ULTRA HYDROPHOBIC SURFACE FABRICATED ON TOLE SUBSTRATE

Vu Thi Hong Hanh*, **Nguyen Thanh Binh**
TNU - University of Education

ARTICLE INFO

Received: 13/5/2022
Revised: 24/6/2022
Published: 24/6/2022

KEYWORDS

Hydrophobic
Functional surface
Water-repellent
Tole
Wet etching

ABSTRACT

The functional surface is a new concept, which refers to the modification Physical-Chemical properties to equip surface with properties that the original material cannot have such as anti-wetting, anti-reflection, avoiding the deposition of substances, anti-ice, etc. However, the fabrication process requires complicated, expensive, and time-consuming technologies for further applications. This study presents a cheap and facile method to fabricate the functional surface on Tole substrate for water repellent and dust removal application. Bare Tole substrate was initially ground using sandpaper to generate the microscale structures and followed by the wet etching method using an acid solution to create the hierarchical structure. The treatment process was followed by the chemical compound coating to ensure the hydrophobicity of the rough surface. After being treated, the surface introduced a complete hydrophobicity, and anti-fouling properties and can be observed by a high-speed camera. The research results will suggest solutions for the fabrication of functional surfaces oriented to outdoor applications.

CHẾ TẠO BỀ MẶT SIÊU KỴ NƯỚC TRÊN ĐẾ TÔN

Vũ Thị Hồng Hạnh*, **Nguyễn Thanh Bình**
Trường Đại học Sư phạm - ĐH Thái Nguyên

THÔNG TIN BÀI BÁO

Ngày nhận bài: 13/5/2022
Ngày hoàn thiện: 24/6/2022
Ngày đăng: 24/6/2022

TỪ KHÓA

Kỵ nước
Bề mặt chức năng
Không thấm nước
Tôn
Ăn mòn ướt

TÓM TẮT

Chức năng hóa bề mặt là một khái niệm mới dùng để chỉ sự tác động, thay đổi các tính chất Lý – Hóa để bề mặt có những đặc tính mà vật liệu ban đầu không thể có được như: chống dính ướt, chống phản xạ, tránh lắng đọng các chất, chống đóng băng.... Tuy nhiên, các phương pháp chế tạo các bề mặt chức năng kể trên đòi hỏi các kĩ thuật phức tạp, tốn kém, và mất nhiều thời gian. Nghiên cứu này sẽ trình bày một phương pháp đơn giản và rẻ tiền được sử dụng để chức năng hóa bề mặt của đế Tôn cho ứng dụng không dính ướt và chống bám bẩn. Các đế tôn sau khi rửa sạch sẽ được mài bằng giấy ráp để tạo nên các cấu trúc micro và tiếp nối bằng quá trình ăn mòn ướt để tạo nên cấu trúc đa lớp micro-nano. Quá trình xử lí được tiếp tục bởi sơn phủ hợp chất hóa học kị nước để đảm bảo tính không dính ướt của bề mặt. Sau khi được xử lý, bề mặt tôn chuyển sang trạng thái hoàn toàn không dính ướt, chống bám bẩn và được quan sát bằng camera tốc độ cao. Kết quả nghiên cứu là cơ sở để đề xuất các giải pháp chế tạo các bề mặt chức năng hướng đến các ứng dụng ngoài trời.

DOI: https://doi.org/10.34238/tnu-jst.5978

* Corresponding author. *Email: hanhvth@tnue.edu.vn*

1. Introduction

Functional surfaces have been focused on in recent decades owing to their urgency and important applications [1], [2]. The functionalization process allows modifying the material surface for specific orientations such as anti-reflection [3]-[5], anti-ice [6]-[15], and anti-biofouling, which the original surface might not have. Various materials such as steel, aluminum, plastic, and glass can all be objects of surface functionalization. The surface treatment approaches are very flexible, ranging from generating structures on the surface or depositing the particles/ layer on the original surface [7], [16], [17]. The application of different techniques to achieve different properties strongly depends on the intended use of each application.

Recently, wetting-controlled surfaces have proposed great potential for outdoor applications such as windshields, self-cleaning glass [18], [19], anti-icing substrates, etc. The ultra hydrophobic surface has been named the strong candidate for mentioned applications owing to its unique properties containing the extremely high contact angle (normally over 155^{o}) and high liquid mobility. An ideal ultra hydrophobic surface can be generated by the etching method or by spraying functionalized particles on the original surface to enhance its hydrophobicity. Superhydrophobic surfaces have revealed the outstanding performance in anti-icing criteria by minimizing the ice-surface adhesion strength [20]-[23], the freezing time [8], [10], and ice repellency aspect [9], [12], [24], [25].

Tole is a compound of iron with zinc and has been used very widely because of its properties such as flexibility, ease of laminate, weather resistance, etc. To the best of our knowledge, the studies so far have never mentioned the fabrication of water repellent, and anti-ice surfaces on Tole material for additional applications.

In this work, nanostructures will be fabricated by the wet etching method using an acid solution. The fabricated surface will be followed by a chemical compound coating to significantly enhance the non-wetting properties. The final Tole sample presented very high hydrophobicity thanks to the combination of nanostructures with hydrophobic chemical compounds, demonstrating the potential for further applications.

2. Materials and fabrication process

Figure 1 describes the fabrication process of the ultra hydrophobic surface generated on the tole plate. Tole substrate was cut by 2 cm, 2 cm, and 0.2 cm in length, width, and thickness, respectively. After being appropriately roughened by sandpaper, the Tole substrate was dipped into the Hydrochloric acid in 15 minutes for the wet etching routine. The concentration of hydrochloric acid was carefully calculated and maintained at 20% (wt.%). The process was followed by cleaning etched surfaces with De-ionized water for at least 30 minutes. After cleaning and drying using nitrogen, the Tole surface was obtained with the hydrophobic chemical compound coating by a vapor deposition method and subsequently presented the extremely high hydrophobicity.

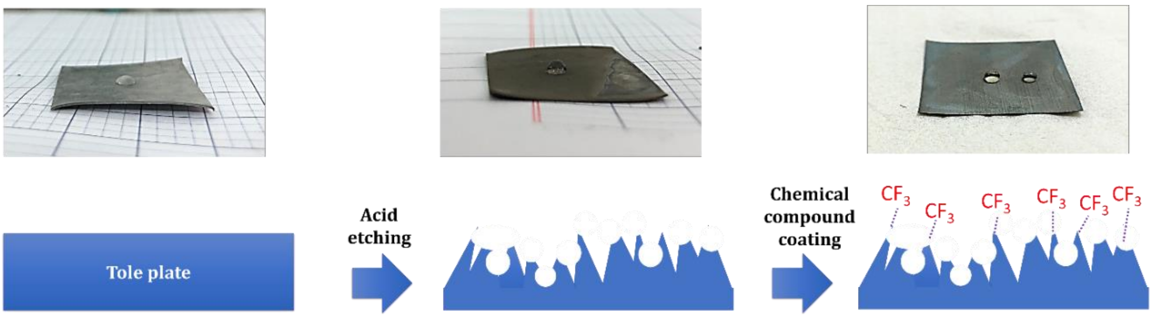

Figure 1. *The fabrication process of ultra hydrophobic surface on Tole plate*

The surface morphology was investigated by Scanning Electron Microscopy (SEM) with different magnifications. FOTS (Fluoro-octa-trichloro-silane) is a water-repellent chemical compound with a long carbon chain with one end being the carbon that will be tightly bound to the tole atom, while the other end being the hydrophilic SCl_3 molecule, which is a water-resistance molecule. The wetting ability was evaluated by using a contact angle meter (Model DM-50, Kyowa Interface Science Co. Ltd. - Japan) to measure the contact angle and sliding angle of water droplets. Contact angle measurement is one of the most typical methods to test the wettability of a solid-liquid surface pair at the solid-liquid-gas interface. The contact angle is measured by the 3-point tangent algorithm (tangent) method and provides accurate results depending on the surface energy. Each surface was measured in at least 5 locations and took the average.

3. Results and discussion

From the physics point of view, because the molecules' attraction at the solid-liquid surface (adhesion) is much larger than the attraction between water molecules (cohesion), water droplets will tend to spread out on the surface. The hydrophilic surface (high surface energy) leads to a larger solid-liquid area. Conversely, the hydrophobic surface (small surface energy) allows water droplets tend to condense to minimize the liquid-solid contact area. A completely ultra hydrophobic surface can only be formed when two factors micro/nanostructure and chemical compounds are combined to minimize surface energy. If only the micro/nanostructure is present, the wetting state will be a completely wet (superhydrophilic) state, while if only the chemical compound is present (on an unstructured surface) the liquid will be hydrophilic or hydrophobic. The combination of micro/nanostructures and hydrophobic compounds results in a Cassie-Baxter state of liquid-surface, meaning that the liquid only contacts the top of the micro/nanostructures and could not penetrate deep into the space between the surface features.

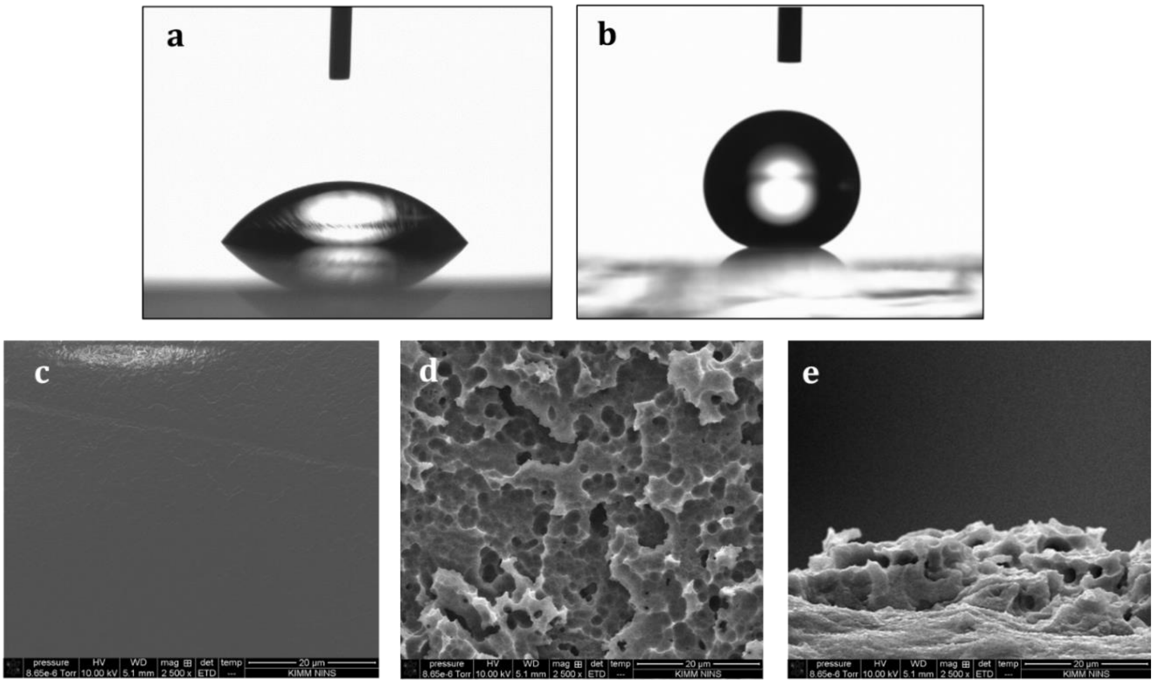

Figure 2. *The contact angle before (a) and after functionalize process (b); The SEM of surface before the etching (c) and after etching (d,e)*

Figure 2a shows the SEM images of the Tole surface after etching. The nanostructure was randomly generated on the surface with the highest height of about 500nm. Such a small and dense nanostructure was sufficient to facilitate an underneath layer for an ultra hydrophobic state. The etched surface was then functionalized by FOTS coating through the vapor deposition method. Figure 2b presents the formation of the water droplets on the surface after chemical modification with a contact angle of about 160^o. The wetting state of ultra hydrophobic was compared with the as-received Tole plate and the etched surface to emphasize the importance of surface energy (Table 1). The bare Tole plate (smooth) revealed the hydrophilic state while the etched Tole presented the ultra hydrophilic formation owing to the presence of micro/nanostructure. Such micro/nanostructure after FOTS coating illustrated very high water-repellent properties with high contact angle and low sliding angle (2^o).

To investigate the self-cleaning ability for functional applications, we used water to deposit on the ultra hydrophobic Tole surface. Fine sand with different diameters was used to simulate the actual surface. Figure 3 demonstrates the good quality of the fabricated surface when the water has completely removed the impurities in its path. Samples are tested for self-cleaning at least 40 times and prove the high repeatability, illustrating the potential for functional applications and industry as well.

Table 1. *Information on investigated surfaces*

Name	Contact angle (^{o})	Sliding angle (^{o})	Note
Bare Tole	68	24	As-received Tole plate
S.Philic	35	36	Etching
U.Phobic	160	2	Etching and FOTS coating

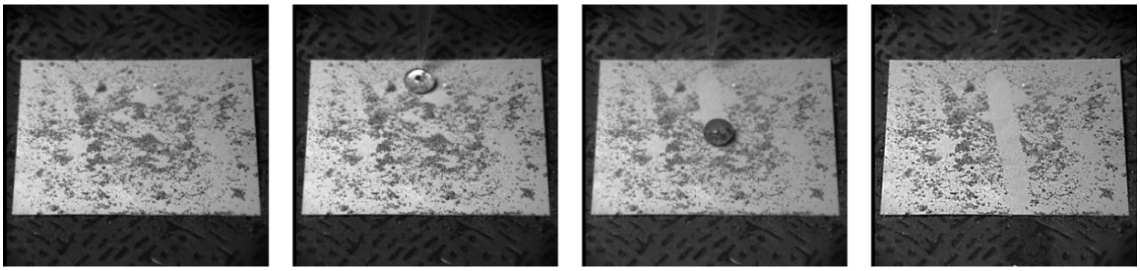

Figure 3. *The water repellent test on an ultra hydrophobic surface*

4. Conclusion

In this work, we proposed an economic and facile method to prepare ultra hydrophobic on the Tole surface. The micro/nanostructure was generated by the wet etching method using Hydrochloric acid. The surface roughness was combined with the hydrophobized chemical compound to present the water-repellent properties. Subsequently, the functionalized Tole sample illustrated the high hydrophobicity and demonstrated the potential for further applications.

REFERENCES

[1] A. A. G. Bruzzone, H. L. Costa, P. M. Lonardo, and D. A. Lucca, “Advances in engineered surfaces for functional performance,” *CIRP Annals*, vol. 57, no. 2, pp. 750–769, 2008.

[2] A. Malshe, K. Rajurkar, A. Samant, H. N. Hansen, S. Bapat, and W. Jiang, “Bio-inspired functional surfaces for advanced applications,” *CIRP Annals*, vol. 62, no. 2, pp. 607–628, 2013.

[3] F. de Nicola, P. Hines, M. de Crescenzi, and N. Motta, “Moth-eye effect in hierarchical carbon nanotube anti-reflective coatings,” *Carbon*, vol. 108, pp. 262–267, 2016.

[4] T. Okabe, T. Yano, K. Yatagawa, and J. Taniguchi, “Polyimide moth-eye nanostructures formed by oxygen ion beam etching for anti-reflection layers,” *Microelectronic Engineering*, vol. 242–243, 2021, Art. no. 111559.

[5] H. Xu, L. Gong, S. Zhang, R. Ma, L. Pan, J. Zhao, and Y. Li, “Biomimetic Moth-eye Anti-reflective Poly-(methyl methacrylate) Nanostructural Coating,” *Journal of Bionic Engineering*, vol. 16, no. 6, pp. 1030–1038, 2009.

[6] B. D. Nguyen and T. B. Nguyen, "Investigate on structure for transparent anti-icing surfaces," *AIP Advances*, vol. 10, no. 8, 2020, Art. no. 085101.

[7] H. Guo, Y. Xing, H. Yuan, R. Zhang, Y. Zhang, and P. Deng, "Improving the anti-icing performance of superhydrophobic surfaces by nucleation inhibitor," *Surface Engineering*, vol. 36, no. 6, pp. 621–627, 2020.

[8] T.-B. Nguyen, S. Park, and H. Lim, "Effects of morphology parameters on anti-icing performance in superhydrophobic surfaces," *Applied Surface Science*, vol. 435, pp. 585-591, 2018.

[9] T. B. Nguyen, T. H. H. Vu, T. N. Ngo, and B. D. Nguyen "Anti-icing efficiency on bio-inspired slippery elastomer surface," *Materials Chemistry and Physics*, vol. 265, 2021, Art. no. 124502.

[10] T.-B. Nguyen, S. Park, Y. Jung, and H. Lim, "Effects of hydrophobicity and lubricant characteristics on anti-icing performance of slippery lubricant-infused porous surfaces," *Journal of Industrial and Engineering Chemistry*, vol. 69. pp. 99-105, 2019.

[11] V.-H. Nguyen, B. D. Nguyen, H. T. Pham, S. S. Laflem, D.-V. N. Vo, M. Shokouhimehr, T. H. H. Vu, T.-B. Nguyen, S. Y. Kim, and Q. V. Le, "Anti-icing performance on aluminum surfaces and proposed model for freezing time calculation," *Scientific Reports*, vol. 11, no. 1, 2021, Art. no. 3614.

[12] T. H. H. Vu, X. T. Mai, and T.-B. Nguyen, "Anti-icing approach on flexible slippery microstructure thin-film," *Cold Regions Science and Technology*, vol. 186, 2021, Art. no. 103280.

[13] B. D. Nguyen, B. X. Cao, T. C. Do, H. B. Trinh, and T.-B Nguyen, "Interfacial parameters in correlation with anti-icing performance," *Journal of Adhesion*, vol. 97, no. 9, pp. 860-872, 2019.

[14] M. A. Sarshar, D. Song, C. Swarctz, J. Lee, and C.-H. Choi, "Anti-Icing or Deicing: Icephobicities of Superhydrophobic Surfaces with Hierarchical Structures," *Langmuir*, vol. 34, no. 46, pp. 13821–13827, 2018.

[15] X. T. Mai, T. H. H. Vu, and T. B. Nguyen, "The integrated contribution of surface topology to anti-icing effectiveness," *Surface Topography: Metrology and Properties*, vol. 10, no. 1, 2022, Art. no. 15036.

[16] S. Farhadi, M. Farzaneh, and S. A. Kulinich, "Anti-icing performance of superhydrophobic surfaces," *Applied Surface Science*, vol. 257, no. 14, pp. 6264–6269, 2011.

[17] J. Yang and W. Li, "Preparation of superhydrophobic surfaces on Al substrates and the anti-icing behavior," *Journal of Alloys and Compounds*, vol. 576, pp. 215–219, 2013.

[18] X. Luo, L. Lu, M. Yin, X. Fang, X. Chen, D. Li, L. Yang, G. Li, and J. Ma, "Antireflective and self-cleaning glass with robust moth-eye surface nanostructures for photovoltaic utilization," *Materials Research Bulletin*, vol. 109, pp. 183–189, 2019.

[19] W. Zhao, L. Xiao, X. He, Z. Cui, J. Fang, C. Zhang, X. Li, G. Li, L. Zhong, and Y. Zhang, "Moth-eye-inspired texturing surfaces enabled self-cleaning aluminum to achieve photothermal anti-icing," *Optics & Laser Technology*, vol. 141, 2021, Art. no. 107115.

[20] Z. He, Y. Zhuo, Z. Zhang, and J. He, "Design of Icephobic Surfaces by Lowering Ice Adhesion Strength: A Mini Review," *Coatings*, vol. 11, no. 11, 2021, doi: 10.3390/coatings11111343.

[21] S. A. Kulinich and M. Farzaneh, "Ice adhesion on super-hydrophobic surfaces," *Applied Surface Science*, vol. 255, no. 18, pp. 8153–8157, 2009.

[22] A. J. Meuler, J. D. Smith, K. K. Varanasi, J. M. Mabry, G. H. McKinley, and R. E. Cohen, "Relationships between Water Wettability and Ice Adhesion," *ACS Applied Materials & Interfaces*, vol. 2, no. 11, pp. 3100–3110, 2010.

[23] D. K. Sarkar and M. Farzaneh, "Superhydrophobic Coatings with Reduced Ice Adhesion," *Journal of Adhesion Science and Technology*, vol. 23, no. 9, pp. 1215–1237, 2009.

[24] T. H. H. Vu, X. T. Mai, Q. T. Tu, and T.-B. Nguyen, "Nature-inspired slippery polymer thin film for ice-repellent applications," *Bioinspired, Biomimetic and Nano biomaterials*, vol. 10, no. 3, pp. 107–113, 2021.

[25] T. H. H. Vu, T. C. Do, V. H. Chu, M. A. Pham, T. M. T. Nguyen, T. T. Bui, T. M. Dam, S. Sonemany, and T.-B. Nguyen, "Icephobic approach on hierarchical structure polymer thin-film," *Advances in Natural Sciences: Nanoscience and Nanotechnology*, vol. 13, no. 1, 2022, Art. no. 15004.