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The Effect of TiO2-SiO2 Nanocomposite as a Filler on the Self-Cleaning Properties of Material

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Abstract

Implementation of TiO2-SiO2 nanocomposites has been a primary focus in the development of innovative materials. This research explores the potential application of TiO2-SiO2 nanocomposite as a filler in coating blends and 3D SLA resin. Achieving optimal self-cleaning properties is the main objective, considering the importance of a material's ability to cleanse itself from external dirt. The study employs the contact angle goniometer test to evaluate the hydrophobic properties of TiO2-SiO2 nanocomposite. The results indicate that samples containing TiO2-SiO2 nanocomposite as a filler exhibit a significant improvement in self-cleaning properties compared to control samples, as demonstrated by an increased contact angle between water and the sample material. This opens up opportunities for other applications, including efficient anti-corrosion coatings and 3D printing resin materials with self-cleaning properties, facilitating maintenance and enhancing the quality and durability of materials across various industrial sectors.

Keywords: TiO_2-SiO_2; filler; coating; hydrophobic; self-cleaning

INTRODUCTION

In addressing the demand for innovative materials, the need for self-cleaning materials is gaining increased attention [1], [2], particularly in the development of materials for metal coatings and as a resin component in the 3D printing process using the SLA method [3], [4]. The role of fillers in materials becomes crucial in designing an optimal composition to achieve specific properties. Fillers, or filling materials, not only serve to occupy empty spaces but also influence the mechanical, thermal, and aesthetic characteristics of the material [5], [6]. One intriguing approach involves the utilization of nanomaterials, specifically TiO_2-SiO_2 nanocomposites, to enhance self-cleaning properties [7], [8], [9]. Nanotechnology has become a primary focus in material research for various applications, and its application to improve sustainability and efficiency in self-cleaning materials is one of its aspects.

TiO_2-SiO_2 nanocomposites are considered a potential solution because the combination of titanium dioxide (TiO_2) which has good physical and chemical stability [10] and silicon dioxide (SiO_2) [11] can create better self-cleaning properties. This combination is not only based on the unique chemical properties of each material but also on their synergistic interactions that can enhance the effectiveness of self-cleaning [12], [13]. However, the potential of TiO_2-SiO_2 nanocomposites to be used as a filler in more specific coating mixtures, such as when blended with metal paint or in the mixture for UV-tough 3D printer resin, still needs further development.

Therefore, the primary aim of this research is to establish TiO_2-SiO_2 nanocomposites as fillers in coating mixtures for metal applications and as resin additives, particularly for UV-tough resin in the SLA 3D printing process. The focus lies in identifying the role of these fillers in achieving optimal self-cleaning properties by observing the occurring hydrophobic characteristics. This study not only integrates technical aspects for industrial applications but also contributes to scientific knowledge by revealing the scientific correlation between the combination of TiO_2 and SiO_2 and their benefits in enhancing the self-cleaning properties of materials. Consequently, the research outcomes are anticipated to make a significant contribution to the advancement of coating technology and 3D printing, providing direction for future research in the development of innovative self-cleaning materials.

METHODS

The TiO_2-SiO_2 nanocomposite employed in this study was synthesized through the sol-gel method based on the experimental findings of the researcher. To illustrate the distribution of elements in the TiO_2-SiO_2 nanocomposite powder, an analysis was conducted using FE SEM-EDS

JIB-4610F produced by Jeol at an operating voltage of 15 kV. Subsequently, specimen images were captured using the Dyno Lite Digital Microscope for each sample, with the aim of visually highlighting the differences among the test specimens.

The sample preparation process for coating applications is illustrated in Fig. 1. The TiO_2-SiO_2 nanocomposite, at a weight percentage of 5%, is mixed and employed as a filler coating material on Nippon Paint Nipple 2000 for Mild Steel JISG3131 SPHC, which has been previously sanded and cleaned. Then, for the sample preparation process for UV-tough resin filler applications, refer to Fig. 2(a). The weight of the filler or TiO_2-SiO_2 nanocomposite used in this mixture is 3% of the total weight of the mixture. The resin mixture is then used as the printing material using the Anycubic Photon Mono SE 3D printer. The parameter settings for the printing process can be found in Fig. 2(b).

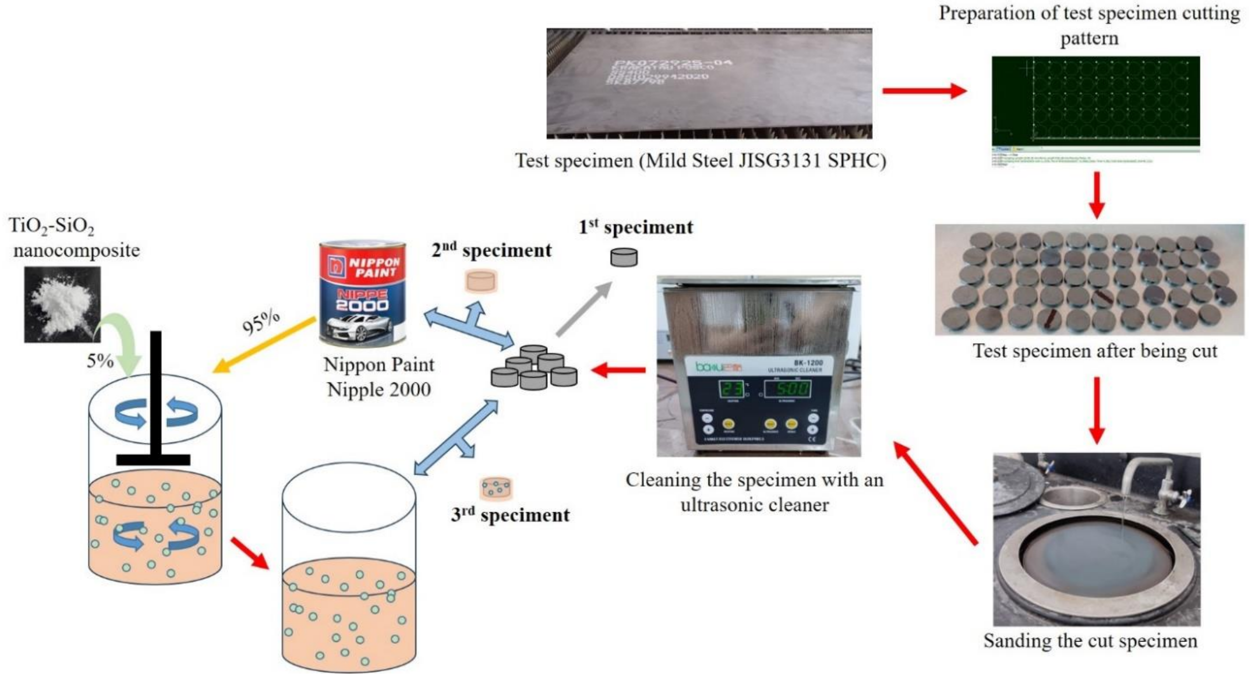


Fig. 1. Preparation of the self-cleaning test using the hydrophobic method on Mild Steel JISG3131 SPHC and TiO_2-SiO_2 nanocomposites as a filler in coating.

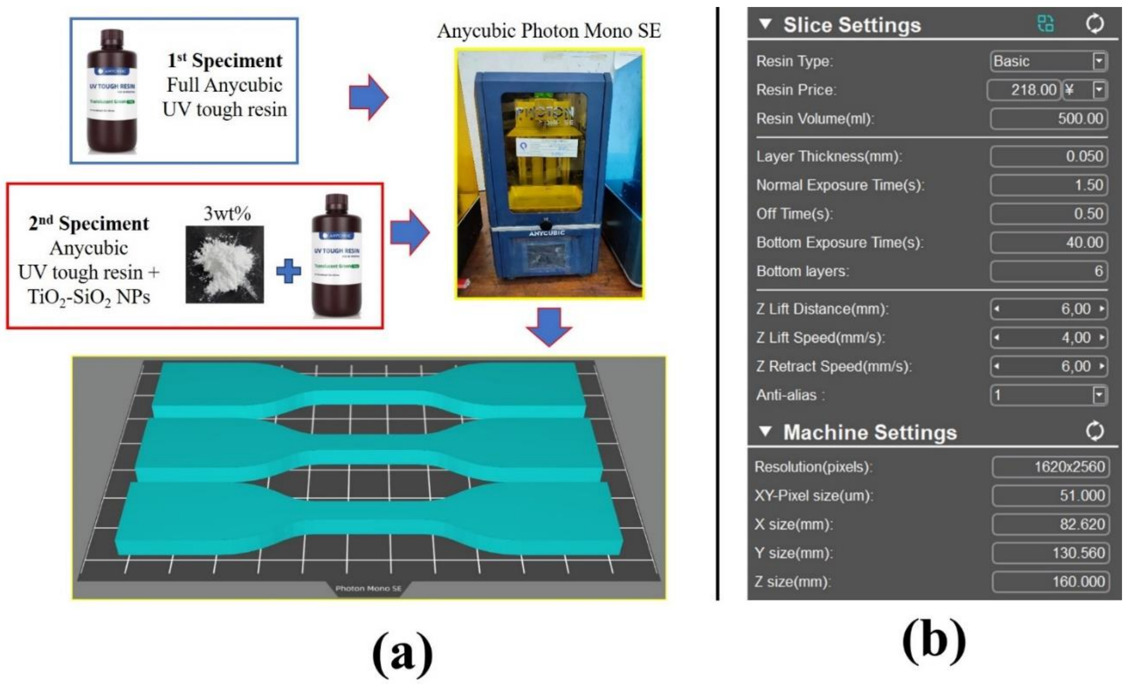
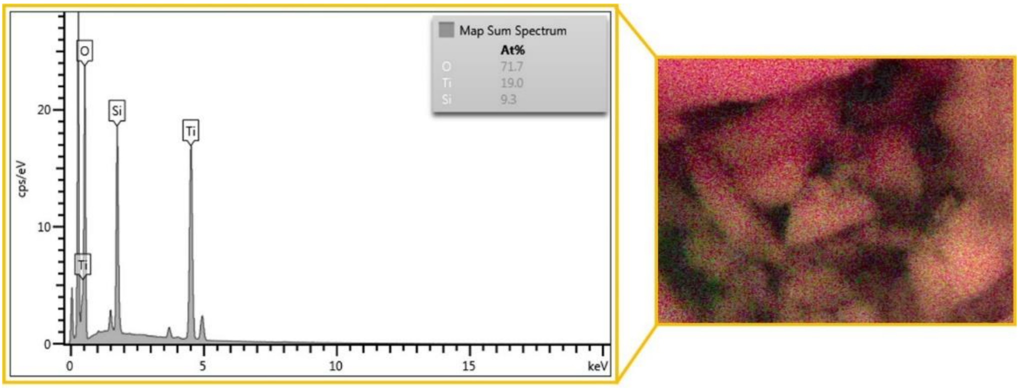


Fig. 2. (a) Preparation of self-cleaning specimens for 3D printer material and (b) 3D printer printing parameters.

Subsequently, distilled water is used as the material to be dropped onto the specimen surface in the self-cleaning test. This testing employs the Ossila Contact Angle Goniometer, and the results will provide the contact angle value between the specimen surface and the distilled water droplet. Hydrophobicity is indicated by a contact angle above 90°, and for superhydrophobic surfaces, the contact angle will be greater than 150°. Conversely, a contact angle below 90° indicates that the specimen has hydrophilic properties. The higher the hydrophobicity of the tested specimen, the more it signifies the presence of self-cleaning properties in the material specimen.

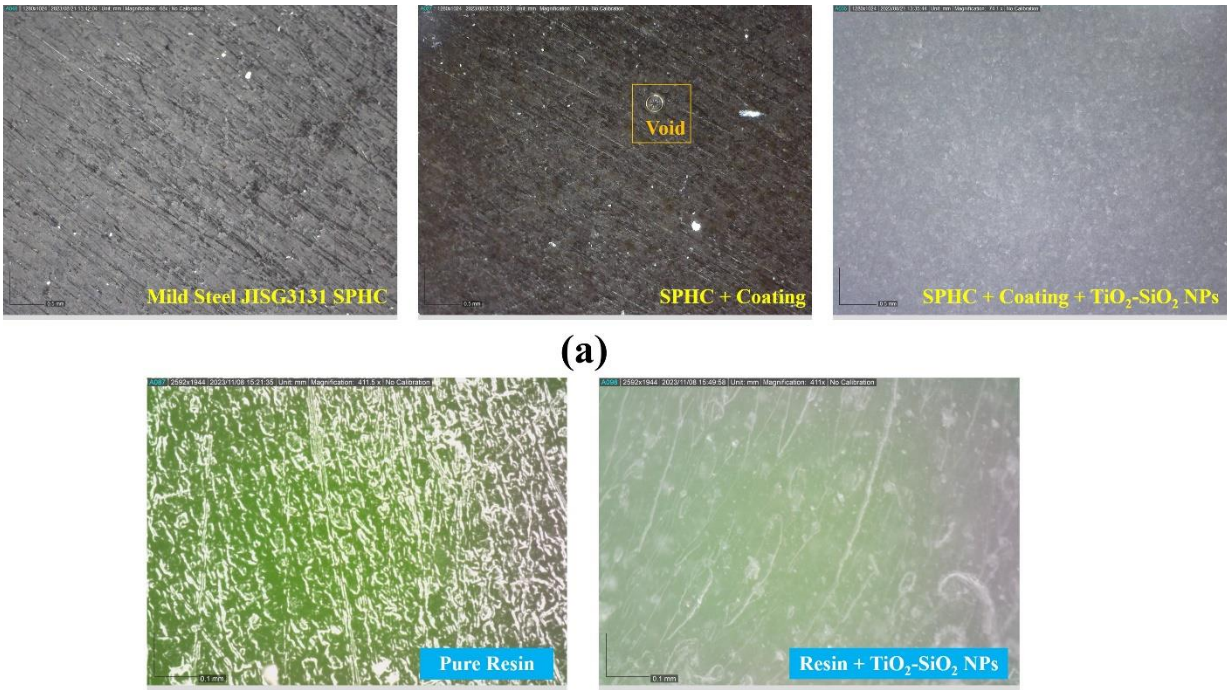
RESULTS AND DISCUSSION

Distribution of TiO_2-SiO_2 nanocomposite elemental dispersion using SEM-EDS (Jeol JIB-4610F) can be observed in Fig. 3(a). The results indicate the detected elements in the sample are Oxygen (O) at 71.7 At%, Titanium (Ti) at 19 At%, and Silicon (Si) at 9.3 At%. This suggests that the powder utilized as a filler in this study is TiO_2-SiO_2 nanocomposite. Subsequently, Fig. 3(b) illustrates the areas of the TiO_2-SiO_2 nanocomposite sample where the elemental distribution testing took place. The color variations in the image reveal the presence of different elements in the sample. Additionally, it is noted from this image that the shape of the particle is irregular.



(a) (b)

Fig. 3. The results of FE SEM-EDS on the TiO_2-SiO_2 nanocomposite sample are presented in (a) compositional distribution based on At%, and (b) capture locations of the sample taken on the TiO_2-SiO_2 nanocomposite.



(b)

Fig. 4. Visual representation of the self-cleaning test specimens: (a) coating for metal, and (b) 3D printer product.

In Fig. 4, the visual appearance of each test specimen using the Dyno Lite Digital Microscope is depicted. In Fig. 4(a), on the left, the test specimen of Mild Steel JISG3131 SPHC without any coating is shown. Moving to the center of Fig. 4(a), the metal test sample coated with Nippon Paint Nipple 2000 is presented. This is characterized by a shinier appearance but with voids or bubbles due to the coating application on the metal. Finally, on the right side of Fig. 4(a), the metal test specimen coated with TiO_2-SiO_2 nanocomposite as a filler is displayed. This is indicated by the specimen turning white as a result of the application of TiO_2-SiO_2 powder in the coating.

Moving on to Fig. 4(b), the visual representation of test specimens from a 3D printer is shown. On the left side of Fig. 4(b), a specimen produced by the 3D printer using pure resin is depicted in a bright green color. Meanwhile, on the right side of Fig. 4(b), a visual representation of the 3D printer result is displayed where the resin used has been mixed with TiO_2-SiO_2 nanocomposite as a filler. This is evidenced by its turquoise green color with distinctive white spots representing the added powder.

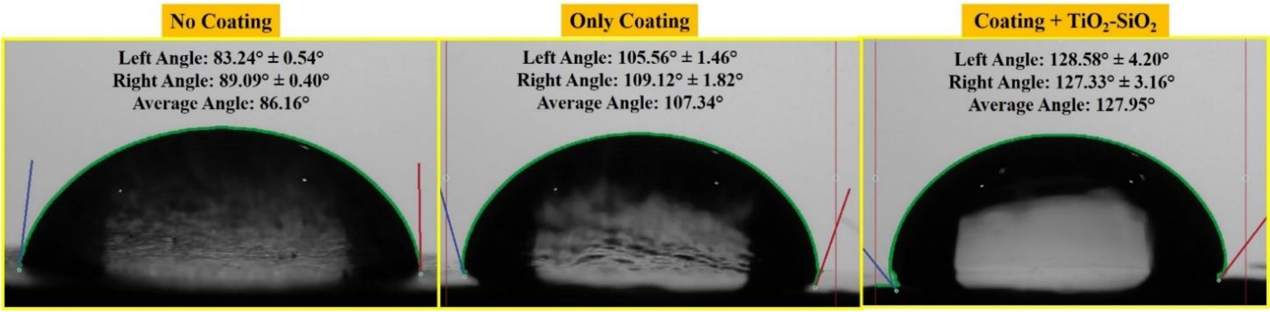


Fig. 5. The visual representation of the self-cleaning test specimens on metal coating.

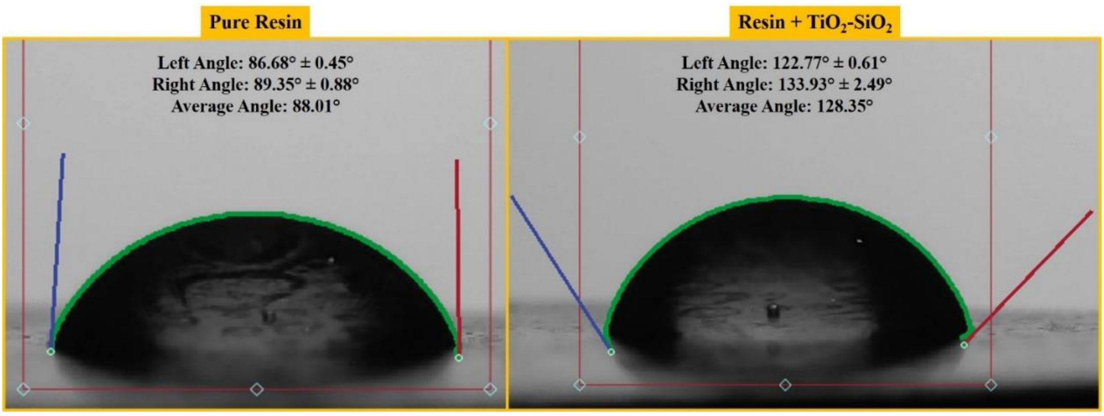


Fig. 6. The visual representation of the self-cleaning test specimens on 3D printer product.

The results of contact angle testing between the test specimens and distilled water to observe the hydrophobic properties of the material can be seen in Fig. 5 and Fig. 6. Hydrophobicity is indicated by a contact angle above 90°, and for superhydrophobic surfaces, the contact angle will be greater than 150°. Conversely, a contact angle below 90° indicates that the specimen has hydrophilic properties. The higher the hydrophobicity of the tested specimen, the more it signifies the presence of self-cleaning properties in the material. In Fig. 5, on the left side, the hydrophobicity test on specimens without coating is shown. The obtained contact angle from the test results is $\theta = 86.16°$. Then, for the coated test specimen (middle sample in the image), the resulting contact angle is $\theta = 107.34°$. This value further increases in the testing of specimens with both coating and TiO_2-SiO_2 nanocomposite as a filler, showing a contact angle value of $\theta = 127.95°$. From these test results, it can be concluded that the application of coating and the addition of TiO_2-SiO_2 nanocomposite as a filler have an enhancing effect on the hydrophobic properties of the material. In other words, this also indicates an improvement in the self-cleaning properties of the material.

In the latest self-cleaning test for the 3D printer specimen, the results can be seen in Fig. 6. For specimens without filler (left image), the contact angle formed between the specimen and distilled water is $\theta = 88.01°$. Then, there is an increase in the contact angle to $\theta = 128.35°$ in the test specimen using TiO_2-SiO_2 nanocomposite as a filler in the resin (right image). This indicates that adding TiO_2-SiO_2 nanocomposite as a filler can enhance the hydrophobic properties of the test specimen, thereby validating the presence of self-cleaning properties in the test specimen. These results align with prior research that utilized TiO_2-SiO_2 as a coating material for gypsum board [14], making it superhydrophobic and the research on TiO_2/SiO_2-silane, which is used to create a thin film coating that generates a superhydrophobic surface on aluminum alloy [15]. This indicates that the characteristics of the TiO_2-SiO_2 nanocomposite are consistent with other studies. They also confirm that the TiO_2-SiO_2 nanocomposite has the ability to improve hydrophobic properties, opening the door to self-cleaning and anti-corrosion capabilities due to its hydrophobic characteristics.

CONCLUSION

Responding to the increasing demand for innovative materials, this study focuses on developing self-cleaning properties in metal coatings and 3D printing resins using TiO_2-SiO_2 nanocomposites as fillers. The synergistic interaction between titanium dioxide (TiO_2) and silicon dioxide (SiO_2) has proven to be promising in enhancing self-cleaning capabilities. The research successfully demonstrates the potential of TiO_2-SiO_2 nanocomposites as fillers, both in metal coatings and UV-tough 3D printer resin. Visual results and contact angle measurements (θ = 127.95° for coated specimens mixed with TiO_2-SiO_2 nanocomposite and θ = 128.35° for 3D printer specimens with TiO_2-SiO_2 nanocomposite filler) show improved hydrophobic properties, validating the effectiveness of the self-cleaning mechanism. This study contributes not only to industrial applications but also advances scientific understanding, paving the way for future research in the field of innovative self-cleaning materials.

DAFTAR PUSTAKA

[1] G. Liu *et al.*, "A review of various self-cleaning surfaces, durability and functional applications on building exteriors," *Construction and Building Materials*, vol. 409. Elsevier Ltd, Dec. 15, 2023. doi: 10.1016/j.conbuildmat.2023.134084.

[2] L. Pinho, M. Rojas, and M. J. Mosquera, "Ag-SiO2-TiO2 nanocomposite coatings with enhanced photoactivity for self-cleaning application on building materials," *Appl Catal B*, vol. 178, pp. 144–154, 2015, doi: 10.1016/j.apcatb.2014.10.002.

[3] E. Koh and Y. T. Lee, "Hybrid nanocomposites of a molybdenum disulfide (MoS2) based hydrophobic filler for a robust self-cleaning effect," *Journal of Industrial and Engineering Chemistry*, vol. 96, pp. 294–306, Apr. 2021, doi: 10.1016/j.jiec.2021.01.033.

[4] M. Younas, A. Khan, D. Amjad, M. Abdul Rehman, A. Niamat Ali Farhad, and U. Mehmood, "Development of robust polyvinylidene fluoride (PVDF)-based self-clean coating for commercial solar cells/panels employing spray method," *Mater Lett*, vol. 355, Jan. 2024, doi: 10.1016/j.matlet.2023.135486.

[5] S. L. Nica *et al.*, "Tailoring the features of modified polysulfone/carbon filler nanocomposites to enhance physical properties for electronic applications," *Mater Today Chem*, vol. 33, Oct. 2023, doi: 10.1016/j.mtchem.2023.101711.

[6] T. Shahnaz *et al.*, "Graphene-based nanoarchitecture as a potent cushioning/filler in polymer composites and their applications," *Journal of Materials Research and Technology*, vol. 28, pp. 2671–2698, Jan. 2024, doi: 10.1016/j.jmrt.2023.12.108.

[7] I. Batool *et al.*, "Self-cleaning study of SiO2 modified TiO2 nanofibrous thin films prepared via electrospinning for application in solar cells," *Solar Energy*, vol. 268, p. 112271, Jan. 2024, doi: 10.1016/j.solener.2023.112271.

[8] D. Wang *et al.*, "Activated carbon fibers functionalized with superhydrophilic coated pDA/TiO2/SiO2 with photoluminescent self-cleaning properties for efficient oil-water separation," *J Hazard Mater*, vol. 465, p. 133373, Mar. 2024, doi: 10.1016/j.jhazmat.2023.133373.

[9] Q. Yuan, C. Shi, and T. He, "SiO2/TiO2 and PDMS modified self-cleaning coating and its application in decorative UHPC surface," *Ceram Int*, vol. 50, no. 4, pp. 6194–6206, Feb. 2024, doi: 10.1016/j.ceramint.2023.11.338.

[10] A. J. Haider, R. H. Al-Anbari, G. R. Kadhim, and C. T. Salame, "Exploring potential Environmental applications of TiO2 Nanoparticles," in *Energy Procedia*, Elsevier Ltd, 2017, pp. 332–345. doi: 10.1016/j.egypro.2017.07.117.

[11] R. Nandanwar, P. Singh, and F. Haque, "Synthesis and Characterization of SiO2 Nanoparticles by Sol-Gel Process and Its Degradation of Methylene Blue," *American Chemical Science Journal*, vol. 5, no. 1, pp. 1–10, Jan. 2015, doi: 10.9734/acsj/2015/10875.

[12] A. Rosales *et al.*, "Hydrophobic agents and pH modification as comparative chemical effect on the hydrophobic and photocatalytic properties in SiO2-TiO2 coating," *Appl Surf Sci*, vol. 593, Aug. 2022, doi: 10.1016/j.apsusc.2022.153375.

[13] M. Zhang, L. E, R. Zhang, and Z. Liu, "The effect of SiO2 on TiO2-SiO2 composite film for self-cleaning application," *Surfaces and Interfaces*, vol. 16, pp. 194–198, Sep. 2019, doi: 10.1016/j.surfin.2018.10.005.

[14] N. Jumrus *et al.*, "Durability and photocatalytic activity of superhydrophobic gypsum boards coated with PDMS/MTCS-modified SiO2-TiO2 NPs," *Mater Lett*, vol. 330, Jan. 2023, doi: 10.1016/j.matlet.2022.133342.

[15] J. Han *et al.*, "Robust superhydrophobic film on aluminum alloy prepared with TiO2/SiO2-silane composite film for efficient self-cleaning, anti-corrosion and anti-icing," *Mater Today Commun*, vol. 34, Mar. 2023, doi: 10.1016/j.mtcomm.2022.105085.