



Unraveling the dynamics of friction in relation to tactile perception and artificial skin characteristics

Izzati Halid ¹, Siti Hartini Hamdan ^{1*}, William W. F. Chong ², Tengku Adibah Izzati Tengku Abdul Rahman ¹, Ng Jo-Han ³, Nurul Syahirah Mohd Pozi ¹, Noorma Rosita ⁴

¹ Technical Foundation Section, University Kuala Lumpur · Malaysia Institute of Chemical and Bioengineering Technology (MICET), MALAYSIA.

² Automotive Development Centre (ADC), Institute for Vehicle Systems and Engineering (IVeSE), Universiti Teknologi Malaysia (UTM), Johor, MALAYSIA.

³ Research Management Centre, University of Southampton Malaysia (Southampton Malaysia), MALAYSIA.

⁴ Department of Pharmaceutical Sciences, Faculty of Pharmacy, Universitas Airlangga, INDONESIA.

*Corresponding author: sitihartini@unikl.edu.my

KEYWORDS	ABSTRACT
Artificial skin Tactile friction Wet skin Dry skin Contact mechanics	This study explores the frictional dynamics between artificial skin and the human finger, emphasizing the influence of sex, age, and finger orientation on tactile perception. Artificial skin was synthesized using polydimethylsiloxane (PDMS) and polyvinyl alcohol (PVA) at varying compositions (1:1, 6:4, and 7:3 PDMS:PVA) to mimic human stratum corneum properties. The 7:3 PDMS:PVA composition demonstrated optimal moisture retention (15.23% water uptake) and surface roughness comparable to human skin. Rheological analysis of anthocyanin, extracted from butterfly pea flower, revealed shear-thinning behavior, indicating excellent spread ability on skin surfaces. Contact angle measurements showed that anthocyanin exhibited superior wettability ($72.97^{\circ} \pm 2.48$) on the 7:3 PDMS:PVA substrate compared to deionized water ($95.25^{\circ} \pm 0.93$), highlighting its potential for cosmetic applications. Friction tests revealed that wet artificial skin required higher applied forces (0.30–0.46 N) compared to dry skin (0.23–0.31 N), with gender-specific differences observed. The application of skincare serum reduced friction by 30–50%, facilitating smoother finger movement. Modifications with sodium chloride increased the moisture content of the 7:3 PDMS:PVA composition to 36.18%, closely mimicking human stratum corneum. The study provides valuable insights into the interplay between friction, material properties, and tactile perception, offering a foundation for developing advanced artificial skin for cosmetic and biomedical applications.

Received 27 February 2025; received in revised form 14 March 2025; accepted 22 June 2025.

To cite this article: Halid et al. (2025). Unraveling the dynamics of friction in relation to tactile perception and artificial skin characteristics. *Jurnal Tribologi* 46, pp.203-219.

1.0 INTRODUCTION

Anthocyanins are water-soluble pigments with potent antioxidative properties (Westfall et al, 2020). Due to its ability to readily permeate biomedical applications, it is progressively used as a colourant in the food and textile industries. Anthocyanin has recently been applied in the cosmetology industries due to its proven antioxidant properties, which inhibit oxidation-scavenging free radicals and reduce oxidative stress (Khan et al., 2019, Westfall et al, 2020) . Westfall et al. (2019) entails anthocyanin in lipstick formulation, while Correia et al. (2021) verified that anthocyanin pigments able to promote skin health through their research.

Typically, the efficacy of anthocyanin is evaluated biologically using in-vivo and in vitro methodologies. Westfall et al (2020) and Li et al. (2019) utilized porcine ear skin and mouse skin as artificial skin in their research to test the permeability of anthocyanin through stratum corneum. While Berkey et al. (2021). and Ezati et al. (2020) used isolated human stratum corneum in their research to acknowledge the permeability of water. However, due to ethical considerations, it is necessary to create artificial skin from synthetic polymers as substitutes in order to understand more about the efficacy of anthocyanin.

Polydimethylsiloxane was one of the polymers commonly used in the development of artificial skin due to its biocompatibility, which has been approved by the American Food and Drug Administration (Yirijor et al., 2022). However, the highly hydrophobic surface of PDMS brings poor surface wettability therefore needs to be improved by either chemical or physical modification. Hence, the mixture of PDMS with hydrophilic resin known as PVA to enhance its wetting behaviour. This polymer has shown desirable characteristics including non-toxic, easily degradable, lightweight, and cost-effective material, making it desirable to be used in many applications including in the development of artificial skin, drug delivery, food packaging and wound healing (Lui et al., 2022, Nasibi et al., 2020). Nevertheless, due to its inherent brittleness and poor mechanical strength, the use of PVA has become unfavourable, prompting its modification with glutaraldehyde to enhance its mechanical behaviour. (Zanela et al., 2018).

Numerous studies have been conducted on the modification of PDMS polymer to enhance its application-specific properties. Boyadzhieva et al (2018) and Trantidou et al., (2017) modified the PDMS composite with PVA for its application in cell culture and microfluidic. The combination of two or more polymeric materials, on the other hand, represents another combination of distinct macromolecules that alter the surface morphology of its products (Popelka et al., 2020). It was an important aspect to be determined in polymer materials since it affects the surface's ultimate properties, such as its wettability and adhesiveness. Morales-Hurtado et al., (2015) in his study demonstrated the ability to develop a human-like artificial epidermis from a 7:3 PVA-PDMS mixture. However, the contact mechanics of different compositions of PVA-PDMS in terms of adhesion were not thoroughly addressed.

Heinrich Hertz, in 1882, defined classical contact mechanics as the behaviour of solids in contact under the influence of an external load. The periodic development of a more comprehensive theory of contact mechanics has led to the recognition of adhesive contact mechanics in the application of daily routines, including in the application of cosmetics. Lamura et.al mentioned that the asperity contact has many aspects to analyze, such as material properties and boundary condition. Figure 1 (a) depicts the relationship between contact mechanics and product application to the skin. The contact angle of a surface with good wetting characteristics is less than 90 degrees, whereas the contact angle of a surface with poor wettability is greater than 90 degrees (Wang et al., 2021).

Good wetting behaviour of the surfaces has a contact angle lower than 90° in contrast, a contact angle more than 90° shows poor wettability of the surface. In this study, the wettability of anthocyanin derived from butterfly pea flower was studied at different compositions of PDMS-PVA from 1:1, 6:4 and 7:3. The rheology behavior of anthocyanin was acknowledged first to discover its flow behavior on the solid surface. The water uptake capacity of artificial skin was then determined to acknowledge its ability to mimic human stratum corneum moisture content. Then, the wettability behavior of deionized water (DI) and anthocyanin (ANC) on artificial skin from the mixture of PVA and PDMS at different compositions was defined. The contact angle of DI was crucial to be analyzed to compare wettability behavior with anthocyanin.

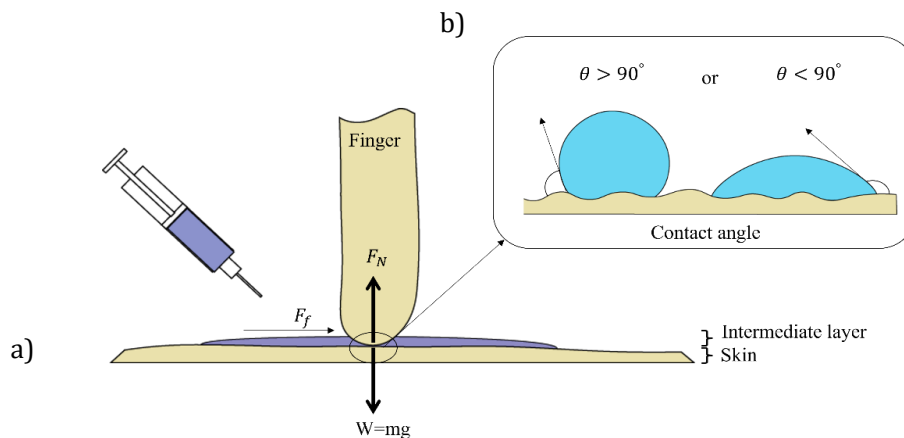


Figure 1: (a) Relationship between contact mechanics and product application on the skin. (b) Possible wetting characteristics of liquids on solid surface.

2.0 EXPERIMENTAL PROCEDURE

2.1 Materials

The dried butterfly pea flower required for anthocyanin extraction was acquired locally from a Melaka farmer. The material used in the development of artificial skin is Polyvinyl alcohol 99% (Mw 89000-98000), Glutaraldehyde (GA) 50 wt.%, and Sodium Chloride 99% was purchased from Sigma Aldrich. While the Slygard 184 Silicone Elastomer Kit provided by Hardwaremise Sdn. Bhd.

2.2 Extraction of Anthocyanin

Dried butterfly pea flower is ground by using the commercial grinder. Then, it is extracted by bath ultrasonicate with acidified distilled water at pH 4 at a ratio of 1:20 (w/v) for 30 minutes. The supernatant was collected by filtering it with a 400-mesh nylon filter and concentrated by drying it at 40°C for 24 hours.

2.3 Rheological Behaviour of Anthocyanin

The rheological behaviour of pure anthocyanin at temperatures ranging from 25 to 65°C , as measured by a Modular compact rheometer (Anton Parr, MCR 302) with a 50 mm spindle and a 0.05 mm gap. The samples were distributed in sufficient quantities to completely occupy the area between the dishes. This apparatus permits the evaluation of sample flow and deformation by

measuring the viscosity and elasticity of fluids as their temperature increases. It is essential to analyse the rheological properties of semisolid formulations in order to determine the quality and stability of anthocyanin.

2.4 Artificial Skin Synthesis

A 20% PVA solution was prepared by continuous stirring for 3 hours before it was heated up to 50 °C for 30 minutes to completely homogenize it. The prepared PVA is then kept for use in the future. The hydrophobic part of the irregular surface was prepared by mixing PDMS with a curing agent in a 20:1 ratio. In order to combine the hydrophilic component of an irregular surface, the obtained PVA will be mixed with GA at a volume ratio of 10% vol. to lower hydrophilicity and provide a network ideal for entrapping biomolecules. The ratio of hydrophobic PDMS to hydrophilic PVA was then combined, ranging from 1:1 to 7:3 PDMS to PVA. The curing process lasted for 24 hours at 50°C.

2.5 Water Uptake Capacity of Artificial skin

The water absorption experiment was carried out following ASTM D570. The specimen was desiccated first to cool down after being dried in the oven and immediately weighed upon chilling. It was then immersed in deionized water at room temperature for 24 hours. In this study, the water uptake capacity was continuously observed for up to 15 days with time intervals of 48 hours. Water uptake capacity was expressed as the increase in weight percent (%) by equation 1:

$$\frac{Wet\ Weight - Dry\ Weight}{Dry\ Weight} \times 100 \quad (1)$$

2.6 Contact Angle Analysis

Figure 2 depicts the set-up of an in-house built goniometer that was used to measure the water contact angle of the artificial skin substrates developed. It is operated according to ASTM D7334 standard operating procedure. The microscope used in this analysis is a camera with a 1/2.33-inch, 34-megapixel CMOS image sensor and an optical zoom lens with a 180-degree magnification range. Using a specially designed Hamilton syringe with a 25 µL capacity, the solution droplet was administered to the tested artificial skin samples. The distance between the needle point and the sample surface was maintained at 3 mm, as specified by ASTM D7334. The particulate size utilised for this study was 6 µL. On each sample of artificial skin, the water contact angle was measured and aggregated over six additional measurements, and the average contact angle was calculated.

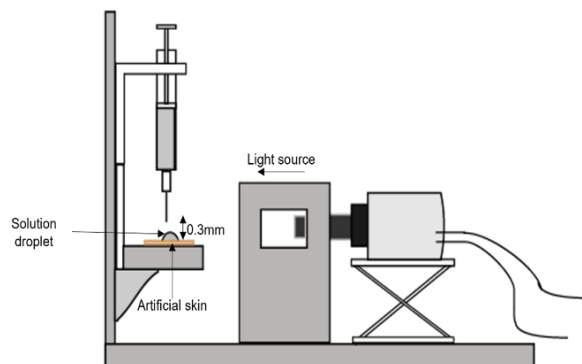


Figure 2: Goniometer Set Up.

3.0 RESULTS AND DISCUSSION

3.1 FTIR characterization of Anthocyanin

Figure 3 displays the FTIR spectra range in the $4000\text{--}400\text{cm}^{-1}$ wave band at 0.1 cm^{-1} resolution. The FTIR spectra showed the presence of anthocyanin and have good agreement with previously reported work (Jeyaram et al., 2020). The intense peak at 3280.94 cm^{-1} alcohols corresponded to the stretching frequency of hydroxyl and O-H. The stretching of the alkyne group was observed at the peak of 2117.70 cm^{-1} . While the presence of carboxylic acids is indicated by the peak at 1640.83 cm^{-1} . Finally, the peak is between 700 and 1000 cm^{-1} indicates the presence of the benzene ring in the Anthocyanin extracted.

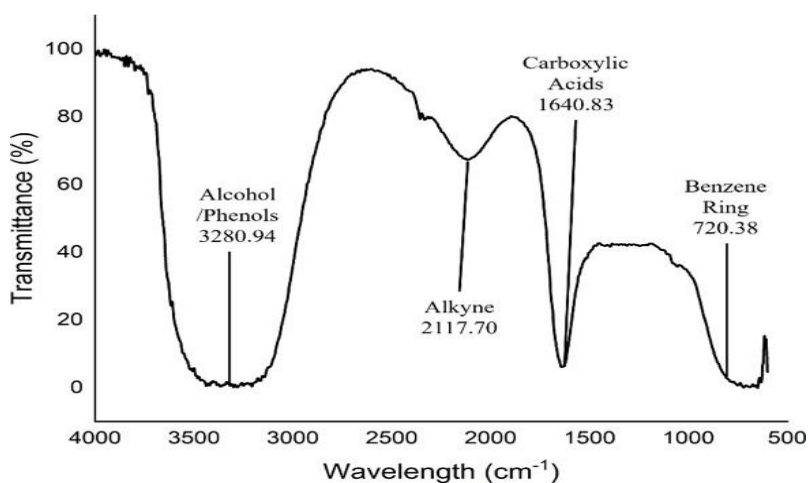


Figure 3: FTIR Characterization of extracted Anthocyanin.

3.2 Rheology Behaviour of Anthocyanin

The rheological behaviour is crucial since it defines the material's response to deformation and flow conditions. Importantly from a contact mechanics standpoint, it can determine how well the substance spreads when applied to the surface. Figure 4 demonstrate the rheological behaviour of anthocyanin at temperatures ranging from 25°C to 65°C. Anthocyanin exhibits shear-thinning behaviour, as its viscosity decreases as the shear rate increases from 0 to 100s⁻¹ suggesting its good spreadability on the skin (Lee et al., 2020).

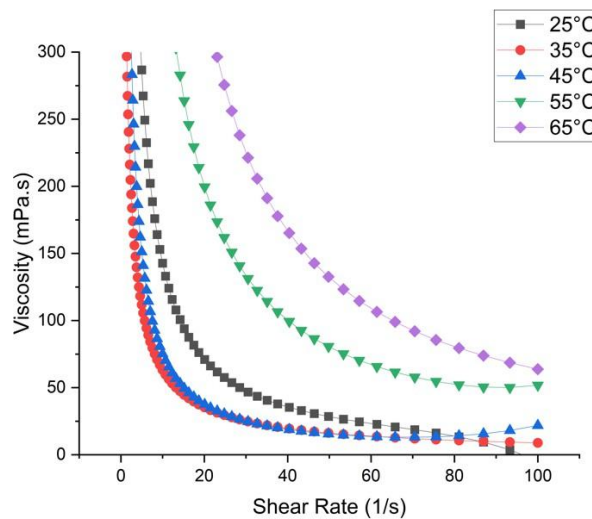


Figure 4: Rheology Properties of Anthocyanin.

3.3 Physical Properties of Artificial Skin

The effects of various PVA-PDMS compositions on the physical properties of the Irregular surface are summarized in Table 1. As the PDMS composition was increased, irregular surface weight loss and film thickness decreased. According to the findings, the irregular surface with a high percentage of PVA exhibited a larger percentage of water loss due to the linear chain, which made it easy to both hydrate and dehydrate. The addition of PDMS in the PVA hydrogel increases the crosslinking density which results in a denser network structure and fewer pores, lowering the water evaporation during the curing process (Ren et al.,2020). The increased PDMS ratio was also significant for the thicker films, which ranged from 0.74 to 1.14 mm (Wang et al., 2021).

3.4 Water Uptake Capacity of Different Compositions of Artificial Skin

Artificial skin materials typically have different water uptake capacities depending on their composition, and their properties. It plays a crucial role in the development of artificial skin to acknowledge the ability of the material to absorb and retain water compared with human skin. Table 2 summarizes the water uptake capacity of different compositions of PDMS-PVA in the development of artificial skin throughout the 15 days.

Table 1: Physical properties of developed artificial skin.


Sample	Ratio	Weight Loss (%)	Thickness (mm)	Picture
A	1:1	40.76%	0.74	
B	6:4	19.46%	1.085	
C	7:3	9.73%	1.1425	

Table 2: Water uptake capacity of artificial skin at the different compositions of PVA-PDMS after 15 days.

Artificial skin	Composition (%)		Water Uptake capacity (%)
	PDMS	PVA	
	0	100	-
1:1	50	50	97.23667
6:4	60	40	20.34
7:3	70	30	15.23
	100	0	0

Based on the data presented in Table 2, the water absorption capacity of various PVA and PDMS compositions decreased with increasing PDMS content. This is a result of the hydrophobic nature of PDMS, which prevents it from absorbing additional water, and the hydrophilic nature of PVA, which has high adsorption when immersed in water. According to Fig 5, the ability of artificial skin with a composition of 1:1 to absorb 124.37% of water after 24 hours indicates a decent water uptake capacity of the surface in contrast to artificial skin with compositions of 6:4 and 7:3, which is only capable of absorbing up to 3.1% and 2.85% of DI water, respectively. Artificial skin with a 7:3 composition is more appropriate for use as artificial skin due to the fact that artificial skin with a 1:1 composition's water uptake capacity decreased to 97.23% after 15 days of immersion and

exhibit a tendency to mimic the shortcoming of PVA properties, in which the material tends to dehydrate over time when left exposed in the air (Low et al., 2019).

Nonetheless, in regard to the human stratum corneum, which is typically reported to have a moisture content between 10 to 30%, it was discovered that the ability of artificial skin with a 7:3 composition (PDMS: PVA) to swell was limited up to 15.23 brings to several modifications have been made to increase the water uptake capacity of artificial skin.

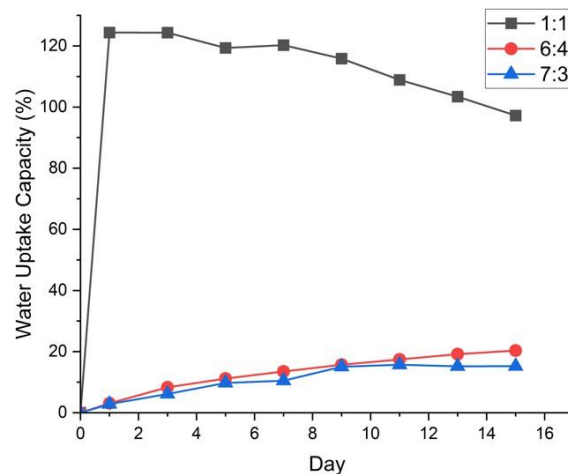


Figure 5: Water uptake capacity (%) of artificial skin at a different composition of PDMS-PVA.

According to Figure 6, the artificial skin in Method 2 has a lower water uptake capacity when compared to Method 1. This was due to the fact that, at a lower pH, the increase in crosslink density between PVA-GA decreased molecular entrapment of deionized water (Khoerunnisa et al., 2021, Matty et al., 2015). The addition of sodium chloride in Method 3, on the other hand, increases the surface's affinity for water by modifying the osmotic pressure and its structure. After 15 days of immersion in deionized water, the developed artificial skin was able to increase its moisture content up to 36.18%. From the result, the modification of the development of artificial skin in Method 3 can achieve human stratum corneum moisture content (Abdeen et al., 2021, Low et al., 2021).

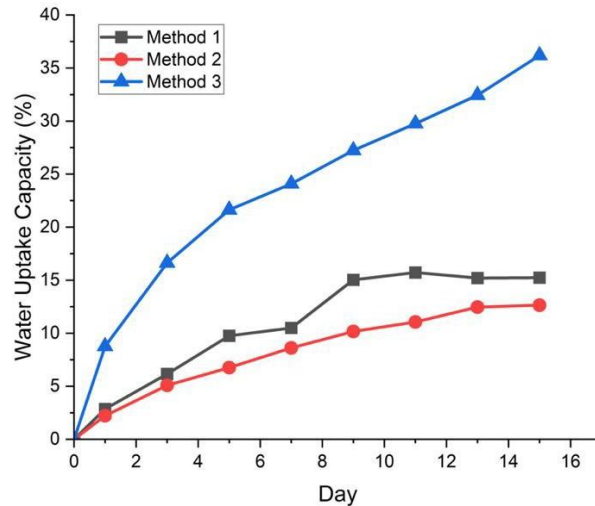


Figure 6: Comparison of water uptake capacity of artificial skin with different methods.

3.5 Effect of Different Composition of Artificial Skin on Contact Angle

The contact angle of the developed artificial skin on various PVA and PDMS compositions is tabulated in Table 3. In order to compare the wettability of developed artificial skin with stratum corneum, deionized water was used as a standard solution to determine the wettability of synthetic skin. According to the results, the contact angle of DI water on PVA and PDMS was $57.2^\circ \pm 3.92$ and $105.95^\circ \pm 1.39^\circ$ which in accordance with literature reported to be less than 70° and $\sim 107^\circ$ (Wang et al., 2018, Elkhyat et al, 2013).

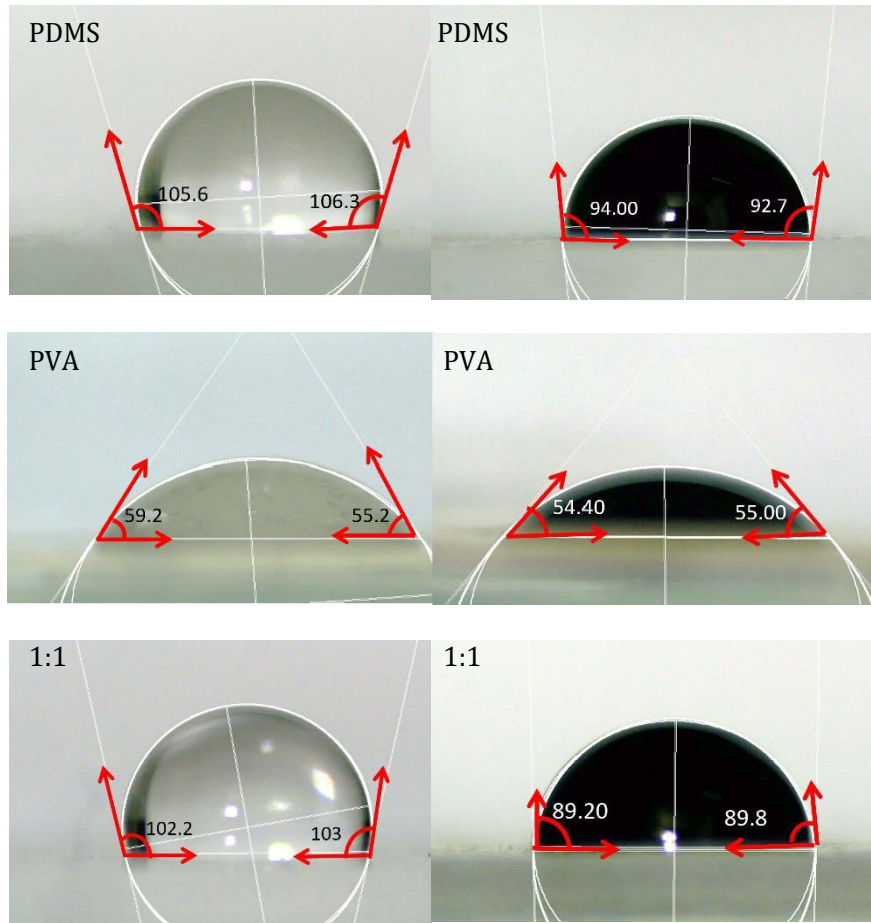
Table 3: Contact angle of deionized water and anthocyanin on artificial skin

	DI	ANC
PDMS	103.25 ± 1.39	89.88 ± 3.25
PVA	60.51 ± 3.92	53.03 ± 3.94
A (1:1)	101.38 ± 3.46	89.33 ± 4.31
B (6:4)	96.9 ± 1.29	86.5 ± 1.83
C (7:3)	95.25 ± 0.93	72.97 ± 2.48

In terms of the contact angle of the artificial at different PVA-PDMS compositions, it is discovered that increasing the PDMS composition in the substrates from 50% to 70% reduces its wettability of deionized water and anthocyanin. The difference in contact angle of deionized water on different compositions of artificial skin was present in Fig 7. The contact angles measured for artificial skin with compositions 1:1, 6:4, and 7:3 in deionized water were respectively 101.38° , 96.90° , and 95.25° . Due to its propensity to dry out when exposed to air, artificial skin with a high PVA content had a low wettability. The results demonstrated that the manufactured artificial skin was capable of imitating human artificial skin at weak sebaceous sites. According to Elkhyat, (2013) the contact angle of water on the human epidermis varied between 91 and 102 degrees depending on the location of the human body.

Deionized Water

Anthocyanin



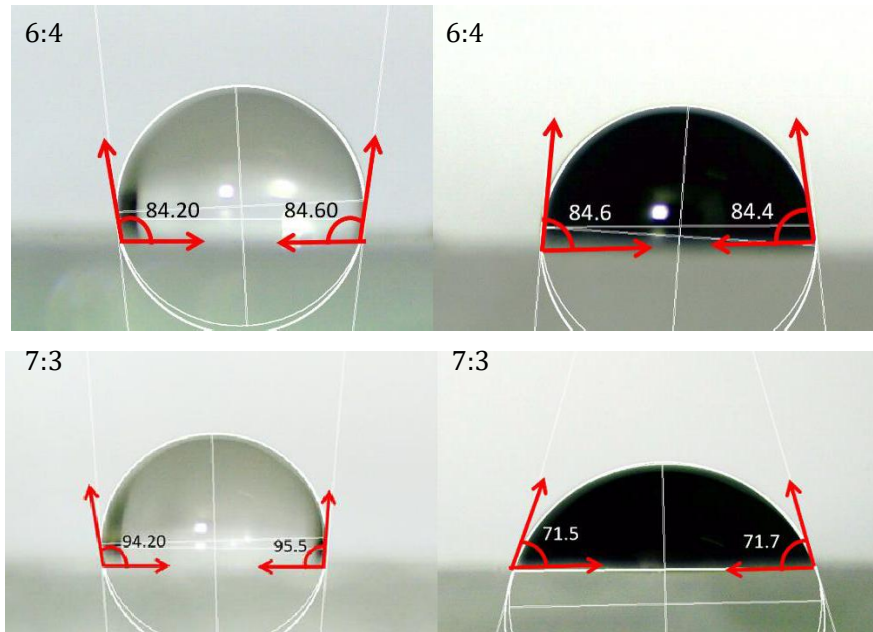
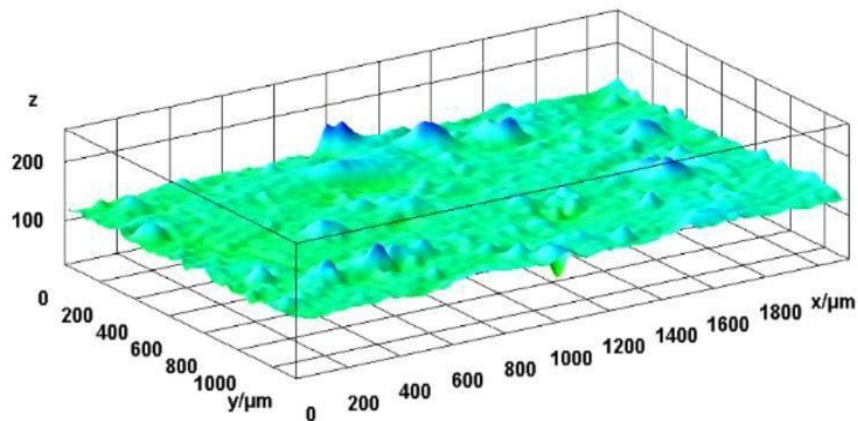
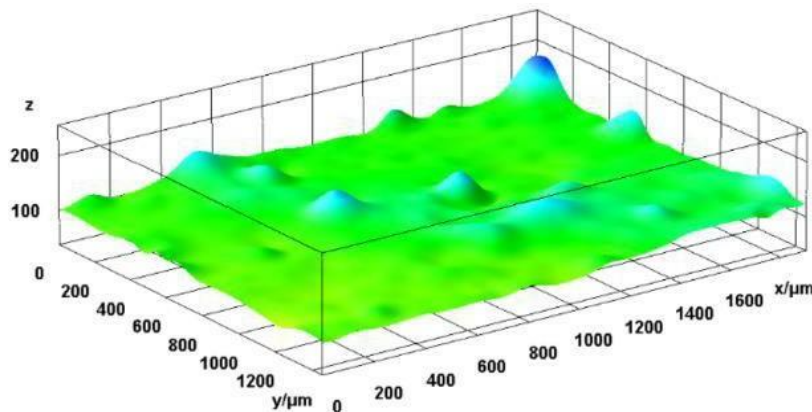


Figure 7: Contact angle of Deionized Water at different compositions of artificial skin.

From the result, artificial skin at moisture content 36% reduced the skin roughness by 15.02% from 25.03 μm . ± 0.53 to 21.63 μm . ± 2.84 . The results are consistent with prior research conducted by (Ren et al., 2020), who demonstrated that an increase in skin moisture content leads to a reduced skin surface roughness. Based on the results, the surface roughness of artificial skin in a wet state able to mimic surface roughness described by literature which in between 12 to 24 μm . Figure 8 illustrates the 3D surface plot of artificial skin AS 4 at (A) dry and (B) wet conditions.



(a) Surface 3D plot for dry artificial skin.



(b) Surface 3D plot for wet artificial skin.

Figure 8: Surface plot of artificial skin AS 4 at (a) dry and (b) wet condition.

Anthocyanin, on the other hand, is 30% more capable of spreading across the surface of artificial skin. This was due to the fact that anthocyanin was classified as an organic compound with a lower surface tension, which increased the adhesion between the liquid and the surface of artificial skin (18, 30). On 1:1, 6:4, and 7:3 substrates, the contact angle of anthocyanin was 89.33 degrees, 86.50 degrees, and 72.97 degrees, respectively. The difference in an anthocyanin's measured contact angle demonstrates its good surface wettability.

3.6 Force Applied on Artificial Skin in Dry and Wet Conditions

The average normal force exerted when female participant rubbed on artificial skin ranges from 0.23 to 0.28 N for dry skin and 0.30 N to 0.33 N for wet skin. In contrast, the applied load of male participant on dry and wet artificial skin varied in between 0.28 N to 0.31 N and 0.36 N to 0.46N respectively. The average applied force of female participants after serum application decreased to between 0.14 to 0.18 N for dry skin and 0.14 to 0.17 N for wet skin.

In the case for male participants, the average applied force by dry skin was between 0.23 N to 0.33 N and 0.26 N to 0.32 N for wet skin. The results show no significant difference in applied

force at dry and wet states after applying the skincare serum. Figure 9 depicts the average force applied when participants rubbed their index finger on the artificial skin in dry and wet states before application of serum and Figure 10 depicts the average force applied when participants rub their index finger on artificial skin at dry and wet state after application of skincare serum.

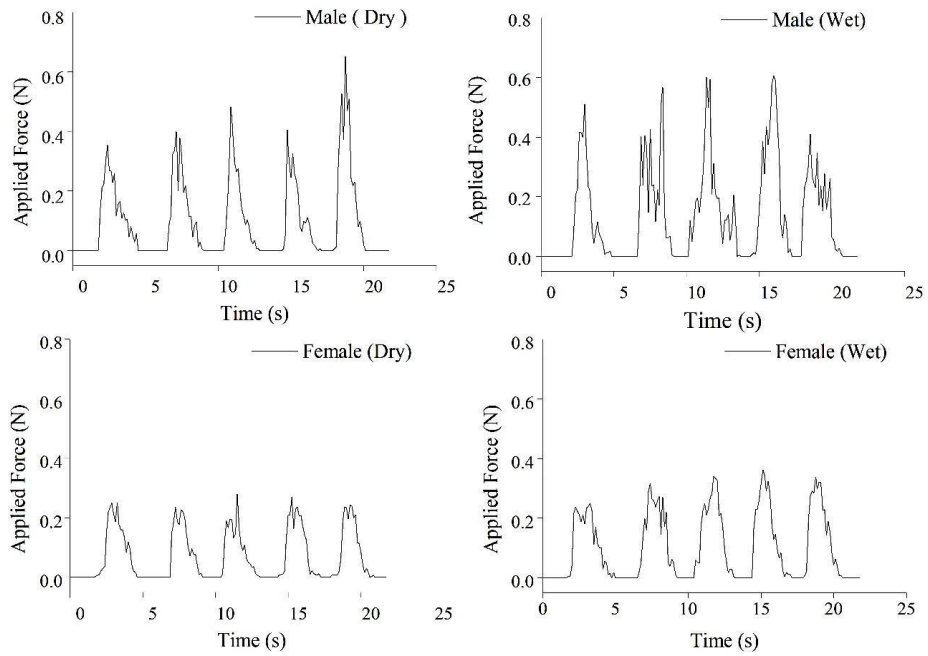


Figure 9: Average applied force for male and female index finger on artificial skin at dry and wet state before application of serum.

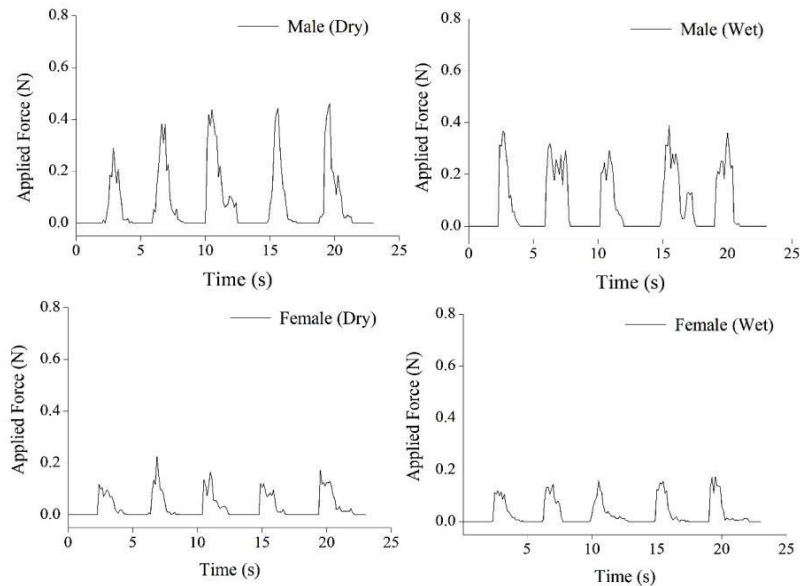


Figure 10: Average applied force for male and female index finger on artificial skin at dry and wet state after application of serum.

The graph indicates that the average force exerted when a finger rub was rubbed on wet artificial skin was higher between 18.75% and 28% for both male and female participants. This was due to the increased adhesive force when the surface of the index finger comes into contact with the artificial skin in wet state. According to Zhang et al., (2022) the factors that influence adhesive force are van der Waals force and electromagnetic forces, which are implied in the theory of surface energy. A greater force must be applied by the index finger to rub on the wet artificial skin due to the attraction between the moisturized surface and the finger.

Different scenarios were obtained when serum was applied on both dry and wet artificial skins. The lower applied force was exerted on the artificial skin for in dry and wet skin states for both male and female participants. From the results, the application of serum reduced the applied force by 30 % to 50 % for both male and female participants at dry and wet condition. The presence of serum forming a thin layer on the surface of artificial skin, thus facilitate the finger movement due to slipperiness. The application of skincare thus reduced the friction, lowering the force required to move the fingers.

CONCLUSIONS

This study highlights the critical role of material composition and surface properties in the design of artificial skin for tactile perception studies. The 7:3 PDMS:PVA composition, modified with sodium chloride, demonstrated optimal moisture retention and surface roughness, closely mimicking human stratum corneum. Anthocyanin exhibited superior wettability, suggesting its potential for cosmetic applications. Gender-specific differences in friction dynamics were observed, with skincare serum significantly reducing friction by 30–50%. These findings provide valuable insights for developing advanced artificial skin for biomedical and cosmetic applications.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support provided by the Ministry of Higher Education Malaysia under the Fundamental Research Grant Scheme (FRGS) (Grant No. FRGS/1/2021/STG01/UNIKL/02/3). This research would not have been possible without the generous funding and resources provided by this grant. We also extend our gratitude to Universiti Kuala Lumpur Short Term Research Grant (STRG) UniKL/CoRI/str21019, UniKL Resources Sdn. Bhd. (URSB) for their administrative and technical support throughout the duration of this project. Special thanks to the Malaysian Institute of Chemical and Bioengineering Technology (MICET) and the Automotive Development Centre (ADC), UTM for their valuable contributions and assistance in this research.

REFERENCES

- Abdeen Z, Swelling and reswelling characteristics of cross-linked poly(vinyl alcohol)/chitosan hydrogel film, *J Dispers Sci Technol*, vol. 32, no. 9, pp. 1337–1344, Sep. 2011.
- Berkey C, K. Biniak, and R. H. Dauskardt, Predicting hydration and moisturizer ingredient effects on mechanical behavior of human stratum corneum, *Extreme Mech Lett*, vol. 46, Jul. 2021
- Boyadzhieva S, S. C. L. Fischer, S. Lösch, A. Rutz, E. Arzt, and K. Kruttwig, Thin film composite silicon elastomers for cell culture and skin applications: Manufacturing and characterization, *Journal of Visualized Experiments*, vol. 2018, no. 137, Jul. 2018.
- Correia, P., Araújo, P., Ribeiro, C., Oliveira, H., Pereira, A. R., Mateus, N. & Fernandes, I. (2021). Anthocyanin-related pigments: Natural allies for skin health maintenance and protection. *Antioxidants*, 10(7), 1038.
- Elkhyat A, Skin Wettability and Friction, in *Handbook of Cosmetic Science and Technology*, A. Elkhyat, Ed., Fourth. 2013, pp. 337–344. (Online).
- Ezati E, M. S. Roberts, Q. Zhang, and H. R. Moghimi, Measurement of hansen solubility parameters of human stratum corneum, *Iranian Journal of Pharmaceutical Research*, vol. 19, no. 3, pp. 572–578, Jun. 2020.
- Jeyaram S and T. Geethakrishnan, Vibrational spectroscopic, linear and nonlinear optical characteristics of Anthocyanin extracted from blueberry, *Results in Optics*, vol. 1, Nov. 2020.
- Khan H. M. S., B. A. Khan, Q. A. Jamil, F. U. Khan, and N. Akhtar, Silicone based water- in-oil emulsion fortified with anthocyanin: In-vitro, in-vivo study, *Pak J Pharm Sci*, vol. 34, no. 3, pp. 981–986, May 2021.
- Khoerunnisa F, Effect of pH, temperature, and electrolytes on swelling and release behaviors of PVA/AAm/GO based hydrogel composites, in *AIP Conference Proceedings*, American Institute of Physics Inc., Jun. 2021.
- Kim D, & Yun, D. (2019). A study on the effect of fingerprints in a wet system. *Scientific Reports*, 9(1)
- Kim G and S. Jin, Hydrochannel-Containing Hydrophobic Polymers by Inverse Emulsion Polymerization for Moisture-Driven Actuators, *ACS Appl Mater Interfaces*, vol. 12, no. 49, pp. 55223–55230, Dec. 2020, doi: 10.1021/acsami.0c14151.
- Lamura MDP, M. I., Ammarullah, M. I., Maula, T. Hidayat, H. A., Wicaksono, M., Ambarita, & A. Priharyoto., Loading and unloading behaviour of an elastic-plastic contact in the presence of trapped fluid interference: biomechanical implications. *Jurnal Tribologi*, 43, 57-70.904, 2024
- Lee, S., Kim, S. R., Lee, H. J., Kim, B. S., Oh, H., Lee, J. B., ... & Park, J. D. (2022). Predictive model for the spreadability of cosmetic formulations based on large amplitude oscillatory shear (LAOS)

- and machine learning. *Physics of Fluids*, 34(10).
- Li, K., Zhang, M., Chen, H., Peng, J., Jiang, F., Shi, X., & Jia, Y. (2019). Anthocyanins from black peanut skin protect against UV-B induced keratinocyte cell and skin oxidative damage through activating Nrf2 signaling. *Food & Function*, 10(10), 6815-6828.
- Liu B, J. Zhang, and H. Guo, *Research Progress of Polyvinyl Alcohol Water-Resistant Film Materials, Membranes*, vol. 12, no. 3. MDPI, Mar. 01, 2022.
- Low, Z. W. K., Li, Z., Owh, C., Chee, P. L., Ye, E., Kai, D., ... & Loh, X. J. (2019). Using artificial skin devices as skin replacements: insights into superficial treatment. *Small*, 15(9), 1805453.
- Matty Maha FS, T Sultan Adiba Kh Amine, *Swelling Behavior of Cross-link PVA with Glutaraldehyde*, 2015.
- Morales-Hurtado M, X. Zeng, P. Gonzalez-Rodriguez, J. E. Ten Elshof, and E. van der Heide, A new water absorbable mechanical epidermal skin equivalent: The combination of hydrophobic PDMS and hydrophilic PVA hydrogel, *J Mech Behav Biomed Mater*, vol. 46, pp. 305–317, Jun. 2015
- Nasibi, S. (2020). A review of Polyvinyl alcohol/Carboxymethyl cellulose (PVA/CMC) composites for various applications. *Journal of Composites and Compounds*, 2(3), 68-75.
- Popelka A, S. Zavahir, and S. Habib, *Morphology analysis, in Polymer Science and Innovative Applications: Materials, Techniques, and Future Developments*, Elsevier, 2020, pp. 21– 68.
- Ren T, J. Gan, L. Zhou, and H. Chen, Physically crosslinked hydrogels based on poly (vinyl alcohol) and fish gelatin for wound dressing application: Fabrication and characterization, *Polymers (Basel)*, vol. 12, no. 8, Aug. 2020.
- Sugiarto B, Y. Rirung, A. N. Ardiyani, and Z. Achmad, Extraction Of Natural Color Of Butterfly Pea (Clitoria Ternatea L) With Variables Ph-Temperature And Concentration For Food Coloring, *Journal Techno*, vol. 8, no. 1, pp. 75–082, 2022.
- Trantidou T, Y. Elani, E. Parsons, and O. Ces, Hydrophilic surface modification of PDMS for droplet microfluidics using a simple, quick, and robust method via PVA deposition, *Microsyst Nanoeng*, vol. 3, 2017.
- Wang Y, Z. Guo, and W. Liu, Adhesion behaviors on four special wettable surfaces: natural sources, mechanisms, fabrications and applications, *Soft Matter*, vol. 17, no. 19. Royal Society of Chemistry, pp. 4895–4928, May 21, 2021.
- Wang, J. N., Liu, Y. Q., Zhang, Y. L., Feng, J., Wang, H., Yu, Y. H., & Sun, H. B. (2018). Wearable superhydrophobic elastomer skin with switchable wettability. *Advanced Functional Materials*, 28(23), 1800625.
- Westfall A, G. T. Sigurdson, and M. M. Giusti, Antioxidant, UV Protection, and Antiphotoreaction Properties of Anthocyanin-Pigmented Lipstick Formulations, *J Cosmet Sci*, vol. 70, no. 2, p. 63–76, 2019, (Online).
- Westfall A, G. T. Sigurdson, L. E. Rodriguez-Saona, and M. M. Giusti, Ex vivo and in vivo assessment of the penetration of topically applied anthocyanins utilizing ATR-FTIR/PLS regression models and HPLC-PDA-MS, *Antioxidants*, vol. 9, no. 6, Jun. 2020.
- Yirijor J, Y. Danyuo, A. A. Salifu, T. Ezenwafor, and F. McBagonluri, Surface coating and wettability study of PDMS-based composites: Effect on contact angle and cell-surface interaction, *MRS Adv*, vol. 7, no. 30, pp. 656–662, Nov. 2022.
- Zanela J, A. P. Bilck, M. Casa12grande, M. V. E. Grossmann, and F. Yamashita, Polyvinyl alcohol (PVA) molecular weight and extrusion temperature in starch/PVA biodegradable sheets, *Polimeros*, vol. 28, no. 3, pp. 256–265, Jul. 2018.
- Zhang L, Y. Zhang, Y., X. Li, Y. Feng, B. Yu, F. Zhou, & D. Wang, Mechanism and regulation of peeling-

electrification in adhesive interface. *Nano Energy*, 95, 107011. 2022.
Zisman WA, Relation of the Equilibrium Contact Angle to liquid and Solid Constitution, vol. 43. American Chemical Society, 1964. (Online).