



Nanotechnology as a modern technique to impart both natural and synthetic fabrics anti-viral, anti-bacterial and water-repellent properties

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Abstract

Textile hanging is a crucial element in interior design, and the pandemic has highlighted the need for unique products with special properties, such as textile hangings that resist microbes. Cellulose fabric, a biopolymer found in plants, animals, minerals, algae, and fungus, is a critical raw material for various applications. Nanotechnology is rapidly growing in architecture and construction, particularly in coating surfaces for functional features like higher tensile strength, self-cleaning capacity, fire resistance, and more. Water repellent textiles are essential in various sectors, and superhydrophobic surfaces, inspired by nature's lotus surface, have gained interest in both academia and industry. Superhydrophobic textiles are created by coating nanoscale particles onto the fiber surface and then post-fluorinating it for low energy.

Keywords: Textile hanging; Nanotechnology; Water repellent textiles; anti-microbial, antiviral.

Introduction

Textile hanging and its design are considered as one of the most important elements in the interior design field that simulate the culture and the environment of the place and society. That is why it gains the attention of creative designers to produce a different way to the art. Due to the pandemic of coronavirus, the reaction between art and science became a must, in order to produce a unique product with special properties[1-5]

This thesis focused onto this idea, which mixes the art with the science, to produce a textile hanging that has the capability to resist microbes including bacteria and viruses specially corona virus, without any side effect or any distortion to the design[6-10]

Cellulose fabric

Cellulose is one of the most intriguing biopolymers, with an almost infinite supply [11]. It is a critical raw material for a variety of applications [12]. Because it is present in diverse places throughout nature, it is the most frequent, renewable, and biodegradable natural compound on the planet [11, 13, 14]. Plants are the most abundant source of cellulose, followed by animals, minerals, algae, and fungus [11, 13, 15].

Cellulose is thought to be the most abundant component in the cell walls of higher plants. It is found in pure form in a few plants[15], such as seeds and cotton hair, but the majority of it is mixed with lignin, hemicellulose, and other components, with cellulose accounting for the biggest percentage of these components[13].

Because of its adaptable structure, cellulose is widely employed in various items used in our daily lives such as paper, medicinal compounds, and textiles (such as cotton, rayon, and cellulose acetate [13, 15, 16].

Chemical structure of cellulose

Cellulose is classified as a polysaccharide [15]. The primary ingredient that forms cellulose is glucose. A single glucose unit is a hexose that can take one of two forms (Alpha or beta) depending on where the hydroxyl groups are located. Cellobiose is a repeating unit in cellulose linear polymer that consists of two units of glucose (Alpha and Beta) [11]. These units are joined together by β -(1-4)glycosidic linkages formed between the C-1 and C-4 of the glucose moieties[12]. Thus, cellulose is a 1,4- β -D-glucan, which is a condensation polymer of β -D-anhydro -glucopyranose with 1,4-glycosidic linkages [17]

There are three hydroxyl groups existing in each anhydroglucous unit. The primary hydroxyl group

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is in the position 6, whereas the two secondary hydroxyl groups are in the position 2 and position 3. the hydroxyl group in position 6 is more active than hydroxyl groups in position 2 and 3[15, 17].

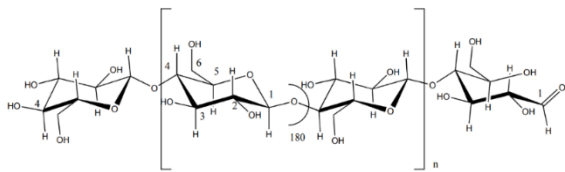


Figure 1. Molecular structure of cellulose representing the cellobiose unite as a repeating unit.

Physical structure of cellulose

Each liner chain has crystalline regions that range from perfect geometric packing of crystal lattice to paracrystalline regions that are short- and medium-range ordering in their lattice, and an amorphous zone that is randomly structured. The presence of hydroxyl groups leads to the formation of intermolecular and intramolecular hydrogen bonds, as well as the second force of Vander Waals attractions, which strengthen the cellulose structure[11, 17] These hydroxyl groups are responsible for the chemical reactivity[17], as well as the effect of the unique structure on the characteristics and reactivity of cellulose materials[15].

The reactivity of cellulose

The accessibility of hydroxyl groups influences the reactivity of cellulose, so the arrangement of cellulose chains influences the reactivity of cellulose, as in crystalline regions, the hydroxyl groups are not readily accessible to react and are completely inaccessible in some cases, so these are not reactive areas in cellulose, whereas in amorphous regions, the hydroxyl groups are highly accessible and easily reacted[17].

Because of the complex and unique structure of cellulose, as well as the presence of functional groups (hydroxyl groups) that allow chemical reactions to occur and are responsible for chemical reactivity, scientists were able to modify cellulose, such as chemical modifications, dyeing, and finishing.

Polyester Fiber

Polyethylene terephthalate is a condensation polymer. Polyester polymers are usually produced by condensation polymerization of ethylene glycol with either dimethyl terephthalate or terephthalic acid. A small molecule is eliminated during the combining of monomers in condensation polymerization. "A polyester is formed when an acid with two -COOH groups and an alcohol with two -OH

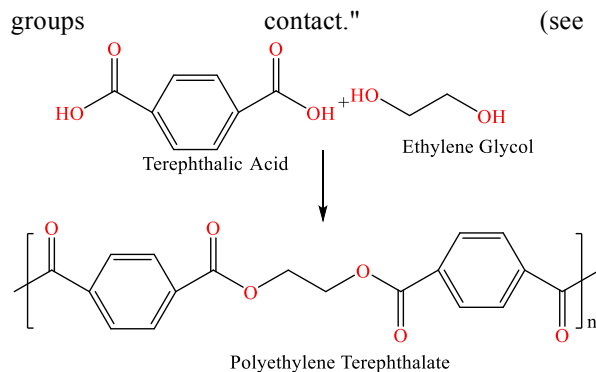


Figure 1.8.[18]

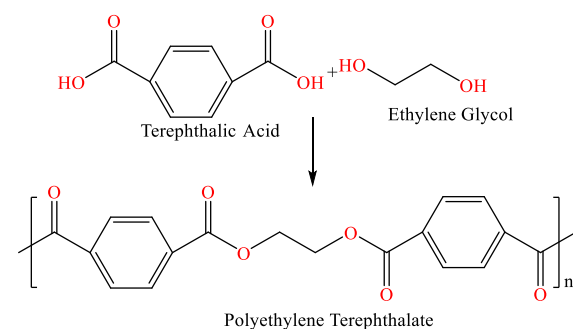


Figure 2: Condensation polymerization of ethylene glycol with terephthalic acid

Textile finishing

It's a process after the preparation and dyeing, throw this process the textile is exposed to a variety of treatments to improve its appearance, feel, or general appeal to consumers, or to impart surface qualities that make it ideal for certain tasks.[19]

Physical modification

Physical technology can also be used to improve the properties of natural fibres. Plasma, laser, electron beam, neutron irradiations, and ion beam are examples of physical processes that have the potential to be valuable enhancements to existing wet processing methods. These physical therapies can be performed without interfering with the overall performance of the fibre. The techniques require no chemical reagents, and the fibre modification is quick, clean, water- and energy-efficient, and produces no pollutants.[20]

Chemical modification

Chemical treatments applied to fibre to provide a specific function typically employ chemicals that are interchangeable across multiple fibre types. Because these reactions may be heterogeneous, challenges such as transporting the reagent to the fibre, interacting with the fibers surface, and reaching the fibers core are crucial. [20]

Nanotechnology

Nanotechnology is widely recognised as one of the most important technologies of the twenty-first century, and its economic significance is rapidly increasing. It has potentials that are already practical in architecture and the construction sector, particularly the coating of surfaces to give them functional features like as higher tensile strength, self-cleaning capacity, fire resistance, and others. Nanomaterial-based additives make ordinary materials lighter, more permeable, and more resistant to wear. Nanomaterials are not just beneficial for roofing and facades; they also expand design options for interior and external rooms and spaces. Nano-insulating materials give up new opportunities for environmentally conscious architects.[21]

water repellent textile

Textile finishing that repels oil, water, and dry dirt is essential in all segments of the fabric market, including technical textiles, garments, and home materials.[22] In a wet climate, the basic demand for clothes and materials is to keep the user dry by being water repellent and/or waterproof.[23] When defining the behaviour of fabric in relation to liquid water, the distinction between the two formulations is critical. When water comes into contact with finished fabric, water repellent polymers generate drops that can be readily removed from the fabric's surface. [24-29]

However, if the material comes into prolonged contact with water or is subjected to a greater pressure difference, it will absorb water. Waterproofing is the property of a textile material that prevents liquid water or fluids from penetrating it. [23, 30-38]

Mechanism of water repellent textile

Water resistant coatings accomplish this property by lowering free energy at fibre surfaces. The drop will spread if the inner cohesive interactions inside the liquid are fewer than the interactions between a drop of liquid placed on the fabric and the fabric. If the inner cohesive interactions inside the liquid are larger than the adhesive interactions between the drop of liquid and the cloth, the drop will not spread.

Surfaces with low energy interactions with liquids are referred to as low energy surfaces. The liquid's surface tension must be greater than the repellent fabric's surface tension or critical surface energy. Water's surface tension is often stronger than oil's surface tension.

Water repellency finishes, such as fluorine-free silicones, do not repel oil, but fluorocarbon oil repellency finishes always repel water. Low energy surfaces also give a measure of dry soil repellency by preventing soil particles from adhering to textile surfaces. Because of the limited contact between

textile surfaces and soil particles, soil particles can be easily removed and displaced by mechanical action.[22]

Water repellent and waterproof treatments are being employed in a variety of textile applications (home textiles, clothing, outdoor products, and technical textiles).

Water repellent fabrics can be created by combining various material groupings.[22, 23] Fluorinated materials are the most super hydrophobic at the moment because fluorinated groups help to minimise surface tension and surface energy. Fluorinated materials, on the other hand, are prohibited from usage in particular industrial locations due to their toxicity.[39]

As a result, the need for green alternative materials grew. Low surface tensions and adequately rough surfaces are required for super hydrophobic surfaces. To obtain the requisite surface roughness, methods such as plasma treatments and templating and moulding lithographic processes are used. However, in general, these techniques necessitate costly and/or complex processing conditions and equipment, and they are only applicable to certain substrates.[40]

As a result, placing nano/micrometer-sized particles on the fabric surface is a more realistic method of creating roughness. Low surface tension is provided by low surface energy compounds (unfluorinated materials) such as fatty acids, higher alkanes, or polydimethylsiloxane (PDMS).[39, 40]

Wettability

Inspired by nature's superhydrophobic lotus surface, has piqued the curiosity and attention of both academics and industry. Theoretical models and production methodologies for superhydrophobic fabrics have been thoroughly examined in this paper.

Ollivier originally reported a very high water contact angle of about 180° in 1907. A soot-coated substrate was used to create this super-antiwetting surface. [41] Superhydrophobic surfaces with a high static water contact angle (> 150°) and a low sliding angle (10°) attracted little attention until the 1997 publication of the "lotus effect" mechanism by Barthlott and Neinhuis.[42] The combination of a waxy covering with a low surface energy and a rough structure with protrusions on lotus leaves was linked to this unique characteristic (Fig.3). [43, 44]

Since then, superhydrophobicity research has evolved enormously, with several works devoted to emulating natural plants, animals, and beings. Great efforts were made to study the link between the structures and unique wettability of natural organisms, resulting in the creation of artificial superhydrophobic surfaces. These superhydrophobic properties have been extensively researched for self-

cleaning, anti-fogging/frosting, oil/water separation, and antibioadhesion applications.

Various micro/nanoscale binary structured superhydrophobic surfaces with a high static water contact angle and low hysteresis have recently opened up new application possibilities in industrial and biological domains.[45-50] Textiles, for example, are porous, rough, flexible, and hydrophilic by nature.

They absorb both water and oil in their raw condition.[51, 52] For obvious reasons, it is preferable to adapt the hydrophilic textile with low surface energy materials to offset the inherent weakness in a variety of applications.

To provide extraordinary wettability for the textile sector, innovative micro/nanostructures inspired by nature would be required. Oilwater separation cloths are useful in combating the issues created by oil spill events.[53, 54]

Furthermore, various unique multifunctional applications for superhydrophobic fabrics, such as UV-blocking, photocatalytic, flame-retardant, asymmetric superhydrophobic/superhydrophilic, and stimuli-responsive, began to combine. These are potentially high-value-added textiles that can be realised through very simple chemical processing.

However, there are possible hazards to workers' and customers' health and safety during production and use. As a result, research on environmentally responsible preparation techniques, as well as the durability and mechanical stability of textiles, should be prioritised.

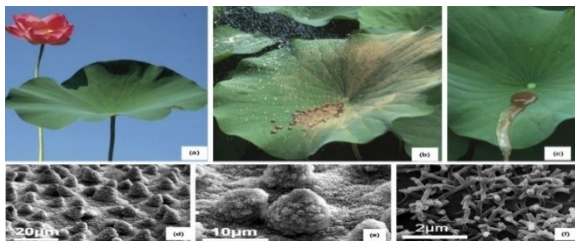


Figure 3. superhydrophobic lotus leaves with self-cleaning properties at different magnifications (Reprinted from Reference[44])

Characterization for super hydrophobic surfaces

Superhydrophobic surfaces have a static water angle of $CA > 150^\circ$ and a sliding angle of $SA 10^\circ$. However, there are two camps of definitions of hydrophobic state. According to the Young's equation, a solid surface with a contact angle $CA > 90^\circ$ was thought to be hydrophobic.

The other view by Volger *et al.* suggested that a CA of 65° divides solid materials into hydrophobic and hydrophilic using a surface force apparatus supported by ancillary techniques.[55] When two planes had a water CA greater than 65° , attractive

forces occurred. Repulsive forces, on the other hand, were discovered between surfaces with a 65° angle.

When evaluating the chemical and structural states of water droplets, this finding clearly suggests that the new split of hydrophilicity and hydrophobicity should be 65° rather than 90° . After examining the apparent and intrinsic CA of numerous polymeric materials, Jiang *et al.* discovered that an angle of 62.7° could discriminate hydrophilicity from hydrophobicity.[56]

As a result, the two primary approaches to fabricating superhydrophobic surfaces are as follows: creating adequate roughness on the material surface or chemically altering the material surface to be hydrophobic with a contact angle greater than 65° . The most basic way to evaluate a superhydrophobic surface is by visual inspection. An intuitive wetting behaviour and selfcleaning phenomena are noticed when a flow of water is introduced to the substrate surface. However, it is critical to quantify the superhydrophobic feature by precisely determining the static water contact angle (WCA) and contact angle hysteresis (CAH).

Notably, superhydrophobic surfaces with comparable water contact angles $CA > 150^\circ$ can exhibit vastly varying contact angle hysteresis.[57, 58] To differentiate between the various superhydrophobic states, five typical wetting states (Fig. 4a-e): [59] have been defined: Surfaces that are entirely wetting in the Wenzel state, totally air-supporting in the Cassie state, the metastable state between the Wenzel and Cassie states (including a "petal" state), surfaces in the micro/nanostructured two-tier "lotus" state, and a partially wetting "gecko" state. There are various examples of anisotropic superwettability in nature.

Water droplets, for example, roll readily in the direction parallel to the rice leaf edge but not in the perpendicular direction.[60] Butterfly wings (Fig. 4g), like rice leaves, display anisotropic rolling/pinning superhydrophobic states.[61] In addition to these instances of low-adhesion superhydrophobic capabilities, other creatures, such as gecko feet, give examples of high-adhesion superhydrophobic properties (Fig. 4j).[62-64] In general, three key wetting theories are used to describe surface wettability: the Young model, the Wenzel model, and the CassieBaxter model.

The static contact angle is defined by the interfacial energies between the solid-vapour phase, solid-liquid phase, and liquid-vapour phase, according to the Young equation. However, most solid surfaces in actuality are rough, limiting Yong's model's capacity to explain the wettability behaviour of the surface. Wenzel refined the Young equation and proposed that over a roughened surface, the true contact area rises.

The liquid is believed to be in total contact with the rough solid surface in the Wenzel state, making it difficult for water droplets to migrate and roll off the surface due to the greater contact area and increased adhesion. Cassie and Baxter then presented a heterogeneous contact model in which the liquid sits on top of the rough surface and air is trapped in between.

As a result, a water droplet can easily travel and roll off the surface, which is referred to as "slippery." [65] The Wenzel state correlates to a lower energy level, according to theoretical study. [66, 67] The existence of surface energy between these two states may inhibit the spontaneous transition from Cassie to Wenzel state, however it is verified that the two models can transit from one to the other under certain conditions.

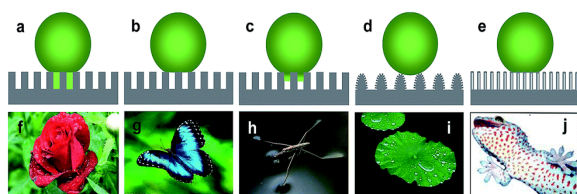


Figure 4. Five typical cases for anti-wetting surfaces

(a: Wenzel state; b: Cassie state; c: Wenzel-Cassie state; d: "lotus" state; e: "gecko" state) and several common phenomenon for antiwetting in nature (f: petal; g: butterfly; h: strider; i: lotus leaf; j: gecko) (Reprinted from Reference [68]).

Fabrication technologies of superhydrophobic textiles

As previously stated, there are two important things to consider when creating a superhydrophobic surface: the proper hierarchical structure with persistent micro/nanoparticles and a low energy surface. A popular technique for textiles with micro-scale fibre structure is to coat nanoscale particles onto the fibre surface to produce the micro/nanoscale structure and then postfluorinate the hierarchical structure for low energy.

Physical and chemical procedures are the most often used strategies for producing a strong superhydrophobic textile surfaces, such as dip coating [69-77], wet chemical deposition [78-81], electro-assisted chemical deposition [82-86], spray-coating [87-89], sol-gel [90-94], chemical etching [95-98], chemical vapour deposition [99-102], plasma processing [103-106] and polymer grafting [107-112].

These production techniques will be examined separately in the following categories by two ways pre-roughening and post-fluorinating or simultaneous roughening and fluorinating (one-pot method).

Pre-roughening and post-fluorinating

To far, the most popular process for preparing cellulose-based superhydrophobic textile surfaces is pre-roughening and post-fluorinating. Typically, functionalization with nanoparticles, nanofilaments, or a layer of film can create the desired roughness.

Nanoparticles such as SiO₂, TiO₂, and ZnO are frequently utilised to embellish textile surfaces in order to provide a rough and lasting superhydrophobic surface. Furthermore, several inorganic or organic chemical compounds in the form of nanofilaments, nanofibres, and even film layers have been described in the literature to create superhydrophobic cellulose-based surfaces. In this section, we will go through the fabrication processes for textile surfaces depending on the formation type (particles, nanofilaments, nanofibre, film).

Dip-coating method:

Wang et al. [69] used a two-step wet chemical approach to create a superamphiphobic fabric with strong self-healing properties against both physical and chemical damage. The cleaned fabric is soaked in a fluoroalkyl surface-modified silica nanoparticles solution for 5 minutes before being coated in fluorinated decyl polyhedral oligomeric silsesquioxane (FD-POSS) and fluoroalkylsilane (FAS) solution, as illustrated in Figure 5

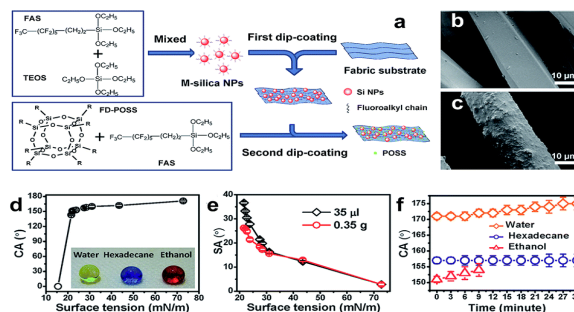


Figure 5. (a) Chemical structures of coating materials and procedure for coating treatment. SEM images of (b) uncoated and (c) coated polyester fibres. The relationship of CA (d) and SA (e) with surface tension and the CA changes of water, hexadecane and ethanol with time (f). (Reprinted from Reference [69]).

After coating, the surface of polyester fabric has a characteristic protrusion structure, whereas the pure polyester fabric surface is smooth. The fabric surface exhibited significant liquid repellence to liquids of varying surface tension after coating, and the CA remained above 150° when the tested liquid had a surface tension more than 22.1 mN m⁻¹ (Fig. 3d). The dependence of SA on constant liquid volume (35 µL) and constant liquid weight (0.35 g) over varied surface tensions was also examined; the

findings showed that SA dropped as liquid surface tension increased (Fig. 5e). Furthermore, the good wettability was validated by measuring contact angle changes over time (Fig. 5f).

Furthermore, the coated fabric exhibits exceptional liquid repellence to water and low surface energy liquids such as ethanol. The static contact angles did not change after 200 cycles of regular machine washing. This indicates that the coating is strong enough to withstand physical and chemical activity.

Chemical bath deposition:

Wang *et al.*[78] used a two-step coating procedure to create a one-way transport oil droplet functional fabric surface with flower-like ZnO nanorods, fluorinated decyl polyhedral oligomeric silsesquioxanes, and hydrolyzed fluorinated alkylsilane. After being subjected to UV light on one side, the superamphiphobic fabric demonstrated an intriguing one-way oil transfer capacity.

Furthermore, it was discovered that selective oil transport is dependent on the particular surface tension of the liquid, and that different types of oils may be chosen by varying the UV irradiation period. This type of one-way oil fluid transfer medium might be used to measure liquid surface tension (Fig. 6a-e).

In the work of Lai and colleagues[79], a resilient flower-like hierarchically structured cotton fabric surface was made in-situ using one-pot hydrothermal technique, in which the cotton piece is immersed in a mixed solution and treated at temperatures ranging from 120°C to 200°C (Fig. 6f). Following that, the extraordinary superhydrophobic cotton surface was created by the chemical modification of fluoroalkylsilane. The cellulose fibre surface was equally covered with flower-like hierarchical TiO₂ micronanoparticles.

With a static contact angle greater than 160° and a dynamic sliding angle less than 5°, this unique wetting superhydrophobic coating repels water extremely well. The simple technique for synthesising hierarchical structure superhydrophobic TiO₂@Cotton is expected to be useful for creating and producing self-cleaning superhydrophobic/superoleophilic materials in air and water.

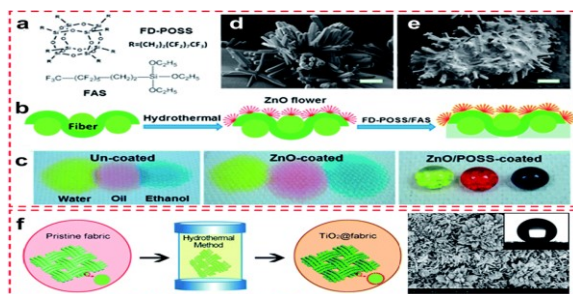


Figure 6. (a) Chemical structures of the coating materials, (b) coating procedure, (c) photographs of yellow-coloured water, red-coloured cooking oil, and blue-coloured ethanol (volume 35 μ L) on cotton fabrics. SEM images of the cotton fabric (d) after ZnO treatment and (e) after both ZnO and FD-POSS/FAS treatment (scale bar = 2 μ m). (Reprinted from Reference [46] with permission). (f) Schematic diagram of a facile one-pot hydrothermal process to construct TiO₂ particles coating on fabrics. (g) High magnification SEM image of flower-like superhydrophobic TiO₂@Cotton fabricated at 150°C for 20 h, inset is a photograph of a water droplet coated on superhydrophobic surface. (Reprinted from Reference[79]).

Electrostatic layer by layer self-assembly:

Lin *et al.* effectively generated a superhydrophobic fabric surface using a flexible electrostatic layer by layer self-assembly approach to build a multilayer of polyelectrolyte/silica nanoparticles and a post-fluorinating procedure[86].

The virgin cotton fabric was treated with a particular solution prior to electrostatic self-assembly to generate a charged polymer layer. Furthermore, the amount of silica-nanoparticles multilayers influenced the surface morphology and hydrophobicity of cotton fabric.

The cloth had a weave structure, and the pure cotton fibre was extremely smooth (Fig. 7a, b). The silica-nanoparticles were randomly scattered onto the fibre surface when the surface was built with 1 or 3 layers PHA-SiO₂, and such surface displayed a sticky behaviour with a high contact angle hysteresis (Fig. 7c, d).

An increasing number of assemble layers may result in homogenous coverage and aggregation of silica nanoparticles deposited on the surface of cotton fibre (Fig. 7e-h). The surfaces were superhydrophobic and had high static contact angles with minimal contact angle hysteresis. Meanwhile, due to the high affinity between PHA-SiO₂ and cotton fibre, the superhydrophobic surface can resist at least 30 cycles of machine washing.

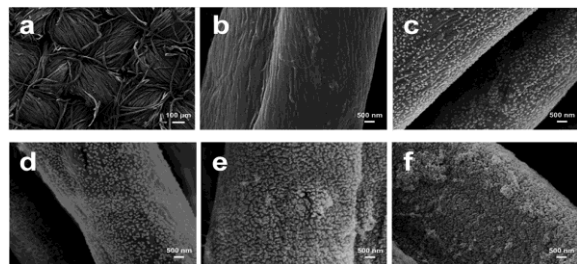


Figure 7. SEM images of untreated cotton fabric (a and b) and cotton fabrics assembled with (PAH/SiO₂)_n multilayers: (c) n = 1, (d) n = 3, (e) n = 5, and (f) n = 7. (Reprinted from Reference[86]).

Antimicrobial textiles

Antimicrobial textiles are functionally active fabrics that can kill germs or limit their growth. The current paper investigates the applications of several synthetic and natural antimicrobial chemicals used to make antimicrobial fabrics. [34, 113-117]

Different forms of antimicrobial fabrics, such as antibacterial, antifungal, and antiviral, have also been discussed. These antimicrobial textiles are utilised in a wide range of applications, including air filters, food packaging, health care, hygiene, medical, sportswear, storage, ventilation, and water purification systems.

During the last few years, there has been an increase in public awareness of antimicrobial fabrics, as well as an increase in economic potential. Not only are antimicrobial capabilities vital for trendy apparel, but so are durability, colour, patterns, and design; as a result, many commercial firms are now focusing on such materials.

Textiles are ubiquitous and serve an important role in human society. Clothing microbiology and the effect and interaction of garments with human skin microbiota have lately been discussed[118]. Natural antimicrobial agent coatings on textiles or fabrics date back to ancient Egypt, when spices and herbal coatings on cloths were utilised to produce mummy wraps. [119-125]

Traditionally, the Chinese utilised bamboo fibers for home construction, which included an antibacterial chemical known as 'Bamboo-kun.' Bamboo fibers have also been investigated for their antibacterial and antifungal activities, which are mediated by 2-6-dimethoxy-p-benzoquinone and dendrocin[126-129].

During the Second World War, antibiotics were widely used; at the same time, antimicrobials to prevent textile rot were in high demand. Tents, tarps, and vehicle coverings were essential to guard from microbial attack during heavy rain and snow, which would kill fibers and raise the likelihood of infection. Several military materials were treated with antimony salts, copper, and a combination of chlorinated waxes to protect them against microbial colonisation and boost their longevity. This not only stiffened the garments but also gave them a unique odour[130].

Initially, the side effects of these antimicrobials were not taken into account; however, more attention was paid to the negative effects of these substances on the environment and health. Following the release of Rachel Carson's book *Silent Spring* in 1962, the notion of safer antimicrobial chemicals and fabrics emerged. Ecologists, scientists, industrialists, and chemists collaborated to create environmentally friendly antibiotics[131].

Antimicrobial fabrics are particularly useful in today's hospitals, environments, and areas that are prone to harmful bacteria. The garments worn by patients, healthcare staff, and physicians may contain a large number of germs that can readily be passed from one person to another. When it comes to reducing the spread of infectious bacteria, commercial potential for antimicrobial textiles abound[132].

Antimicrobial textiles are classified according to their antibacterial, antifungal, or antiviral properties. Several antimicrobial fabrics may also function against bacteria, fungus, and viruses at the same time. Some compounds, known as antimicrobials, can be used to target a wide spectrum of bacteria[133].

In popular public areas such as hotels, restaurants, or trains, this sort of fabric is in great demand, for example, the towel used to mop up spills, curtains, and carpet might be a source of infection.

There are also evident unfulfilled odour control requirements, which is another developing study subject in this field. The cloth may contain many pathogenic germs that can spread from an affected individual to others. Continuous laundering of garments is the only viable and effective technique to reduce the microbial load from textiles, but this is not practicable in hospitals with continuous shifts.

On the other hand, producing antimicrobial textiles is another technique to limit the possibilities of microbial illness spreading from one person to another via textile. These antimicrobial fabrics may also be beneficial to individuals involved in sanitary work and those working in sewage treatment, where there is a significant danger of infection.

Surface modification of textiles, such as electrospinning, nanotechnologies, plasma treatment, polymerization, microencapsulation, and sol-gel methods, has been used to impart unique functional features to textiles, such as water repellency, flame retardancy, and antibacterial activity[134].

Antimicrobial winter apparel is becoming more popular since these garments are rarely laundered and are rarely exposed to sunshine. These clothing are often stored for a longer period of time, which may allow bacteria to develop, thus antimicrobial fabric may be a good alternative. Similarly, antimicrobial fabrics may be beneficial in locations where non-plastic bags are utilised.

Food packaging made of biodegradable materials is better for the environment and does not affect food characteristics; nonetheless, antimicrobial coating in such wrappers is needed to inhibit the growth of pathogenic and food spoilage bacteria. The following industries, in particular, demand antimicrobial textiles, as well as appealing colour, pattern, and design combinations:

- Apparel: caps, jackets, sanitary pads, sportswear, undergarment, winter wear
- Commercial: carpets, covering for seats, window, vehicle, etc.; dusting cloths, military fabric, tent, uniform
- Health care: bandage, earbuds, scrub, mask, lab coats, protective kits
- Households: bedding, carpet, cover, curtains, mop, pillows, towel

Active antimicrobial agents

Nanoparticles

Nanoparticle-based coatings are fairly widespread in both natural and synthetic fabrics, among other things. Silver nanoparticles (AgNPs) have high toxicity toward a wide spectrum of bacteria but minimal toxicity toward human cells, as well as long-term stability and dyeability. Silver (Ag) nanoparticles are widely known for their antibacterial and self-cleaning properties[120, 135, 136].

AgNPs (10 nm in size) have also shown antiviral effectiveness against SARS-CoV-2 (the virus that causes COVID-19)[137]. Aside from silver, various metals and metal oxide nanoparticles such as titanium, tin, zinc, gold, and copper have been used on natural and synthetic fabrics. As previously stated, the antimicrobial activity of functionalized CuONPs coated textile materials against Gram-positive and Gram-negative bacteria can be attributed to three main mechanisms: the release of copper ions, direct contact of CuO NPs with bacteria, and the production of reactive oxygen species[138].

The relevance of biosynthesis and uses of nanostructured inorganic materials in the creation of antimicrobial textiles has grown. Selenium brooms were manufactured using almond skin extract, and the morphology changed from NPs in 15 seconds to selenium brooms in 45 minutes. Cotton-coated cloth with these structures demonstrated antibacterial efficacy against *Bacillus subtilis*[139].

The functional ecofriendly nanohybrid material created utilising oligochitosan (obtained from crab shells) and nano-silica (obtained from rice husk) proved resistant to *Phytophthora infestans* fungal attack, indicating that advanced research in green agricultural application is underway[35, 140-144].

Agglomeration prevention, desirable shape, and homogeneous size of nanoparticles have long been difficult challenges in NPs research. To circumvent such difficulties, ligand capping is commonly utilised. Several natural capping agents have been utilised, and the cloth is well coated with them.

The pad-dry-cure technique was used to coat seaweed capped zinc oxide nanoparticles (SW-ZnO NPs) on cotton fabric, which demonstrated antibac-

terial activity against Gram-positive (*Staphylococcus aureus* and *Streptococcus pyogenes*) and Gram-negative (*Escherichia coli* and *Klebsiella aerogenes*) bacteria[145]. Similarly, date seed extract, another natural capping agent, was employed to generate capped ZnO NPs, which likewise displayed antimicrobial activity and UV protectant function in cotton fabric[146].

The antibacterial activity of amino-capped TiO₂ NPs coated functional cotton fabric was proven utilising a two-step sol-gel and hydrothermal technique against *S. aureus* and *E. coli*[147]. To achieve efficient surface stability of the NPs on cellulose-based fabric, pre-activation or pre-treatment is required. To create a long-lasting functional textile, several human skin-friendly bioadhesive compounds or processes must be investigated. Even after numerous washing cycles in hot water, simultaneous sonochemical deposition of ZnO NPs utilising an enzymatic cross-linked phenolic network of gallic acid displayed strong antibacterial efficiency[148].

Natural compounds

Aside from curcumin, several natural active compounds have been isolated and employed to create antimicrobial fabrics. Plant extracts, essential oils, and animal products, such as honey, have also been utilised in textiles to treat wound infections. Antimicrobial activity of certain natural dyes, pigments, and mordants has also been investigated.

Natural substances such as cyclodextrins can be used to provide sustainable antibacterial textile finishing. These cyclic oligosaccharides contain a lipophilic inner chamber and a hydrophilic outer surface. The textile industry is seeing an increase in the use of cyclodextrin and its derivatives (α -cyclodextrin, β -cyclodextrin and γ -cyclodextrin)[149, 150].

In plants, lignin provides resistance against microbial assault. This dark-colored phenolic component is often eliminated during the cellulose fibers production process. The antibacterial activity of a lignin-coated cloth manufactured from sugarcane bagasse against *Staphylococcus epidermidis* was demonstrated. Based on its MIC, the lignin coating concentration showed that bacterial growth might be suppressed to prevent further multiplication within 6 hours of contact[151].

Because of its antibacterial and anti-odor properties, chitosan is frequently utilised in antimicrobial textile preparation and processing. Chitosan is a cationic polymer derived from the alkaline deacetylation of chitin. Chitosan hydrogel applied to cellulosic fabric shown antibacterial action against *S. aureus*, *E. coli*, and *Listeria monocytogenes*[152-154].

With contrast, one study found that when cotton and polyester materials were coated in a mixture of silica sols and chitosan, the antibacterial characteristics were not significantly affected[155]. Edible chitosan/pectin-based silver nanoparticle films derived from natural biodegradable polymers, on the other hand, displayed effective antibacterial action against *E. coli*. These antimicrobial films may extend the shelf life of items and be used in food packaging[156].

Virus categorization and identification

Viruses, as previously stated, are acellular and are thought to exist in a grey region between the living and the nonliving. Viruses are tiny protein capsules that contain genetic information. Viruses are made out of nucleic acid and a protein coat[157]. A virus's nucleic acid can be either Deoxyribonucleic Acid (DNA) or Ribonucleic Acid (RNA), but never both. The protein coat encases the nucleic acid, and some viruses are also surrounded by envelopes, which are layers of fat and protein molecules.

The virus's size changes depending on its structure. Viruses are host cell required in order to proliferate. They begin by replicating the genetic material within the cell and producing viral progenies to infect additional cells[158]. Viruses are classed generally based on their shape, symmetry, chemical composition, genomic structure, and mechanism of reproduction.

Viruses that infect humans are classified into twenty-one groups based on their genomic structure and chemical makeup [157]. The classification of viruses causing infections in humans is presented in Figure 8.

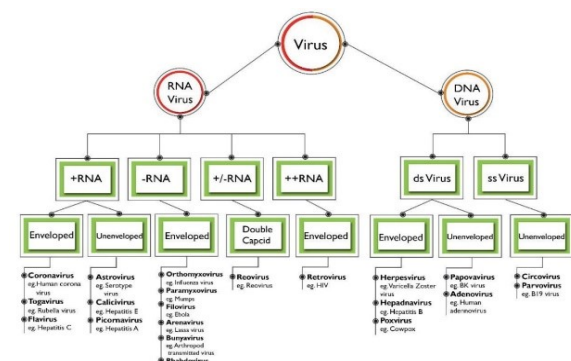


Figure 8: Classification of viruses

Transmission of viruses

A virus can spread in a variety of ways. Virus transmission is mostly determined by the virus's capacity to overcome a barrier. A virus can spread from cell to cell, animal to animal, person to person, or even species to species. It can be spread through either direct or indirect contact.

In the event of direct contact, the virus is passed from an infected host to an uninfected individual by physical contact. While the virus spreads through numerous media such as fabrics, contaminated surfaces, and so on in the event of an indirect encounter, disease-bearing organisms known as vectors can also transfer viruses to an uninfected individual in the form of blood-sucking insects such as mosquitoes [159].

Figure 9 depicts the most likely and significant ways for a virus to infect humans. Diseased animals, polluted environments, and infected people are all thought to be key sources of a virus.

Droplets released by an infected human or animal in the form of a cough, sneeze, blood stains, and so on contaminate a location or a person. Droplets with virus particles less than 1 µm in size contribute to the propagation of airborne infections.[158]

According to Wells[160], the watery half of a droplet evaporates fast in the air, and the remnant known as the droplet nuclei travels around the corners, eventually contaminating the location and the individuals who share the same air supply.

Because certain viruses have big particles that make them heavy, they do not contribute to the transmission of airborne infections. The longevity of these heavy viruses outside of a host cell has a significant impact on their transmission. SARS-CoV-2, for example, may live for roughly 24 hours on cardboard and 3 to 4 days on plastics and stainless steel [161], whereas astroviruses, Hepatitis A, and Polio viruses can live for up to 2 months[162].

Because of their lengthy existence outside of a host cell, some viruses are more lethal to humans. However, researchers have discovered that the majority of human health problems are caused by micro-sized virus particles having an aerodynamic diameter of less than 1 µm [158].

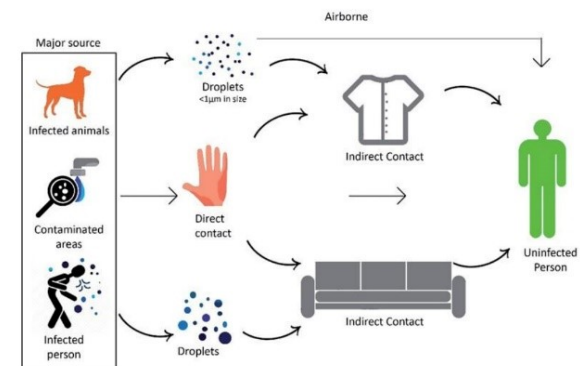


Figure 9. Modes of virus transmission

Replication of viruses

Viral replication is a biological process that generates new viruses during the host cell infection.

As a result, a virus must first penetrate its host cell before it can replicate. A virus cannot replicate itself in the absence of a host cell because it lacks organelles such as nuclei, mitochondria, ribosomes, and the cytoplasmic components required for the production of its own structure. [159]

During viral replication, a virus particle or virion initially binds to the host-cell membrane and injects its DNA or RNA into the host cell to commence the infection. In general, a virus enters a human host cell via membrane fusion. The viral genome gains access to host cell organelles and enzymes after a virion enters the cell.

This eventually starts the replication of the viral nucleic acid (DNA or RNA) and the structural protein with its coding. This newly produced nucleic acid, along with the structural proteins, is subsequently assembled into new virus particles. Finally, either through cell lysis or the budding process, these young viruses leave the host cell and are ready to infect other host cells. [163]

The role of textiles in virus prevention

Viruses, as previously said, are regarded a grey region between the living and the non-living, and they require a host cell to multiply themselves. As a result, a virus will be unable to replicate itself on a textile surface. Textiles, on the other hand, can operate as an active medium for viral transmission. [164, 165]

Frequent cleaning or disposal of infected textiles may be an efficient method of limiting viral transmission via textiles. [166] The second option is to imbue textiles with antiviral qualities. A typical textile fabric does not contain antiviral qualities, but the addition of certain components to textiles can make them antiviral. The introduction of an antiviral drug into textiles can occur at various stages and in various ways.

The following section of this study discusses various approaches to produce antiviral textiles. Antiviral agents render treated textiles antiviral by using either of the two processes listed below, or by combining them. In the first mechanism, the chemical used reduces the surface energy of a textile surface.

This will prevent viral transmission through textiles by limiting viruses to the textile surface. Textiles' low surface energy can also degrade a virus's outer lipid barrier, rendering the viral genome inactive by preventing it from entering a host cell. [167]

When a virus comes into touch with a textile surface treated with an antiviral treatment, the active agents bond to the virus's outer coat and hinder its critical functions. These antiviral drugs infiltrate the virus structure by oxidising and dissolving the lipid or glycoprotein coating. Finally, these antiviral

medicines bind to the genome (i.e., the virus DNA or RNA) and deactivate it by fragmenting it.

As a result of these interactions, the virus disintegrates, resulting in the leaking of the viral genome and a loss of infectivity, rendering the viral particle inactive on the treated textile surface [168-170]. Figure 10 depicts a schematic diagram of the antiviral mechanism via virus annihilation (i.e. the second way).

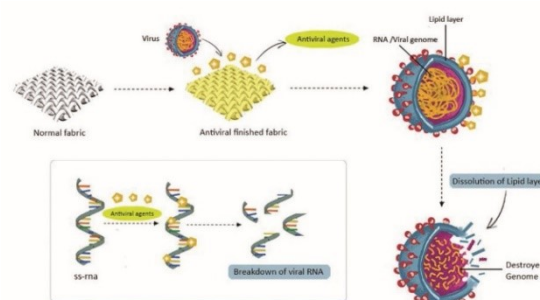


Figure 10. Antiviral mechanism through virus destruction on textile fabric surface

Antiviral treatments for textiles

Textile materials are not naturally antiviral. Because of their high moisture retention and surface area, textile fabrics are prone to microbial development. [171] Textiles can be rendered antiviral by the application of appropriate antiviral chemicals. The introduction of an antiviral drug into textiles can occur at various stages and in various ways.

Depending on the antiviral agents and their application technique, antiviral finishing on textile material can be done on textile fibre, yarn, fabric, and final products. Antiviral application onto the cloth is recommended for simplicity of application and ongoing production.

Surface treatments such as the exhaust approach, the pad-dry-cure method, microencapsulation, and the coating technique are used to treat fabrics such as cotton, wool, silk, and other synthetic fibres, either alone or in combination, depending on the antiviral composition and fabric quality. Antiviral agents can also be integrated into manmade fibres by incorporating appropriate antiviral agents into the polymer matrix prior to fibre extrusion [172, 173].

The exhaust process is the most widely used and widely accepted way of dyeing and finishing textile materials. This technique is also suitable for antiviral finishing of natural fibres and polyamide fabrics. The application is carried out below the boiling temperature, which is quite similar to the dipping technique. The high-temperature exhaust approach is preferable for polyester fabric.

The application is carried done at 120-130 °C and the technique is quite similar to disperse dyeing. Another approach for applying an antiviral

compound to textile material is the pad-dry-cure process. The fabric is padded in an aqueous medium with the antiviral mixture and a suitable binder, then dried and cured for proper fixation. This strategy can be used alone or in conjunction with others [133, 174, 175].

Micro-encapsulation is a method in which an active ingredient is stored as a core substance within a polymeric shell. A microcapsule solution is created for antiviral finishing on textile material by mixing and swirling the antiviral composition and the polymeric coating material in an emulsion reactor at 1000-10000 rotations per minute for 6-48 hours. A microencapsulated shell's size typically ranges between a micrometre to a millimetre.

In an agitator, this antiviral microcapsule solution is applied to the textile substrate along with additional binding formulations, followed by drying and curing. This approach is gaining prominence in the field of textile finishing, particularly for fragrance, antimicrobial, and other finishes for sportswear and medical fabrics [176-178].

The covering material is put onto the textile substrate in the coating procedure to improve the surface qualities. Similarly, in textiles, an anti-pathogenic component and an appropriate binding agent can be coated on the fabric. Coating processes such as reverse roll, rod, spray, and gravure are preferred.

The coating process necessitates a porous substrate. Because the majority of nonwoven substrates are porous, different coating processes, such as spray and dip-coating, can be used. Controlled release of antiviral medicines may be required in some applications.

Microencapsulation may be included in the coating in this situation. The coating might be single-layered or multi-layered. In multi-layered coating, the substrate is first coated with an active component solution using the spray-coating method, and then the second layer is coated with the binding solution using the rod-coating method [179].

Triclosan based antiviral finish

Triclosan has a well-known antibacterial action, particularly against bacteria [133, 180]. However, when treated with triclosan and sodium pentaborate pentahydrate, a textile fabric can demonstrate antiviral properties. Figure 11 depicts the chemical structures of triclosan and sodium pentaborate pentahydrate molecules.

Iyigundogdu et al. [133] produced a triclosan-based antiviral solution containing 0.03% triclosan, 3% sodium pentaborate pentahydrate, and 7% glucapone 215 CS UP. A cotton fabric treated for 30 minutes with the above-mentioned antiviral solution by the exhaustion method at pH 5 shows promising effectiveness against adenovirus and poliovirus.

Glucapone 215 CS UP acts as an emulsifier, and triclosan inhibits viral growth by limiting lipid production. The role of sodium pentaborate pentahydrate in the above formulation is unknown, however its presence improves triclosan's antiviral activity. A cotton cloth treated with the above-mentioned solution can reduce viral titre by 60%, according to the Spearman-Karber test method.

Iyigundogdu et al. [133] projected that textiles treated with triclosan and sodium pentaborate pentahydrate would be effective against enveloped and non-enveloped DNA and RNA viruses such as hepatitis B, HIV, HCV, Ebola, MERS, and SARS.

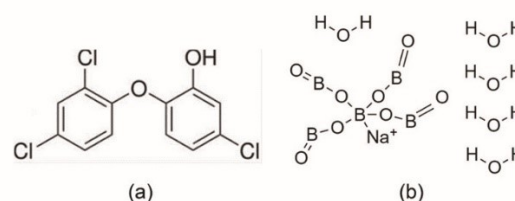


Figure 11. Chemical structure (a) Triclosan (b) Sodium pentaborate pentahydrate [181, 182]

Treatment with honeysuckle extract

Honeysuckle has been utilised in traditional Chinese medicine since ancient times to treat windheat, respiratory tract infection, fever, and inflammatory disorders [183]. Honeysuckle extract contains chlorogenic acid, which is an antiviral agent.

Chlorogenic acid inhibits viral mRNA transcription and, as a result, protein translation. Figure 12 depicts the chemical structure of chlorogenic acid. Chlorogenic acid has been shown to be effective against a variety of viruses, including HIV, adenovirus, hepatitis B, and HSVs. [184, 185].

The microencapsulation process can be used to treat textiles with honeysuckle extract. An active chemical agent is often kept within a polymeric shell in microencapsulation.

A microencapsulated shell's size typically ranges between a micrometre to a millimetre [177, 178]. Jinmei (Patent No. CN101324026B, 2011) discovered that using the microencapsulation technique, treating a cotton fabric with a drug component solution containing honeysuckle (30% to 60%), Radix Glycyehizae (20% to 50%), and Weeping forsythia (20% to 50%) extracts imparted antiviral properties to the fabric surface.

In an emulsion reactor, the microcapsules were made by combining the aforesaid drug solution with polylactic acid (mass ratio 1:2). The microcapsules (30% to 60%) were then applied to a cotton fabric using a nano zinc oxide solution (5% to 20%) and an aqueous polyurethane solution (10% to 15%), before curing at 150 °C [178]. Figure 13 depicts the preparation of microcapsules and their application to cotton fabric.

The nano zinc oxide kills pathogens effectively, while the aqueous polyurethane binds the microcapsules and nano zinc oxide to the cotton fabric. The resulting cloth is skin-friendly and antiviral, even after 20 washes, with a virus inhibitory rate of more than 80% against the influenza and herpes simplex viruses [178].

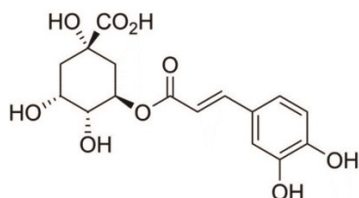


Figure 12. Chemical structure of chlorogenic acid [186]

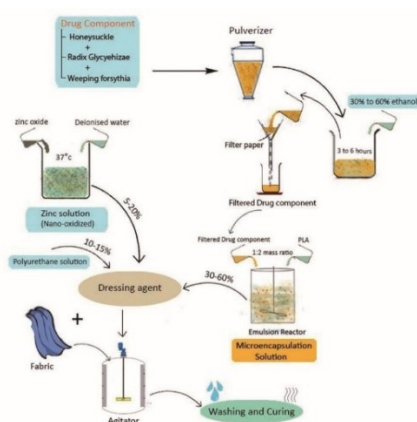


Figure 13. Preparation of antiviral microcapsules and their application onto cotton fabric by using honeysuckle extract

Povidone iodine-based coated textiles

Ripa *et al.* [180] discovered that iodophors, such as povidone iodine and iodine tinctures, have strong antibacterial activity against a wide range of viruses. Almost all pathogenic bacteria are vulnerable to free iodine produced by the povidone iodine complex.

Using the coating technique, povidone iodine can be added to textile materials to make them antiviral. Coating is a process that involves layering functional materials onto a substrate in order to improve the surface qualities. [187]

Reverse roll, rod, and gravure coating processes can be used to apply uniform coating to a textile surface. Coatings can be single-layer or multi-layered. The antiviral characteristics of the multi-layer coated cloth are improved. Snyder (US5968538A, 1999) created a coating solution that includes an active ingredient (71.5%) and a premix solution (28.5%).

The active ingredient was Nonoxynol 9 (N9) at 6.7% and polyvinyl-pyrrolidone-iodine complex at 93.3%. (PVP-I). The binder premix solution contained 54.6% polyethylene glycol, 5.4% hydroxy-

propyl methylcellulose, 7.2% polyoxyethylene sorbitan, 11.5% hydrous magnesium silicate, and 21.3% ethanol. The combination of PVP-I and N9 gave the coated substrates antiviral and hydrophilic characteristics. When the covering material absorbs moisture, PVP-I releases free iodine, which acts against viruses [179].

According to Bigliardi *et al.* [169], free iodine has good biofilm penetration, which speeds up iodine penetration through the virus cell wall. Iodine's virucidal function entails inhibiting essential systems by oxidising fatty/amino acids and deactivating proteins as well as DNA or RNA [188]. When compared to polyhexanide, chlorhexidine, and 70% ethanol, the antiviral efficacy of 10%-povidone-iodine shows excellent results against some viruses [179].

Antiviral textiles treated with copper compound

Textile fabrics treated with copper-based compounds exhibit strong antibacterial capabilities, prompting researchers to investigate their impact on viruses.

Organic and inorganic colloidal, nano-sized copper compound particles can be applied to textile substrates using a variety of methods, including high-temperature exhaust, sol-gel, foulard, and spray methods [174].

Borneman [174] used the high-temperature exhaust procedure to treat a polyester cloth with copper pigments in an acidic environment. The treated fabric was then padded with a polymer binder and dried to adhere the copper pigment to the fabric surface.

When tested against the bacteriophage MS2, the antiviral test result suggested that the completed cloth was effectively sanitary. It absorbed 91% of the virus from the damaged source while also reducing 90% of the virus concentration in the cloth.

The copper emitted electrically positive charged particles, which ruptured the virus's outer membrane. They also damaged the genetic complex, rendering the virus incapable of replication [189, 190].

Current study indicates that copper particles interact with oxygen molecules to create reactive oxygen species (ROS). When the ROS reacts to inactivate the virus, it fragments the virus's DNA on the copper surface, ensuring that the inactivation is irreversible [191].

When a fibre with a carboxyl functional group is impregnated in a dispersed divalent copper compound solution, Fujimori *et al.* (Patent No. EP2786760A1, 2014) discovered that a salt-stabilizer is necessary to manage the uniform attachment of the divalent copper ion onto the fibre surface.

This limits the quantity of copper compound that may be bonded to the fibre, resulting in inadequate antiviral performance. Instead of a divalent copper compound, the antiviral activity of these fibres can be enhanced by adding a monovalent copper compound such as CuCl, CuI, CuBr, or an iodide compound of Cu, Ag, Sb, Ir, Ge, Sn, Tl, Pt, Pd, Bi, Au, Fe, Co, Ni, Zn, In, or Hg.

The results of the tests show that copper (I) chloride (CuCl) has the highest antiviral effectiveness when compared to the other chemicals indicated above. With the help of a binder, the dispersed CuCl solution can be applied to various types of textile surfaces, immobilising the CuCl on the fabric surface. Antiviral synthetic fibre can be created by adding CuCl to the molten polymer prior to fibre extrusion[192].

According to Gabbay (Patent No. US7169402B2, 2007), an antiviral synthetic fibre can be generated by adding ionic copper powder with particle sizes less than 10 microns to the polymer slurry before extrusion with a solid concentration ranging from 0.25% to 10%. It was discovered that the active copper particles enclosed in the fibre protrude and expose from the surface of the polymeric fibre, making the fibre antiviral.

With only 1 minute of exposure, the viral inactivation rate of 0.25% CuCl is 99.9999% against influenza and Feline Calicivirus [193]. Diaz (Patent No. WO2015035529A2, 2015) claims that copper filaments can be used to create an antiviral fabric. As shown in Figure 14, a plied yarn was created by combining copper filament and a textile yarn. This yarn was then turned into a textile fabric.

When the copper filament comes into contact with ambient oxygen, it oxidises into cuprous oxide and cupric oxide. These copper oxides form a coating on the copper surface and emit positively charged copper ions, which inactivate the virus further [194].



Figure 14: Plied yarn with copper as a component

Chitosan based antiviral treatment

Because of their eco-friendliness, biodegradability, and non-toxicity, biomaterials are increasingly being used in the development of protective fabrics. Among biomaterials, chitosan is widely used for multi-functional textile finishes such as antibacterial finishes, insect repellent finishes, wrinkle resistant finishes, and so on[195, 196].

Figure 15 depicts the chemical structure of chitosan. Chitosan is often derived from crab shells, shrimp shells, lobsters, and the exoskeleton of zooplankton such as corals and jellyfish[197-199].

It has a high concentration of positively charged nucleophilic amino groups, which harm the virus's cell membrane. When a textile material is treated with chitosan, an organic acid crosslinking agent, plant extract, and sodium phosphate, the antiviral activity of chitosan is improved.

Xinming (Patent No. CN105506984A, 2016) created an antiviral solution with 0.5% hydroxypropyl chitosan, 0.6% O-carboxymethyl-N, N, N-trimethyl ammonium chloride chitosan, 1% butane tetracarboxylic acid, 1% citric acid, 2% sodium phosphate, 0.6% folium artemisiae argyi extract. The fabric was then dried at 100-120 °C before being roasted at 150-190 °C for 2.5-5 minutes. After testing, it was discovered that the treated fabric had a high efficacy (more than 99.9%) against a wide range of viruses[200].

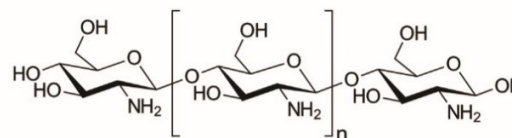


Figure 15. Chemical structure of chitosan [201]

Antiviral treatment for nonwoven textiles

Nonwoven fabrics are a variety of fibrous materials generated through direct fibre web formation. Because of their excellent air permeability, abrasion resistance, consistent construction, and other characteristics, they are commonly utilised for filtration[202].

When treated with acidic polymers, a nonwoven fabric can also be used to limit the growth of bacteria, particularly viruses. As an acidic polymer, poly carboxylic acid polymer is preferred for treating nonwoven fabric. The acidic polymer can be added to nonwoven fabric in various ratios with organic acid, plasticizers, or surfactants to improve the antiviral performance of the treated fabric.

Biedermann et al. (2008, Patent No. WO2008009651A1) created a loading solution containing 2% (w/w) carbopol ETD 2020, a poly carboxylic acid polymer, and 1% (w/w) citric acid and coated a polypropylene nonwoven fabric with the loading solution. When a virus made contact with the coated nonwoven surface, it reacted with the acidic polymer and became imprisoned.

The acidic polymer's acidic environment (pH 2 to 2.5) inactivated and neutralised the virus. When nonwoven fabric coated with the acidic polymer was tested against avian influenza, a reduction in virus titre of roughly 99.97% was found. An hour of contact with an NIBRG-14 H5N1 virus [203].

Kim (Patent No. KR101317166B1, 2013) used the kimchi enzyme to manufacture a nonwoven fabric antiviral. Kimchi is a fermented Korean dish. Kimchi enzyme is produced by cultivating lactic acid bacteria after the kimchi has aged. An aqueous antiviral solution containing kimchi enzyme (10%) and polyvinyl alcohol resin (25%) was produced and electrospun onto a nonwoven polyester fabric before drying at 100 °C. The completed cloth had a kimchi enzyme content of 3% by weight and a polyvinyl alcohol resin content of 7% by weight.

When evaluated against the influenza A virus after an hour of incubation, the virus log reduction value of the nonwoven fabric treated with kimchi enzyme is greater than 4.9 (>99.87%). Kimchi elements like green onion and ginger further inhibit viral development[204].

The concept of producing antiviral fabrics is innovative. Only a few studies on the development of antiviral textiles have been conducted, and the majority of these studies have been patented. The viruses used in antiviral testing, as well as the testing settings, vary from study to study.

As a result, there is virtually little information available for comparing existing antiviral fabrics. The efficiency and durability of antiviral finishes are studied in this comparison of various antiviral treated textile materials. The efficiency of an antiviral textile material is determined by the antiviral chemicals utilised and the virus being studied.

When tested against the influenza virus, textile fabrics treated with monovalent copper compound, metal phthalocyanine, acidic polymer, and kimchi enzyme revealed a virus reduction rate of more than 99% [175, 192, 193, 203, 204]. When tested against the feline calicivirus, textiles treated with a cationic surfactant and textiles treated with chitosan produce identical results[200, 205].

The antiviral finish on the textile material's durability is determined by how frequently the product is washed. Durability is least important in single-use health care and hygiene items, but it influences the effectiveness of daily worn garments and home textile products. Fabrics treated with honeysuckle extract, chitosan, kimchi enzyme, and metal phthalocyanine have been found to last for multiple washes[175, 178, 200, 204].

The premix binder solution makes povidone iodine-coated textiles durable and adds sanitising action to the finished product [179], whereas cationic surfactant-treated textiles are semi-durable. Aside from effectiveness and durability, skin-friendliness is a key factor in determining whether a finished textile is suitable for garment manufacturing. Kimchi enzyme, chitosan, and honeysuckle are derived from natural sources.

When these bio-extracts are applied to the textile fabric within the permitted limits, the treated

textile materials are safe for the skin [178, 200, 204] Textiles treated with an acidic polymer and a cationic surfactant are also skin-friendly because the aforementioned compounds have good antiviral properties at a very low add-on level.

Polyester fabric coated with copper pigment and CuCl has good antiviral activity, but it is not suggested for clothing since it causes skin irritation when in direct and continuous contact with the skin [192, 193, 206].

Possible areas of application of antiviral textiles

Given the history of lethal virus outbreaks and the ongoing pandemic situation, antiviral property should be one of the most desirable qualities for any textile product. Textile materials, on the other hand, are not intrinsically antiviral; they must be treated with an appropriate chemical agent to confer the antiviral characteristic.

This treatment enhances the final product's cost, and not all antiviral drugs are environmentally friendly. As a result, antiviral fabrics should be used where necessary.

The healthcare industry should be the primary user of antiviral textiles because staff in this sector have direct contact with virus-affected patients. Textile for the healthcare sector is classified into two groups based on the number of uses: single-use products and multiple-use products.

Surgical gowns, surgical caps, facemasks, and other single-use textile items are examples, while patients' bed covers, pillow covers, window curtains, and other multiple-use textile products are examples.

Graphene

Graphene is a single-atom-thick sheet of sp²-hybridized carbon atoms arranged in a honeycomb lattice.[207, 208] Graphene's huge surface area, superior electrical conductivity, high mechanical strength, and unique physicochemical features are all due to its structure.[209-211] Because of its simplicity of surface functionalization and controlled selectivity, it is widely used in the field of nanomedicine.[212]

Due of their antibacterial and antiviral properties, two-dimensional graphene sheets have received a lot of attention recently.[213]Differentially functionalized graphene oxide sheets have the ability to distort and enclose bacteria, severely limiting their contact with host cells.[214-220]

Electrochemistry of Copper in Aqueous Glycine Solutions

Copper and its alloys are widely utilised in a variety of environments and applications due to its comparatively high corrosion resistance, superior

electrical and thermal conductivity, ease of manufacturing, resistance to biofouling, and other appealing qualities.

Copper corrosion has been examined in various solutions, and the literature on the subject has been evaluated.[221-223] Copper is a moderately noble metal that is resistant to corrosion in noncomplexing, oxidizing-free solutions, as indicated by potential-pH diagrams for the Cu-H₂O system.[224]

It is, nevertheless, corrosive to acidic or strongly alkaline solutions containing oxidising agents. Copper's corrosion resistance is greatly reduced when exposed to aqueous solutions containing complexing agents such as ammonia and cyanide.

Complexation of the Cu²⁺ and Cu⁺ ions dramatically widens the solubility domain of copper while significantly decreasing the predominant zones of cuprous and cupric oxide, according to potential-pH diagrams for the Cu-CN₂-H₂O[225] and Cu-NH₃-H₂O[226] systems.

The domain of thermodynamic immunity to corrosion is reduced to much lower electrode potentials. As a result, even in the absence of significant oxidising agents, these complexing agents aggravate copper corrosion.[227]

Glycine is a carboxylic acid and amine group amino acid. Glycine is employed as a levelling agent in acidic copper plating baths in trace amounts. Although it impacts the distribution of copper on a microscale during plating, it has minimal effect on overall cathodic kinetics at trace concentrations.[228]

Glycine, through its complexing activity, can increase the solubility of copper ions in aqueous solutions. Halpern and colleagues[229] looked at the kinetics of copper dissolution in aqueous solutions of various α -amino acids. The behaviour of glycine was comparable to that of complexing agents like ammonia[230] and ethylenediamine.[231]

At low oxygen partial pressures, the rate of copper dissolution was proportional to the partial pressure of oxygen and independent of glycine content. However, at sufficiently high oxygen pressures, the rate was independent of the partial pressure of oxygen but reliant on the concentration of glycine, whether in the zwitterionic (HL) or anionic (L⁻) form (discussed in more detail below) Dissolution rate (in mg cm⁻² h⁻¹) 5 kL[L⁻] 1 kHL[HL] [1] [227]

where square brackets denote analytical concentrations. The rate constants kL and kHL were 49 and 31, respectively, indicating that the anionic form is more reactive.

Keenan and colleagues [232] discovered that the corrosion rate of copper was substantially associated with the concentration of anionic glycine and

was only marginally influenced by the zwitterionic form.

The current study attempts to improve our fundamental understanding of copper electrochemical dissolution and passivation in glycine solutions. The thermodynamics of copper complexation in aqueous glycine solutions are first examined, followed by potential-pH diagrams for the copper-glycine-water system. The results of experimental measurements of the polarisation behaviour of copper in various compositions of glycine solutions are then described.

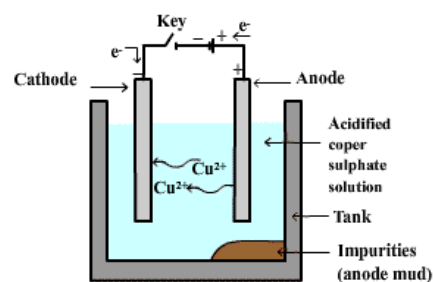


Figure 16. Electrolysis of copper

Acros Organics Co. provided glycine (>99%) as a reagent and solution. Fisher Scientific Co. provided reagent grade cupric nitrate hemipentahydrate. The pH of the electrolyte solutions was adjusted to 60.1 units using NaOH or HNO₃ (both reagent grade from Fisher Scientific Co.). Before usage, the electrolyte was either aerated or deaerated.

Breathing (medical) air was purged into the electrolyte for 18 hours to provide aeration. After aeration, the pH was adjusted with NaOH to account for CO₂ absorption. Ultrapure nitrogen gas (99.999% N₂) was sparged for 24 hours to deaerate the system; this had no effect on the pH.[227]

Synthesis of GO

The Hummers' method[233] was used to make GO by oxidising graphite. Typically, H₂SO₄ and NaNO₃ were poured in a 250-mL flask in an ice bath while being mechanically stirred, followed by the slow addition of 1.0 g graphite powder and KMnO₄.

The suspension's temperature was kept below 5 °C. After the system had reacted for 2 hours, the temperature was raised to 35 °C for 4 hours. Following that, 46 mL of deionized water was added to the reaction system, and the temperature was raised to 95 °C for another 30 minutes.

After lowering the temperature to 40 °C, 60 mL of deionized water was progressively added, followed by 5 mL of 30% H₂O₂, causing the solution's colour to shift from dark brown to yellow. To remove metal ions, the solution was centrifuged and treated with 5% HCl aqueous solution before being

washed with distilled water to remove the acid. Finally, solid GO was produced by freeze drying.

Hummers method

The Hummers method is the most widely utilised method for producing graphene oxide (GO) from graphite [209, 234, 235]. According to Dimiev [236], the creation of GO from bulk graphite involves three processes. Graphite is transformed into a stage-1 graphite intercalation compound (GIC) in the first step, with sulfuric acid (H_2SO_4) frequently utilised as the intercalation agent [237].

$\text{C}(21-28)+\text{HSO}_4-2.5\text{H}_2\text{SO}_4$ represents the stoichiometry of stage-1 H_2SO_4 -GIC. The stage-1 GIC is an important step in the synthesis of GO because it permits oxidising chemicals to diffuse into graphite interlayer gaps. The stage-1 GIC is transformed into pristine oxidised graphite in the second step (PGO).

This rate-determining phase controls the entire diffusion process. When PGO is exposed to water in the third phase, it is transformed into GO. As a result, graphite intercalation is required for further exfoliation while making GO.

Researchers have developed enhanced Hummers procedures that use potassium permanganate (KMnO_4) as the major oxidant of graphite [238] and various auxiliary agents such as sodium nitrate (NaNO_3) to boost GO output. However, the synthetic process of GO alters its final properties [239-242] [7-10], making precise control of GO structure difficult.

Improvements to the Hummers' approach have mostly focused on avoiding the usage of NaNO_3 [238, 243, 244] and increasing the quantity of KMnO_4 used to replace NaNO_3 [245]. These investigations indicate that using NaNO_3 has no effect on GO preparation; nevertheless, the mechanism of action of NaNO_3 during GO preparation has not been well investigated. Many recent research, on the other hand, used NaNO_3 in the synthesis of GO, and the amount of NaNO_3 needed for the same weight of graphite varied [246, 247].

Sherif [248] reported that the mechanism of action of NaNO_3 during GO production is that it acts as an oxidant. Other researchers, notably Tour [249], have ruled out NaNO_3 as an oxidant due to its insignificant impact in graphite oxidation.

Given the low oxidation potential of NaNO_3 , Chen [250] proposed that the main job of NaNO_3 is to enhance H_2SO_4 intercalation, which is favourable to the oxidant's oxidation of graphite. According to Wu [251], NaNO_3 works as an intercalation agent for graphite prior to GO production. Mombeshora [252] investigated the impact of graphite/ NaNO_3 ratio on GO oxygen concentration and physicochemical characteristics.

The most frequent type of graphite used to make GO is flake graphite. The flake graphite structure contains various flaws that can act as oxidation reaction sites. However, the complicated structure of flake graphite and its inherent flaws make determining the mechanism of GO synthesis difficult [236].

The majority of research has been on converting C-C bonds to C-O bonds [253]. Most previous investigations, however, did not take into account the structural alterations of graphite sheets or the influence of oxidant diffusion. Because the initial graphite source is made up of several graphene layers, the oxidant must penetrate the interlayers before the oxidation reaction can take place [254].

As a result, raw graphite particle size influences graphite oxidation. Trung [255] confirmed that the oxidation degree of GO increased as graphite particle size decreases. Seyyedeh [256] discovered that the oxidation duration is highly influenced by the particle size of the original graphite.

Reduced particle size reduces oxidation time, showing that small graphite particles are acceptable for large-scale GO synthesis. Because of their lower resistance, graphite particles with relatively small diameters should save significantly more time than bigger graphite particles under identical conditions [237].

In conclusion, the intercalator and oxidant utilized in GO synthesis, as well as the particle size of raw graphite, are essential elements determining the chemical structure of GO. However, there are few systematic investigations on this topic in the literature. In this study, a series of GOs were synthesised from graphite with varying particle sizes and doses of H_2SO_4 , KMnO_4 , and NaNO_3 .

Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), Raman spectroscopy, ultraviolet-visible (UV-Vis) spectroscopy, scanning electron microscopy (SEM), dynamic light scattering (DLS), X-ray photoelectron spectroscopy (XPS), thermogravimetric analysis (TGA), and atomic force microscopy were used to investigate the factors influencing GO prepared using the Hummers' method. The findings offer some theoretical basis for the creation of high-quality GO.

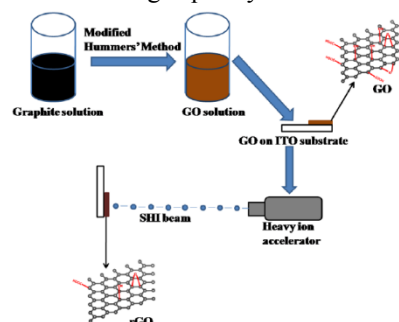


Figure 17. Schematic of preparation of GO using Hummers' method and rGO sample by irradiation method.

glow in the dark

The phosphorescence of printed samples with glow in the dark inks were observed in the dark clearly, this light emission was due to the energy loss of the excited electrons “quantum” when return back to the ground state shell, the light intensity increase with the increase of the ink concentration, the emission still occurred until all the excited electrons returned to ground state, it take about 6 hours in this case study[257, 258].

Glow-in-the-dark materials are used in emergency signs, watches, and paint all around the world. This beneficial feature powers a global market worth around \$400 million.

Nevertheless, the inorganic crystals currently required to achieve this level of performance necessitate the use of rare-earth metals and fabrication temperatures of above 1000 degrees Celsius.

Researchers from Okinawa Institute of Science and Technology Graduate University (OIST) and Kyushu University in Japan have found a method to make glow-in-the-dark light using more widely available organic materials, as reported in Nature Materials.

Furthermore, environmental impact assessment and toxicity testing were carried out in accordance with the rules and regulations of the United States Environmental Protection Agency (U.S. EPA) in order to determine the impacts of GiD material on the environment and human health. The durability and safety of the produced material in terms of real-world use have been evaluated by these experiments.

Engineers and researchers, as well as regulatory organisations, can use the information presented to set standards for the usage of the newly discovered material in infrastructure projects.

Furthermore, the produced prototype can be utilised to improve safety and living conditions in a variety of ways, including bicycle lanes, pedestrian crossings, building basements, walkways, concrete barriers, and curbstones, as well as other architectural and aesthetic uses.[259, 260]

Photochromic

Photochromic textiles have received increasing attention due to their wearable properties and reversible discoloration[38, 261-264].

photo chromic ink

The change of design from colorless to colored, was noticed when the sample was exposure to UV light, sun-light has about 5% UV, so it shows a clear and speed color change[38, 262, 264-269].

The appearance of colors may be due to the excitation of the pigment molecules that help to make new bonds in between, leads to form bigger molecules with high resonance that is why the color of the pigment molecule was shifted from non-observed to an observed area, which is between UV and IR[270].

In the other hand the effect of UV may be enhance the formation of double bond into the pigments molecules that create such temporary chromophoric groups which is the responsible for the achieved colors.

Photochromic compounds are of interest in both science and industry for their unique characteristic of changing colour reversibly in response to stimulation from light[266].

Color shifts in photochromic materials are typically caused by a shift in optical absorption caused by a change in molecular structure or conformation. Spirooxazine dyes, for example, open their oxazine ring when exposed to UV light, forming a merocyanine structure with a larger conjugated molecular system . as shown in scheme 1.[271]

Silica features a large number of "nano-sized" microscopic pores that make an ideal host for photochromic molecules as these tiny pores give enough free volume for the photochromic molecules to complete the photochromic transformation[266].

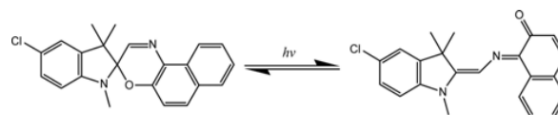


Figure 19. The photochromic effect[271]

Hydro chromic ink.

Smart textiles, which provide natural fibres with appealing and interactive qualities, are promise for the future of the textile industry. In this context, it is feasible to highlight chromic materials, such as hydrochromic, which change their visual qualities (colour) in response to an external input (water) [272, 273].

The goal of this project is to functionalize and characterise cotton knitted fabric with a hydrochromic chemical while investigating the print's reversibility and fastness features. The particles were found to be well disseminated and adhered to the natural fibre surface, with no notable changes in colour after further washing and rubbing fastness cycles[274, 275].

The limited lifetime of the open photomerocyanine-form (PMC-form), which thermally reverts to the closed colourless spiropyran-form, limits the use of SPs to such devices (SP-form) (Scheme 2)[276]

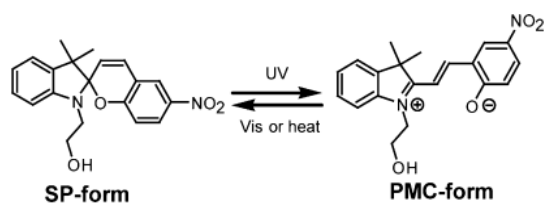


Figure 19. Reversible photochromic reaction of the SP- and PMC-forms[276]

Summary

Textile hanging is a crucial element in interior design, showcasing a place's culture and environment. The pandemic has highlighted the need for unique products with special properties, such as textile hangings that can resist microbes, especially coronavirus. Cellulose fabric, a biopolymer found in plants, animals, minerals, algae, and fungus, is a critical raw material for various applications. Physical and chemical modifications are essential for improving the properties of natural fibres. Nanotechnology is rapidly growing in architecture and construction, particularly in coating surfaces for functional features like higher tensile strength, self-cleaning capacity, fire resistance, and more.

Water repellent textiles are essential in various sectors, including technical textiles, garments, and home materials. They repel oil, water, and dry dirt, and are used in various textile applications. Superhydrophobic surfaces, inspired by nature's lotus surface, have gained interest in both academia and industry. They have various multifunctional applications, such as UV-blocking, photocatalytic, flame-retardant, asymmetric superhydrophobic/superhydrophilic, and stimuli-responsive.

Superhydrophobic textiles are created by coating nanoscale particles onto the fiber surface to create a micro/nanoscale structure and then postfluorinate it for low energy. Physical and chemical procedures are commonly used to produce strong superhydrophobic textile surfaces. Pre-roughening and post-fluorinating are the most popular processes for preparing cellulose-based superhydrophobic textile surfaces.

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Conflict of Interest

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

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تقنية النانو كتقنية حديثة لإضفاء خصائص مضادة للفيروسات ومضادة للبكتيريا وطاردة للماء للأقمشة الطبيعية والصناعية

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المستخلص:

تعتبر معلقات المنسوجات عنصرًا حاسمًا في التصميم الداخلي، وقد سلط الوباء الضوء على الحاجة إلى منتجات فريدة ذات خصائص خاصة، مثل معلقات المنسوجات التي تقاوم الميكروبات. يعد نسيج السليلوز، وهو بوليمر حيوي موجود في النباتات والحيوانات والمعادن والطحالب والفطريات، مادة خام مهمة لمختلف التطبيقات. تنمو تكنولوجيا النانو بسرعة في الهندسة المعمارية والبناء، وخاصة في طلاء الأسطح للميزات الوظيفية مثل قوة الشد العالية، والقدرة على التنظيف الذاتي، ومقاومة الحريق، وأكثر من ذلك. تعتبر المنسوجات المقاومة للماء ضرورية في مختلف القطاعات، وقد اكتسبت الأسطح المقاومة للماء، المستوحاة من سطح زهرة اللوتس الطبيعية، اهتمامًا في كل من الأوساط الأكاديمية والصناعة. يتم إنشاء المنسوجات فائقة الكارهة للماء عن طريق طلاء جزيئات نانوية الحجم على سطح الألياف ثم فلورتها بعد ذلك للحصول على طاقة منخفضة.

الكلمات المفتاحية: تعليق المنسوجات؛ تكنولوجيا النانو. المنسوجات المقاومة للماء؛ مضادة للميكروبات ومضادة للفيروسات