TRANSACTIONS ON ELECTRICAL AND ELECTRONIC MATERIALS
Vol. 18, No. 3, pp. 148-150, June 25, 2017

Regular Paper

pISSN: 1229-7607 eISSN: 2092-7592
DOI: https://doi.org/10.4313/TEEM.2017.18.3.148
OAK Central: http://central.oak.go.kr

Characterization of a Functional Coating Film Synthesized on the Ceramic Substrate for Electrical Insulator Application according to Coating Method

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Received March 23, 2017; Revised April 3, 2017; Accepted April 6, 2017

For the improvement of the anti-fouling features of porcelain electrical insulators, in this study, the surface of an insulator was coated with a functional material to expand the insulator's self-cleanness. The anti-fouling and mechanical features of the functional film coating of ceramic substrates made from components like an electrical insulator were analyzed. The coating methods that were used were spray coating, dip coating, and fabric coating. Following the coating, the contact angle of the coated surface was measured, revealing that the spray coating method offered the lowest angle (13.7°) and a strong hydrophilic feature. The anti-fouling analysis showed that the anti-fouling features improved as the contact angle decreased. The mechanical properties – hardness and adhesion – were both excellent at 9H and 5B, respectively, regardless of the coating method that was used.

Keywords: Electrical insulator, Functional coating, Self-cleaning, Anti-fouling, Coating method

1. INTRODUCTION

Of the existing electrical insulators, the porcelain insulator, a perfect inorganic material, offers excellent insulation capacity and strong surface durability against ultraviolet light or flame discharge. Thus, it has long been used as an electrical insulator [1]. A major issue with their use, however, is that impurities adhere onto their surfaces, causing contamination [2,3], and subsequently, flashovers [4,5]. The insulation capacity loss of such insulators triggers accidents each year, including severe human and property damage. To prevent such accidents, the contaminants adhering onto the insulators' surfaces should be removed [6] to lengthen the insulator life span and prevent the lowering of the insulators' insulation performance. Not all the contaminants adhering onto the electrical insulators' surfaces can be removed by natural rainfall, and therefore contamination needs to be managed regularly. In particular, the insulators installed in electric railroad subway sections and in tunnel sections need to receive regular surface contamination treatment, increasing their maintenance costs. Thus, technologies designed for preventing contamination are needed without changing the current porcelain electrical insulator structure or shape, or using new materials. TiO_2-based photocatalysts [7,8] have a self-cleaning capacity and are used in many areas requiring the prevention of contamination, but photocatalysts cannot exercise their functions in areas without light, such as in underground and tunnel sections.

This study investigated our development of different methods of improving the anti-fouling features of insulators by coating them with a functional thin film with a self-cleaning function that works even without light. The functional film coating methods that can be utilized for the rugged insulator surface were used, and the anti-fouling and mechanical features were analyzed by coating method.

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2. EXPERIMENTS

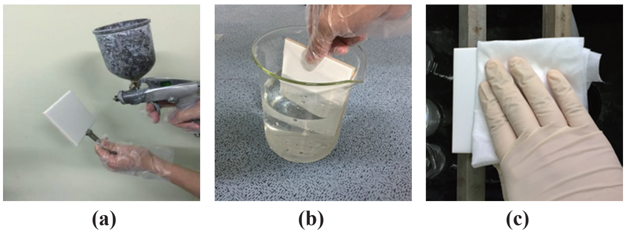

Fig. 1. The three coating methods that were used in this experiments, (a) spray coating, (b) dip coating, and (c) fabric coating.

Samples were prepared using 100×100 mm ceramic substrates that were manufactured using components like porcelain electrical insulators. The ceramic substrate surface was cleaned before coating, by supersonically washing it using acetone, methanol, and deionized water for 10 minutes each, and then drying it using nitrogen gas. The dried substrate surface was coated with the functional film using spray, dip, and fabric coating. Of these methods, spray and dip coating can be conveniently used for heavily rugged surfaces like the insulator surface, and fabric coating can be conveniently used for the existing installed insulators. These coating methods are presented in Fig. 1.

To improve the durability of the functional film coating, the samples were subjected to a 300℃ plasticity process in an oven. As a result, the samples' anti-fouling features were analyzed using a permanent marker. A standard hardness testing method (ASTM D3363) was performed using a surface hardness tester (CT-PC1, Coretech). For the hardness testing pencil (Mitsubishi, Japan), the following were used: H-9H, F, HB, and B-6B. Also, a standard adhesion testing method (ASTM D3359) was employed using transparent tape (3M, South Korea). A contact angle analyzer (Phoenix 300 Touch, S.E.O.) was used to check the wettability of the film.

3. RESULTS AND DISCUSSION

Contact angle measurements have been used in various applications, such as in surface tension measurements, in the determination of the liquid-solid adhesion quality, and in surface property analyses. Many studies have been conducted of late on surface properties such as superhydrophobicidics and superhydrophoilicidics, due to their prospective applications in self-cleaning, antifouling, nanofluidics, and electrowetting [9]. A low contact angle generally indicates that the material's surface has high wettability or hydrophilicity and high surface tension energy. Conversely, a high contact angle shows that the material's surface has low wettability or hydrophobicity and low surface tension energy.

Figure 2 presents the measured contact angle images, where (a) is an uncoated ceramic substrate's contact angle image. Its contact angle was measured as 34.4°. Spray coating, Fig. 2(b), offered the lowest contact angle (13.7°). All of the coating cases offered lowered contact angles compared to the uncoated one. This is presumably because the functional film coating made the ceramic substrate surface hydrophilic.

To assess the anti-fouling features by coating method, the ceramic substrate surface was marked using a permanent maker, and was then sprayed with water to induce it to react thereto. The consequent measured anti-fouling features by coating method are presented in Fig. 3.

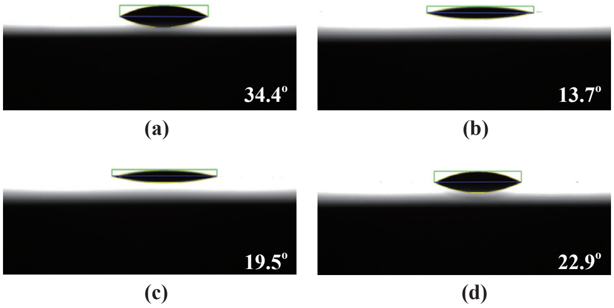

Fig. 2. Surface contact angle by coating method, (a) uncoated substrate, (b) spray-coated substrate, (c) dip-coated substrate, and (d) fabric-coated substrate.

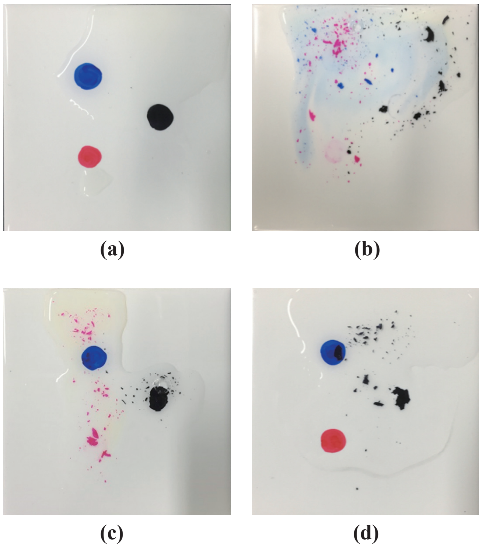

Fig. 3. Anti-coating feature by coating method, (a) uncoated substrate, (b) spray-coated substrate, (c) dip-coated substrate, and (d) fabric-coated substrate.

Figure 3(a) presents an uncoated ceramic surface, which did not react to water spraying. By contrast, all the coated samples reacted with water, destroying the contaminants. The spray coating method presented the most excellent anti-fouling features. This, as confirmed with the contact angles above, allowed the spray coating method to have the lowest contact angle and thus strongest hydrophilic features. We conclude that these features present an excellent self-cleaning capacity against impurities.

The film coating's hardness was measured using a pencil hardness gauge. The pencil hardness classes were set as 9H-1H, F, HB, and 1B-6B, of which 9H was the strongest. Figure 4 presents the measured hardness of the functional film by coating method. The pencil-drawn line on the coated surface was erased, and then the surface status was examined to assess the hardness of the film coating [10]. The measurement results revealed that all the three coating methods offered the highest hardness (9H).

The functional film's adhesion was measured by coating method. A lattice line was drawn on the coated ceramic substrate, and a transparent tape was attached thereto and then removed. Thus, the adhesion was assessed according to the lattice line exfoliation degree. The line-to-line distance was 1~2 mm. If the lattice line was clean, the adhesion was 5B; if the lattice line exfoliation degree was under 5%, the adhesion was 4B; if 5~15%, 3B; if 15~35%, 2B; if 35~65%, 1B; if over 65%, 0B [11].

Figure 5 presents the adhesion measurement results. All the three coating methods offered the highest adhesion (5B).

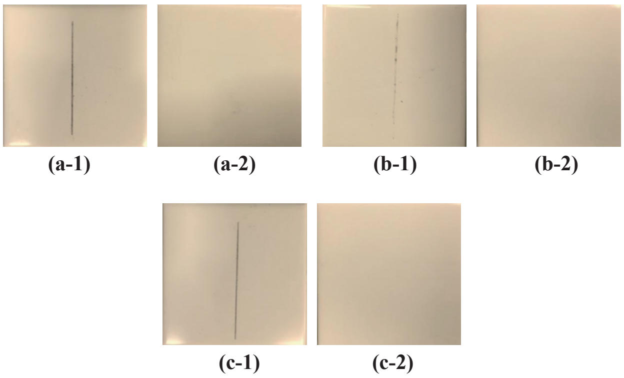

Fig. 4. Measurement of surface hardness by coating method: (a-1) pencil lines drawn on the spray-coated surface, (a-2) after erasing the pencil line traces on the spray-coated surface; (b-1) pencil lines drawn on the dip-coated surface, (b-2) after erasing the pencil line traces on the dip-coated surface; and (c-1) pencil lines drawn on the fabric-coated surface, (c-2) after erasing the pencil line traces on the fabric-coated surface.

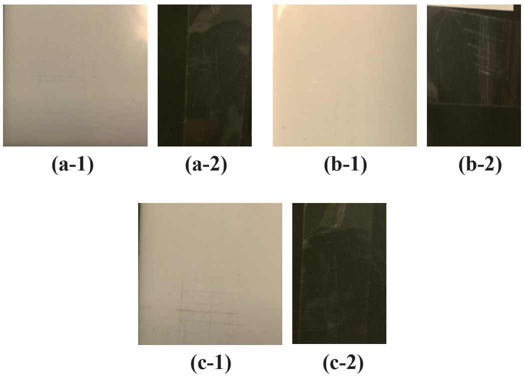

Fig. 5. Measurement of adhesion by coating method: (a-1) lattice lines drawn on the spray-coated surface, (a-2) tape attached to and detached from the spray-coated surface; (b-1) lattice lines drawn on the dip-coated surface, (b-2) tape attached to and detached from the dip-coated surface; and (c-1) lattice lines drawn on the fabric-coated surface, (c-2) tape attached to and detached from the fabric-coated surface.

4. CONCLUSIONS

To improve the anti-fouling features of the porcelain electrical insulator, a functional film coating method was applied to the insulator surface. Using ceramic surfaces with the same component as the porcelain electrical insulator, three coating methods – spray, dip, and fabric coating – were experimented with. After the experiment, the coated surface's contact angle, cleanness, hardness, and adhesion were assessed to test its functional features. Spray coating showed the lowest contact angle and strongest hydrophilic surface. The anti-fouling features were measured, revealing that regardless of the coating method that was used, the anti-fouling features improved, and in particular, as the contact angle decreased, the self-cleaning features improved. All the coating methods offered excellent mechanical hardness and adhesion of the film coating. The proposed coating technology can be used in electrical insulators to prevent contamination and to enhance maintenance efficiency and safety. It can also be used in all electrical devices, which need prevention from contamination, in addition to electrical insulators.

REFERENCES

[1] R. A. Islam, Y. C. Chan, and M. F. Islam, *Mater. Sci. Eng.*, B., **106**, 132 (2004). [DOI: https://doi.org/10.1016/j.mseb.2003.09.005]

[2] P. J. Lambeth, *Proc. Inst. Electr. Eng.*, **118**, 1107 (1971). [DOI: https://doi.org/10.1049/piee.1971.0245]

[3] R. S. Gorur, E. Cherney, C. de Tourreil, D. Dumora, R. Harmon, H. Hervig, B. Kingsbury, J. Kise, T. Orbeck, K. Tanaka, R. Tay, G. Toskey, and D. Wiitanen, *IEEE Trans. Power Delivery*, **10**, 924 (1995). [DOI: https://doi.org/10.1109/61.400837]

[4] K. K. Yu, G. J. Zhang, G. Q. Liu, X. P. Ma, and G. X. Li, *IEEE Trans. Dielectr. Electr. Insul.*, **15**, 1464 (2008). [DOI: https://doi.org/10.1109/TDEI.2008.4656257]

[5] R. Sundararajan and R. S. Gorur, *IEEE Trans. Dielectr. Electr. Insul.*, **3**, 113 (1996). [DOI: https://doi.org/10.1109/94.485522]

[6] Y. Z. Lv, C. R. Li, F. C. Wang, Y. F. Du, Y. J. Yang, Y. P. Liu, and W. Cai, *Proc. IEEE 9th International Conference on the Properties and Applications of Dielectric Materials* (Harbin, China, 2009) P. 158. [DOI: https://doi.org/10.1109/ICPADM.2009.5252481]

[7] K. Woan, G. Pyrgiotakis, and W. Sigmund, *Adv. Mater.*, **21**, 2233 (2009). [DOI: https://doi.org/10.1002/adma.200802738]

[8] C. W. Zou and W. Gao, *Trans. Electr. Electron. Mater.*, **11**, 1 (2010). [DOI: https://doi.org/10.4313/TEEM.2010.11.1.001]

[9] G. Bracco and B. Holst, *Surf. Sci. Tech.*, **51**, 333 (2013). [DOI: https://doi.org/10.1007/978-3-642-34243-1]

[10] A. K. Tiwari, H. Kumar, R. Bajpai, and S. K. Tripathi, *J. Chem. Pharm. Res.*, **2**, 172 (2010).

[11] M. E. McKnight, J. F. Seiler, T. Nguyen, and W. J. Rossiter, *J. Prot. Coat. Linings.*, **12**, 82 (1995).