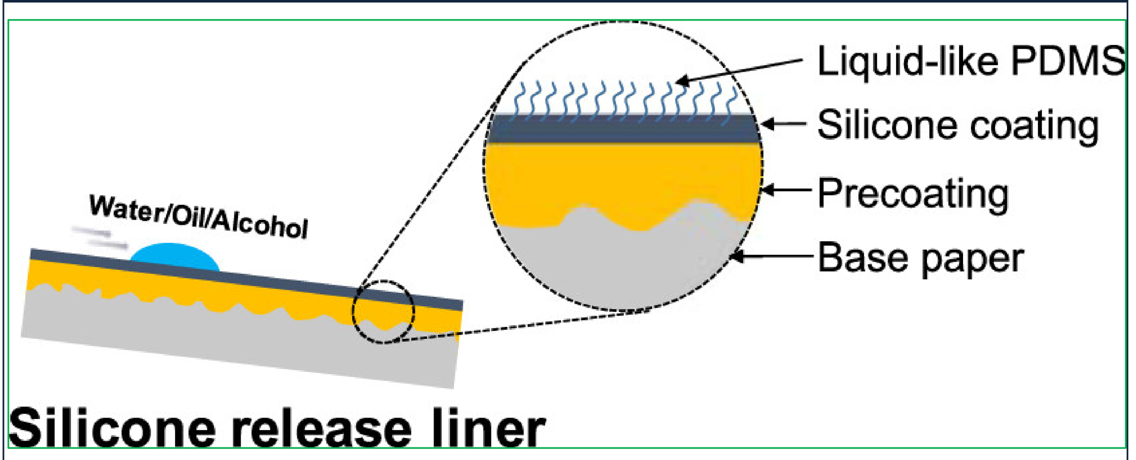
Abstract

PFAS (Per- and polyfluoroalkyl substances), which are extensively employed for water and oil repellency, present significant environmental and health hazards, such as bioaccumulation and water contamination in rural agricultural regions. The objective of this initiative is to enhance the sustainability of rural Maine by substituting PFAS-containing materials with PFAS-free paper alternatives. These safer materials will cultivate a clearer and more sustainable future for Maine's farming communities by protecting soil and water, promoting healthier crops, and supporting long-term agricultural resilience.

Introduction



Our research aims to replace PFAS with biologically and environmentally safe alternatives. We developed a PFAS-free omniphobic [1] paper using vapor-phase deposition of chlorosilane molecules, forming a nanoscale (< 5 nm) layer of flexible, "liquid−like [2]" polymer brushes. This solvent-free process prevents damage like deformation and wrinkling from liquid exposure. The resulting paper features low contact angle hysteresis (CAH < 6°) across a broad range of surface tensions (72.8 to 22.4 mN/m), making it suitable for applications in food packaging [3], and agriculture uses.

Methods

Three distinct release liners (RL1, RL2, RL3) were chosen to evaluate the adaptability of our PFAS-free coating on diverse substrates. Commercial coatings (Unidyne TG-5601, Vapor-Coat 2200R, Rust-Oleum 282073) functioned as controls for evaluating liquid repellency efficiency. Plasma treatment was followed by the deposition of 1,3-dichlorotetramethyldisiloxane to enhance hydrophobicity. Microfluidic channels were created on paper to illustrate regulated liquid manipulation. Surface morphology and composition were examined using SEM (Scanning Electron Microscope), EDS (Energy-Dispersive X-ray Spectroscopy), and confocal microscopy to ascertain coating uniformity and link surface characteristics with performance.

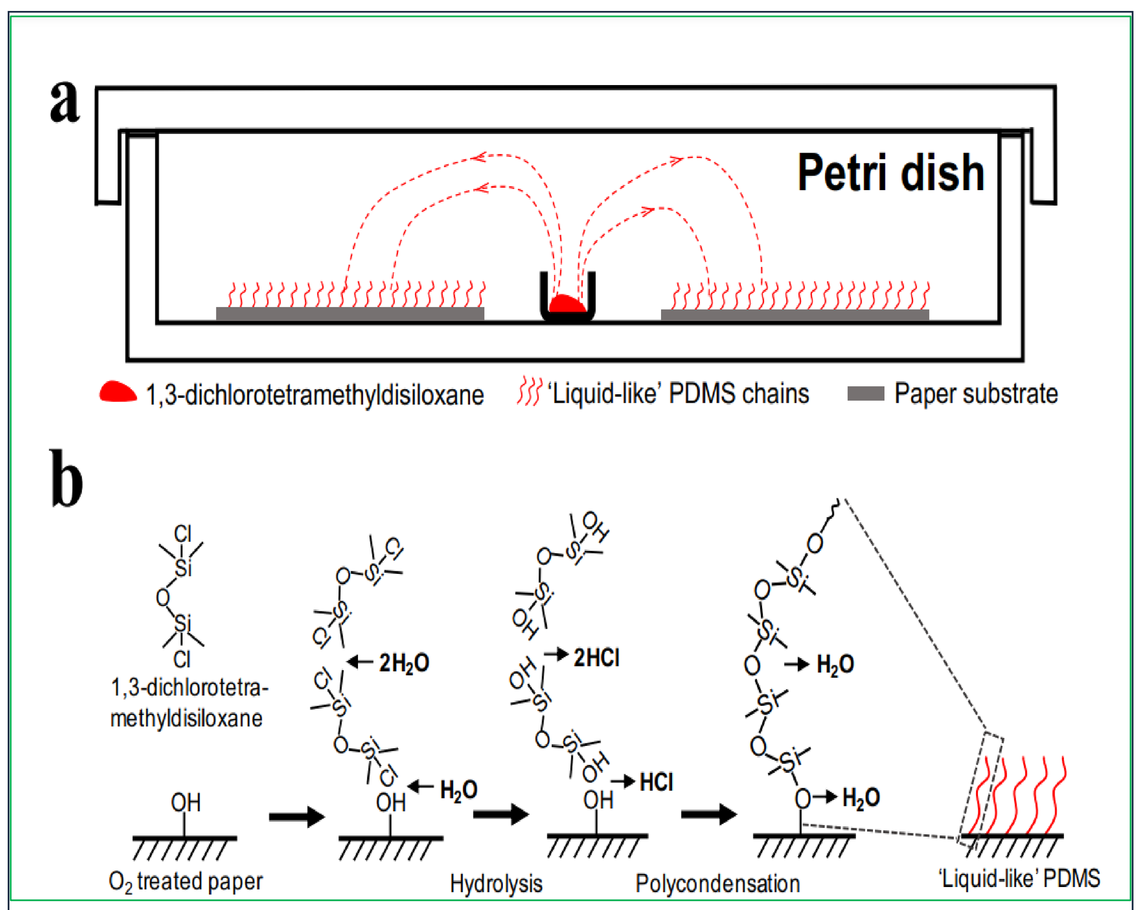


Figure 1. (a) Vapor-phase deposition of 1,3-dichlorotetramethyldisiloxane in a Petri dish at room temperature and (b) schematics showing the formation of the liquid-like PDMS coating by hydrolysis and polycondensation of silanols on the O_2-treated paper substrate [1].

Results and Discussion

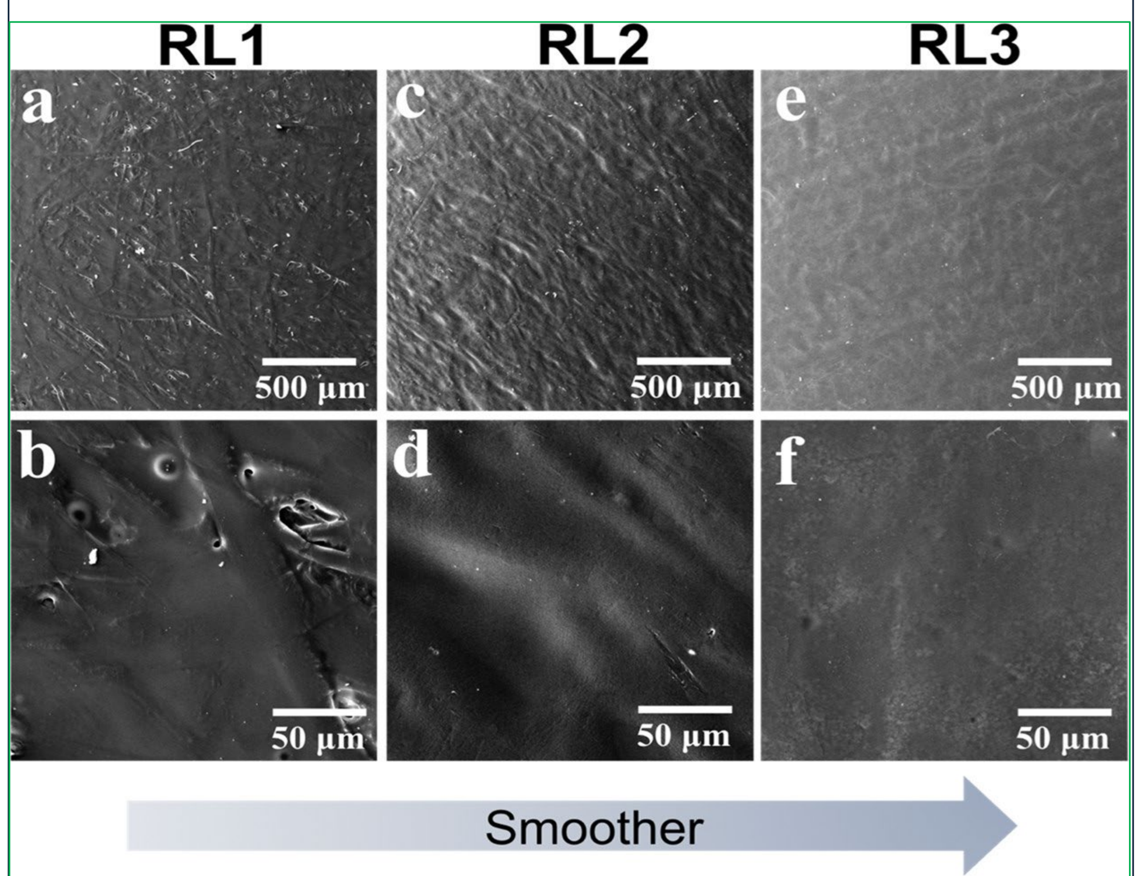


Figure 2. SEM images of the three release liners (a,b) RL1, (c,d) RL2 and (e,f) RL3 explored in this work [1].

1. Paper-Based Microtiters Plates

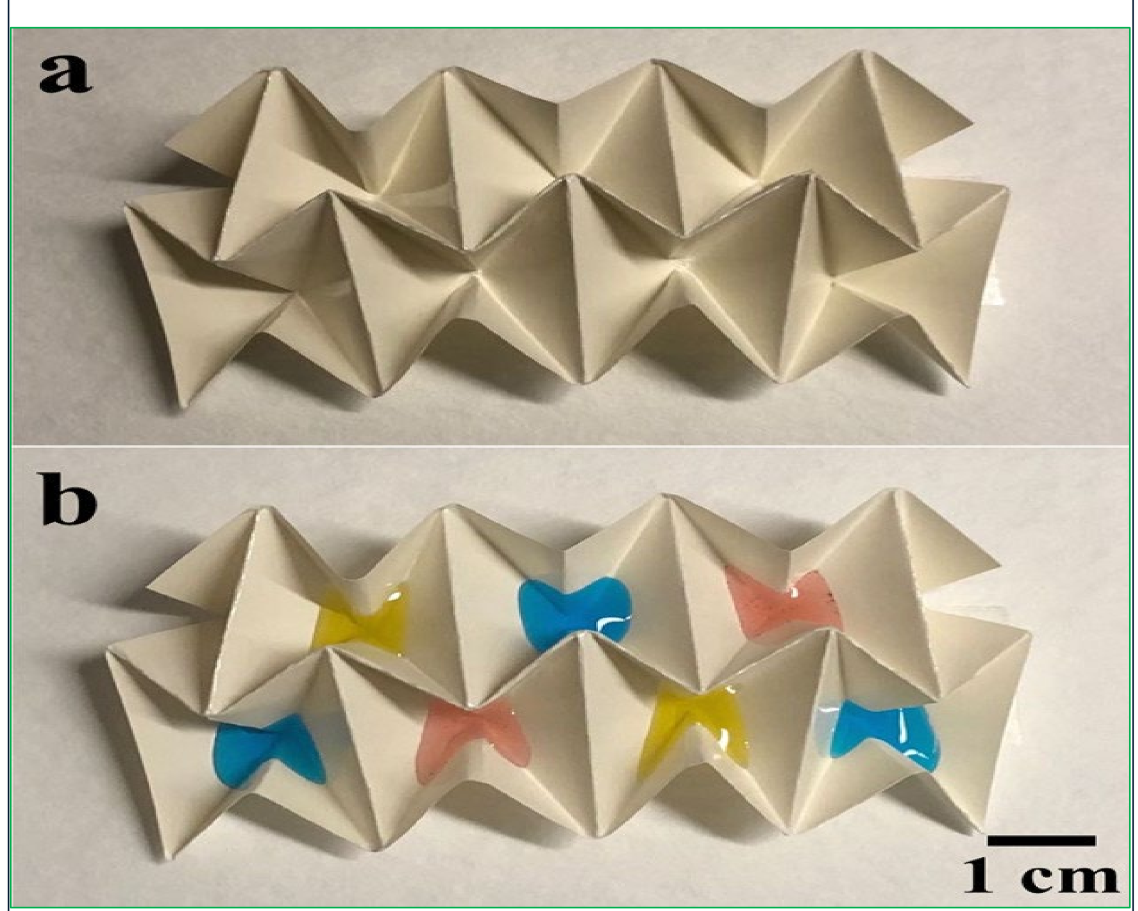


Figure 3. (a) Paper-based microtiter plate fabricated by folding RL3 grafted with the liquid-like PDMS. (b) Microtiter plate structures were able to contain 0.5 mL of deionized water (blue), olive oil (yellow), and ethanol (red) for 48 h without absorbing the liquids [1].

2. Paper-Based Food Packaging Containers

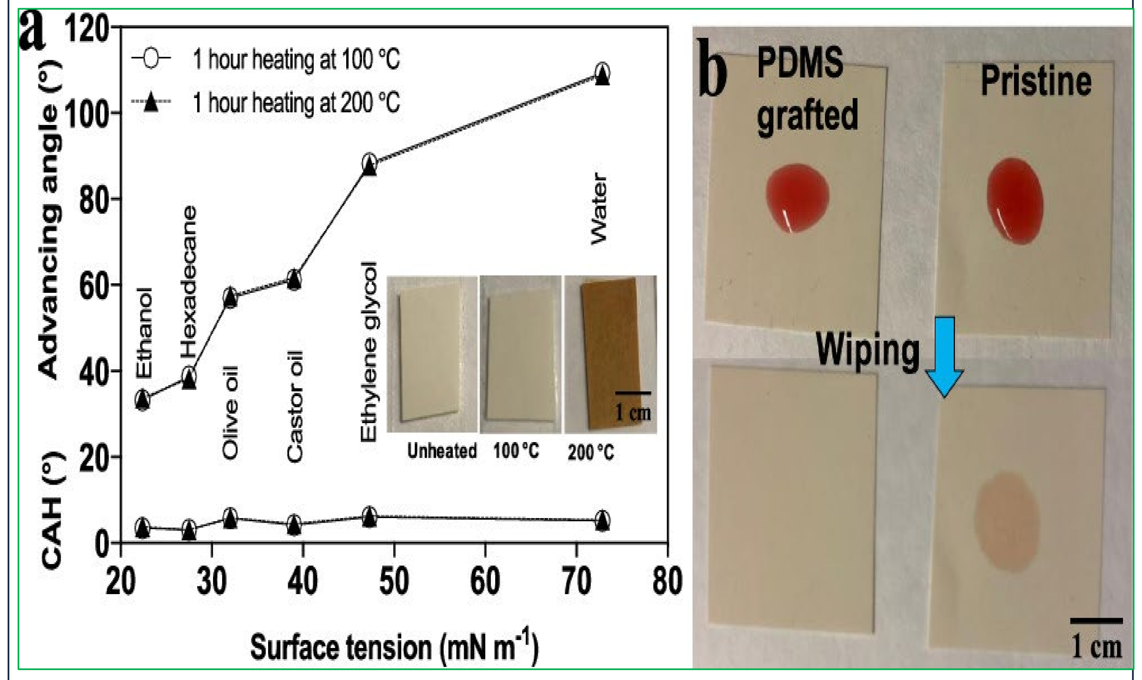


Figure 4. (a) CAH and advancing contact angles vs surface tension for PDMS-grafted RL3 after 1 h heating at 100 and 200 °C. The inset shows the images of the chlorosilane-modified RL3 samples after the thermal exposures. Although the wettability was unaffected by the thermal treatment, significant discoloration was observed after 200 °C. (b) Grease resistance—Kit test (TAPPI T559 pm-96) was performed on the PDMS-grafted RL3 and pristine RL3 using Kit liquid number 12 (highest grease resistance) [1].

Conclusion

We developed a PFAS-free omniphobic paper with a nanoscale chlorosilane coating that offers outstanding liquid repellency and structural integrity, making it a sustainable choice for food packaging and agriculture, especially tailored for the needs of rural Maine. Our solvent-free methodology enhances performance while preserving mechanical properties, surpassing conventional coatings in environmental safety. Future applications may include advanced microfluidic devices, addressing the urgent need for safer materials and promoting ecologically friendly methods in material science.

References

1. Zhao, Xiaoxiao, Md Arifur Rahman Khandoker, and Kevin Golovin. "Non-fluorinated omniphobic paper with ultralow contact angle hysteresis." *ACS applied materials & interfaces* 12.13 (2020): 15748-15756.

2. Li, Zhengyuan, et al. "Robust Transparent Photothermal Omniphobic Coating for Efficient Anti/Deicing and Antifogging." *ACS Applied Materials & Interfaces* 16.27 (2024): 35805-35814.

3. Ghasemlou, Mehran, et al. "Engineered Sustainable Omniphobic Coatings to Control Liquid Spreading on Food-Contact Materials." *ACS Applied Materials & Interfaces* 16.13 (2024): 15657-15686.