Development of Multifunctional Flame-Retardant and Superhydrophobic Sponge Coatings for Industrial Applications

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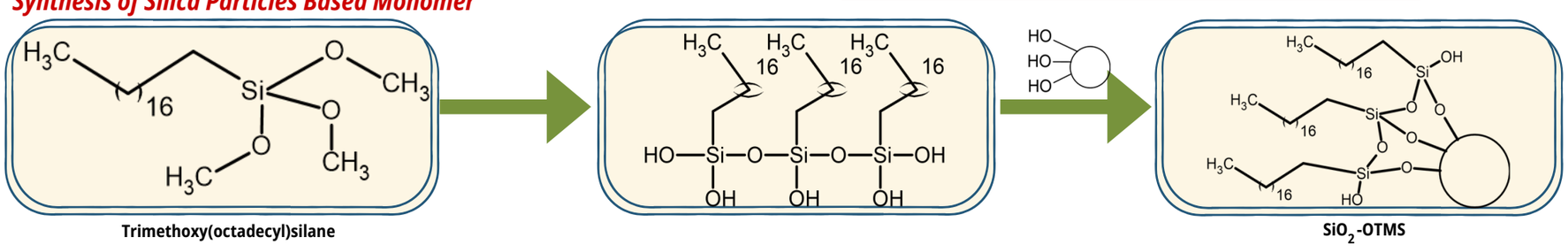
INTRODUCTION

Sponges with flame-retardant and superhydrophobic properties offer a dual advantage by enhancing both environmental protection and fire safety (1-3). These advanced materials hold significant potential in industrial applications, particularly in oil spill management, marine pollution mitigation, and wastewater treatment, while also ensuring safety in fire-prone environments.

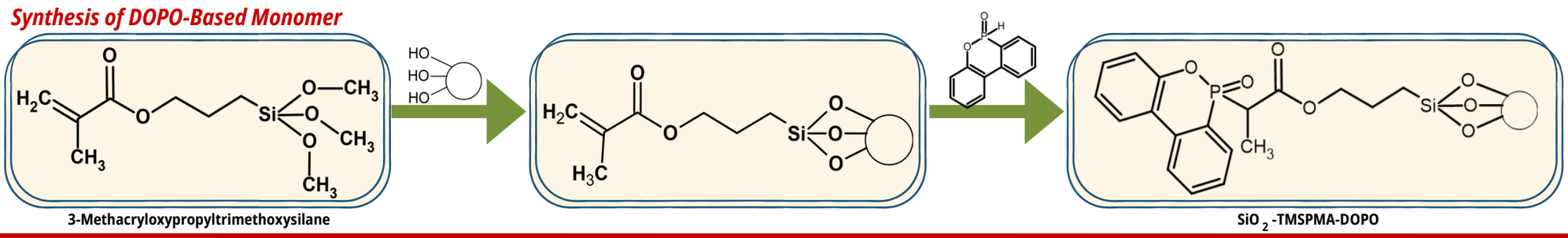
In this study, a novel multifunctional sponge coating with robust superhydrophobicity, superior flame retardancy, and high chemical stability was developed for efficient oil/water separation. The coating material, synthesized using a polymeric resin composed of silica nanoparticles (SiNPs), polydimethylsiloxane (PDMS), and 9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide (DOPO), was applied to the sponges via dip-coating to enhance their functional properties.

METHODOLOGY

Synthesis of Silica Particles Based Monomer



Synthesis of DOPO-Based Monomer



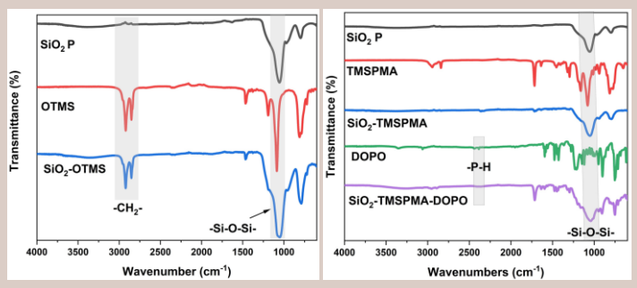
Two different monomers containing silicon-based chemicals with other additives were synthesized. Paper, fabric, and sponge coatings were prepared by adding the synthesized monomers to the polydimethylsiloxane base formulation at different amounts. The structure of two monomers was confirmed with FTIR.

RESULTS AND DISCUSSION

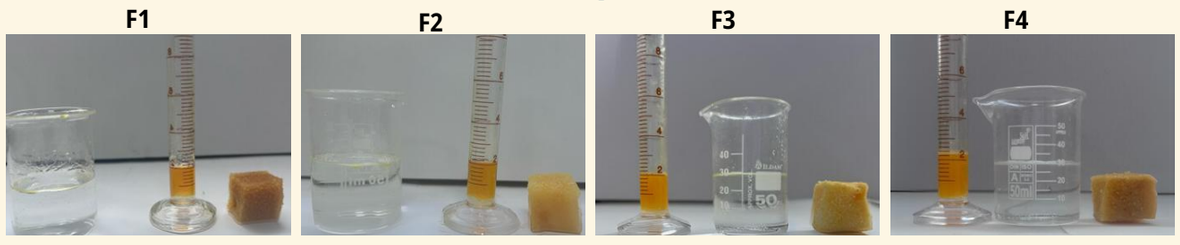
Codes of Coating Formulations

Codes	Coatings
F0	Uncoated
F1	PDMS + TEOS
F2	PDMS + TEOS + SiO_2-OTMS
F3	PDMS + TEOS + SiO_2-TMSPMA-DOPO
F4	PDMS + TEOS +SiO_2-OTMS + SiO_2-TMSPMA-DOPO

FTIR Characterization

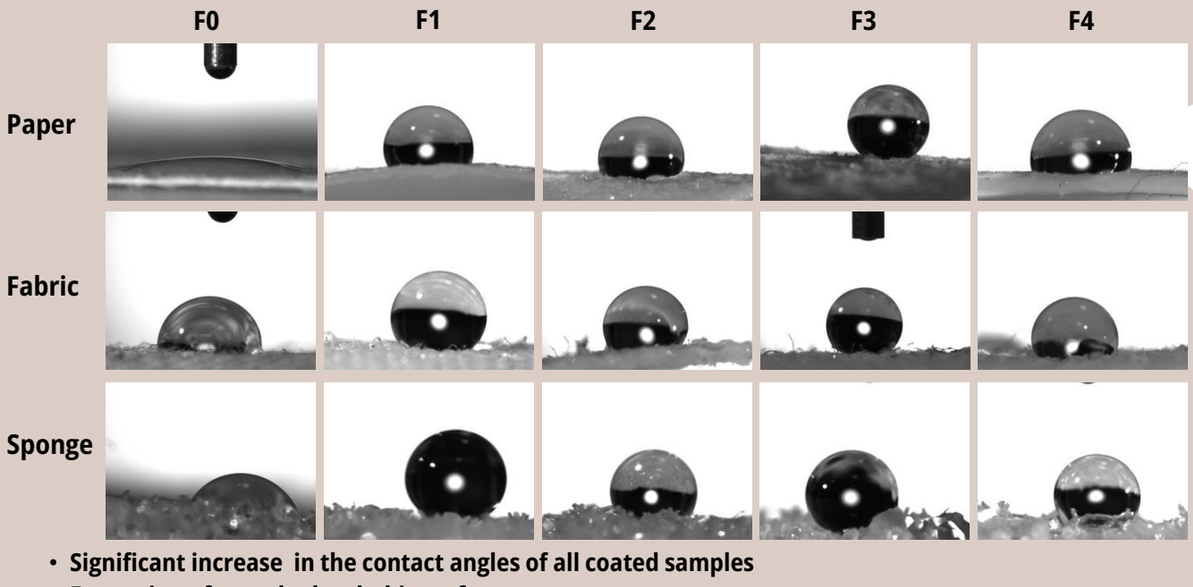


Oil Water Separation



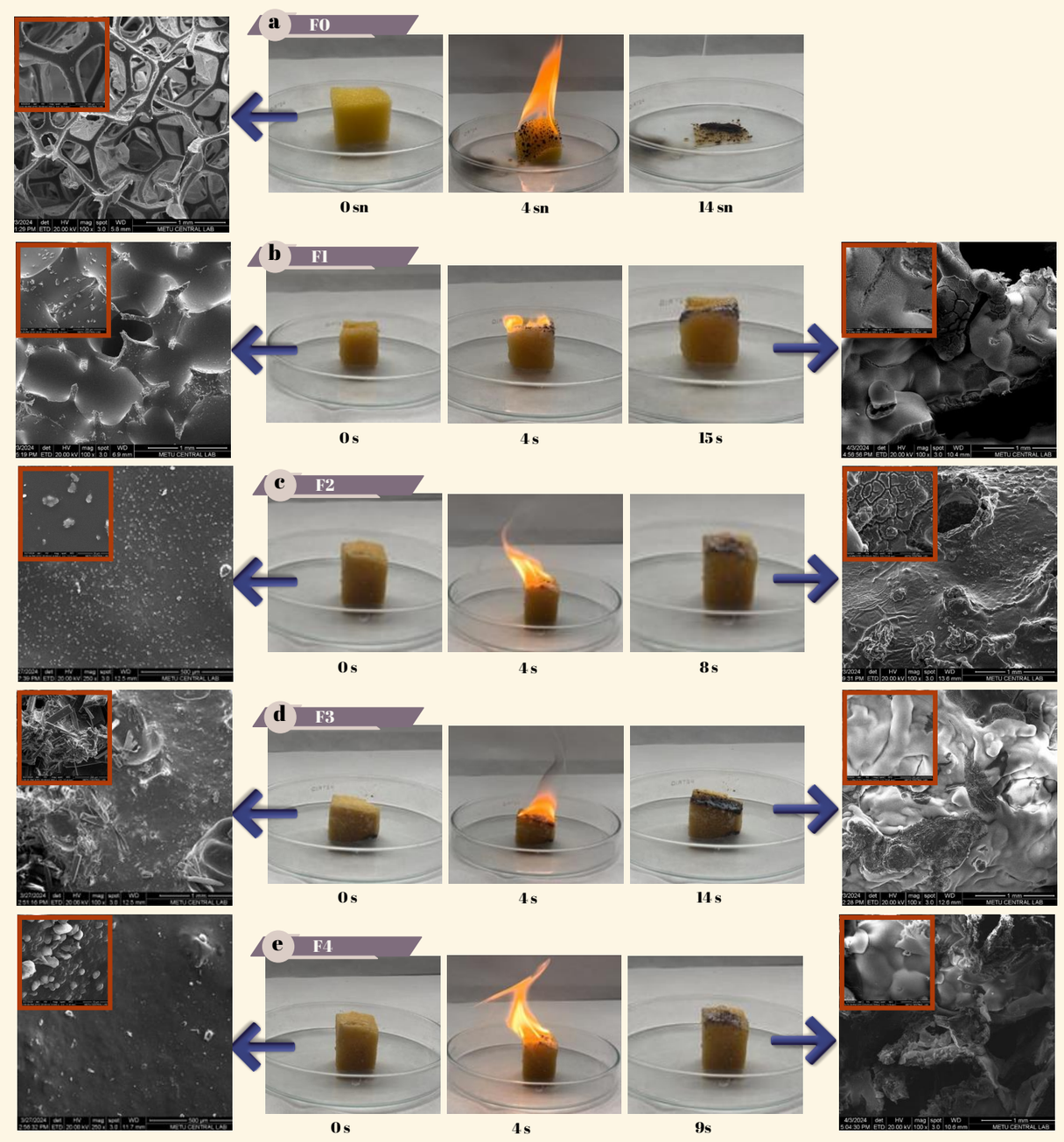
- Uncoated sponge,F0,: ineffective oil absorption
- Coated sponges: successful oil absorption
- Separation efficiency: over 95%

Contanct Angle Characterization



- Significant increase in the contact angles of all coated samples
- Formation of superhydrophobic surfaces
- The best result : 164° of the paper coated with the PDMS + SiO2-TMSPMA-DOPO, F3,

Burning Test



- Uncoated sponge: ignited quickly, completely burnt, no residue
- Coated sponges: well-preserved after combustion and exhibited self-extinguishing properties

CONCLUSIONS

- The superhydrophobicity and oil/water separation efficiency of the coated sponges were systematically evaluated through contact angle measurements and oil absorption tests.
- The highest recorded water contact angle (152°) was achieved with the PDMS/SiNPs/DOPO formulation, confirming the formation of a highly hydrophobic surface.
- The coated sponges demonstrated an oil/water separation efficiency exceeding 95%, whereas uncoated sponges exhibited significantly lower oil absorption capacity.
- The flame-retardant performance was assessed through combustion tests. While the uncoated sponge ignited instantaneously, underwent complete combustion, and left no residual structure, the coated sponge exhibited self-extinguishing behavior within 10 seconds and retained its structural integrity post-combustion.
- SEM analysis of the char layer revealed the formation of a ceramic-like structure, which acted as an effective thermal barrier, significantly enhancing fire resistance.
- These findings highlight the considerable potential of the developed sponge coatings in enhancing fire safety and environmental protection for industrial applications.

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