Effect of Surface Texturing on the Morphology and Wettability Properties of Plasma Sprayed TiO_2 Coating

Yusliza Yusuf[1,2](✉), Mariyam Jameelah Ghazali[1], Mohd Fadzli bin Abdollah[3], Yuichi Otsuka[4], Susumu Nakamura[5], and Sarita Morakul[6]

[1] Centre for Materials Engineering and Smart Manufacturing, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, UKM, 43600 Bangi, Selangor, Malaysia
yusliza@utem.edu.my

[2] Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[3] Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[4] Department of System Safety, Nagaoka University of Technology, 1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan

[5] Department of Electrical and Electronic Systems Engineering, National Institute of Technology, Nagaoka College, 888 Nishikatakai, Nagaoka, Niigata 940-8523, Japan

[6] Graduate School of Material Science, Nagaoka University of Technology, 1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan

Abstract. Recently, titanium dioxide (TiO_2) coatings have drawn great attention due to its photo-catalytic, antibacterial, and self-cleaning properties. However, in order to exhibit the self-cleaning features, it is necessary to promote its super hydrophilic function. In this study, the effect of textured surface performed by LST technique on TiO_2 coating, and its wettability properties were investigated. The textured surface morphology was observed using a digital microscope and the surface wettability analysis was conducted by measuring the static water contact angle (CA). It was observed that all dimples were efficiently engraved on the TiO_2 coating without any visible cracks or damages. The non-textured coatings also exhibit a CA of 58.5° indicating hydrophilic behavior while the laser-textured samples showed CA less than 5° promoting super hydrophilic features. It was proven that laser surface texturing (LST) technique had increased the total surface area of the coatings, leading to greater exposure to potential chemical and/or physical interactions. All in all, prominent super hydrophilic features that were obtained in this study indicated that a facile method like LST is capable to develop a self-cleaning surface.

Keywords: TiO_2 coating · Self-cleaning · Super hydrophilic

1 Introduction

Laser surface texturing (LST) is a technique that involves the creation of macrotextures on the surface with a specific pattern (dimples, grooves, squares, etc.), which serves to

S. Samion et al. (Eds.): MITC 2020, LNME, pp. 36–40, 2022.
https://doi.org/10.1007/978-981-16-9949-8_7

operate for improving load capacity, wear rates, lubrication lifetime and reduce friction coefficients. Besides, the use of LST technology to create textures on metal surfaces in order to change the wettability properties has also been widely explored [1]. Compared to other processing techniques, LST can comprehend the preparation of a large-area functional surface through a simple and rapid processing which can be applied to any mass industrial production [2, 3].

Recently, titanium dioxide (TiO_2) coatings have drawn great attention due to its photo-catalytic, antibacterial, and self-cleaning properties. TiO_2-derived materials have been explored to understand the fundamental principles of self-cleaning with hydrophilic and hydrophobic surfaces [4, 5]. The hydrophilic character of TiO_2 was first reported by Fujishima and co-workers in year 1995. They reported that TiO_2 film is irradiated with light, and reduction of the contact angle to 0° results in the spreading of water droplets on the surface [6]. Therefore, in this study, TiO_2 coating has been selected due to its ability to control surface wettability for self-cleaning effects. However, in order to exhibit the self-cleaning features, an external source of UV light illumination is necessary to promote its super hydrophilic function. Then, it is desirable to develop a TiO_2 coating technique that could enhance superhydrophilicity without any UV light radiations for example for use in areas where there is no sunlight. Thus, in this study, proposed to investigate the effect of textured surface performed by LST technique on TiO_2 coating and its wettability properties.

2 Materials and Methods

2.1 Preparation of TiO_2 Coating

Commercial TiO_2 (Metco 102 Oerlikon Metco, ≥99.0 wt%) with a nominal particle size distribution of 11–45 μm was used as raw materials. The coatings were deposited onto carbon steel with dimensions of 30 cm (length) × 5 cm (width) × 7 mm (thickness) by an atmospheric plasma spray system with a SG-100 torch (Praxair, USA) mounted on an ABB IRB industrial robot under the parameters presented in Table 1. The surface morphologies of coating was observed by scanning electron microscope (SEM, Zeiss Leo 1450 VP) at an acelerating voltage of 15.0 kV.

2.2 Laser Surface Texturing

TiO_2 ceramic coatings with areas of 8 mm × 8 mm on were subjected to laser surface texturing. A Q-switched Nd: YAG picosecond laser system was used to create micro-dimpled surface textures on the TiO_2 coatings. As illustrated in Fig. 1, the texturing technique involved covering a series of intermediate lines with dimples by applying a laser with a wavelength of 532 nm and a power of 1 W. Scanning was repeated for 2000 shots per point to produce a dimple. Non-textured samples were used for comparison to measure the effectiveness of the textured samples. The morphology of dimples was observed using a Keyence VHX-1000 digital microscope with a 900× magnification.

Table 1. Process parameters for plasma spraying process.

Parameter	Value
Arc current (A)	600
Primary gas argon (psi)	80
Secondary gas helium (psi)	40
Carrier gas argon (psi)	30
Powder feed rate (rpm)	4
Spraying distance (mm)	80
Robot speed (mm/s)	250
Pre heat (cycle)	2

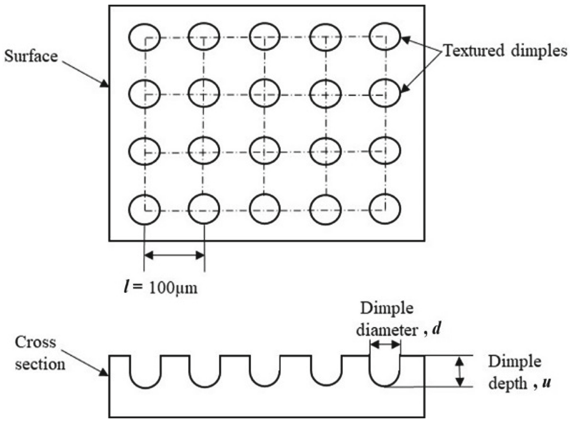

Fig. 1. Scheme of the texturing pattern.

2.3 Wettability Analysis

Static contact angle (CA) imaging and angle measurement of the plasma-sprayed non textured and laser surface-textured TiO_2 coating were conducted using a sessile droplet method at room temperature and humidity. The static CA was measured by placing a 1 μL sessile droplet of water on the sample surface. The image was captured and analyzed to calculate the CA. A DMe-201 high-speed camera (Kyowa Interface Science Co. Ltd) was used for the CA measurement. Image analysis and measurements were performed using the FAMAS software.

3 Result and Discussion

3.1 Coating Morphology

Top view surface profile micrographs of laser- textured and non-textured TiO_2 coatings are shown in Fig. 2. The profile images revealed that melted and non-melted particles were combined with pores and crack (Fig. 2(a)). The laser impact sites surrounding the dimples underwent material transformation (Fig. 2(b)). Ejected matter associated with the coating material can be observed around the dimples' vicinity. The material temperature is expected to increase during the laser–material interaction until melting and ejection occur on the surface as a result of a pressure drop. The laser texturing process produced dimples with uniform diameters under the given operating parameters. Besides, it was observed that all dimples were efficiently engraved on the TiO_2 coating without any visible cracks or damages.

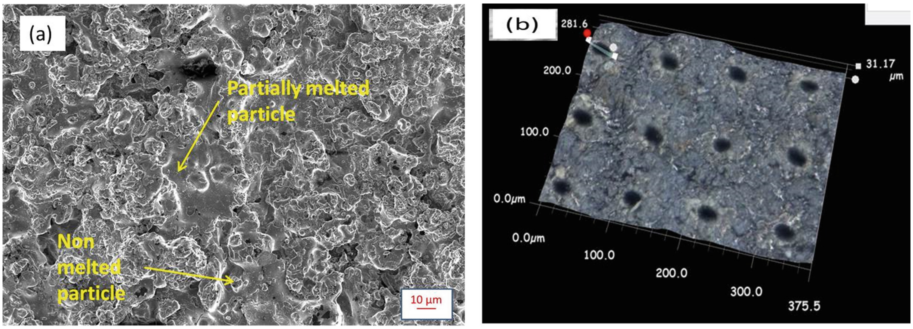

Fig. 2. (a) Non-textured TiO_2 coating (b) laser-textured TiO_2 coating.

3.2 Wettability Properties

The comparisons of the CA of the non-textured TiO_2 coating with a laser textured TiO_2 surface are shown in Fig. 3. The plasma-sprayed TiO_2 coatings exhibiting a water CA of 58.5° presented a hydrophilic surface and the laser-textured TiO_2 coating sample with an extremely low CA of less than 5° exhibited a super hydrophilic surface. In the present study, the laser-textured surface had increased the total initial surface area of the TiO_2 coating with the presence of dimples. The increased of the surface area of TiO_2 coating exposed to moisture, thereby providing the surface with super hydrophilic properties. This result may be attributed to the modifications of chemical composition (hydroxyl group) and surface morphology during laser texturing. The hydrophilic process of TiO_2 can be expressed as follows reasons:

(i) The electrons tend to reduce the Ti (IV) cations to the Ti (III) state; oxygen atoms are ejected, and oxygen vacancies are created.
(ii) Thus, it produces more Ti defects and oxygen vacancies [7].
(iii) Then, water molecules occupy these oxygen vacancies, thus producing ad-sorbed hydroxyl (OH) groups. The hydroxyl can form hydrogen bonds with water; therefore, the increase in hydroxyl content on the surface of TiO2 thin films tends to make the surface hydrophilic. Moreover, the stably chemisorbed OH groups can make the structure of $Ti3+ – OH$ stable [8], which also results in the enhancement of hydrophilicity.

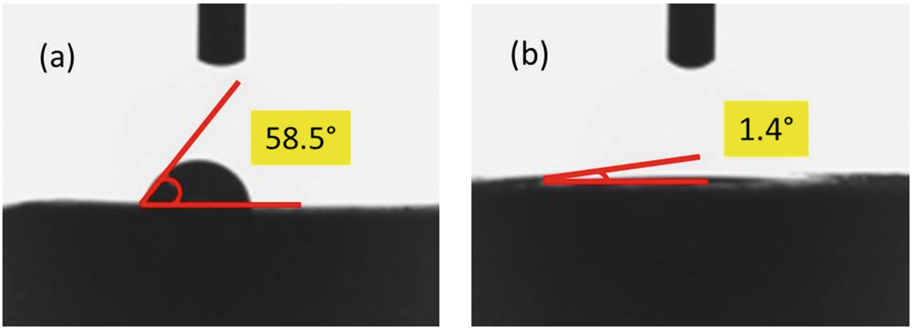

Fig. 3. Contact angle (CA) value on top of surface of plasma sprayed (a) non – textured and (b) laser textured TiO_2 coating.

4 Conclusion

All in all, prominent super hydrophilic features that were obtained in this study indicated that a facile method like LST is capable to develop a self-cleaning TiO_2 surface. The surface water drops spread over the surface of laser textured TiO_2 and formed a water film. During spreading water film, the contamination on the surface was washed away.

Acknowledgements. This work was supported by the Ministry of Higher Education Malaysia, Universiti Kebangsaan Malaysia (FRGS/1/2018/TK03/UKM/02/8) and Universiti Teknikal Malaysia Melaka internal grant (PJP/2020/FTKMP/PP/S01737). The authors also thank Nagaoka University of Technology, Japan and JASSO Scholarship for their support and cooperation during the experiments. The first author also acknowledges Universiti Teknikal Malaysia Melaka for financially supporting her Ph.D. study.

References

1. Yang, C.-J., Mei, X.-S., Tian, Y.-L., Zhang, D.-W., Li, Y., Liu, X.-P.: Modification of wettability property of titanium by laser texturing. Int. J. Adv. Manuf. Technol. **87**(5–8), 1663–1670 (2016)
2. Shivakoti, I., Kibria, G., Cep, R., et al.: Laser surface texturing for biomedical applications: a review. Coatings **11**, 1–15 (2021)
3. Shamsul Baharin, A.F., Ghazali, M.J., Wahab, J.A.: Laser surface texturing and its contribution to friction and wear reduction: a brief review. Ind. Lubr. Tribol. **68**, 57–66 (2016)
4. Banerjee, S., Dionysiou, D.D., Pillai, S.C.: Self-cleaning applications of TiO2 by photo-induced hydrophilicity and photocatalysis. Appl. Catal. B: Environ. **176–177**, 396–428 (2015)
5. Do, T.-O., Mohan, S.: Editorial: special issue on “emerging trends in TiO_2 photocatalysis and applications.” Catalysts **10**(6), 670 (2020)
6. Adachi, T., Latthe, S.S., Gosavi, S.W., et al.: Photocatalytic, superhydrophilic, self-cleaning TiO2 coating on cheap, light-weight, flexible polycarbonate substrates. Appl. Surf. Sci. **458**, 917–923 (2018)
7. Li, W., Ismat Shah, S., Huang, C.P., et al.: Metallorganic chemical vapor deposition and characterization of TiO2 nanoparticles. Mater. Sci. Eng. B Solid-State Mater. Adv. Technol. **96**, 14–16 (2002)
8. Nakamura, M., Sirghi, L., Aoki, T., Hatanaka, Y.: Study on hydrophilic property of hydro-oxygenated amorphous TiOx:OH thin films. Surf. Sci. **507–510**, 778–782 (2002)