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Recent Developments in the Utilization of Polymer Nanocomposites in Textile Applications

Menna Zayed, Mai Baker and Heba Ghazal*

Textile Printing, Dyeing, and Finishing Department, Faculty of Applied Arts, Benha University, Egypt.

Abstract

THE most significant reasons for functionalizing textiles are the enhancement of current qualities and the development of new material properties. Polymer nanocomposites provide the opportunity to create a new class of nano-finishing materials for textiles with their own system of structure-property relationships that are only indirectly connected to their components and their micron and macro-scale composite counterparts. Polymeric matrix nanocomposites made up of inorganic nanoparticles and organic polymers are a new class of materials that outperform compared to their microparticle counterparts. Incorporating inorganic nanoparticles into a polymer matrix can have a significant impact on the matrix's properties. The characteristics of polymer nanocomposites are determined by the type of nanoparticles used, their size and shape, their concentration, and their interactions with the polymer matrix. When polymer nanocomposite coatings are applied to textiles, they give materials various functionalities, as they can be used in protective fabrics, medical textiles, and conductive textiles…. Etc.

Keywords : Nanocomposites, Polymeric matrix, Nanoparticles, Textile.

Introduction

Nanotechnology is the science of small objects with dimensions less than 100 nm. Scientists have discovered that tiny-scale materials, such as nano particles and thin films, may have significantly different characteristics than larger-scale materials. [1-4]. Textile nano finishing produces long-lasting surface coatings that are cost-effective. Nanotechnologies are being developed and applied to the textile finishing process with the goal of lowering environmental impact. Nanotextiles can be classified into three major categories as follow [5]: **Surface-coating :** The nanoscale property of the textile substrate is added through nanocoating, nanoparticle treatment, and engineering the nanostructured surface of the textile material (knitted, woven and nonwoven). **Nanocomposite:** composites that include finely dispersed phases at least one of which is with dimensions in the nanoscale (usually < 10%). **Nanofibrous textiles:** These are textiles composed of nanoscale fibers.

The form of nanoparticles is the first commercial application of nano finishing materials in textiles. However, because of the poor fixation of these nanoparticles on the textile surface, these finishes do not tolerate successive washing, so nanocomposites can especially offer advanced multiple functions by overcoming the limitations related with other materials[6-50].

Polymer nanocomposites are materials with a significant potential for producing a new type of textile coating system to overcome the aforementioned issue. Nanocomposites are a completely unique category of composites that include finely dispersed phases at least one of them is with dimensions in the nanoscale (usually < 10%) [3-6]. It is produced by mixing polymers (or monomers) with different materials or additives having nanometer-scale dimensions. A wide range of

*Corresponding author: Heba Ghazal, E-mail: drheba_ghazal@yahoo.
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materials and synthesis processes have been developed over the last several decades to permit molecular-level control over the design and structure of nanocomposite materials[8].

Nanocomposites can be categorized into three classification[9]:Ceramic matrix nanocomposites ,Metal matrix nanocomposites, Polymer matrix nanocomposites.

Polymeric matrix nanocomposites made up of inorganic nanoparticles and organic polymers are a new class of materials that outperform compared to their microparticle counterparts. Incorporating inorganic nanoparticles into a polymer matrix can have a major impact on the matrix's properties[51]. The composite that produces may have better thermal, mechanical, rheological, electrical, catalytic, fire retardancy, and optical characteristics. The characteristics of polymer nano composites are determined by the type of nanoparticles used, their size and shape, concentration, and interactions with the polymer matrix[52]. When polymer nanocomposite coatings are applied to textiles, they give textile various functionalities, like UV protection, antimicrobial properties, antistatic properties, flame retardancy…. Etc.

In this review, we will focus on the fabrication and the application of nano-composite polymers in textile to produce multi-functional textiles.

Types of polymers

polymer nanocomposites can be categorized into two categories depending on the types of the polymer used:

- biodegradable polymer.
- non-biodegradable polymer

biodegradable polymer nanocomposites

Currently, particularly as a result of the major pollution problem that we have reached on a global scale, there is a trend toward the search for and usage of biodegradable polymers, polymeric compounds, and polymeric nanocomposites. The fundamental feature and advantage of biodegradable polymers is that, once they cease degrading, their polymer chains tend to break down into simpler molecules and structures than the original structure, due to the attack of microbes, radiation, oxygen, and so on.[53, 54] Because of the deterioration of the polymer chains, the articles made from these materials are broken and disintegrated into small fragments that cause minor damage to the environment or, in some cases, depending on the polymer, the degradation products can arrive to be beneficial to the environment where disintegration occurs. Biopolymers are an example of this because, as part of a compost structure, once the polymer degrades, the chemicals from the decomposition might enhance the environment[55].

In general, polymers can be classified into the following 3 categories[54]:

Biodegradable natural polymers

These natural polymers are also known as ecologically degradable polymers since they are made by living organisms and are completely biodegradable as well as renewable. Polymers are classified in this way: polysaccharides (such as starch), chitosan [54, 56].

Biodegradable synthetic polymers

They are biodegradable polymers that are susceptible to enzyme decomposition. Aliphatic polyesters, which can be hydrolyzed by lipases and esterase, and poly (-caprolactone) (PCL), which can be degraded by the action of Penicillium spp., are examples of this type of material. PCL is one of the most commonly used polymers to create biodegradable synthetic polymer nanocomposites.[54, 57].

Biodegradable polymer blends

Materials that are the consequence of combining biodegradable and non-biodegradable polymers are classified in this category. These materials are susceptible to biodegradation, as well as being less costly than pure biodegradable natural polymers. Some examples are those made by combining low density polyethylene with starch or poly (3-hydroxybutyrate), where the inclusion of the biodegradable polymer allows for partial biodegradation, making the combination a viable alternative to completely biodegradable polymers.[54].

Non-biodegradable polymer

As the name implies, they are polymers that are not broken down into simpler compounds by biological processes and, because of their propensity to remain intact over time, are inflicting harm to our environment. Some non- biodegradable polymer examples are: polyethylene terephthalate, polypropylene and polystyrene[58].

Synthesis of polymer nanocomposites

Integration of polymer matrix with nanoparticles can be accomplished in a variety of methods, as summarized below:

Sol–gel processing

Sol-gel processing is the first approach for fabricating polymer-based organic-inorganic nanocomposites, and it has been studied for over two decades. At mild temperatures, sol–gel processing of nanoparticles inside a polymer dissolved in non-aqueous or aqueous solutions results in the formation

of interpenetrating networks between inorganic and organic moieties, which improves constituent compatibility and creates strong interfacial interaction between the two phases[59].

In general, sol–gel formation happens in four stages: (a) hydrolysis, (b) condensation and polymerization of monomers to create chains and particles, and (c) polymerization of monomers to produce chains and particles. (c) particle growth, and (d) aggregation of polymer structures, followed by network creation that extends across the liquid media, resulting in thickening through gel formation. Once the hydrolysis reaction is started, both the hydrolysis and condensation reactions proceed at the same time.[60].

Jian et al. synthesised an acrylic resin/SiO2 nanocomposite by combining nano-SiO2 sol gel and acrylic resin. In a round flask fitted with a reflux condenser, a thermometer, and a magnetic stirring bar, an acrylic resin and nano-SiO2 sol mixture was inserted. The reaction was maintained at a certain temperature and stirring speed for one hour. Finally, the mixture was ultrasonically dispersed for 20 minutes. The results showed that incorporating nano-SiO2 sol gel into an acrylic resin matrix improves the compatibility of two phases. [61].

This method follows a bottom-up approach paired with In Situ formation of nanofillers and In Situ polymerization utilizing sol gel process. This approach allows for the dispersion of inorganic materials with dimensions smaller than the polymer matrix's molecular chain length[62].

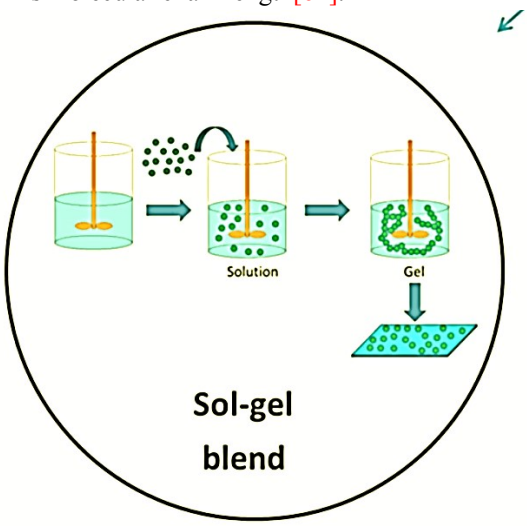

Figure (1): Preparation of nanocomposites using Sol–gel process.

Blending

The most traditional and easy method for producing polymer/inorganic nanocomposites is direct mixing of nanoparticles with polymer. Blending can be accomplished by solution or melt blending. Because nanoparticles have a strong tendency to form agglomerates, the primary issue in the mixing process is achieving appropriate dispersion of the nanoparticles in the polymer matrix.[59].

This process follows a top-down approach in which materials reduced to nanoscale[62].

Solution blending

Solution blending is a liquid state powder processing technology that gives a high level of molecular mixing and is extensively employed in material preparation and processing[52, 63].in a study, van Zyl et al. used solution blending to synthesize poly amide /silica nanocomposites. They dissolved nylon-6 in formic acid while controlling the pH of the solution and then added a solution of silica with particle sizes in the range of 10–30 nm under continuous stirring at room temperature. The solution was then cast, and the solvent was evaporated[64].

Melt blending

Polymeric nanocomposites are created during melt processing by combining nanomaterial with a polymeric matrix material using traditional melt equipment such as an extruder figure (2). The basic advantages of this technology are that it produces a homogeneous dispersion of nanomaterials throughout the nanocomposite and does not need the use of any solvents, making it both industrially and ecologically acceptable. [52, 63, 65]. Prasert et al. Polypropylene/ ZnO Nanocomposites were made by melt mixing. They dried Polypropylene and ZnO in an oven (80 °C, 12 h) to remove moisture before combining, then chilled to room temperature. For sample homogeneity, polypropylene and ZnO nanoparticles were combined in a high-speed mixer, then compounded in a twin screw extruder.[66].

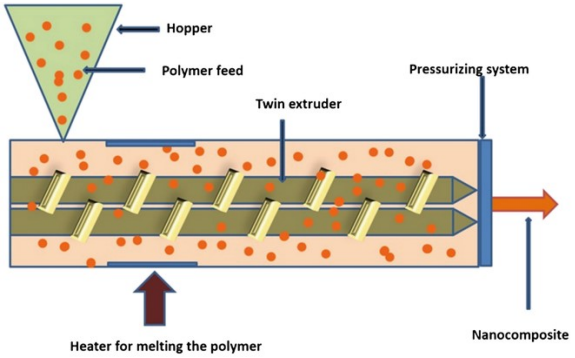

Figure (2): Preparation of nanocomposites using Melt blending.

In situ method

There are three common methods for obtaining nanocomposite in situ method: 1) in situ growth of nanoparticles in polymer matrix; 2) in situ polymerization of polymer in the presence of pre-formed nanoparticles; 3) double in situ method, **figure (2)** as described in the following[59]:

In situ growth of nanoparticles in polymer matrix

In this approach, nanoparticles are synthesized from precursors, while polymer matrix is pre-formed. In situ nanoparticle preparation can be conducted in a number of ways, including chemical reductions, photo-reductions, and acid/alkali-induced hydrolysis [59, 67]. Eisa et al. employed this approach to make Ag NPs in polyvinyl alcohol (PVA)/polyvinyl pyrrolidone in situ (PVP). The samples were made by first dissolving each polymer in deionized water individually (6 g of polymer per 100 ml deionized water). The two polymer solutions were then mixed together under continuous stirring until homogenous solutions were achieved. Following that, 10 ml of the mixture was acidified with 0.12 ml of 0.1 M HNO3 aqueous solution. After that, 0.6 ml of 0.05 M AgNO3 was added to the aforesaid mixture and stirred continuously for about 2 hours to ensure that the solutions were well homogeneous. Silver nitrate was converted to silver, which nucleated and grew inside the polymer matrix, in a nutshell. The incorporation of Ag NPs into the polymer matrix was remarkably good.[68].

In situ polymerization of polymer in the presence of nanoparticles

To make hybrid materials, monomer polymerization can be done around the pre-formed nanoparticles. In this method, inorganic nanoparticles are disseminated in monomers first, followed by monomer polymerization. This method may produce homogenous dispersion of nanoparticles due to the low viscosity of the monomers. [59, 67]. Junli et al. used an in situ method to make a Polyacrylate/ZnO nanocomposite. A set of nanostructural ZnO particles was individually incorporated into polyacrylate in more detail. It was discovered that the majority of ZnO nanoparticles could be evenly disseminated in polyacrylate.[69].

Double in situ method

A twofold in situ method has been invented, in which the polymer and nanoparticles (NPs) are created at the same time. Precursors of nanoparticles are disseminated into polymerizable monomers, and the polymer matrix is formed concurrently as the NPs are being produced. As a result, the produced in-situ metal surfaces can accelerate or begin polymerization by transferring electrons from the metal surface atoms to the monomers. It has been determined to be the most efficient method for creating stable polymer-based organic-inorganic nanocomposites. [59, 67] Silver/polyaniline nanocomposites were created by reducing silver salt in aniline in situ. The reduction of silver salt in aqueous aniline produces silver NPs, which accelerate the oxidation of aniline to polyaniline. [70]**.**

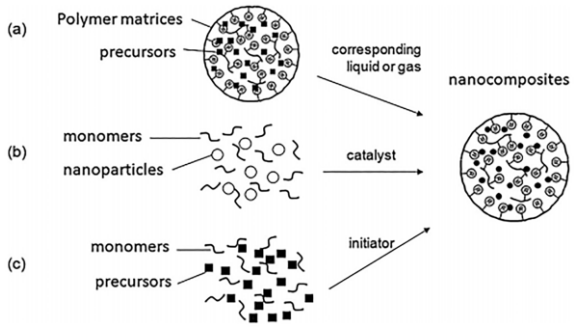

Figure (3): in situ method a) In situ growth of nanoparticles in polymer matrix, b) In situ polymerization of polymer in the presence of nanoparticles, c) Double in situ method[67].

Application of polymer nano composites in textile wet processes

Polymer nanocomposites have the potential to provide a new class of nano finishing materials for textiles. Several different textile functionalities may be accomplished by changing the structure of textiles with polymer nano composites, allowing for the lucrative use of functional textiles in specific applications. Textile antibacterial, UV protection, flame retardancy, and conductivity qualities are some of the most effective uses. Nanocomposites have a

unique potential for smart applications. They have the potential to improve smart textiles in a range of domains, including electronics, protection, defence, and electronics [71].

Application of polymer nano composites in protective textiles

Protective textiles are a type of technical textile that is used for its performance or functional properties rather than its decorative or aesthetic properties. Extreme environmental protection has long been a critical necessity for textile goods [72].

Thermal (cold) protection, flame protection, chemical protection, radiation protection, biological protection, and electrical protection are some of the end-use functions of protective textiles. There is a large range of personal protective garments available, each designed to meet a specific end use requirement [73].

In a protective clothing–human body–environment system, the interface between clothing and human body creates an environment that impacts human comfort, while the interface between clothing and environment functions as a barrier to keep the human body safe from dangerous dangers. In a summary, the protective clothing performs three functions[74]:

- Protection: The primary objective of protective clothing is to protect the user from environmental risks.
- Clothing comfort: provide human comfort, such as tactile and thermal comfort.
- Mobility: maintain human mobility while the wearer carries out certain tasks.

The clothing system is also required to maintain the three primary functions in certain conditions; therefore, a fourth requirement of protective clothing is the durability of the clothing:

- Durability: the capability of the clothing system maintains the three primary functions (protection, comfort, and mobility) under various environmental conditions after repeatedly external insults.

Specific protective clothing is designed for use in defined environments to protect wearers from targeted environmental hazards. Environmental hazards are frequently grouped according to their properties. Some typical examples are shown below[74]:

- Thermal hazards: flame, fire, heat.
- Water: rain, snow, seawater, wastewater, ice, water vapour, etc.
- Chemical hazards: oil, petrol, solvent, paint, alkali, acids, salt, heavy metals, toxic, flammable, and erosive chemicals.
- Biochemical and biological hazards: bacterial, virus, blood, body fluid, drugs, etc.
- Electrical hazards: high voltage, high current electricity, lightning, electrical spark, and arc.
- Electromagnetic wave hazards: infrared, UV, laser, invisible light, sunlight, high intensity light.
- Radioactive hazards: X- ray, beta ray, gamma ray, protons, and neutrons, negative electron rays.

Fabric may be treated with nano composite polymers to create functional protective textiles. Mingwei Tian et al. synthesized chitosan/graphene nanocomposites that also functioned as a UV blocker; the simple pad-dry-cure procedure was used to deposit the nanocomposites on the surface of cotton fabric. The results indicated that the modified fabric's UV protection efficacy was improved. The rather good dispersion of graphene with the help of chitosan also led to such remarkable UV blocking. The coated cotton fabric is excellent for long-lasting UV protection garments [75].

Gowri et al. synthesized ZnO–poly(methylmethacrylate) nanocomposites by dispersing ZnO nanoparticles in a poly (methyl meth acrylate) (PMMA) solution and padding them on polyamide textiles. The dispersion of ZnO nanoparticles in the polymer matrix PMMA is homogeneous at the nanoscale level, as revealed by SEM investigation. The results demonstrated that the combination of low surface energy PMMA and nanosized ZnO in ZnO–PMMA nano finishing on polyamide textiles produces super hydrophobicity.[76].

Elhalawany et al. formed poly aniline/zinc/aluminum nanocomposites by polymerizing aniline monomer in the presence of Zn^{+2} and Al^{+3} ions in a 1:1 ratio in an acidic medium. The nanocomposites generated in the form of colloidal solutions were applied to cotton textiles to create multifunctional smart cotton fabrics that resist germs and fungus as well as damaging UV radiations. Measurements of antibacterial activity revealed an increase in the inhibition zone for textiles treated with the produced nanocomposites. The inhibitory zone expanded as the weight % of metal salts increased. Furthermore, the UPF for the treated textiles was assessed, and it was discovered that the nanocomposite provided excellent protection against damaging UV rays [77].

Montaser et al. used redox copolymerization using potassium persulfate as an initiator to create Chitosan-grafted-Polyvinyl acetate (Cs –g- PVAc). TiO_2 and TiO_2 doped ZnO, previously synthesised using the sol-gel process, were added to the emulsion of polymer – metal oxide nanocomposites. Cotton

textiles were treated with citric acid and sodium hypophosphite-treated emulsions (Cs grafted polyvinyl acetate, Cs-g-PVAc/ TiO_2, and Cs-g-PVAc/ZnO/TiO_2). The Cs-g-PVAc/ZnO/ TiO_2 nanocomposites -coated cotton textiles have a remarkable and stable self-cleaning function, as evidenced by their photocatalytic destruction of coffee stain and antibacterial activities, in addition to increased protection against damaging UV-radiation [78].

In one study, cotton fabric was cross-linked using 1,2,3,4-butanetetracarboxylic acid in the presence of sodium hypophosphite as a catalyst. An in situ chemical polymerization approach was used to create polypyrrole–zinc oxide (ppy–ZnO) and polypyrrole–zinc oxide–carbon nanotube (ppy–ZnO–CNT) composites. Using a pad-dry-cure process, the cotton fabric was treated with the composite. The treated cotton fabric's flame retardant and UV-protection capabilities were examined and compared to those of untreated fabric. Flame retardant of (ppy–ZnO–CNT) treated fabric was found to be better than that of untreated fabric. The UPF value of cotton treated with (ppy–ZnO) and (ppy–ZnO–CNT) was determined to be 28 and 48, respectively. As a result of the findings, ppy–ZnO–CNT coated cotton textiles appear to be promising multifunctional textile materials for flame retardant and UV-protection applications [79].

Fluoropolymer/SiO_2 nanocomposites were created by Wang et al. The dip-pad-cure method was used to apply the nanocomposites to the polyester textiles. The coated fabrics demonstrated excellent acid-proof properties, with contact angles of 137.1, 141.2, and 139.5 for H_2SO_4 (80%), HCl (30%), and HNO_3 (40%), respectively, which can be attributed to the combination of a specific micro-nano rough surface and fluoropolymer layer Figure 4, which were both stable to strong acid [80].

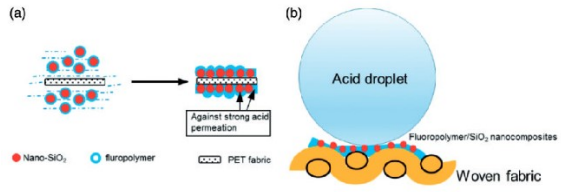

Figure (4): (a) coating of organic/inorganic nanocomposites on Polyester fabric and (b) the contact between acid droplet and the micro-nano rough surface.

Application of polymer nano composites in medical textiles

Textiles are now employed in a variety of industries and for a wide range of uses. One of them is the medical industry. The medical, hygiene, and health sector is a significant and growing segment of the textile industry. Medical textiles are one of the most significant, ever-expanding, and rapidly rising fields in technical textiles. Medical textiles are constructions that have been conceived and completed for a medical use. From a single thread stitch to sophisticated composite constructions for bone replacement, and from a simple cleaning wipe to advanced barrier textiles used in operating rooms, the applications are numerous. Textile materials and products that have been created to satisfy specific criteria are appropriate for any medical and surgical application that requires a mix of strength, flexibility, and, in certain cases, moisture and air permeability.[81, 82].

The medical textile industries have diversified with new materials and innovative designs. Recently, application of textiles has started going beyond the usual wound care, incontinence pads, plasters etc., Latest innovation i.e., wide variety of woven, non-woven, knitted forms of textile increasingly finding their way into a variety of surgical procedures[82].

Classification of Medical Textiles:

Medical Textiles can be classified in four categories as follow (Figure5):

Non-Implantable Materials

These materials are used for external body applications and may or may not come into contact with skin. This comprises wound care, bandages, plasters, pressure garments, orthopaedic belts, and other similar items...[81].

Implantable Materials

These materials are utilised to restore the body, whether it is by wound closure (sutures) or replacement surgery (vascular grafts, artificial ligaments, and so on) [81].

Extra Corporeal Devices

These are extracorporeally placed devices that aid in the function of important organs such as the kidney, liver, lung, heart pacemaker, and so on. Extracorporeal devices are mechanical organs used for blood purification, such as the artificial kidney (dialyzer), artificial liver, and mechanical lung. Fiber and textile technology improves the function and performance of these gadgets [81].

Table 1 Application of polymer nano composites in protective textiles

Polymer	Nanoparticles	Synthesis of polymer nanocomposites	substrate	Application	Properties	References
Soluble starch	Zinc oxide	In situ growth of nanoparticles in polymer matrix	Cotton	pad–dry–cure The cotton fabric was immersed in the solution containing Zinc oxide–soluble starch nanocomposites and acrylic binder (1%) for 5 min and then it was passed through a padding mangle, with a pressure to reach an average wet pickup of 80% 100% wet pick-up was maintained for all the samples. After padding, the fabric was air-dried and then cured for 3 min at 140 ^{o}C to polymerize the acrylic binder. The fabric was then immersed for 5 min in 2 g of sodium lauryl sulfate to remove unbound Zinc oxide–soluble starch nanocomposites. Then the fabric was rinsed ten times to completely remove all the soap solution. The fabric thus washed was air-dried.	Antibacterial activity- UV-protection	[83]
Chitosan	Graphene nanosheet	Blending	Cotton	pad-dry-cure the cotton fabrics were impregnated in chitosan/graphene solution for 2 h, and then padded through two dips and two nips to reach an average wet pickup of 80%; the padded fabrics were then washed to remove the unreacted starting compound, and then dried at 70 ^{o}C for 10 min; the following curing was carried out at 110 ^{o}C for 10 min.	UV-protection	[75]
poly(methylmet-hacrylate) (PMMA)	Zinc oxide	Blending	Polyamide	Pad-dry-cure (PMMA) was dissolved in toluene to prepare stock solution of 5 wt.%. ZnO nanoparticles were mixed with PMMA. The mixture was stirred vigorously in order to get a homogeneous dispersion. The plasma pretreated fabric was immersed in the solutions containing nano-ZnO at different concentrations for 15 min under ultrasonic vibrations. Then the fabric was passed through padding mangle to remove excess solution. After padding the fabric was air dried. Then the fabric was rinsed with deionized water and air dried again.	UV-protection-superhydrophobic fabrics	[76]
Chitosan	titanium dioxide and/or zirconium oxide	Blending	Cotton	coating technique. Coated cotton fabric samples were dried in an oven at 70 ^{o}C for 10 min. Dried fabric samples were cured in an oven at 170 ^{o}C for 5 min. Cured fabric samples were washed with alkaline water for 30 min at 90 ^{o}C and then washed with tap water and finally dried.	UV-protection-Antibacterial activity	[84]
Poly aniline	Zn/Al	In situ growth of	Cotton	pad dry cure	Antibacterial activity- UV-	[77]

		nanoparticles in polymer matrix		The purified powdered samples of the prepared PANI/Zn/Al nanocomposites have been redispersed in 100 ml of distilled water and followed by ultra-sonication using for 30 min to form the corresponding stable colloidal solutions. The bleached cotton fabric has been soaked for 45 min in a solution containing 0.5 g of detergent agent for removal of the undesired impurities present on the cotton surface. The cleaned bleached cotton fabrics have been then immersed for 1 min in the stable colloidal solutions of the prepared nanocomposites under vigorous stirring. Pure PANI colloidal solution have been also used as blank solution for comparison. After that, the treated cotton samples have been submitted to squeeze with pick up 100% using pad dry cure method. The squeezed samples were dried at 70 ^{o}C for 5 min and cured at 120 ^{o}C for 1 min.	protection	
Thermoplastic polyurethane (TPU)	MnO_2-$FeTiO_3$ (MnO_2-FT)	In situ polymerization of polymer in the presence of nanoparticles	Cotton	coating technique. The solution dispersion containing MnO_2-FT in to TPU was poured on the cotton fabrics. Both sides of the cotton fabrics were initially coated with the solution using tilt shaker. After the coating the coated fabrics was dried at 60 ^{o}C for 10 h. The dried samples were kept between the two hot plates and pressed for 30 min at a temperature of 75 ^{o}C to obtain an impregnated nanocomposite coated fabrics.	UV blocking- fire resistance- durable hydrophobic cotton fabrics	[85]
Butyl acrylate/Acrylonitrile (BA/AN) copolymer	silica nanoparticles	Blending	Polyester- cotton	coating via silk screen printing technique cotton and polyester were printed using a homogenized paste containing BA/AN copolymer /silica nanocomposites as functional binder, thickner, urea, pigment and water. All the printed samples were fixed via Thermo fixation at 180 °C for 3 min and washed	self-cleaning- UV protection	[86]
Chitosan/clay	Silver	In situ growth of nanoparticles in polymer matrix	Cotton	pad-dry-cure The cotton fabrics were immersed for 1 h in Chitosan /AgNPs/clay nanocomposites. The treated samples were squeezed to 100% wet pick-up using pad-dry-cure method at constant pressure. Samples were dried at 90 °C for 5 min, followed by curing at 140 °C for 1 min	Flame retardant- Antibacterial activity- UV-protection	[87]
Chitosan-grafted-Polyvinyl acetate	TiO_2 and ZnO /TiO_2 nanoparticles	Blending	Cotton	pad-dry-cure the cotton fabric padded by the solutions followed by dry process at 100°C for 30min. the dried samples thermo- fixated under high temperature at 150°C for 5 min.	Water repellent-UV Protection-Antibacterial Activity-Self - cleaning	[78]
diphosphate malonate (DPHM)	Silver	In situ growth of nanoparticles in polymer matrix	Polyester- cotton-cotton/polyester blend	spraying technique. DPHM-AgNPs solution was sprayed on the surface of the textile samples completely. Then dried and this step was	flame retardant and antibacterial Activity	[88]

				repeated three times. Finally, rinsed in distilled water for wash and then dried.		
Poly pyrrole	zinc oxide–carbon nanotube	in situ chemical polymerization	Cotton	pad-dry-cure The padded fabrics were air-dried and cured at 180 ^{o}C for 5 min in a hot-air oven.	flame retardant- UV Protection	[79]
fluorinated acrylic polymer	Silica	semi-continuous emulsion polymerization	Polyester	dip-pad-cure The PET fabrics were immersed in the fluoropolymer/ SiO_2 solution (50 g/L, pH was adjusted to 8–9 by ammonium hydroxide) for 10 min, and then squeezed using an automatic padder This process was repeated twice. The fabrics were then dried at 100 ^{o}C for 150 s and cured at 170 ^{o}C for 120 s in the oven.	acid-resistant	[80]
chitosan	CuO	Double in situ method	cotton and cotton/polyester	pad-dry-cure Cotton fabric was padded in the CuO/chitosan colloidal solution to wet pick up of 100%; padded fabric was dried at 80 ^{o}C. Dried fabric samples were cured at 160 ^{o}C for 4 minutes.	Antibacterial activity	[89]
chitosan	ZnO	Double in situ method	Cotton	pad-dry-cure Chitosan/ZnO nanoparticles powder was suspended in water and was sonicated for 10 min. In these suspensions bleached cotton fabric samples were padded in two dip and nip and then squeezed to a wet pick-up of 100%. The samples were then dried at 100 ^{o}C for 10 min and cured at 170 ^{o}C for 5 min.	Antimicrobial and UV Protection	[90]
starch/corn silk	ZnO	In situ growth of nanoparticles in polymer matrix	polyester	pad-dry-cure the PET fabric was put in the starch/corn silk/ZnO solution under constant stirring at 95 °C for 1 h. The treated fabric was removed from the bath and dried at 100 °C for 45 min, fixed at 140 °C for 20 min, then rinsed with water and dried at room.	fire retardant-antibacterial/antifungal and self-cleaning activities	[91]

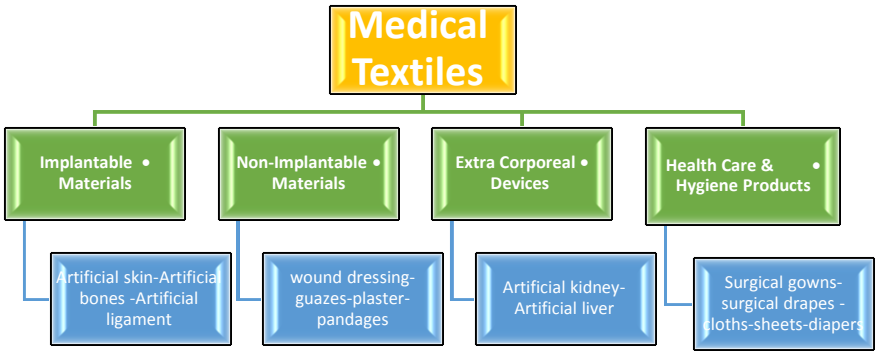

Figure5: Classification of Medical Textile.

Health Care & Hygiene Products

The healthcare and hygiene industry, among other medical uses, is a major field of textile. The range of healthcare and hygiene goods available is extensive, however they are often utilised in the operating theatre or in hospital wards for hygiene, care, and safety of workers and patients. They might be disposable or washable. Bedding, clothes, surgical gowns, cloth wipes, and other items fall under this category.[81].

Polymer nanocomposite can be used in treating fabrics to have medical textiles. Amir et al, modified polyester fabric using polyamidoamine/β-cyclodextrin (β-CD)/silver nanocomposites to make a fabric with antibacterial and drug delivery properties. The aminolysis of polyester fabric with polyamidoamine led to the possible stable linkages with (β-CD)/Ag composites. the treated fabrics indicated 100, 100 and 99% microbial reduction against E. coli, S. aureus and C. albican. Furthermore, the drug absorption and release behaviour of the textiles was studied in water and phosphate buffer solutions, indicating that 45 percent of the loaded drug was slowly released in the buffer solution after 3 hours.[92].

Polymer nanocomposite can be used in treating fabrics to have wound dressing textiles. Nafiseh et al, produced β-cyclodextrin/ ketoconazole/Ag NPs (β-CD/KZ/Ag) nanocomposite and applied on cotton fabric via two diverse procedures of exhaustion and padding to create a novel antimicrobial drug delivery system (**Figure6)**. The exhaustion method is mostly recommended due to the much more nanocomposite loading on cotton fabric. The best antimicrobial effects reported for the treated sample with β -CD/KZ/Ag 2% that indicated 100% reduction in C. albicans and A. niger and about 85% in E. coli and S. aureus. The presence of Ag NPs in the composite prevented the nanoparticles from aggregation and reduced its loading on the cotton fabric that possibly reduced the drug side effects. Finally, the good durability of β -CD/KZ/Ag nanocomposite on cotton fabric in consecutive washes leads to the superior antimicrobial activities, breathability, water and moisture absorption with reasonable tensile strength that can be offered as a safe product with both the antifungal and antibacterial features[93].

Mina et al. treated standard cotton gauze with a chitosan/Ag/ZnO nanocomposite. The treatment will increase its capacity to care for wounds using contemporary wound dressings. As a natural polysaccharide, chitosan is a nontoxic, biodegradable polymer with appropriate biological activity. It demonstrated a great potential for retaining nanoparticles as well as covering cotton gauze. Such nanocomposite emulsions may be easily applied to textile textiles utilising a simple approach such as the dip-dry-cure procedure. Antibacterial effectiveness values of treated cotton gauze with chitosan/Ag/ZnO were higher than for each nanoparticle independently, showing a synergetic effect for a chitosan/Ag/ZnO nanocomposite. The treatment of cotton gauze with chitosan/Ag/ZnO nanocomposite enhanced drying time, wicking ability, and water absorbency; all of which are important indicators of a contemporary wound dressing [94].

Application of polymer nano composites in wastewater treatment

Water pollution is a big issue in modern life because of the severe effects it has on human health, sustainability, and the environment. Water contamination is separated into municipal and industrial wastewater based on the source of the waste. Municipal waste comes from households and businesses, and this wastewater frequently comprises faeces and urine. Sources of industrial wastewater are the industrial and agricultural activities, and this wastewater, in addition to domestic compositions, also contains organic and inorganic chemicals. Synthetic dyes are a major cause of water pollution in a variety of sectors, including leather, textile, printing, cosmetic, and pharmaceutical enterprises.[95-97] To date, numerous approaches for overcoming this difficulty, particularly for the removal of dye from coloured effluents, such as ion exchange, flotation membrane filtration, electrochemical treatment, photocatalysis, chemical precipitation, and adsorption, have been developed.[98]

Table 2 Application of polymer nano composites in medical textiles

Polymer	Nanoparticles	Synthesis of nanoparticles	substrate	Application	Properties	References
β-cyclodextrin/ polyamidoamine	Silver	In situ growth of nanoparticles in polymer matrix	polyester	one step processing (130 °C, 1 h) was used for modification of polyester fabric in the poly amidoamine/β-cyclodextrin/silver nanocomposites solution	drug delivery and antimicrobial properties	[92]
β -cyclodextrin/ ketoconazole/	Silver	In situ growth of nanoparticles in polymer matrix	Cotton	cotton fabric was treated by using two diverse methods. **1)** the nanocomposite was loaded on the fabric through exhaustion (1 h at 80 ^{o}C with stirring and drying at 80 ^{o}C similar to dyeing). **2)** padding (the fabric immersed in the solution squeezed and dried at 80 ^{o}C finally cured at 140 ^{o}C for 4 min) procedures. Further, citric acid as a cross-linking agent and sodium hypophosphite as a catalyst were added to the nanocomposite solution.	antifungal and antibacterial drug delivery system	[93]
Chitosan	silver / Zinc Oxide	Blending	Cotton Gauze	dip-dry-cure The cotton gauze was dipped in the CS/Ag/ZnO colloidal solution; dried at 80 ^{o}C and cured at 160 ^{o}C for 4 min.	wound dressing Treating cotton gauze with chitosan/Ag/ZnO nanocomposite also increased drying time, wicking ability, and water absorbency; the main indexes of a modern wound dressing.	[94]
Chitosan	Herbal extract nanoparticles (Senna auriculata and Achyranthes aspera)	Blending	Cotton	Pad-dry-cure the PET fabric was put in the chitosan and herbal nanocomposites solution, padded with 100% wet pickup followed by drying and curing at 160 ^{o}C for 5 min.	antimicrobial properties, wash durability, air-permeability and biocompatibility	[99]

Poly vinyl alcohol	Silver	Blending	Cotton	Coating technique A clear homogeneous solution of polymer nanocomposite was spin coated on cloth substrates at 3000 rpm for 20 s. After each spin coating, the substrates were dried in a furnace at 100 ^{o}C for 20 min for evaporating the solvent. The entire process was repeated 25 times.	wound healing applications	[100]
Alginate/poly hexamethylene biguanide (PHMB)	Silver	Blending	Cotton gauzes and polyamide	dip-dry Samples immersed in the sodium alginate–Ag NPs–PHMB solutions for about 30 min. Thereafter, the samples were taken out and dipped into calcium chloride (2% w/v) solution, remained undisturbed for 30 min to cross-link with Ca_2+ forming calcium alginate and ensure the deposition of calcium. Then, the treated samples were dried in an oven (75 °C) for 15 min.	wound dressing with antibacterial and hemostatic properties	[101]
salicyl-imine-chitosan/ oxytetracyline hydrochloride drug	Silver	Layer by layer	Cotton gauze	dip-dry the fabrics were immersed in AgNO3 solution and placed in water bath at 90 °C. After that, 10 ml of 3 % trisodium citrate (TSC), as reducing and capping agent, was added drop wise to each 100 ml silver nitrate solution and kept at 90 °C for 30 min. Subsequently, the modified fabrics were removed, squeezed and rinsed by running tap water and left to dry at ambient condition. then, the cationized cotton gauze fabrics/Ag NPs samples were immersed in the Oxytetracyline hydrochloride antibiotic solution (1 %) and allowed to remain stand still for 1 h in the solution. Finally, The cationized cotton gauze fabrics/Ag NPs/drug was dipped in salicyl-imine-chitosan for I h, then was dried at room temperature.	antimicrobial and burn wound healing properties	[102]

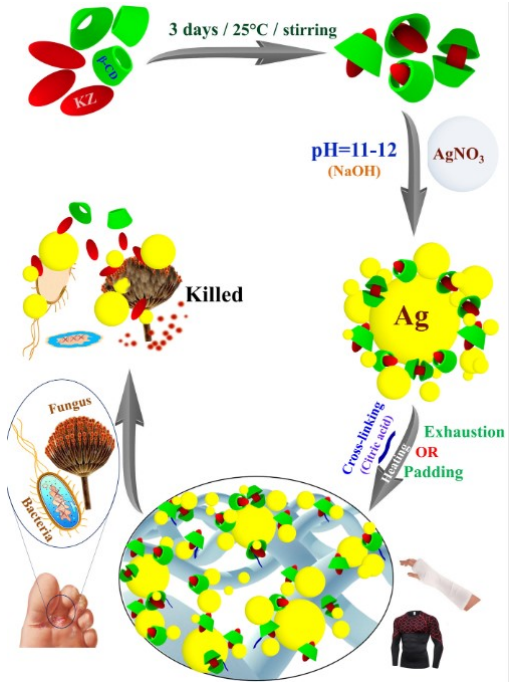

Figure6: Preparation of nanocomposite and its application to cotton fabric.

Adsorption is a simple, efficient, and practical technique of pollution removal. The use of a suitable adsorbent makes the adsorption process appropriate, low cost, simple to operate, versatile, and an effective approach for the removal of colours and metals from wastewater. As innovative functional materials, polymer nanocomposites are at the forefront of water and wastewater treatment procedures. [103] Because of their ideal pore size, high mechanical strength, simplicity of manufacture, high selectivity, and regeneration processes, nanocomposites have been widely employed as an adsorbent in environmental remediation for metal ions or dye removal with high adsorption capacity.[104] Many polymer-based nanocomposites have widely utilized for the elimination of a variety of toxic dyes and metal ions, from wastewater for example A poly pyrrole–chitosan–Fe3O4 magnetic nanocomposite for removing carbamazepine (CBZ)[105], magnetite nanocomposite (GA- ***g***- PCHPMA/Fe_3O_4)for adsorption of MB, R6G, Cu(II) and Hg(II)[96], polyaniline (PANI) and polyaniline/ montmorillonite clay (PANI/MMT) nanocomposites for adsorption of Acid Green 25 dye.[106]

Nanocomposite hydrogels with various functional groups have the potential to remove pollutants from water with great capacity and selectivity. For the treatment of radioactive waste, a new polyfunctional nanocomposite hydrogel (NCHG) was created. It is based on magnetic composite nanoparticles (MCNPs), which are created by encapsulating magnetite in a micro emulsion of polystyrene-co-poly methacrylic acid (PS-co-PMAA). After that, the MCNPs were employed as a physical crosslinker in the graft polymerization of sodium styrene sulfonate SSS and acrylic acid AA in the presence of polyacrylamide PAM to generate an interconnected NCHG with diverse functional groups. The NCHG was used for the removal of Cs, Co_2, and Sr_2 ions from simulated radioactive waste. The initial concentration was studied from 50 to 600 mg/L, and the equilibrium adsorption capacities of Cs, Co_2, and Sr_2 were found to increase from 8.49 to 53.37, 11.17–80.69, and 10.75–65.35 mg/g, respectively. [107]

Manal F. Abou Taleb et al. created an N-vinylpyrrolidone/chitosan/ Fe_3O_4 (NVP/CS/Fe_3O_4) nanocomposite as a magnetic nano-adsorbent by in-situ iron salt co-precipitation in the CS/NVP hydrogel matrix. The results showed that the hydrogels had a strong electrostatic contact, which resulted in the creation of a more stable NVP/CS co-polymer. As a model dye, the NVP/CS/ Fe_3O_4 nanocomposite was utilised as a sorbent for the removal of methyl orange (MO) (See **Figure8**). The adsorption processes are affected by time, starting concentration, and adsorbent dosage. The magnetic CS/NVP nanocomposites might be used for the efficient and effective removal of MO dye from wastewater.[98]

Novel PVA-co-Aam /TiO_2/SiO_2 nanocomposites adsorbents were created by copolymerization crosslinking of PVA and AAm incorporated with TiO_2/ SiO_2 nanoparticles at different irradiation doses of 10, 30, and 50 kGy to improve the removal and adsorption of BB_3 and Cu (II) ions from their aqueous solutions. At 7 h contact time, pH 11, adsorbent dose 0.4 g, and starting concentration 150 mg/L, the equilibrium adsorption for BB_3 was around 140.9 mg/g with a removal of 93.5 percent. At 6 h, pH 6, adsorbent dose 0.4 g, and starting concentration 200 mg/L, the equilibrium adsorption for Cu (II)ions was approximately 190.3 mg/g with a clearance of 95.2 percent. According to the adsorption kinetics, the adsorption of both BB_3 and Cu (II) ions best accorded with the pseudo-second-order model. [104]

Qihua Cao et al. created Ag_3PO_4/CS/CdS nanocomposites by crystallising Ag_3PO_4 using chitosan as a capping agent and then assembling with CdS nanoparticles in situ. The addition of chitosan and a little quantity of CdS enhanced the nanocomposite's energy-band structure, specific surface area, and adsorption property, as well as its catalytic activities and stabilities. Under visible-light illumination, the nanocomposites containing Ag_3PO_4/CS/CdS had the best photocatalytic efficiency for MO decolorization. After three irradiation cycles, the Ag_3PO_4/CS/CdS nanocomposites remained stable, with only a minor drop in decolorization rates. As a result, Ag_3PO_4/CS/CdS nanocomposites with high photocatalytic activity and good stability are projected to have potential uses in the purification of dyeing effluent. [108]

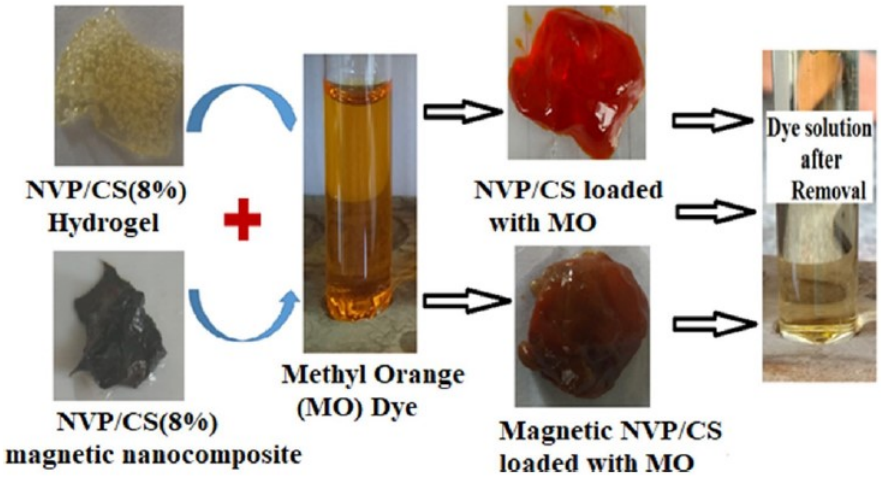

Figure8 Photographic illustration for the adsorption process of MO dye using NVP/CS (8%) and NVP/CS (8%)/Fe_3O_4 magnetic nanocomposite

Shivani Kalotra, Rajeev Mehta, and colleagues investigated the synthesis, characterization, and adsorption of polyaniline (PANI) and polyaniline/montmorillonite clay (PANI/MMT) nanocomposites. In situ polymerization with ammonium persulfate as an oxidizing agent yielded PANI and PANI–MMT clay nanocomposites. The adsorption of AG25 dye by the produced PANI and PANI nanocomposites was investigated. the study reports that PANI/MMT nanocomposite is an efficient adsorbent for AG25 textile dye adsorption and is a better adsorbent then PANI. [106]

In study, superabsorbent nanocomposite hydrogels have been formed by grafting copolymerization of acrylic acid and acrylamide onto natural polysaccharide (green starch) with incorporation of NPs such as nickel ferrite (NiFe2O4) NPs and TiO2 NPs into the hydrogel matrix, aiming to enhance the removal of hexavalent chromium (Cr(VI)) and Congo red dye from aqueous solutions. The results show that, NiFe2O4/SANCH composite has effective photoefficiency towards Cr(VI) and CR than TiO2/SANCH. The producibility of the reused NiFe2O4/SANCH and TiO2/SANCH composites were also investigated for five cycles with high efficiency. [109]

4-2. Application of polymer nano composites in conductive textiles

Conducting polymers are a new class of organic materials which have extensive
delocalization of π-electrons in a conjugated structure with wide applications
in number of technologies such as energy storage, molecular recognition, EMI
shielding, opto-electronic devices, corrosion protection, micro-wave absorption,
gas separation, sensors and heat generation.[110, 111]

Conducting polymers are divided into two subgroups:

Intrinsically conductive polymers

ICPs have grabbed attention as promising polymer materials having long conjugated double bonds in their backbone chain, these chains then combine to form intrinsically conductive polymers. The presence of these double bonds is a sign of enhanced conductivity of polymers. They can be synthesized simply by two methods i.e., chemical oxidative and electrochemical methods. The most promising materials in these polymer groups are polyaniline, polyacetylene, polypyrrole, and poly (3,4-ethylene dioxythiophene), a derivative of polythiophene. [111]

Extrinsically conductive polymers

Another class of polymers is also synthesized by the blending (melt mixing or solvent mixing) of thermosetting plastic, thermoplastic or insulating polymer materials with conductive fillers. This class of polymers is referred to as conductive polymer composites (CPCs), or extrinsically conductive polymers
(ECPs). Filler family include: ICP, Metal (Silver, stainless steel), Carbon (CB, CNT), oxide /non-organic (ITO, CuS).[112]

Conducting polymer composites (CPCs) have been versatily utilized in actualizing advanced devices such as supercapacitors, biosensors, photovoltaic cells, batteries, catalysts, chemical sensors, and so on. Conducting polymer nanocomposites (CPNCs) are derived from hybridization of intrinsically conductive polymers (CPs) with inorganic entities thereby fabricating multifunctional materials with enhanced performances. [113]

Table 3 Application of polymer nano composites in wastewater treatment

Type of pollution	**Polymer**	**Nanoparticles**	**Synthesis of polymer nanocomposites**	**Removal Process**	**Removal efficiency**	**Application**	**References**
Methyl orange (MO) dye	Chitosan	Ag	In situ growth of nanoparticles in polymer matrix	Photocatalytic decolourization	81%	The experiments were carried out in the photo reactor Heber Visible Annular Type Photo reactor equipped with 300 W tungsten halogen lamp (8500 lm). The optimum conditions (pH 7, time 180 min, dye solution concentration 0.8 mg/L	[114]
	Ag_3PO_4/ CS	cadmium acetate (CdS)	In situ growth of nanoparticles in polymer matrix	photocatalytic	98.9%	catalysts (10 mg) were dispersed in a solution of MO (50 mL, 10 mg L^{-1}) with constant magnetic stirring at room temperature and PH 5, and then the suspension was exposed under a 300 W Xe light source (15A) fitted with a 420 nm cutoff filter for 30 min. The irradiation source was positioned 15 cm away from the surface of solution, and a water recycling equipment was designed for the removal of the concomitant heat during illumination.	[108]
	N-Vinylpyrrolidone/ chitosan (NVP/CS) copolymer	Fe_3O_4	in situ	Hydrogel adsorption		Dye adsorption was carried out by immersing 0.1 g of NVP/CS (8%) hydrogel and its nanocomposites hydrogel into 20 mL of methyl orange solutions at different concentrations (150, 250, 5000 and 1000 mg/L). All adsorption experiments were examined through a batch method on a stirrer with a constant speed 120 rpm.the best conditions are PH7, 8% NVP/CS nanocomposite, 750 mg/g dye concentration and 250 min.	[98]
Basic blue 3 dye (BB3) and Cu (II) ions	polyvinyl alcohol (PVA) and acrylamide (AAm)	TiO_2/ SiO_2	Blending	Adsorption	197.7%	adding an appropriate amount of 0.2 g of each adsorbent to 50 ml of the aqueous solution of dye or Cu (II) ions with initial concentration 200 mg/Lat room temperature for 2 h with shaking at an agitation speed of 100 rpm. Then, the decrease in UV absorbance was measured using T60 UV/Vis spectrophotometer from PG instruments	[104]

						limited to select the better adsorbent for further batch adsorption experiments.	
Brilliant Black dye (BB)	Lignin/chitosan	titania (TiO2)	sol gel	adsorption	90%	A stock solution of 500 mg/L of BB was prepared and further diluted to obtain different concentrations from 10 to 100 mg/L. Adsorption studies were carried out at ambient temperature using 15 mL of the dye solution and about 0.2 g of the absorbent and under agitation at 250 rpm. The optimum conditions (pH 5.8, time 30 min, initial solution concentration 50 mg/L, 60 mg Chitosan-lignin-titania nanocomposite)	[115]
methylene blue (MB)	HA/Au	Gold Hydroxyapatite	Ex-situ	adsorption	200 **mg/g**	A stock solution of MB (500 mgL^{-1}) was prepared and further diluted to the desired concentration. A known weight of the adsorbent was taken in a 100 mL dye solution for each experiment and absorbance of residual dye solution was measured after every 10 min by a UV-visible spectrophotometer at a wavelength of 663 nm. The optimum conditions (pH 7, time 90 min, dye solution concentration 30 mg/L, 2.0 mg HA/Au nanocomposite)	[116]
Acid Green 25 dye	polyaniline (PANI)	Montmorillonite clay (MMT)	in situ polymerization	adsorption	100%	Adsorption studies were done by diluting a stock solution of Acid Green 25 dye (1 g/L) into different dye concentrations solutions (50–200 mg/L). The dye removal is mainly dependent on the initial dye concentration, temperature and adsorbent amount. Nearly 100% removal of AG25 dye is achieved in 30 min at *C*o = 50 mg/L, pH = 6, adsorbent = 0.4 g, *T*= 20 °C. At higher temperatures, i.e., 45 °C and 50 °C, the PANI/MMT removed 100% dye within 10 min of contact time. The kinetic adsorption data of AG25 dye were found to fit	[106]

						pseudo-second-order kinetic model	
carbamazepine (CBZ)	Poly pyrrole / chitosan	Fe_3O_4	in situ polymerization	adsorption	94.5%	15 mg of the PPy–CS– Fe_3O_4 MNC was dispersed in the 50 mL of 20 mg L^{-1} of CBZ solution by stirring at 400 rpm for 25 min at ambient temperature. The supernatant solution was withdrawn at different time periods and replaced by fresh phosphate- buffered solution (PBS). The supernatant sample was subjected to UV–Vis analysis at 284 nm to evaluate the concentration of CBZ remaining in the supernatant. The maximum CBZ removal was obtained at 15 mg adsorbent dose, 25 stirring time, and pH 6.5 for initial concentration of 20 mg L^{-1}	[105]
Cr(VI) CR dyes	starch-g-poly(acrylic acid-co-acrylamide)	TiO_2	In situ polymerization	adsorption/photodegradation	99.7 ± 0.541% 97.7 ± 0.498%	the photoreduction of Cr(VI) conditions, 300 mL of 50 mg/L of CR aqueous solutions was added to 300 mg of the photocatalysts. The concentration of CR was determined at λmax = 498 nm. The reusability and stability of the prepared hydrogels were estimated by the regeneration experiment. After each process of photodgradation and photoreduction process, hydrogels were immersed into 1 M HNO_3 acid (50 mL) and stirred for 12 h. The hydrogels were collected by centrifugation, then rinsed in deionized water and dried. This procedure was repeated after each cycle of photo-process. Under the same conditions, this process was repeated for five times using new solution The maximum Cr(VI) and CR removal was obtained at 1.5 mg adsorbent dose, time 25 ◦C, and pH 4 for Cr(VI) and CR concentration of 50 mg/L	[109]

Conducting polymer bionanocomposites (CPBs) are electrically conducting biocomposites derived from mixing of CPs with biopolymers such as proteins, cellulose, guar-gums, chitosan, chitin, gelatin, and so on, resulting in emancipation of CBs for use in biomedical, agricultural and food engineering due to attainment of biocompatibility, biodegradability, and electrical conductivity.[113, 117]

Nanotechnological advancements in Conducting polymer nanocomposites (CPN) have revealed materials exhibiting high surface area, manipulatable architecture and tunable electrical behaviors with superior performance haven potential for versatile applications. CPN behaviors and performances on both morphological disposition and quality of individual component, and also on the selected fabrication technique[113]

Electro-conductive textiles can be produced by following techniques – (i) giving acoating of conductive polymer or polymer nanocomposites on textiles substrates ,(ii) in corporation of conducting nanofillers in polymer matrix for making conductive polymer nanocomposite fibers, and (iii) making polymer or polymer nanocomposite based conductive nanofibers.[118]

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التطورات الأخيرة في استخدام المركبات البوليمرية النانوية في تطبيقات النسيج

منة زايد ، مي بكر و هبة غزال *

قسم طباعة المنسوجات والصباغة والتجهيز ـ كلية الفنون التطبيقية ـ جامعة بنها ـ الجيزة ـ مصر

المستخلص: تتمثل أهم أسباب تفعيل المنسوجات في تعزيز الصفات الحالية وتطوير خواص جديدة للمواد. توفر مركبات البوليمر النانوية الفرصة لإنشاء فئة جديدة من مواد التشطيب النانوي للمنسوجات مع نظامها الخاص لعلاقات خصائص البنية التي ترتبط فقط بشكل غير مباشر بمكوناتها ونظيراتها الميكرون والمركبة على نطاق واسع. تعتبر المركبات النانوية ذات المصفوفة البوليمرية المكونة من جزيئات نانوية غير عضوية وبوليمرات عضوية فئة جديدة من المواد التي تتفوق في الأداء مقارنة بنظيراتها من الجسيمات الدقيقة. يمكن أن يكون لدمج الجسيمات النانوية غير العضوية في مصفوفة بوليمر تأثير كبير على خصائص المصفوفة. يتم تحديد خصائص المركبات النانوية البوليمرية حسب نوع الجسيمات النانوية المستخدمة وحجمها وشكلها وتركيزها وتفاعلاتها مع مصفوفة البوليمر. عندما يتم تطبيق طلاء البوليمر النانوي على المنسوجات ، فإنها تعطي المواد وظائف مختلفة ، حيث يمكن استخدامها في الأقمشة الواقية ، والمنسوجات الطبية ، والمنسوجات الموصلة.... إلخ.

الكلمات المفتاحية: المركبات النانوية ، المصفوفة البوليمرية ، الجسيمات النانوية ، النسيج.