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Potential Applications of Nanotechnology In Functionalization of Synthetic Fibres *(A Review)*

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Abstract

Nanotechnology has been ongoing for more than two decades, and it is a scientific sector that deals with materials in the range of 1nm to 100 nm. It is used in a multitude of sectors, including medicine, energy, aerospace, mechanics, electronics, textiles, optics, and plastics.

In the textile industry, nanotechnology is described as the study, exploitation, and control of materials at a specified length to enhance chemical, biological and physical features of materials. Thus, producing materials, tools, architectures, and systems of high – grade. Nanotechnology is utilized for functionalizing textile materials, as it possesses a lot of distinct properties that allow it to be employed in the manufacturing of innovative and smarter textiles with a variety of functions.

Nanoparticles such as silver, gold, zinc oxide, titanium dioxide, copper oxide, gallium dioxide silica and noanoclay can be imparting textiles desired properties such as fire retardant, antimicrobial activities, ultraviolet protection, self-cleaning, dirt repellency, water repellency, and several physical and mechanical properties. This state of art focuses on the potential applications of nanoparticles on synthetic fibers.

Key Words: Nanotechnology, Nanoparticles, Synthetic fibres, Applications.

1. Introduction

Nanotechnology is used in a multitude of sectors, including medicine, energy, aerospace, mechanics, electronics, textiles, optics, and plastics. Numerous efforts have been made to develop smart and sophisticated textiles by incorporating various nanoparticles or the creation of nanostructured surfaces and nanofibers, resulting in an unprecedented level of textile efficiency[1].

The term "nanotechnology" derives from the Greek word "Nanos," which indicates dwarf. Scientists use this prefix to denote a billionth of a billionth of a billionth (10^{-9}) [1-3]

2. Approaches in nanotechnology

"Bottom-up" and "top-down" are the main process used in nanotechnology."Bottom-up" or self-assembly" process (from specific moves to general) describes the building of nanomaterials from the atomic scale [4].While in the case of the "*top-down*" one (from general to specific)is a term that involves the process of deconstructing bulk materials (macro-crystalline) structures while keeping their original integrity (Fig 1).

3. Nanomaterials

Nanomaterials have unique properties in comparison to the macro scale, providing a range of uses. This occurs when the size of a molecule is lowered to the nanometric size, the properties of the substance are changed [5-9]. Furthermore, fabrics treated with TiO_2 and MgO nanoparticles can be replaced for fabrics treated with activated carbon, which was previously employed as a chemical and biological protective agent [6, 7]. Suppose nanocrystalline piezoelectric ceramic particles are included into the fabric. In that case, the resulting material can convert exerted mechanical power to an electrical signal that can be utilized to monitor biological functions such as heart rate and pulse (if used near the skin).

4. Application of Nanotechnology in Textile Field

Nanotechnology can enhance the performance of the textile and produces multifunctional uses, including

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hygienic properties, tissue engineering scaffolds,

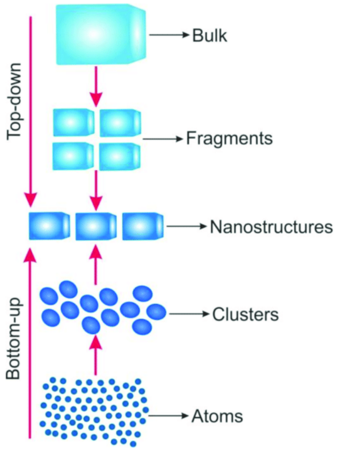

Fig. 1: Top-down and bottom-up approaches in nanotechnology [4]

antibacterial, UV blocking, antistatic properties, improved surface cleaning, wettability, comfort, wrinkle-resistant, strength enhancement, stain resistant, water repellence, soil treatment, odor management, surface friction modification, decreased abrasion impact, and color enhancement qualities in comparison to unaltered surfaces(fig. 2) [10, 11].

Moreover, nanotechnology has a huge economical potential as it reduces the production cost when compared to the traditional process, such as economics, energy conservation, eco-friendliness, controlled substance release, packaged foods, segregating and storing materials on a microscale for later use as well as release under controlled conditions. Another advantage of nanotechnology is that it enables the creation of multifunctional textile systems without impairing the textiles' natural qualities, such as washability, softness, and elasticity [12].

5. Nanomaterials used in the textile field

Nanomaterials can be divided into three main types

- *Production of nanofibers:* The electrospinning process is a suitable way to produce nanofibers. Electrospinning or melt-spinning can be used to spin conventional fibers such as PP (Polypropylene), PET (Polyester), and PA (Polyamide)into the nanoscal.[14]. Nanofibres have various desirable properties, including a large surface area, a tiny fiber diameter, high permeability and excellent filtering characteristics. [15].
- *Production of nanocomposite:* A nanocomposite is made up of two or more nanometer-sized components, thereby resulting in a material with increased specialized qualities resulting from the components' combined properties and/or structuring impacts [16]. Nanomaterials are introduced into fibers to enhance their biological, mechanical, electrical, and optical capabilities. Additionally, nanocomposite coatings can involve a number of nanofillers, whiskers, and nanofibers with modified structures[17, 18].
- *Nanoparticles* are coated onto fibers or textiles using layer-by-layer, plasma polymerization, or sol-gel processes. Nanoparticles can be used to create multifunctional fabrics associated with flame retardant properties, antimicrobial effect, self-cleaning properties, UV protection, oil, and water repellent properties, and good durability [19, 20].

Fig. 2: A diagrammatic representation of various utilization of nanotechnology-based textiles [13]

5.1. Nanofibres

Nanofibers are fibers with a diameter in the nanometric range that can be made from a variety of polymers. As a result, their physical characteristics and application potential vary depending on the polymer employed. Nanofibers have a variety of features, including high permeability, excellent filtration, thin layers,a large surface area, and a tiny fiber diameter. Nanofibers can be synthesized using a variety of procedures, including melt blowing, flash spinning, electrospinning, bi-component spinning, force spinning, and phase separation [21–25].

Electrospinning is regarded as the best approach for producing nanofibers since it allows for precise control over the size and shape of the nanofibers produced (fig. 3) [26]. Numerous economic and technological applications for nanofibers include cancer diagnosis, optical sensors, tissue engineering, drug delivery, lithium-air batteries, wound dressing, and air filtration.

Nanofibers can operate as a filtration system for viruses, poisonous gases, and other airborne contaminants. Nanofibers can trap bacteria, germs, and viruses due to their large surface area and small hole size. Additionally, nanofibers are employed as active layers in face masks to protect patients toward infections like Covid-19 [27].

Emergency services employees and military people alike could benefit from protective garments of nanofibers, as nanofibers can be used to create fabrics that are inexpensive, flame retardant, and antimicrobial effect.

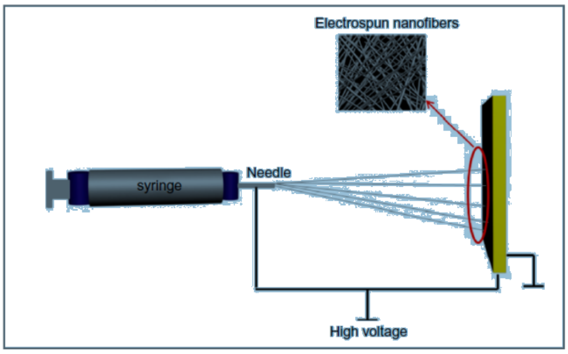

Fig. 3: Nanofibres produced by electrospinning technique [28]

Carbon black nanoparticles and Carbon nanofibers are two of the most often utilized nanofillers. Nanofibers with carbon nanotubes (Fig. 4)[29].

Carbon nanofibers can effectively boost the tensile strength of composite fibers, whereas carbon black nanoparticles can be used to increase their abrasion resistance and hardness. Polyester, nylon, and polypropylene are employed as matrices, with filler content ranging from 5% to 20% [30].

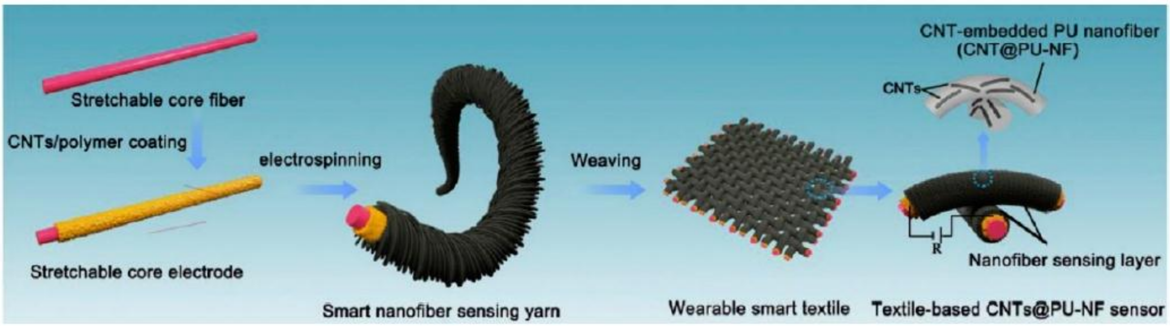

Fig. 4: Processes for fabricating carbon nanotube-encased nanofiber sensing yarn[29]

5.2. Nanocoating and Nanocomposites

The traditional coating process shows certain disadvantages such as poor durability, low strength, high rigidity, and bending length [31].

As a result, functionalization methodologies should be developed to address these issues. These disadvantages can be solved with nanocoating by deposition of a thin layer of nanoparticles and/or nanocomposite on the synthetic fibers through the use of thin-film deposition, cross-linking, and sol-gel technique[32].

Nanocomposites are materials that contain nanometric particles into a polymeric standard material. Addition of nanoparticles is a drastic development of some properties such as mechanical strength, toughness and electrical or thermal conductivity.[33].

Nanocomposite fibers are generated by dispersing nanosize fillers into a fiber matrix and forming multifunctional nanofibres with high performance (fig. 5). Nanocomposite formed by incorporation of metal, metal oxides, or nanoclay in polymeric fibers. It is applied in synthetic fibers to impart some desired properties such as antimicrobial, water/soil release, UV protection, water repellence, flame retardant, and antistatic properties[34]. Nanocomposite also improves the mechanical, electrical, optical, and biological activity of textile materials[35]. Lots of research were done to create nanocomposites used to multifunctionalize the textile materials.

Abou El-Kheir et al. [36] developed a nanocomposite by dispersing nanoclay, namely, nanokaoline in a soluble polymer-forming sodium polyacrylate /kaoline nanocomposite, and applied it on viscose fabric which exhibited improvement in the tear strength, tensile strength and enhanced the dyeability towards reactive and direct dyes.

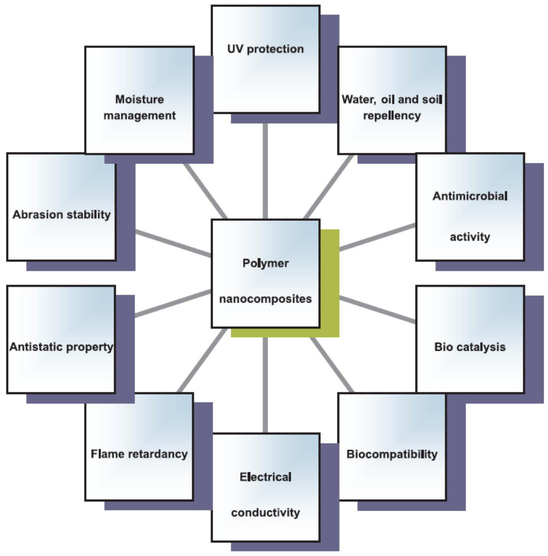

Fig. 5: Applications of nanocomposites in textile finishing [34]

It was reported that sodium polyacrylate/bentonite nanocomposite enhanced the transfer printability with disperse dye for acrylic fabric and improved its wettability, and imparted very good protection to UVA and UVB radiations [37].

Silver nitrate was dispersed in a soluble acrylic fiber-forming polyacrylonitrile/silver nanocomposite film, which has produced a multifunctional film with electrical conductivity, antimicrobial, catalytic, UV protection, and surface increased raman scattering properties (SERS) [39].

In addition to the montmorillonite(MMT) nanoclay into the polypropylene (PP) polymer, the dyeability of the fibers was improved. This improvement is due to the mixing of MMT with PP, which reduces the crystallinity of PP and leads to additional polymer chains within the polypropylene matrix would be available. Additionally, the increased dyeability of the PP nanocomposite is attributed to the creation of high-energy inter phase surfaces and the presence of van der Waals forces between the clay particles and the distributed dye molecules [38].

A nanocomposite formed of silver nanoparticles and diphosphate malonate (DPHM) was produced as an organic phosphate. The antimicrobial and flame retardant characteristics of textile materials treated with that nanocomposite were dramatically enhanced[40].

5.3. Polymer/carbon nanotube application in textile

Polymer/carbon nanotube is one of the nanocomposites used to finish textile [41-48]. The carbon nanotube is an efficient nano-filler due to the large specific surface area, durability, and chemical inertness of the material. Polymer/carbon nanotube produces multifunctional textiles [49-51] of wastewater treatment, sensors, fire retardant, antimicrobial, and UV blocking (fig. 6).

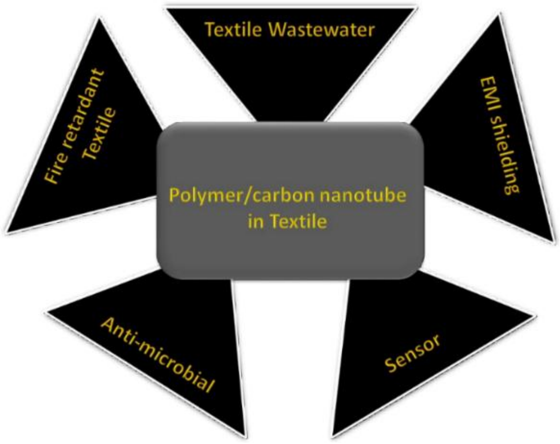

Fig. 6: Polymer/carbon nanotube applications in textile [45]

5.4. Nanoparticles

Inorganic nanoparticles such as TiO_2, ZnO, SiO_2, Cu_2O, Ag NPs, Au NPs, and nanoclay have been used in textiles functionalization because of their greater surface area, thermal and chemical stability, permanent processability, and lack of toxicity when contrasted to organic materials[52].Nanoparticles have a wide range of uses in composite materials such as construction, and tissue engineering. They may be a more advantageous alternative to the conventional micron particles used in surface treatments to remove filth since they are stain-resistant, flame retardant, wrinkle-resistant, humidity management, antimicrobial, antistatic, UV protection, and have a better dyeing capacity[53].

Numerous techniques are utilized to cover the surface of nanoparticles, including padding, spraying, washing, transfer printing, rinsing, so-gel. On the other hand, padding is the most frequently employed way of coating, as the nanoparticles are deposited onto textile materials using a padding solution under appropriate speed and pressure. The fabric will be dried and cured after this procedure [54].Sol-gel coating approaches have recently gained popularity in nanocoating due to their low processing temperatures, elevated chemical homogeneity, and ability to manage particle size and morphology [55].

Polypropylene, Nylon, polyester, and acrylic are the most frequently used synthetic fibers in residential and industrial uses. However, the great disadvantages of these fabrics are hydrophobicity and low moisture regains[56]. Many trials were performed to alter the synthetic fibers' surfaceto improve various properties such as softness, dyeability, absorbance, and wettability [57]. Numerous nanoparticles types were utilized to treat synthetic fibers in order to get the necessary qualities[58, 61]. For instance, self-cleaning, antistatic properties, flame retardant, antibacterial activity, antifungal, UV protection, and waterand oilrepellent [59 – 61].

5.4.1. Flame retardant Applications

Synthetic fibers such as nylon, polyester, and acrylic fibers are extensively utilized to manufacture a number of textile items[62, 63]. However, most of them are flammable. Therefore, the utilization of nanoparticles in the finishing of the synthetic fabrics as flame retardant is an interesting approach to avoid fires and rescue human life.

In general, the synthetic fibers are melt (when exposed to fire source),producing species that degrade into flammable, volatile compounds, and they fuel the flame in the presence of oxygen. Then the synthetic fibers can be easily burned. The combustion cycle, as depicted in figure 7.

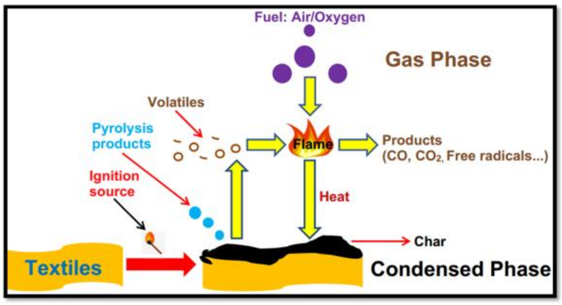

Fig. 7: Combustion cycle of a typical synthetic textile material [67]

Some compounds were used as a flame retardant, including halogenated compounds such as chlorine and bromine. The conventional mechanism involves the release of particular radicals (e.g., Cl• and Br•) that can combine with reactive species (e.g., H• and OH•) to generate less reactive halogen atoms [64-67]. The phosphorous compounds industry is committed to the usage of halogen-free chemicals. Phosphorus compounds create species (e.g., PO•, PO_2•, as well as OHPO•) that can react with (H• and OH•) and prevent the fibers from oxidizing. This results in the combustion process being interrupted[67, 68]. The combustion intermediates produce as follows

$PO^{\bullet}+H^{\bullet}\rightarrow HPO$

$PO^{\bullet}+OH^{\bullet} \rightarrow HPO_2$

$HPO_2^{\bullet} + H^{\bullet}\rightarrow H_2O + PO$

The main advantage of using nanoparticles as fire-retardant materials is that a low amount can be effective in flame resistance [69]. The flame retardant system depends on the concentration, dispersion of nanoparticles onto textile fabrics, morphology, and chemical properties of nanoparticles.

Silicon nanoparticles [70, 71]treated the synthetic fibers protect the polymeric fibers from contact with oxygen gas which then reduces the heat transfer. It was reported that [72] by layering a multilayered thin film of silica onto polyester textiles (PET), the flame retardant properties are improved. Additionally, the plasma technique was used to activate the surface of polyester fabrics in order to increase the adsorption of clay nanoparticles, hence improving the materials' thermal stability and flame retardant qualities. It was confirmed that the flame retardant effect of SiO_2 on PET, polyamide, and polyacrylonitrile fibers (PAN) increase their thermal stability, necessitating a greater amount of energy to initiate combustion[73].

SiO_2 nanoparticle was mixed with polypropylene (PP), which hence improved the flame-retardant and mechanical characteristics of polypropylene (PP) as the tensile strength of PP composite was improved compared to the native PP[75].Novel fire protection of synthetic fibers by nanoparticles adsorption was developed [76]. The effect of immersing various nanoparticles into fabrics in the form of clay nanoparticles, TiO_2 or silica or mixing of them are studied. The use of silica using the pad-dry-cure technique results in flame retardant with decreasing of CO_2 and CO amount. A mixing of Hydrotalcite ($Mg_6Al_2(OH)_{16}(CO_3).4H_2O$)) with SiO_2nanoparticles improved the flame retardant properties [77].It was observed that mixing of nanoparticles using the pad-dry-cure technique significantly enhances the flame retardant properties compared to using of a single type of nanoparticles [78]. Abou El-Kheir et al. [79, 80] were treated native polyester fabric, and alkali-treated one with different concentrations of SiO_2 (20-22 nm) dioxide and bentonite nanoparticles utilizing the pad-dry-cure approach. The results indicated a great enhancement of the thermal stability for polyester after treatment with nanoparticles and significantly improved some characteristics, including antibacterial activity, moisture regain, and UV protection [79, 80].

It was recommended to create a flame retardant for polyester fabrics by utilizing a pad-dry-cure approach using zinc oxide (ZnO) nanoparticles [81]. The findings indicate that raising the nano ZnO dosage (from 0.25 to 0.5%) reduced the fabric's flammability[81].

Apaydin et al. [82]said that polyamide and polyester textiles were demonstrated to display considerable flame retardant characteristics as well as improved surface characteristics (e.g., wettability and surface energy) following treatment with TiO_2 nanoparticles mixed with polyelectrolytes via layer-by-layer assembly.

The polyester fabric was treated with carbon nanotubes, improved the flame retardant properties as it was duplicated the burning time compared to native polyester fabrics [82].

It was observed that treating polyamide 6, 6 (PA6, 6) fabrics with titanium dioxide (TiO_2), silicon dioxide (SiO_2), inositol hexaphosphate (IP6) ($C6H_{18}O_{24}P_6$), and/or a combination of these compounds through the use of the pad-dry-cure approach improved the hydrophilic and flame retardant characteristics of the said fabrics. It was found that treatment of the fabric with (IP6)-TiO_2raised the limiting oxygen index (LOI) of untreated fabric from 19.5% to 24.5% for treated fabric. Additionally, chitosan (CS) introduction into the IP6-TiO_2/SiO_2 mixture decreased the peak heat release rate (pHRR) by 25%.Moreover, after treatment with TiO_2/SiO_2, the tensile strength of polyamide textiles was elevated. It was concluded that TiO_2/SiO_2 was better than halogen and phosphorus compounds for producing polyamide 6, 6 with flame retardant properties[83].

5.4.2. Antimicrobial Activity Applications

Microorganisms have a greater proclivity for causing damage to textile materials[fig.8] including microbes, algae, fungi, viruses, and bacteria [84-87].

The utilization of nanomaterials, in particular nanoparticles, showed positive antimicrobial properties of textiles, unlike those in the bulk state [88].

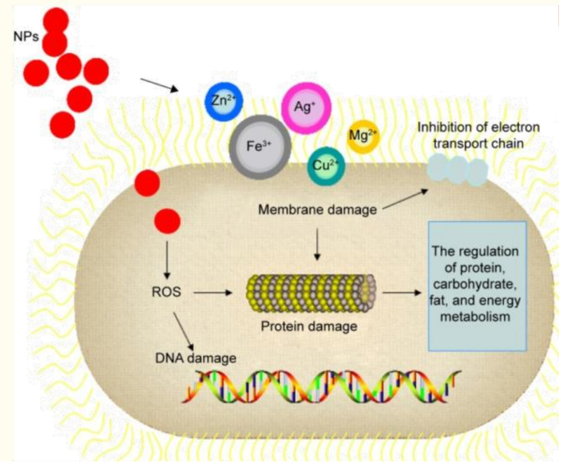

Fig. 8: Mechanism of nanoparticles action in bacteria cells [88]

Nowadays, gold and silver NPs [89], titanium dioxide, zinc oxide, carbon nanotubes, copper oxide, and gallium oxide[89-92]are used as antimicrobial resistance against fungi, positive and negative bacteria.

5.4.2.1. Antimicrobial activity of synthetic fibers by Silver nanoparticles

Silver is a higher antimicrobial agent, showing excellent biocidal activity against microorganisms [93]. Due to its superior antibacterial action, it is used in a variety of industries, including the medical industry, preservation of food, sewage treatment, and textile materials [94].

The typical mechanism of antimicrobial by silver nanoparticles [95] can be described(fig. 9) as follows:

- Electrostatic attraction between silver ions and bacteria's cell wall improves the cytoplasmic membrane's permeability, resulting in the rupture of the bacterial wrapping[96, 97].
- After that, the free silver ions can interrupt adenosine triphosphate production by disturbing the respiratory enzymes [98].
- Silver ions are interacting with the sulfur and phosphorus in DNA cause DNA damage [99].

- Silver nanoparticles can prevent infection by accumulating in the pores in the cell wall, resulting in hydrolysis of the cell membrane. [100].

Numerous researchers investigated the impact of silver ions and its nanoparticles on microorganism suppression on synthetic fibers.

Silver-tricalcium phosphate nanoparticles (Ag/TCP) were used to treat polyamide 6 (PA6) fabrics to elevate antimicrobial resistance towards microorganisms, including such E. coli and S. sanguine, which were 99.99% and 100%, consecutively [101]. Shastri et al. [102]developed the production of nanostructured silver into fibers and investigated the effect of silver NPs on antimicrobial activity, which causes foot disease.

Jiang et al. [103] formed a thin layer of AgNPs (50 nm) via sputtering polyester fabricto achieve superior protection against UV radiation, hydrophilicity, and antibacterial activity vs. a variety of pathogens. The presence of a homogenous layer of AgNPs on the polyester surface was demonstrated by SEM pictures.

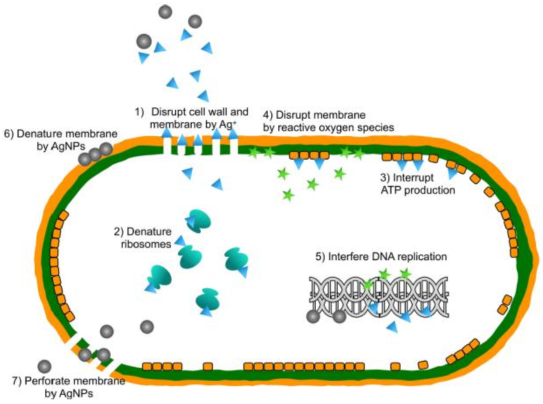

Fig. 9: The antibacterial actions of silver nanoparticles (AgNPs) [100]

Plasma technology was used to activate the fiber surface; this method facilitates the binding of colloidal AgNPs onto polyester or polyamide fabrics showing antibacterial resistance and laundering durability [104]. Falleta et al. [105] used $AgNO_3$ to prepare silver nanoparticles and applied it onto polyester by pad dry cure technique, which helps complete deposition of nanosilver onto the fabric surface. In comparison to the untreated cloth, the treated fabric demonstrated resistance to a variety of pathogens.

Polyester and polyamide fabrics were treated with Tollen's reagent ($Ag(NH_3)_2OH$) as a source of silver ions and using Tollens'' reaction to deposit the prepared nanoparticles onto the mentioned fabrics. Due to the complete conversion of silver ion Ag^+ to Ag^0, a thin layer of silver NPs was formed on the indicated textiles. The reduction was done using glutardialdehyde (GDA), as the aldehyde group is responsible for the reduction step. The silver-finished polyamide and polyester fabrics show excellent resistance for E. coli and excellent durability [106].

It was suggested that the polyester cloth was coated with a dopamine aqueous solution. Then, at room temperature, silver NPs were generated in-situ on the surface of the dopamine-modified polyester textiles using an aqueous solution of silver nitrate. The silver NPs finished fabrics showed a robust and durable antibacterial activity [107, 108].

Polyester fabrics were deposit with a thin film of silver nanoparticles using sputtered DC and pulsed DC-magnetron. It was noticed that Ag sputtered using DCP penetrated the polyester fiber more deeply than Ag sputtered using DC. The fabric covered with silver nanoparticles using the DCP-sputtering method showed highly antibacterial resistance against E. coli. [109].

Nylon, and polyester were treated with silver nanoparticles using ultrasound irradiation to release the nanoparticles onto the indicated textiles' surfaces. The treated fabrics showed the excellent killing of bacteria. The coated fabrics can be used to purify medical and culinary equipment, as well as for household cleaning [110].

In-situ reduction of silver nitrate ($AgNO_3$) with stannous chloride ($SnCl_2$) was carried out in the existence of cetyltrimethyl ammonium chloride (CTAB) as a stabilizing agent [111]. Polyamide (PA) fabrics were treated with the reduced silver nanoparticles. The finished polyamide fabrics indicated good antibacterial characteristics against different species of bacteria [111].

$AgNO_3$ was used as the source of silver ions; silver ion was directly reduced to silver nanoparticles, the formed nanoparticles were incorporated in polyamide 6 using in-situ polymerization method. This method performed a uniform dispersion of silver in PA6. In comparison to native PA6, the antimicrobial resistance capabilities of nano-Ag/PA6 nanocomposites were enhanced [112].

In another experiment, trisodium citrate was employed to reduce Ag^+ to Ag^0 as well as to stabilize and associate AgNPs with the fabric surface. Finished acrylic fabrics displayed superior antibacterial resistance toward E. coli, with gram-negative bacteria reaching 95% after ten washing cycles [113].

Waste polyacrylonitrile was dissolved in N, N-dimethylformamide (DMF), then different amounts of silver nitrate were added, and in-situ reduction was performed using kitchen microwave, and thus, PAN/Ag nanocomposites were obtained. The synthesized nanocomposite film inhibited bacterial growth completely (99, 98 %) and exhibited strong antifungal activity [39, 114].

The acrylic fiber treated with AgNPs under ultrasound irradiation was performed by Azadbakht [115]. Silver nanoparticles treated fibers shown a significant level of antibacterial resistance towards *E. coli* and *S. aureus.*

The antibacterial, long-lasting Ag/polyacrylonitrile hybrid nanofibers were synthesized using atmospheric plasma ablation and electrospinning. The hybrid nanofibers released silver ions slowly and continuously, resulting in long-lasting antibacterial action [116]. These fiber mats demonstrated a mortality effectiveness of 99.99%, which is extremely advantageous for clinical applications like skin regeneration processes and wound healing [117].

The water soluble photoinitiator (PI) 4-(trimethyl ammonium methyl) benzophenone chloride/UV system was used in the synthesis of silver nanoparticles (AgNPs). The PI/UV system was further utilized to fix AgNPs onto acrylic fabrics by photo crosslinking to impart durable antibacterial properties. The treated acrylic fabrics exhibited antibacterial activity against *S. aureus* and *E. coli* [118].

Gawish et al. [119], observed that the melt-spinning technique was used to fabricate the PP/Ag composite fibers, and the antibacterial efficacy was determined by the corresponding decrease in proliferation of *S. aureus* and *E. coli*. Through the spray process, silver nanoparticles were applied to the nonwoven polypropylene. The results indicated that the nanosilver-coated layer fully eliminated *S. aureus* and *E. coli* from the flowing air [120].

5.4.2.2. Antimicrobial activity of synthetic fiber by ZnO

ZnO nanoparticles were used on the synthetic textile surface in combination with various surfactants to sustain and compress the coating, thereby increasing the longevity of ZnO NPs and reducing their leaching. They demonstrated the highest antibacterial and antifungal activity against a variety of pathogenic fungi and bacteria, with a high decrease of over 90%[121]. Typically, ZnO NPs-coated materials are synthesized by adding supporting material to stabilize and enhance the durability of the ZnO NPs[122]. Consequently, ZnO has been combined with a variety of capping agents during the fabrication of ZnO nanocomposite coatings on textiles, including multiamide compounds [123, 124], sulfated cyclodextrin [124], hexamethyltriethylene tetramine [125], chitosan [126], and sodium alginate [127].

Polypropylene hydroentangled nonwoven was coated with ZnO and CuO separately using the pulsed laser deposition method. Significant antibacterial activity was found from ZnO, and CuO coated PP hydroentangled nonwovens, with an advantage over gram-negative *E.coli* and gram-positive *S.aureus*.. ZnO and CuO coated PP nonwoven fabrics can offer scope for use as wound dressings with the impregnation of suitable antibiotic drugs [128].

Zinc oxide was used to nanocoating the surface of polyamide 6 (PA), polyethylene terephthalate (PET), and polypropylene (PP) fabrics to provide an antibacterial layer. Chemical bath deposition (CBD) was used to produce ZnO microrods on ZnO nanoparticles (NPs) as nucleus centers. ZnO-modified textiles were found to exhibit substantial antibacterial action, notably against Gram-negative bacteria. The highest concentration of ZnO microrods was found on PA, followed by PET and PP.As a result, the maximum bactericidal effect was reported for PA-ZnO, which is due to the higher content of ZnO onto the said fabric [129].

Polyester fabrics were treated with ZnO nanoparticles. It was indicated that the smaller nanoparticles' size ZnO usage, the higher the antimicrobial resistance against microorganisms. It was observed that the obtained fabric could be used as sportswear clothes [130].

After various washing cycles, polyester fabrics were allowed to treat with aqueous suspensions of zinc oxide (ZnO) with particle diameters ranging from 50 to 300 nm to impart antibacterial resistance against *S. aureus* and *K. pneumoniae*, whereas nanoparticles with a diameter of 10 nm exhibit enhanced optical visual effect [131].

Antimicrobial assessment of a polyester fabric treated with ZnO nanoparticles revealed the greatest inhibitory effect against *S. aureus* (5.8 cm zone of inhibition), preceded by *E. coli* (3.7 cm zone of inhibition).*S. aureus* and *E. coli* were reduced by 94.16% and 86.5%, consecutively, on fabrics treated with ZnO nanoparticles. On the other hand, ZnO bulk-treated fabrics demonstrated a lower reduction percentage. In contrast, untreated fabrics demonstrated a negative reduction percentage, indicating that the final number of bacterial cells will be significantly greater than the initial number due to the absence of bactericidal activity [132].

Hybrid polymers depending on nanosized zinc oxide particles and glycidiltrimethoxisilane (GPTMS) were developed. These hybrid materials were padded onto polyester textiles. The modified textiles' antibacterial activity was completely inhibited by both *E. coli* and *M.luteus* due to their low ZnO content and small particle size [133].

5.4.2.3. Antimicrobial activity of synthetic fiber by TiO_2

TiO_2 can endow synthetic fibers with a variety of qualities, including self-cleaning, antimicrobial effect, and UV protection.

By spraying titanium dioxide nanoparticles onto polyester woven and knitted fabrics, with a 1% dose of acrylic binder, the nanoparticles were applied to both sides of the fabric. Titanium dioxide coating added antimicrobial, UV-blocking, and self-cleaning properties to the fabric surface.

The sol-gel approach is an effective method to arrange nano titanium dioxide solution. Tetrabutyl titanate was employed as a supply of titanium, and ethanol was used as a solvent in this preparation approach. The fabric has been padded. The treated fabrics exhibited antibacterial resistance to *S.aureus* and *K.pneumoniae* [132]. Polyester fabric treated with naturally polysaccharide alginate and colloidal TiO_2 nanoparticles shown superior antibacterial resistance to *E. coli.* Polyester fabric treated with TiO_2nanoparticles significantly improved UV protection. The treated Fabrics also showed photodegradation of methylene blue [134].

Deposition of TiO_2 on polyester surface occurred by hydrolyzing of the polyester fabric with protease to activate its surface. Hydrolysis was employed to increase the adsorption of nanoparticles onto the fabric surface. The antibacterial against *E. coli* was significant improved in the treated samples [135].

Suspended TiO_2 was nanocoated of polyester fabric as corona discharge was used to modify polyester fabric. The treated fabrics exhibited a variety of features, including excellent UV protection, antibacterial resistance, and self-cleaning[136].

5.4.2.4. Antimicrobial activity of synthetic fibers by other nanoparticles

It has been demonstrated that nanometals and/or nanometal oxides such as, silica (SiO_2), copper oxide, gold NPs, and gallium oxide can also be used as an antimicrobial activity for polymeric textiles.

Polyester textiles coated with silica were adhered to the polyester surface using an acrylate copolymer as an adhesive molecule. The treated fabrics demonstrated outstanding antibacterial characteristics and launder-ability[137].

The polyester fabric was treated with silica ranges from 20-22 nm after hydrolyzingthe fabric with NaOH to activate its surface and facilitate the penetration of silica into the polyester fabric. The results showed a higher reduction against*S. aureus, E. coli, C. albicans,* and *A. flavus* compared to the untreated one [79].

AuNPs are applied in various fields, including optical and medical sectors. They are typically considered as drug delivery, cosmetic materials, medical materials, and antimicrobial agents[138, 139].

Kam Ling Chan et al. [140] have synthesized AuNPs using chloroauric acid ($HAuCl_4$) as precursor salt, $NaBH_4$ as reducing agent, and sodium citrate as a capping agent. They were coated on synthetic fabrics using a drop-wise deposition. The result indicates the efficacy of Au NPs against gram-positive bacterium *S. aureus*.

Abou Elmaaty et al. [141] have used a simple method, printing, and paste, to coat the AuNPs onto the polyester fabrics. The gold nanoparticles were synthesized using gold (III) chloride hydrate and sodium citrate. After that, the solution was made into a paste, and it was printed using the flat-screen technique. The treated polyester fabrics showed significant resistance to different species of bacteria [142].

Cu nanoparticles have an antibacterial effect as they bind to the bacteria envelop and release the ions inside the wall cell. The released Cu and CuO nanoparticles bind with DNA and intercalate with nucleic acid strands, resulting in the oxidation of lipids and degradation of the bacteria's wall and membrane [143].

Gallium oxide (Ga_2O_3) nanoparticles with 100nm in diameter demonstrating antibacterial activity against *E. coli* and *S. aureus* [144].MgO nanoparticles exhibit a broad spectrum of antimicrobial resistance against a variety of pathogenic bacteria[145].

5.4.2.5. Antimicrobial activity of synthetic fibers by nanoparticlesmixtures

There are other ways to impart antimicrobial-resistant to synthetic fibers. This method can be performed by combining the nanoparticles together(Ag/ZnO, Ag/SiO_2, Ag/TiO_2).

Polyester fabrics were treated with a mixtureof (Ag/ZnO). The treated fabric was investigated against E. coli and M. luteus. The findings indicate that the antibacterial effect of Ag/ZnO nanoparticles is greater than that of ZnO alone, and that it rises with increasing silver concentrations[146].

Nanoparticles of silver/silica complex have been created in order to test the generated complex's against antibacterial activity[147].Silver/silica complex nanoparticles treated polyester fabrics demonstrated remarkable antibacterial action towards *S. aureus* and *E. coli*. Antibacterial activity was reported to diminish when polyester fabrics were treated with silica alone.

The fabric treated with TiO_2/AgNPs was tested against *E. coli*, *S. aureus*, and *C. albicans.* The findings indicate that fabrics treated with a TiO_2/AgNPs mixture exhibit increased antibacterial activity in comparison to fabrics treated exclusively with AgNPs[148].

5.5. UV protection Applications

UV (ultraviolet) radiation is a type of electromagnetic radiation emitted by the sun with wavelengths ranging from 100 to 400 nanometers (nm). UV radiations are classified into three types: UVA (315-400 nm), UVB (280-315 nm), and UVC (100-280 nm). The majority of ultraviolet (UV) radiation emitted by the sun that reaches the earth is UVA ray, with the remainder being UVB rays. On the other hand, UVC rays don't reache the ground because it reacts with ozone(O_3) in atmosphere(in the stratosphere of the Earth's atmosphere).

Prolonged exposure to ultraviolet (UV) radiations can cause several harmful effects to humans, including skin cancer, sunburn, tanning, wrinkles, eye injuries, cataracts, immune system suppression, and cellular genetic damage[149, 150]. According to the Occupational Safety and Health Administration (OSHA), protecting the skin from UV radiation can be accomplished by covering it with woven fabrics, sunscreen creams, and UV absorption compounds [151].

UV radiation blockers can be used with inorganic nanoparticles because they are non-toxic and chemically stable when exposed to UV light. ZnO[151] and TiO_2 [152]were used due to their photocatalytic behavior. They were discovered to have increased durability, more intense absorption, and better UV blocking (fig 10).

UV light excites electrons from the valance band to the conduction band, resulting in the formation of a positively charged hole in the valance band (fig. 11). As a result, light below these wavelengths contains sufficient energy to excite electrons and is absorbed by metal oxides, converting it to infrared radiation that they dispose of as heat [153].

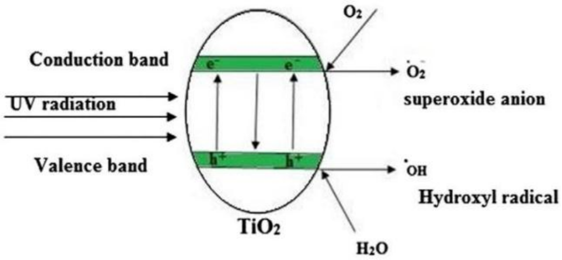

Fig. 10: Photocatalytic oxidation on the surface of TiO_2 nanoparticles [152]

Polyamide fabric treated with three industrially-prepared nano-TiO_2. It was found that monocrystalline TiO_2 showed excellent protection against UV rays (UPF 50), as well as the super-hydrophilicity of TiO_2-modified polyamide fabrics, was obtained [154].

Polyamide 6 (PA-6) was grafted using poly quaternary ammonium salts in existence of the mixture of metal oxides in nanosize (TiO_2 or ZnO), and the procedure was carried out utilizing the pad-dry-cure approach. The treated fabrics displayed excellent resistance to ultraviolet radiations, without impairing the fabric's physical properties [155].

Nylon fabric was modified with nano gold prepared with in-situ synthesis treatment in the presence of a reducing and stabilizing agent, trisodium citrate. The findings reveal that gold nanoparticles significantly enhanced the UV protection of nylon fabrics [156].

Nylon knitted fabric was treated with silica nanoparticles (by sol-gel method) and applied on the mentioned fabric by the pad-dry-cure technique. The treated fabric exhibited excellent resistance to UV rays and higher hydrophobic properties even after10 washing cycles [157].

The curing procedure was used to apply ZnO nanoparticles to polyester fabrics. Nanorod ZnO treated polyester fabricillustrated high UV protection with high UPF value. The superior UV protection of ZnO nanorod-treated fabric results from the crystallinity and enhanced electerical properties of the nanostructured material [158].

Alkali hydrolysis polyester fabric was treated (separately and in one time)with ZnO nanoparticles. Both fabrics were coated with different concentrations of ZnO solution with the exhaustion method. The results exhibited that increasing zinc oxide nanoparticles concentration increased the UV resistance and self-cleaning of the polyester fabrics regardless of the treatment method [159].

Polyester treated with NaOH was coated with a thin layer of suspended nanoclay with different concentrations using the pad-dry-cure technique. It was shown that the nanoclay imparted excellent protection of UV radiation and the UPF value increased as the clay NPs increased [80].

The acrylic fabric was coated with a sodium polyacrylate nanocomposite containing bentonite nanoparticles. The prepared nanocomposite was deposited on the surface of acrylic fabric using a pad dry cure technique. The treated fabric demonstrated good resistance to UVA and UVB radiations [37].

Acrylic fibers were treated in-situ with silver nanoparticles using varying concentrations of silver nitrate and trisodium citrate (TSC) as a reductant and stabilizer. Multifunctional acrylic fibers were produced with superior antimicrobial activity, excellent UV protection, and self-cleaning characteristics [160].

5.6. Self-Cleaning Applications

Self-cleaning has generated considerable interest due to its unique features and applicability in a wide variety of fields. In nature, the "Lotus plant" is the greatest criterion of self-cleaning surfaces since its leaves remain clean indefinitely due to the ease with which dust and water roll off and thoroughly clean the surface. Self-cleaning is associated with a superhydrophobic textile surface with a contact angle of more than 150 degrees and a very low roll-off angle. Textiles that self-clean can indeed be made by covering them with a thin layer of hydrophobic nanoparticles. TiO_2 and ZnO nanoparticles are most effective in their self-cleaning properties as a result of their photocatalytic activity [161]. In the photocatalytic self-cleaning process, the fabric surface is coated with TiO_2 or ZnO nanoparticles. When one of the nanoparticles indicated above is exposed to light of energy exceeds its bandgap, electrons are transported from to the valence band to the conduction band. The negative electrons and oxygen interacts to form O_2^- radical ions, whereas the positine holes and watergenerates hydroxyl radicals OH• is generated as the positive holes interact with water. Since these two radicals are chemically unstable, thus dirt, pollutants, and microorganisms fall on the photocatalyst materials' surface and combine with the produced radicals, and separated into carbon dioxide and water (fig. 11)[162].

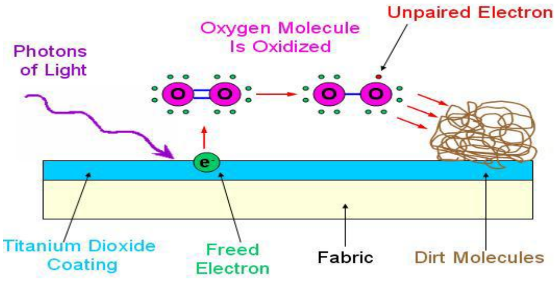

Fig. 11:The photocatalytic self- cleaning mechanism [162]

With the aid of binders, various concentrations of titanium dioxide nanoparticles in the form of anatase were attached to polyester using a pad–dry-cure approach to create photocatalytic self-cleaning thin films. After eight washing cycles, TiO_2 nanoparticles are sonicated at room temperature, and treated polyester fabrics display strong photocatalytic self-cleaning characteristics to destroy coffee stains [163].

ZnO nanospheres and ZnO nanorods are produced from zinc acetate by sodium hydroxide with different conditions of the bath treatment (stirring and ultrasound). After treating the polyester fabric with caustic soda, adsorption of nanoparticles onto the fabric was increase. Under UV irradiation, the self-cleaning capability of treated polyester fabrics for various types of stains was enhanced. Also, their antibacterial activity against various microorganisms was improved. Ultrasound-treated polyester textiles had significantly higher photocatalytic and antibacterial activity than stirrer-treated materials [164].

To achieve the surface self-cleaning property of the polyester fabric, various sizes of TiO_2 NPs were used.It was found that, increasing the size and concentration of TiO_2NPs increasing the content of nanoparticles on the fabric surface. Under UV or sun irradiation, polyester fabric coated with TiO_2NPs demonstrated excellent self-cleaning characteristics for organic colors, coffee, and red wine [165].

TiO_2NPs were applied on nylon 6 fabric by corona discharge to impart the self-cleaning features of the mentioned fabric. The self-cleaning performance of the treated fabric was tested using staining nylon fabric treated with corona/TiO_2 with methylene blue (MB).The treated fabrics displayed very good self-cleaning properties[166].

Polyamide 6 fabric was treated with ZnO dispersed in methanol and then coated onto the fabric surface. It was shown that deposition of ZnO onto polyamide 6 fabric gave a good potential for using the treated fabric in the textile industry, such as self-cleaning and antibacterial properties[167].

Titanium dioxide (TiO_2) nanoparticles were combined with polypropylene at various concentrations, and fiber was generated using single screw extrusion. 20 wt% of TiO_2 in the PP fibers improve the self-cleaning features under 5 hours of 20 watts of UV radiation. However, as the amount of TiO_2 increased, the tensile strength of the TiO_2-PP fibers reduced [168].

Three distinct varieties of metal oxide nanoparticles were used to pre-treat acrylic fabrics, comprising titanium oxide, magnesium oxide, and zinc oxide, accompanied by printing with basic pigments. The color intensity of the coated acrylic fabrics was increased. Additionally, the treated fabric demonstrated superior photocatalyticself-cleaning, superior ultraviolet protection, enhanced the colorfastness of printed fabrics, and significant antibacterial activity [169].

6. *Future outlook*

Functional textiles and clothing need to add some characteristics, for example, appearance, easy-care, as well as some new features and functions such as flame resistance, thermal conductivity, deodorant, antibacterial and antifungal protection. These new functions can be obtained through nanotechnology. These treatments will be applied to textile materials during both the raw material manufacturing stage and/or the application of some nanoparticles during the downstream treatments using different technologies.

Future studies on synthetic waste fibers can be enhanced to prepare nanofibres or films which can be treated with nanomaterials as well. The nanofiber industry is useful in fiber waste disposal and in obtaining fibers that have the ability to ion exchange to remove metal residues, oils, and dyes wastes, as well as in water desalination processes. The formation of nanofibers using electrospinning in presence of nanoparticles with plasma technology are promising technologies in the future to improve all textile functional properties. It is easy to add nanomaterials during the preparation of the nanofibers, and thus the nanofibers can be given the desired properties. To enhance the properties of nanofibers, different spinning methods were used with different additives or treatments. It is expected that the applications of these nanofibers will increase in the medical field and the filter industry.

Today, the textile industry is expected to benefit from research on materials encapsulated in nano-capsules to enhance the final outcome features as functional clothing. One of the increasing applications used is the incorporation of nano-capsules material to impart functional properties such as antimicrobial as well as UV protection. The property of nano-encapsulated phase change materials can be harnessed to increase comfort for sportswear users, bedding, medical clothing, and many other consumer products.

7. References

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