

Enhancing Tribological Performance and Wettability of Snakeskin-Inspired Surfaces via PDLLA Nanosheets

Sitti Aishah Najamudin^{1,4)}, Mohd Danial Ibrahim^{1,4)*}, Endu Yollanda Jubilee¹⁾, Dayang Salyani Abang Mahmood¹⁾, Pierre Barroy²⁾, Anna Cantaluppi²⁾, Michael Lejeune²⁾, Andreas Zeinert²⁾, Yuta Sunami³⁾, Abang Mohammad Nizam Abang Kamaruddin¹⁾, M Azlan B Mas'od⁵⁾, Ahmad Beng Hong Kuch^{1,4)}

¹⁾Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Sarawak, Malaysia

²⁾Laboratoire de Physique de la Matière Condensée, Université de Picardie Jules Verne, Amiens, France

³⁾SUNAMI Co., Ltd, Room A, 2-3-27 Minamiyana, Hadano City, Kanagawa Prefecture, 257-0003, Japan

⁴⁾UNIMAS Water Centre (UWC), Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Sarawak, Malaysia

⁵⁾PETRONAS Research Sdn Bhd, Petronas Research & Scientific, Selangor, Malaysia

*Corresponding author: imdaniel@unimas.my

This study explores integrating snakeskin-inspired microstructures into PDLLA nanosheets to enhance tribological properties and wettability for biomedical and hydropower turbine applications. Thinner PDLLA coatings (50 nm) led to increased surface energy, resulting in drastically improved wettability (reducing the water contact angle from 115.3° to 48.0°) and a 15–20% reduction in friction, which is beneficial for fluid interaction by potentially reducing drag. Consistent with M. D. Ibrahim et al., these bioinspired surfaces showed enhanced frictional properties, suggesting a promising pathway for improving energy efficiency in turbine applications. Future work should focus on refining replication techniques and assessing biological stability.

Keywords: PDLLA, nanosheets, surface energy, biomimicry, tribological properties

1. Introduction

Snakeskin's frictional properties inspire biomimetic designs. The ventral scales of *Malayopython reticulatus* reduce friction in one direction while maintaining grip in another, creating anisotropic friction. Figure 1 shows three sliding orientations: caudal (head to tail), rostral (tail to head), and lateral (side to side), evaluated relative to the snake's microstructures. This directional friction is key to utilizing snakeskin in tribological engineering. This study investigates the use of PDLLA nanosheets on preserved and PDMS-replicated snakeskin to enhance tribological and surface energy properties.

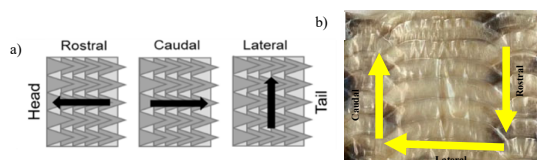


Figure 1: Schematic representation of the three sliding directions (rostral, caudal, lateral) relative to microstructures, adapted from [1]. (b) Slide directions on the actual snake ventral scale sample

2. Methodology

PDLLA nanosheets were fabricated using a roll-to-roll method by applying a PVA solution to a PET substrate, followed by PDLLA coatings (5–30 mg/mL). After drying, the nanosheets were detached in water and transferred to silicon substrates. Preserved snakeskin samples served as master templates for soft lithography. Negative molds were fabricated using epoxy resin, from which positive replicas were cast using Polydimethylsiloxane (PDMS). These PDMS replicas were subsequently used as the substrate for PDLLA nanosheet transfer to ensure surface consistency during tribological testing. Surface roughness, wettability, and chemical composition were analyzed through profiling, contact angle measurements, and FTIR spectroscopy.

3. Results

Surface Properties and Performance: The application of 50 nm PDLLA nanosheets significantly enhanced the surface characteristics of the bioinspired replicas. The coating drastically improved wettability, shifting the contact angle from 115.3° (uncoated) to 48.0°, indicating a transition to a hydrophilic state favorable for fluid film retention. Concurrently, the smoothed roughness profile described above contributed to a 15–20% reduction in friction. These combined physicochemical and mechanical improvements align with the efficiency gains observed in previous bioinspired turbine studies [1].

Surface Roughness: Profilometry measurements assessed the surface topography of the bioinspired structures. The application of a 50 nm PDLLA coating resulted in a surface roughness (R_a) of 5.243 μm (Figure 13). Increasing the coating thickness to 150 nm further smoothed the surface, reducing the R_a to 5.138 μm (Figure 14). This trend indicates that the PDLLA nanosheets effectively mask the coarser texture of the underlying substrate, creating a consistent interface favorable for reducing hydrodynamic drag in fluid applications.

FTIR Analysis: FTIR spectra confirmed that PDLLA coatings retained ester and aliphatic functional groups, while preserved snakeskin exhibited more complex protein and lipid components.

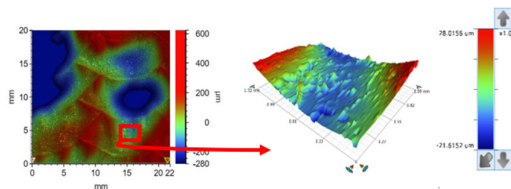


Figure 13: 3D optical profilometry map of PDMS-replicated snakeskin with a 50 nm PDLLA coating ($R_a = 5.243 \mu\text{m}$). The topography exhibits improved isotropic uniformity, where the nanosheet layer mitigates the sharp, coarse texture of the underlying replica while retaining the mesoscopic scale structure.

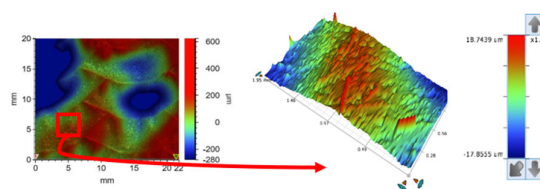


Figure 14: 3D optical profilometry map of the replica coated with a thicker 150 nm PDLLA layer ($R_a = 5.138 \mu\text{m}$). The image demonstrates enhanced surface smoothing and tighter conformal contact, further masking the substrate roughness compared to the 50 nm coating.

4. Conclusions

Thinner PDLLA coatings (50 nm) improve wettability, reduce friction, and enhance performance in biomedical and hydropower applications. Bioinspired coatings optimize energy efficiency by reducing drag and enhancing fluid flow. Future work should refine replication techniques and assess biological stability.

5. References

- [1] M. D. Ibrahim et al., "Friction measurement of modified PDMS surfaces inspired by *Malayopython Reticulatus*," *Biotribology*, vol. 33, p. 100240, 2023. [Online]. Available: <https://doi.org/10.1016/j.biotri.2022.100240>