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Multifunctional textile facades for coastal city buildings

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Abstract

Textile building facades comprise a large area of unexplored potential that present large surface footprints in the archetype of the buildings, which is properly designed to solve multiple environmental issues at different levels. In the present work, the authors investigated the treatment of cotton/polyester blended fabrics with hybrid coatings based on zinc oxide, chitosan, Pyrovatex and room temperature vulcanized (RTV) silicone in one-bath pad-dry-cure technique. These treatments impart multifunctional properties, such as antibacterial finishing agents, fire retardant, water repellent, solar (UV) protections and self-cleaning, to cotton/polyester fabrics. All the required parameters and measurements are carried out and included in this paper.

Keywords: Textile facades; Flame retardant; UV protection; Self-cleaning; Antibacterial.

1. Introduction

Functional materials have been known to possess particular characteristics and functions. [1-27] Textile facades are a brand-new class of screens and fabric architecture that are used sparingly on the outside of buildings in modern architecture. Buildings of any age or construction may be swiftly and easily dressed. It may be applied to a wide range of structures, including office buildings, malls, sports arenas, and residential structures. The clear-span design, flexibility, speed of installation, ease of relocation, and portability are just a few of the beneficial characteristics of textile facades. They also require less upkeep, little labor, and a longer material life cycle. [28]

A composite material with interesting properties for buildings is created by combining polymeric coatings with fibrous structures (fabrics) based on high-performance synthetic fabric. This material has a high mechanical strength, the ability to support loads and its own weight, and is tear-resistant. [29] In order to obtain the appropriate level of strength, translucency, and impermeability, synthetic polymers like polyester, glass, and aramid are frequently employed as fabric materials. The yarns or fibers are interwoven in two mutually perpendicular directions (0° and 90°). Silicone, polyvinylidene difluoride (PVDF), polytetrafluoro ethylene (PTFE), and polyvinylchloride (PVC) have all been used as coatings. [30] Depending on the latency and functional requirements, several solutions are used.

In order to obtain technical materials as a sustainable alternative to steel and concrete, textile facade materials are functionalized with antibacterial (fungi) finishing agents, fire retardant, water repellent, thermal comfort and solar (UV) protections, air pollutants, chemical agents and abrasion, adverse atmospheric conditions (humidity, rain, snow, etc.), and providing geometrical stability to the fabric. [29, 31, 32] In order to produce antibacterial activity for environmentally friendly operations that may be carried out without hazardous textile chemicals, some compounds have

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been utilized. For antibacterial purposes, biomaterials like chitosan (chitin) have been used. Flame retardants are often applied to textiles by coating or spraying one side of the fabric (back coating) or by impregnating the textile material in a solution containing a flame retardant. [33-40] The prevention of photodegradation of the polymers, fibers, and technical textile goods is the goal of UV protection for technical textile materials. For UV protection, inorganic oxides like TiO_2, CeO_2, and ZnO are most frequently utilized. Due to the fact that sol-gel coatings are mostly made of inorganic and amorphous material, some chemical finishes make surfaces of materials hydrophobic and provide a water-repelling effect. [41-43] The sol-gel approach typically uses modified SiO_2 particles, although fluorocarbons, which are applied via a wet chemical process, [44, 45] are the most extensively used hydrophobic and oleophobic textile finishing technology.

2. Materials and Methods

2.1. Materials

Cotton/polyester blend fabric (35/65) was kindly obtained from El-Mahalla Company for Spinning and Weaving, El-Mahalla, Egypt. Pyrovatex (durable flame retardant) is provided by Huntsman Chemicals, Egypt.

Decoseal RTV-silicone rubber (water repellent finishing) is supplied by ADMICO, Egypt. [46, 47]

Chitosan (low molecular weight) and zinc oxide (nano powder, ≤50 nm particle size; >97%) are purchased from Sigma-Aldrich, Egypt. Other used auxiliaries as sodium alginate, calcium chloride and toluene are of laboratory grade and are all purchased from Al-Goumhoria Pharmaceutical Company, Egypt.

2.2. Methods

- Cotton/polyester blended fabrics of weight 12 gm are divided into 6 samples.
- Sodium alginate (low viscosity, conc.3%) is dissolved in 600 ml of distilled water with LR (1:50) at 80 °C within 10 min.
- The solution is divided into 6 beakers where chitosan is added to each beaker 5 wt% and Zinc oxide is added with 3 different concentrations which are (2, 5, 10) wt%.
- The samples are completely covered with the solution and stirred continuously at room temperature.
- After removing the samples, these chemicals are fixed by encapsulation process by using calcium chloride (10wt%) at room temperature within 15 min. After encapsulation, the RTV 15wt% and Pyrovatex 450 g/l are combined making silicone rubber.
- The RTV/Pyrovatex 20 ml is dissolved in 80 ml of toluene as an organic solvent. Keeping the samples under the solution with continuous stirring within 15 min. at room temperature.
- After removing the sample from the final solution and get rid of the excess of silicone, put the samples in a dryer within 10 min. at 60ºC.

2.3. Measurements and Analysis

2.3.1. Morphological Study

Using a Quanta FEG-250 (Czech Republic) and an accelerating voltage of 20 kV, a scanning electron microscope (SEM) is used to study the surface morphology and elemental analysis of the coated layer., magnifications range from 150x-1kx, working distance 13 mm and view field 925 µm.

2.3.2. Hydrophobicity screening

The contact angle was analyzed using OCA 15 EC (Data physics, Stuttgart, Germany).41. With 1 L of triple-distilled water and a 1 L/s dosing rate, contact angle characteristics were measured. To generate a flat surface, cloth substrates were attached to glass cover slips using double-sided adhesive tape.

2.3.3. Self-Cleaning Activity

The breakdown rate of methylene blue is used to evaluate the photocatalytic performance of cotton/polyester textile that have been pre- and post-treated (Aldrich, United States). Using a Cary Varian 300 ultraviolet-visible (UV-Vis) spectrophotometer in the wavelength range of 320-400 nm, the amount of ultraviolet transmission through textile was measured. The performance of the photocatalytic self-cleaning was evaluated by observing the methylene blue degradation under visible light at wavelengths greater than 410 nm. A fluorescent lamp (TC-L18W, AC230V-50 Hz, China) was used to provide visible light illumination at a distance of 5 cm and a light intensity of 44 W cm^2). To achieve an adsorption/desorption equilibrium between the photocatalysis and methylene blue under ambient circumstances, the samples are swirled for 30 minutes in a mixture of 1 g in 50 ml of an aqueous solution of methylene blue (10 mg/L at pH 6.5). After that, the samples are subjected to visible light radiation. A sample of roughly 5 mL of solution was obtained after each irradiation interval time, and it was analyzed using a spectrophotometer. By measuring the absorption maxima at 665 nm as a function of the irradiation period, the concentration of methylene blue was determined. The following equation was used to measure the photocatalytic degradation:

$$\text{Photocatalytic degradation} = \frac{(C_o - C_t)}{C_o} = \frac{(A_o - A_t)}{A_o}$$

Where A_o is the initial absorption, C_o is the initial methylene blue concentration, C_t is the concentration at various irradiation times, and A_t is the variable absorption at various irradiation times. [36, 48-55]

2.3.4. Ultraviolet Shielding

The AATCC 183 2010 UVA standard technique is used to calculate the ultraviolet protection factor (UPF). AATCC 183:2010 UVA Transmittance was used to measure the ultraviolet transmission through the cotton/polyester fabric, and the results showed outstanding UPF performance. [56]

2.3.5. Flame Retardancy

By using the standard (BS) 5438 (1989) approach, the flammability test is evaluated. The flammability test of the treated cotton/polyester fabrics is detected with char length 44 and 39 mm respectively, and char width was 17 mm. [33-36]

2.3.6. Antimicrobial Activity

The disc agar diffusion technique is used to examine the antibacterial properties of cotton/polyester. Staphylococcus aureus ATCC 6538-P (G+ve), Escherichia coli ATCC 25933 (G-ve), Candida albicans ATCC 10231 (yeast), and Aspergillus Niger NRRL-A326 were the four typical test organisms employed (fungus). In the case of bacteria and yeast, nutrient agar plates are frequently intensively infected with 0.1 ml of 105-106 cells/ml. To assess the antifungal effects, 0.1 ml (106 cells/ml) of the fungal inoculum was planted into potato dextrose agar plates. The inoculation plates were covered with 15 mm-diameter textile-treated discs. To allow for maximal diffusion, plates were then maintained at a low temperature (4°C) for 2-4 hours. The plates were then incubated for the bacteria at 37°C for 24 hours and for the organisms to develop as much as possible at 30°C for 48 hours in an upright posture. The diameter of the inhibition zone was used to measure the test agent's antimicrobial activity (mm). The experiment was run many times, and the average reading was recorded. [57-60]

3. Results and Discussion

3.1. Microscopic Observation of the fabric surface

Analyses at the microscopic level are crucial in nanotechnology. In order to provide a magnified image in nanoscale materials, scanning electron microscope is one of the most popular analytical tools. The resulting image has a three-dimensional appearance and can be used for nanostructure imaging, composition determination, physical property measurements, surface condition, purity, and the structure of uncoated fabrics. [48, 61-63] It frequently calls for sputter coating, which necessitates a vacuum environment, to cover the sample with metal. The surface morphology of textile and nano-coats can be directly seen using SEM. [63-65]

The surface of untreated cotton-polyester textile is particle-free microfibers. Figure 1 shows a thin film coat layer of hydrophobic nanoparticles on the surface of coated textile with various types of nanoparticles. It is clear that the nanoparticles are comparatively evenly distributed throughout the surface, covered in a thin layer of silica, [66, 67] and have a rough structure suitable for hydrophobic applications and antimicrobial applications. ZnO/Chitosan mix films developed an uneven surface that was covered in small, thick granules. Figure 1 shows that a homogeneous layer of RTV-silicone rubber was formed, [65, 68] which is what gave the treated textile their water-repellency. Particle size distribution and nanoparticle form are also studied using SEM images. [69-72] ZnO nanoparticles are verified in the treated cotton-polyester samples, where ZnO grains exhibit a greater size distribution and somewhat larger agglomerates. [73]

Because chitosan is a semicrystalline polymer and that deacetylation is often carried out in the solid state, the resulting structure is irregular. The straightforward chitosan film has a flat surface that is demonstrated in Figure 1. [74]

3.2. Hydrophobicity and Self-Cleaning Activity

Low surface energy and both nano- and micro-hierarchical surface roughness are acknowledged as powerful heuristics to achieve superhydrophobic property, which is essential to the production of waterproof materials.

The capacity to produce a thin layer of nanoparticles as a result of the Lotus effect increases the fabric surface's hydrophobic characteristics. The most commercially effective metal oxide nanoparticles are Pyrovatex and RTV-silicone, both of which use a unique self-cleaning process that combines an initial photocatalysis with a second hydrophobic step. Metal oxide nanoparticles that have been exposed to UV light release free electrons that interact with oxygen and water molecules in the atmosphere to form free radicals.

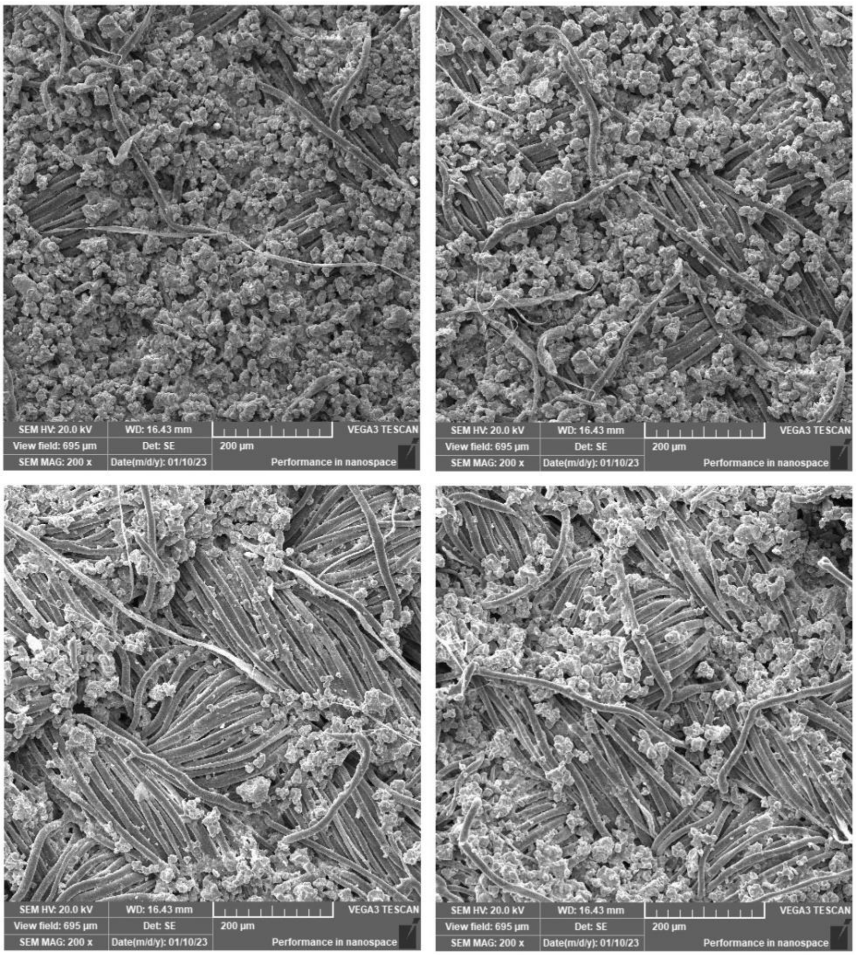

Figure 1. SEM images of cotton/polyester fabric coated with ZnO nanoparticles, chitosan and RTV-silicone rubber.

These free radicals have the power to break down organic material that has accumulated on the surface of the cloth. RTV silicone is a kind of silicone rubber that can be vulcanized at room temperature and may be cured with the aid of a catalyst like dibutyltin dilaurate. The properties of RTV silicone include good temperature, ageing, chemical (acid/base) resistance, good mechanical and thermal stress resistance, low viscosity and shrinkage, good hardness, and ease of use. In order to increase the flame retardancy, hydrophobicity, and durability of Pyrovatex due to the synergistic effect of nitrogen provided by trimethylolmelamine in the presence of phosphorous, Pyrovatex needs the least expensive and most effective trimethylolmelamine cross-linker. Additionally helpful for improving Pyrovatex's attachment to fabric's polymeric chains is trimethylol melamine.

As a surface with roughness was prepared by pad-dry-cure applied on the samples dip-coated in RTV/Pyrovatex solution, describing the creation of hydrophobic surface as opposed to using expensive substances, which are then applied by means of time-consuming and difficult procedures, the distribution of RTV/Pyrovatex on fibrous surface is homogeneous and detected at a low concentration. [75] Therefore, it is a technological difficulty to introduce a super/hydrophobic surface utilizing our straightforward, inexpensive method without needing sophisticated equipment. Furthermore, this straightforward approach may be used to produce substrates on a large scale for useful uses, such as superhydrophobic tents with flame resistance. The fabric surface may then be washed clean by water thanks to the hydrophobic effect produced by the metal oxide nanoparticles and RTV/Pyrovatex coating on the fabric surface. Using RTV/Pyrovatex solution and ZnO nanoparticles, the static contact angle measurements of untreated and treated cotton/polyester textiles were explored. [68, 76, 77] The contact angle of untreated cotton/polyester fabric was detected at 63.5°, whereas the contact angle of treated cotton/polyester fabric was detected at 125.3°.

3.3. Flame Retardancy

Proban and Pyrovatex finishing processes are two important flame-retardant treatments that are used in the creation of flame-retardant finishes on mixed fabrics as well as other cellulosic substrates.

Untreated cotton/polyester fabric failed the flammability test and burned completely, demonstrating the material's weak flame retardancy within 42 seconds. Localized burns that are particularly severe are caused by this hot, sticky, and melting material.

It is well known that RTV silicone cannot give cloth any flame retardancy on its own. However, the flame-retardant quality is significantly improved when RTV and Pyrovatex are combined with toluene. The fabric burning was stopped immediately by removing the fire source. Pyrovatex ACS standard cure at 450 g/L and RTV at 15 percent weight to cotton/polyester fabrics result in good flame retardancy. The char length of cotton/polyester fabric was detected at 44 mm, respectively, with char width of 17 mm.

3.4. Ultraviolet Protection

The chemical properties, physiochemical type of fibers, UV absorbers present, fabric structure (thickness, extension, porosity, moisture content), colour, and finishing applied to the fabric all affect how well textile materials block UV rays.

Depending on the substrate and its circumstances, numerous sorts of interactions can happen when UV light strikes textile materials. In general, it has been discovered that the concentration of metal zinc oxide nanoparticles, which function as UV absorbers, increases with increasing the UV protection of the treated materials. The cotton/polyester fibers are shielded from sunlight-caused photodegradation using UV absorbers. The impact is mostly determined by the fiber type and hygroscopicity as well as conditioning time, which cause swelling phenomena from moisture absorption, which lowers the interstices and, as a result, the UV transmission. However, water diminishes scattering effects since its refractive index is closer to that of the textile polymer. As a result, there is more UV transmission and a lower UPF when water is present.

The UV protection factor (UPF) and the percentage of the ultraviolet transmission are calculated using the transmission results. The findings show that the majority of treated samples had adequate UV protection. Due to their high refractive index, ZnO particles absorb and scatter UV light, producing the observed findings. Through the use of absorbance spectroscopy, the UV radiation shielding capabilities of untreated cotton/polyester textile were investigated. The results indicated UPF values of 20 and 15 for untreated fabrics, and 35 and 45 for treated fabrics, respectively. [73]

3.5. Antimicrobial Activity

Depending on the kind and amount of metal oxide nanoparticles present, the active agents can be chemically or physically integrated into a textile product to impart antimicrobial activity. Due to the effective photocatalytic action of ZnO nanoparticles, greater decrease of bacterial percent was exhibited by these particles. When exposed to light, electrons are stimulated up to the conduction band by photons with energies greater than the ZnO bond-gap. These overexcited electrons in the crystal's structural structure interact with air oxygen to produce free radical oxygen atoms that can destroy the bacterial cell membrane while also being able to oxidise and break down the bacterial cell wall.

Because of its polycationic nature, chitosan is also recognized as an antibacterial polysaccharide with the capacity to immobilize microorganisms. Its protonated amino groups obstruct bacteria' protein sequences, preventing further spread. Chitosan adheres to the negatively charged bacterial surface, disrupting and changing the permeability of the cell membrane. This permits substances to escape from the bacterial cells, which causes cell death. Additionally, mRNA, which is in charge of protein synthesis, can be inhibited by chitosan by binding to DNA inside of cells.

According to recent research, chitosan is more efficient than chitosan oligomers at preventing bacterial growth. [48] It has been suggested that the molecular weight of chitosan oligomers affects their antibacterial activity. Scientist Hans Christian Gram divided microorganisms into Gram-positive and Gram-negative categories based on the structural variations in their cell walls. Chemical reactions occur as a result of the enzymes found in the cell wall. Gram-positive organisms include Staphylococcus aureus (S. aureus), whereas Gram-negative organisms include Escherichia coli (E. coli.).

As was said in the experimental section, the viability is determined by the concentration of formazan that is produced when living microorganisms are present. As a result, the viability is directly correlated with the number of living bacteria.

The obtained results might be explained by local interaction at the nanoscale of several ZnO and CS action mechanisms on fungus and microbial cells. [61, 65]

With more ZnO nanoparticles disseminated in chitosan matrix, antimicrobial activity rises.

The survivability of S. aureus bacteria in the presence of composite coatings applied to cotton/polyester textile. The S. aureus bacteria exhibit a higher level of inhibition than the E. coli bacteria, with the similar pattern of decreasing bacterial viability with more ZnO nanoparticles contained in the chitosan matrix being seen. Similar to this, the antibacterial potential of Gram-positive S. aureus bacteria is more significant than that of Gram-negative E. coli bacteria. The two types of bacteria's cell walls have distinct compositions and structures, which might be the cause of their divergent behaviors. [61] In contrast to the Gram-positive bacterial wall, the cell wall of Gram-negative bacteria is made up of lipids, proteins, and lipopolysaccharides (LPS), which offers effective protection against the detrimental effects of chemical biocides.

Even while all of the samples under investigation show a considerable reduction in the viability of the bacterial species, the composite coatings put to cotton/polyester exhibit the most advanced reduction. This results from the coating solution's diverse interactions with distinct functional groups and varying fabric porosities, as well as wettability and capillary effects. Even though more composite coating is absorbed when using cotton/polyester fabric, the antibacterial activity is lower than when using cotton/polyester. This difference might be attributed to the lower concentrations of nanoparticles on the surface of porous cotton fibers. Pure cotton fibers are porous, which enables for greater quantities of particles to enter the fiber pores while less amounts stay on the surface. This reduces the quantity of ZnO nanoparticles and chitosan that come into contact with bacteria. [62] The ZnO/Chitosan nanocomposite sols under investigation's antibacterial activity For both E. coli and S. aureus bacteria, the sols impregnated in the disc paper put on the bacterially occulted surfaces killed the majority of the bacteria under and surrounding them, creating distinct zones of inhibition (clean regions with no bacterial growth) around them.

4. Conclusion

This study examines the current state of knowledge and research on the usage of textile facades with an emphasis on multifunctional thin-coating textile finishing applications. Generally, metal oxide nanoparticles, chitosan and both of Pyrovatex and RTV-silicone achieve satisfied properties. Flammability, UV protection, hydrophobicity and self-cleaning properties are found to be achieved with great efficiency by ZnO and RTV/Pyrovatex coatings. ZnO metal oxide nanoparticle and chitosan composite coatings have effective antibacterial properties and can lessen the viability of bacteria. The most sophisticated result is seen when composite coatings are used on cotton/polyester textile. Additionally, compared to Gram-negative bacteria E. coli, S. aureus, yeast (C. albicans), and fungus (A. Niger) have stronger antibacterial activity. The results are proved by studying surface morphology of cotton/polyester with scanning electron microscope (SEM), Cary Varian 300 UV-VIS spectrophotometer and Thermogravimetric analysis (FR).

5. Conflict of Interest

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

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