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Self-cleaning cotton textiles enhanced with nanotechnology

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Abstract

Cotton textiles gain self-cleaning properties through nanotechnology. The concept of self-cleaning is inspired by natural phenomena observed in various surfaces, such as lotus leaves. Lotus leaves possess a hydrophobic surface due to waxy coatings, allowing them to thrive in dirty environments while maintaining purity. Nanoparticles like titanium dioxide (TiO2) are used in textile finishing to achieve self-cleaning abilities. When exposed to UV light, TiO2-coated cloth exhibits photocatalytic capabilities that break down stains and colors. The two primary methods of self-cleaning are hydrophobicity and hydrophilicity, where water rolling droplets and sheeting water clean hydrophobic surfaces, while hydrophilic materials chemically break down dirt when exposed to sunlight. The self-cleaning mechanism of lotus leaves is attributed to their super-hydrophobic nature, hierarchical structures, and microscopic bumps that allow water droplets to remove contaminants.

Keywords: Cotton textiles, nanotechnology, self-cleaning properties, titanium dioxide (TiO2), photocatalytic capabilities

Introduction

Cotton textiles are regarded as one of the most significant textile fibers in the world, With several benefits over all other types of textile fibers. Nanotechnology allows to this textile textiles to gain a variety of qualities like self-cleaning properties. [1-8]

The self-cleaning notion originated from natural phenomena that may be observed on fish scales, lotus leaves, rice leaves, butterfly wings, and other surfaces.

Lotus leaves are a particular kind of plant that can thrive in dirt without losing their purity. The lotus leaves have an exceptionally hydrophobic surface due to their waxy coatings. [9, 10]

Several types of nanoparticles with special qualities have been used in the last several decades to create high-performance fabrics. The intriguing qualities of titanium dioxide (TiO_2) nanoparticles, such as their optical, catalytic, long-term stability, and non-toxicity, make them widely valued. Additionally, its use in textile finishing yields self-cleaning. [11]

The self-cleaning qualities of Cotton textile made possible by photoactive titanium dioxide (TiO_2) coating have drawn a lot of interest. When exposed to UV light, the titanium dioxide (TiO_2)-coated cloth demonstrates significant photocatalytic capabilities and breaks down stains and colors. And other photocatalysts such as zinc dioxide (ZnO), tungsten dioxide (WO_3) and carbon dioxide (CO_2). [11, 12]

Therefore, it can be said that There are two primary methods by which can self-cleaning: hydrophobicity and hydrophilicity. Water causes hydrophobic and hydrophilic surfaces to clean themselves by removing dirt by rolling droplets and sheeting water like what happens in lotus leaves. And also hydrophilic materials also possess an attribute that can help them chemically break down the dirt that has been adsorbed when exposed to sunlight. This process is known as hydrophilic photocatalytic coating by using photocatalysts. [2, 9]

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The mechanism of the lotus leaves

The holy lotus (Nelumbo nucifera), a radiantly beautiful aquatic perennial that has greatly influenced the religions and civilizations of India, Myanmar, China, and Japan, is where the tale of self-cleaning materials begins in nature.

The lotus is highly esteemed due to its remarkable purity. Although it develops in murky water, its leaves appear to be clean and stand meters above the water when they emerge. Rainwater removes dirt from lotus leaves more easily than from any other plant, and drops of water on them have an otherworldly sheen. [13]

Because of lotus plant superhydrophobic leaves, which have tiny bumps all over their surface and are crucial to the plant's ability to reject water, lotus are able to clean themselves. An additional layer of rough nanoscopic wax crystals applied to these bumps amplifies the impact. It lets the drops of water run across, washing away the filth. [9]

It was aware from elementary physics classes that the leaves should be water-hating only by virtue of their waxiness, but lotus plant has different properties the combination of the leaf surface's waxiness, hierarchical structures for leaves and the tiny microscopic bumps (a few microns in size) covering it is what gives lotus its effect. It was aware from elementary physics classes that the leaves should be water-hating only by virtue of their waxiness, but in lotus plant when the water droplets on the leaves roll off, any contaminants are removed from their surfaces, resulting in self-cleaning. It has been noted that the naturally super-hydrophobic and self-cleaning leaves have a hierarchical structure. [13, 14]

The Contact angle between drop liquid and the surface of fabric

The surface contact angle and the self-cleaning phenomena are connected. This angle is measured between the fabric's surface and the drop liquid surface. If the contact angle is referred to as a hydrophilic surface, in general Any surface that has a contact angle (CA) less than 90° is considered hydrophilic. In a similar vein, a surface is considered hydrophobic if its water contact angle is greater than 150°, and ultra (super) hydrophobic if its contact angle is close to zero. For instance, it is relatively simple for the droplets to roll off the surface (lotus leaves) when the droplet contact angle becomes closer to 180°. [10, 15, 16]

Water-Repellent Plant Surfaces

Any ecosystem have plants with water-repellent leaves that makes its leaves clean although their unclean environment, and marsh plants greatly benefit from this trait. Aquatic or semi-aquatic habitats are defined by high air humidity and the availability of water, which supports a large number of pathogenic organisms. Most aquatic and semi-aquatic plants are delicate herbs with thin cuticles, making them susceptible to infection. The plants reduces risk of injury by creating a water-repellent surface that is cleansed with every precipitation and preventing the adhesion of water required for pathogen germination, plants lower their risk of harm. [17, 18]

Although plants and insects have different natural, they can both benefit from the water-repellent phenomena. The Insects like (butterflies) with water-repellent and self-cleaning wings, can lessen the effects of wind, rain, fog, dew, and dust. [19, 20]

Types of Coatings

Hydrophobic coatings (Lotus Effect)

Nature has already perfected advanced method for using physics and chemistry to produce hydrophobic and self-cleaning surfaces. The finest example of a surface that cleans itself is "lotus leaves".

The lotus plant, whose leaves are well-known for their capacity to self-cleaning by resisting water and dirt, is the model for the idea of hydrophobic surfaces. Because dirt particles are unable to attach surfaces, rain or a quick water washing will eliminate them. A cleaning surface with an extremely low roll off angle and a water contact angle higher than 150.When water passes over these surfaces, it rolls off with ease and thoroughly cleans the surface. When a surface possesses both of these characteristics, it's referred to be super-hydrophobic or ultra phobic.

Hydrophobic surfaces are not just water-repellent but also odor, dirt, and microbe-repellent. And it is not only the lotus plant that has this characteristic, but there are many plants that maintain their cleanliness through flowing drops of water. For this reason, it is essential to know how water droplets behave on a surface while producing self-cleaning fabrics. [21, 22]

Hydrophilic coatings

The self-cleaning qualities of plant leaves gave rise what known as to the Hydrophobic coatings "Lotus Effect", hydrophilic coatings which use sunlight have similarities to photosynthesis. Unlike this coatings, the second class of self-cleaning surfaces is hydrophilic rather than hydrophobic and does not rely on water movement to remove dirt. When these coatings are exposed to light, they chemically decompose dirt, a process known as "photocatalysis". Of course, the coating functions as a catalyst, not the incident light. [22]

Photocatalysts

The use of photocatalytic semiconductor techniques such as TiO_2, ZnO and other materials as catalysts is receiving more interest. Utilizing sunshine or indoor light, photocatalysts break down dirt and other pollutants. They are also inexpensive, non-toxic, and with the ability to solve environmental pollution problems. [20, 23, 24]

Technique of photocatalysis

The Photocatalytic technique in the presence of a catalyst is known as photocatalytic method. By using sunshine, this technique will break down the dirt molecules. Through the use of the photocatalyst-induced photoreaction, the organic pollutants will be broken down into air and water. [9]

The two primary phases of the photocatalysis process are reduction and oxidation. Electrons in the conduction band (CB) of a material will jump to the valence band (VB) through the bandgap leaving positive holes, when it is exposed to photons with energy equal to or greater than its bandgap. This process is known as (reduction). Reactive oxygen species (ROS) like O_2 and OH are created as a result of reduction, where electrons and holes are produced (oxidation). [25, 26]

Reactive oxygen species are potent oxidizers break down the majority of carbon-based molecules. These reactions eventually lead to the breakdown of organic molecules which include dirt, pollutants, and microorganisms, to produce water (H_2O) and carbon dioxide (CO_2). [27]

Photocatalytic

Titanium dioxide (TiO_2)

Titanium dioxide (TiO_2) is the most well-liked and extensively utilized semiconductor metal oxide because to its many advantages, including its optical and electrical qualities, low cost, strong photocatalytic activity, chemical stability, and non-toxicity. [2, 4, 7, 28-34]

There are three crystalline forms of titanium dioxide (TiO_2): rutile, anatase, and brookite. Rutile is the most stable of these three types, outlasting the other two. Under the action of heat, anatase and brookite would transform into rutile. While the structures of rutile and anatase are tetragonal, those of brookite are orthorhombic. [35]

It is commonly known that titanium oxide (TiO_2) and in particular nanometric anatase shows photoactivity, and it is a photocatalytic process that involves the creation of (electron-/hole+) pairs when exposed to UV light. Although rutile (TiO_2) is more photo catalytically active than anatase (TiO_2), combining the two crystal forms can improve photocatalytic performance over using only one of them alone. [36, 37]

Generally, Photocatalytic activity rises as (TiO_2) particle size is lowered to the nanoscale for two reasons: first, the light band-gap expands for quantum size, and second, the effective surface area is increased. Due to their photocatalytic properties of (TiO_2)-based coatings have garnered attention and are frequently utilized in antibacterial, stain removal, anti-ultraviolet, self-cleaning glass, lithium batteries, photocatalysts and paint applications [23,24,26].

In particular, the most often used photocatalyst to finish textiles is nano titanium dioxide. For example, (TiO_2) NPs made using the (sol-gel) technique have a simple preparation procedure, tiny particle size, high purity, and good homogeneity. These properties may both increase the photocatalytic efficiency and UV protection performance of cotton fabric at the same time. [38]

Despite all these advantages, it showed some drawbacks only in the presence of UV light can nano-(TiO_2) exhibit photocatalytic activity. Furthermore, the poor efficiency of titania is caused by the high electron-hole recombination rate. Attempts were made to solve this issue by combining titanium dioxide (TiO_2) with a second component. for example, karimi and colleagues treated cellulose textiles with (Ag/TiO_2) nanocomposite and saw a considerable increase in the fabric's antibacterial and self-cleaning capabilities. [39]

Zinc oxide (ZnO)

Although both titanium dioxide (TiO_2) and zinc oxide (ZnO) are semiconductors used in the field of photocatalysis and they are similar in low cost, high oxidative capacity, chemical and physical stability and easy availability. But (ZnO) differs from (TiO_2) in that (ZnO) has a considerable possibility in delivering electrical photonic and spin-based functionality (spintronics), because of its huge exciton binding energy of about ~ 60 meV and extremely broad band gap of (3.37eV). This qualifies it for use in both existing and anticipated high-tech applications, including those in ceramics, optical coatings, gas sensors, varistors, high-speed and display devices, photocatalysts, and photovoltaics. [40]

Zinc oxide (ZnO) can absorb light at (376 nm). The wave length of ultra violet light is (376 nm) and zinc oxide is capable of absorbing this light. Zinc oxide's photo-catalytic characteristic enables it to function as antibacterial and self-cleaning agents for fabrics when exposed to ultraviolet light, as well as providing UV blocking capabilities for cosmetic goods. [41]

Other Photocatalytic

Zirconium oxide (ZrO_2), (WO_3) and (CO_2) are examples of other photocatalysts that may be employed, two-dimensional nanosheets like graphitic carbon nitride ($g-C_3N_4$) and bismuth oxyiodide (BiOl) have also been used to create self-cleaning textiles. [42]

These photocatalytic' primary purpose is removing stains and pollutants from textiles by using the photocatalytic activity of integrated nanomaterials such as Zinc oxide (ZnO) and Titanium dioxide (TiO_2), in the right kind of light. Nevertheless, this technology needs for UV light to activate the self-cleaning capability. [42]

Self-Cleaning on Fabric

One of a human's characteristics is to wear clothes. Human skin has to be protected from the elements such as heat, cold, and rain. Humans utilize clothes as a social tool to express their culture, but more lately, the textile industry has focused on non-clothing textile applications, such as modern textile. [7, 43-47]

Modern textiles are primarily used for performance qualities and technical functions; aesthetics are not as important. By applying nanoparticles to textiles, modern textiles have proven useful in a variety of applications such as self-cleaning, water resistance (hydrophobic), and stain resistance [31,32]

A novel idea for very durable, self-cleaning textiles is made possible by nanotechnology. Furthermore, a coating of nanoparticles on textiles won't change their breathability or tactile feel through photocatalytic layers since solar irradiation destroys organic material (such as dirt, contaminants, and microorganisms) because of a layer of nanocrystalline titanium dioxide. [48]

Cotton fabric can also be given a hydrophobic quality by applying a thin layer of plasma that is nanoparticulate. To increase a cotton fabric's ability to resist water, a hydrophobic nanoparticulate coating was sprayed using the audio frequency plasma of particular fluorocarbon chemicals. The roughness of the fabric's surface produced super hydrophobicity without compromising cotton fabric's softness or abrasion resistance. [48]

Research is being done on the next two methods to make clothing self cleaning. A photocatalytically active coating comprising a photocatalytically active oxide of a transition metal (MO) or (MO_2), such as zinc oxide (ZnO) or titanium dioxide (TiO_2), can provide textile materials a self-cleaning effect or another method for creating self-cleaning materials uses nanocrystals to modulate surface contact and wettability, this rendering the surface water- or oil-repellent. Compared to the titanium dioxide coating, this is a whole different notion Scientists have developed a coating that can be incorporated into almost any type of cloth the coating, which is a polymer film combined with silver nanoparticles, causes dirt and other materials to bounce off the fabric's small bumps, Thus, the idea of self-cleaning textiles keeps bringing in new research and development opportunities. [43, 49-51]

Conflict of Interest

There is no conflict of interest in the publication of this article.

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References

1. Lie, D. Visual studio and sound, (2024).

2. Diaa, M. and Hassabo, A.G. Self-cleaning properties of cellulosic fabrics (a review), *Biointerf. Res. Appl. Chem.*, **12**(2) 1847 - 1855 (2022).

3. Attia, E.F., Helal, T.W., Fahmy, L.M., Wahib, M.A., Saad, M.M., Abd El-Salam, S., Maamoun, D., Mahmoud, S.A., Hassabo, A.G. and Khattab, T.A. Antibacterial, self-cleaning, UV protection and water repellent finishing of polyester fabric for children wheelchair, *J. Text. Color. Polym. Sci.*, **20**(2) 181-188 (2023).

4. Mahmoud, M., Sherif, N., Fathallah, A.I., Maamoun, D., Abdelrahman, M.S., Hassabo, A.G. and Khattab, T.A. Antimicrobial and self-cleaning finishing of cotton fabric using titanium dioxide nanoparticles, *J. Text. Color. Polym. Sci.*, **20**(2) 197-202 (2023).

5. Tarek, D., Mohmoud, A., Essam, Z., Sayed, R., Maher, A., Maamoun, D., Abdel Salam, S.H., Mohamed, H., Hassabo, A.G. and Khattab, T.A. Development of wrinkle free and self-cleaning finishing of cotton and polyester fabrics, *J. Text. Color. Polym. Sci.*, **20**(2) 175-180 (2023).

6. Adel, M., Mohamed, M., Mourad, M., Shafik, M., Fathallah, A., Maamoun, D., Abdelrahman, M.S., Hassabo, A.G. and Khattab, T.A. Enhancing the self-cleaning properties of polyester fabric with rtv – silicone rubber, *J. Text. Color. Polym. Sci.*, **21**(1) 91-95 (2024).

7. Roshdy, Y.A., El-Shamy, M.N., Mohamed, H.A., Gaafar, Z.S. and Hassabo, A.G. Self-cleaning cotton textiles enhanced with nanotechnology, *J. Text. Color. Polym. Sci.*, - (2024).

8. S., S., A., S., A., S., S., A., Maamoun, D., Hassabo, A.G., Mahmoud, S.A. and Khattab, T.A. Self-cleaning finishing of polyester fabrics using znonps, *J. Text. Color. Polym. Sci.*, **21**(1) 103-107 (2024).

9. Saad, S.R., Mahmed, N., Abdullah, M.M.A.B. and Sandu, A.V. Self-cleaning technology in fabric: A review, IOP conference series: materials science and engineering, IOP Publishing, p. 012028 (2016).

10. Diaa, M. and Hassabo, A.G. Self-cleaning properties of cellulosic fabrics (a review), *Biointerf. Res. Appl. Chem*, **12**(2) 1847-1855 (2022).

11. Derakhshan, S.J., Karimi, L., Zohoori, S., Davodiroknabadi, A. and Lessani, L. Antibacterial and self-cleaning properties of cotton fabric treated with tio 2/pt, (2018).

12. Ahmad, I., Kan, C.-w. and Yao, Z. Photoactive cotton fabric for UV protection and self-cleaning, *RSC Adv.*, **9**(32) 18106-18114 (2019).

13. Forbes, P. Self-cleaning materials, *Scientific American*, **299**(2) 88-95 (2008).

14. Bhushan, B., Jung, Y.C. and Koch, K. Micro-, nano-and hierarchical structures for superhydrophobicity, self-cleaning and low adhesion, *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, **367**(1894) 1631-1672 (2009).

15. Ganesh, V.A., Raut, H.K., Nair, A.S. and Ramakrishna, S. A review on self-cleaning coatings, *Journal of Materials Chemistry*, **21**(41) 16304-16322 (2011).

16. Xu, Q., Zhang, W., Dong, C., Sreeprasad, T.S. and Xia, Z. Biomimetic self-cleaning surfaces: Synthesis, mechanism and applications, *J R Soc Interface*, **13**(122) (2016).

17. Neinhuis, C. and Barthlott, W. Characterization and distribution of water-repellent, self-cleaning plant surfaces, *Annals of botany*, **79**(6) 667-677 (1997).

18. Solga, A., Cerman, Z., Striffler, B.F., Spaeth, M. and Barthlott, W. The dream of staying clean: Lotus and biomimetic surfaces, *Bioinspiration & biomimetics*, **2**(4) S126 (2007).

19. Nguyen, S.H., Webb, H.K., Mahon, P.J., Crawford, R.J. and Ivanova, E.P. Natural insect and plant micro-/nanostructsured surfaces: An excellent selection of valuable templates with superhydrophobic and self-cleaning properties, *Molecules*, **19**(9) 13614-13630 (2014).

20. Chen, G., Cong, Q., Feng, Y. and Ren, L. Study on the wettability and self-cleaning of butterfly wing surfaces, *WIT Transactions on Ecology and the Environment*, **73** (2004).

21. El-Khatib, E.M. Antimicrobial and self-cleaning textiles using nanotechnology, *RJTA*, **16**(3) 156 - 174 (2012).

22. Rios, P., Dodiuk, H. and Kenig, S. Self-cleaning coatings, *Surface engineering*, **25**(2) 89-92 (2009).

23. Banerjee, S., Dionysiou, D.D. and Pillai, S.C. Self-cleaning applications of TiO2 by photo-induced hydrophilicity and photocatalysis, *Applied Catalysis B: Environmental*, **176-177** 396-428 (2015).

24. Nasr, M., Eid, C., Habchi, R., Miele, P. and Bechelany, M. Recent progress on titanium dioxide nanomaterials for photocatalytic applications, *ChemSusChem*, **11**(18) 3023-3047 (2018).

25. Yang, J., Wang, D., Han, H. and Li, C. Roles of cocatalysts in photocatalysis and photoelectrocatalysis, *Accounts of chemical research*, **46**(8) 1900-1909 (2013).

26. Tatarchuk, T., Peter, A., Al- Najar, B., Vijaya, J. and Bououdina, M. Photocatalysis: Activity of nanomaterials, *Nanotechnology in environmental science*, 209-292 (2018).

27. Samal, S.S., Jeyaraman, P. and Vishwakarma, V. Sonochemical coating of ag-TiO2 nanoparticles on textile fabrics for stain repellency and self-cleaning- the indian scenario: A review, *Journal of Minerals and Materials Characterization and Engineering*, **9**(6) 519-525 (2010).

28. El-Zawahry, M.M., Abdelghaffar, F., Abdelghaffar, R.A. and Hassabo, A.G. Equilibrium and kinetic models on the adsorption of reactive black 5 from aqueous solution using eichhornia crassipes/chitosan composite, *Carbohydrate Polymers*, **136** 507-515 (2016).

29. Kamel, M.Y. and Hassabo, A.G. Anti-microbial finishing for natural textile fabrics, *J. Text. Color. Polym. Sci.*, **18**(2) 83-95 (2021).

30. Mohamed, A.L., El-Naggar, M.E. and Hassabo, A.G. Preparation of hybrid nano-particles to enhance the electrical conductivity and performance properties of cotton fabrics, *Journal of Materials Research and Technology*, **12** 542-554 (2021).

31. Hassabo, A.G., Ragab, M.M. and Othman, H.A. Ultraviolet protection of cellulosic fabric, *J. Text. Color. Polym. Sci.*, **19**(1) 51-61 (2022).

32. Mohamed, A.L., El-Zawahry, M., Hassabo, A.G. and Abd El-Aziz, E. Encapsulated lemon oil and metal nanoparticles in biopolymer for multifunctional finishing of cotton and wool fabrics, *Indust. Crop. Prod.*, **204** 117373 (2023).

33. Hassabo, A.G., Khaleed, N., Shaker, S., Abd El-Salam, N.A., Mohamed, N.A., Gouda, N.Z. and Othman, H. Impact of various treatments on

printing wool techniques, *J. Text. Color. Polym. Sci.*, **21**(1) 75-86 (2024).

34. Noman, M.T., Ashraf, M.A. and Ali, A. Synthesis and applications of nano-TiO2: A review, *Environmental Science and Pollution Research*, **26**(4) 3262-3291 (2019).

35. Karimi, L., Mirjalili, M., Yazdanshenas, M.E. and Nazari, A. Effect of nano TiO2 on self- cleaning property of cross- linking cotton fabric with succinic acid under UV irradiation, *Photochemistry and photobiology*, **86**(5) 1030-1037 (2010).

36. Ortelli, S., Blosi, M., Albonetti, S., Vaccari, A., Dondi, M. and Costa, A. TiO2 based nano-photocatalysis immobilized on cellulose substrates, *Journal of Photochemistry and Photobiology A: Chemistry*, **276** 58-64 (2014).

37. Pisitsak, P., Samootsoot, A. and Chokpanich, N. Investigation of the self-cleaning properties of cotton fabrics finished with nano-tio.

38. Zhang, G., Wang, D., Yan, J., Xiao, Y., Gu, W. and Zang, C. Study on the photocatalytic and antibacterial properties of TiO2 nanoparticles-coated cotton fabrics, *Materials*, **12**(12) 2010 (2019).

39. Nazari, A. Superior self-cleaning and antimicrobial properties on cotton fabrics using nano titanium dioxide along with green walnut shell dye 20: 2503–2509, (2019).

40. Georgekutty, R., Seery, M.K. and Pillai, S.C. A highly efficient ag-ZnO photocatalyst: Synthesis, properties, and mechanism, *The Journal of Physical Chemistry C*, **112**(35) 13563-13570 (2008).

41. Nourbakhsh, S. Self-cleaning and antibacterial properties of ZnO nanoparticles on cotton fabric treated with maleic acid, *Materials Science*, **27** 90-95 (2021).

42. Pakdel, E., Zhao, H., Wang, J., Tang, B., Varley, R. and Wang, X. Superhydrophobic and photocatalytic self-cleaning cotton fabric using flower-like n-doped TiO2/pdms coating, *Cellulose*, **28** 1-14 (2021).

43. Nath, S. and Dutta, A. Application of nanotechnology in textile industry: A review, *J. Text. Assoc.*, **85/1** 40-47 (2024).

44. Abou-Okeil, A., Eid, R.A.A. and Amr, A. Multi-functional cotton fabrics using nano-technology and environmentally friendly finishing agents, *Egy. J. Chem.*, **60**(Conference Issue (The 8th. Int. Conf. Text. Res. Div., Nat.Res. Centre, Cairo)) 161- 169 (2017).

45. Hassabo, A.G., Elmorsy, H., Gamal, N., Sediek, A., Saad, F., Hegazy, B.M. and Othman, H. Applications of nanotechnology in the creation of smart sportswear for enhanced sports performance: Efficiency and comfort, *J. Text. Color. Polym. Sci.*, **20**(1) 11-28 (2023).

46. Abd El-Aziz, E., El-Desoky, S.S., El-Bahrawy, G.A., Ezat, H.A., Abd El-Rahman, R., abdelraouff, A. and Hassabo, A.G. Nanotechnology to improve the performance of silk fabric, *J. Text. Color. Polym. Sci.*, **21**(1) 33-38 (2024).

47. Mohammed, N., Nawar, S.H., Etawy, M.S., Nassar, G.E. and Hassabo, A.G. Nanotechnology and its applications in industry and product design, *J. Text. Color. Polym. Sci.*, **21**(2) 273-284 (2024).

48. Wong, Y., Yuen, C., Leung, M., Ku, S. and Lam, H. Selected applications of nanotechnology in textiles, *Autex Research Journal*, **6** (2005).

49. Qian, L. and Hinestroza, J.P. Application of nanotechnology for high performance textiles, *JTATM*, **4**(1) 1-7 (2004).

50. Asif, A.K.M.A.H. and Hasan, M.Z. Application of nanotechnology in modern textiles: A review, *Int. J. of Current Eng. and Technol.*, **8**(2) 226-231 (2018).

51. Hassan, B.S., Islam, G.M.N. and Haque, A.N.M.A. Applications of nanotechnology in textiles: A review, *Advance Research in Textile Engineering*, **4**(2) 1038-1047 (2019).