Crimson Publishers
Wings to the Research

Mini Review

Nanotechnology in Textiles: Unleashing Innovation and Value Addition

Gajendra Kumar Tyagi* and Amit Madhu

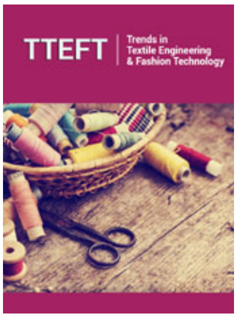
The Technological Institute of Textile & Sciences, India

Abstract

In recent years, nanotechnology has revolutionized various industries, including textiles. Nanotechnology enhances textile properties, leading to the development of smart and functional fabrics. This overview explores diverse nanotechnology applications in textiles, such as nano coatings, nanofibers, Nano sensors, and nanoparticles for eco-friendly and energy-harvesting textiles. We also discuss the significant impact of nanotechnology on adding value to textile products. Furthermore, we address potential challenges and future directions for further research and development in this exciting field.

Keywords: Nanotechnology; Nano coatings; Nanofibers; Eco-friendly; Energy-harvesting textiles

ISSN: 2578-0271



***Corresponding author:** Gajendra Kumar Tyagi, The Technological Institute of Textile & Sciences, Birla Colony Bhiwani-127021, India

Submission: July 27, 2023
Published: August 07, 2023

Volume 9 - Issue 1

How to cite this article: Gajendra Kumar Tyagi* and Amit Madhu. Nanotechnology in Textiles: Unleashing Innovation and Value Addition. Fashion Technol. 9(1). TTEFT. 000702. 2023. DOI: 10.31031/TTEFT.2023.09.000702

Introduction

Nanotechnology has transformed, offering enhanced functionalities and improved performance [1]. Nanomaterials, with particle sizes between 1 to 100 nanometres, possess extraordinary properties due to their high surface area and quantum effects. Common nanomaterials in textiles are nanoparticles, nanofibers, and nanocomposites [1-3]. To incorporate nanoparticles into textiles, various techniques are used. Electrospinning, a recent method, is favoured for creating nanofibers [4,5]. Coating technologies involve applying organic and inorganic compound-based nanoparticles (e.g., Copper, Silicon, Copper oxide, Titanium dioxide (TiO_2), Graphene oxide. etc.) directly through printing, spray coating, or impregnation techniques [2-4]. These nanoparticles add antimicrobial, ultraviolet resistant, electrically conductive, optical, hydrophobic and flame-retardant properties to textiles and garments [3,5]. Additionally, nanomaterial- based smart devices are integrated into textiles for functions like energy harvesting and storage, sensing, drug release and optics [4,6]. These advancements find wide applications in the fashion industry and are being developed for defence, healthcare and on-body energy harnessing applications [3,6].

Nanofibers for improved strength and comfort

Nanotechnology has revolutionized the production of nanofibers, which are extremely thin fibres with diameters in the nanometre range. These nanofibers possess unique properties, including a high surface area-to-volume ratio, exceptional strength, and breathability [7]. Integrating nanofibers into textiles enhances their mechanical properties without sacrificing flexibility or comfort [8], resulting in lighter, more flexible designs with improved protection and performance [9]. Moreover, nanofiber-based textiles contribute to sustainability by reducing material usage and waste [1]. One application of nanofibers is in the field of composites, where carbon nanofibers (CNFs) are utilized as reinforcing agents. This application is especially prevalent in industries like aerospace and automotive, where CNF composites offer superior strength-to-weight ratios, making them ideal for light weight and high- strength applications [8]. In sportswear, nanofibers, derived from synthetic polymers are incorporated to enhance mechanical properties. This allows sportswear to withstand repeated stretching and movement during physical activities [9]. The breathable and moisture-wicking characteristics of nanofiber-based fabrics ensure that athletes stay comfortable and dry during workouts, offering superior wearing experience [1,10].

During the COVID-19 pandemic, nanofiber-based face masks gained attention for their excellent filtration efficiency. Electro spun nanofibers made from polymers like polypropylene create a dense network of ultrafine fibers that effectively trap airborne particles, including viruses and bacteria. These masks provide improved protection and comfort due to their lightweight nature and breathability, making them more comfortable to wear for extended periods [11]. In the medical field, nanofiber mats made from biocompatible materials like chitosan, collagen, polyvinyl alcohol (PVA) are used for wound healing. These nanofibers wound dressings offer improved comfort and accelerated healing compared to traditional dressings [12], as they provide a porous and scaffold-like structure for cells to adhere and proliferate [13]. Nanofiber filters are extensively used in air purifiers and water purification systems. The fine pores of nanofibers efficiently capture particulate matter, bacteria and viruses, leading to superior filtration efficiency [14]. These filters provide cleaner air and water and require less pressure for filtration, resulting in enhanced energy efficiency and improved user comfort [7,15]. Additionally, nanofibers can also be incorporated into adhesives and coatings to improve their mechanical properties. Nanofiber-reinforced adhesives offer stronger bonding between materials, leading to increased durability and comfort in products like footwear, electronics, and automotive components [16].

Nano coatings for enhanced performance

Nanotechnology in textiles primarily focuses on nano coatings, which are ultra-thin layers of nanoparticles applied to textile surfaces to enhance specific properties. These coatings offer various functionalities [5,14], making textiles safer, more durable, and suitable for a wide range of applications [7,8,17].

Water Repellency and Moisture Management: Nanocoatings can create hydrophobic surfaces that repel water and stains, benefiting outdoor clothing, sportswear and upholstery [18]. Nanoparticles like fluorine, silicones, ZnO, silver, Carbon nanotubes (CNT) etc. result super hydrophobicity in materials while maintaining breathability [18-20]. Thus, super hydrophobicity can be achieved by properly treating fibres with nanoparticles, without sacrificing the comfort, softness, or durability of textiles [21].

Antibacterial and Antimicrobial Properties: Nanocoatings with antimicrobial properties inhibit the growth of bacteria and fungi on textiles, making them valuable in medical textiles, sportswear, and clothing worn in humid environments, reducing infection risk and Odors [22,23]. Active nanomaterials can be integrated chemically or physically into fabrics to create antibacterial textiles [24] and a variety of techniques, including electrospinning, nanoprecipitation and self-assembly can be implemented for their application [25]. Face masks built of nanomaterial have drawn a lot of interest since the COVID-19 outbreak. Researchers have developed antiviral face masks and PPE kits using nanomaterials to combat infections like SARS-CoV-2 [11,25]. They contend that metallic nanoparticles like Ag, Cu, TiO_2 and others might take the place of traditional disinfectants such chlorides, quaternary amines, peroxides, and alcohols because of their better antiviral characteristics [26].

Ultra-violet Protection: Nanomaterials like TiO_2 and ZnO [27,28] can scatter or absorb UV radiation, offering UV-blocking properties to protect wearer from harmful ultraviolet radiation. It is simple to use TiO_2 nanoparticle as UV blocker on cotton and ZnO nanoparticles as UV scatter layer to cotton and polyester [12,29]. This feature is crucial in protective gear, swimwear, and outdoor clothes [30,31].

Flame Retardancy: Nanocoating enhances the fire resistance of textiles, making them self-extinguishing or slowing down flame spread. These flame-retardant nanocoated fabrics are used in industrial workwear, home textiles, and automotive interiors to improve safety [24,32]. The sol-gel process has been explored to produce efficient flame-retardant fabrics through various synergistic effects [28,33]. In summary, nanocoatings in textiles offer water repellence, antimicrobial properties, UV protection and flame retardancy, enhancing the functionality and safety of various textile products.

Textiles sensors

Nanotechnology has revolutionized textiles with the integration of nano sensors, enabling them to sense and respond to environmental changes. These smart textiles can adjust their properties to regulate body temperature, change colors based on light intensity, and detect various factors like temperature, humidity and pressure [34]. This innovation has opened opportunities in healthcare, sports and fashion, enhancing comfort, performance and aesthetics. Carbon-based nanomaterials such as carbon nanotubes (CNT), graphene and carbon nanofibers are extensively used for their application as light weight, flexible and high strain sensors [35-37]. Temperature and humidity sensors are also incorporated into textiles using advanced techniques like photolithography and inkjet printing [38-39].

The introduction of sensors and actuators in the textile industry relies on the conductive properties of the material. Conductive yarns are now replacing traditional warp threads to establish connections between sensors within the fabric [40]. Conducting polymers nanostructured polyaniline (PANI), (PPy) and polythiophene (PT) are the widely used in the textile industry due to their enhanced mechanical strength, optical and conducting characteristics in the synthetic fibers. Additionally, conductive nanomaterials like Graphene [40], carbon nanotubes (CNT) [41] are incorporated into fibres to produce electro-conductive textiles for various electronic applications.

Colour changing textiles

Nanoparticles play a significant role in developing color-changing textiles that respond to changes in pH, temperature, or light. Textiles can sense changes in temperature or light intensity. Textiles can sense variations in temperature or light intensity through photochromic and thermochromic polymers. Textiles can sense variations in Retroreflective ink-printed fabrics are widely used in security gear [42]. These smart textiles also incorporate electroluminescent wires, fluorescent fibres, optical fibres, and photonic band gap fibres, enabling diverse functionalities like temperature monitoring, humidity sensing, pressure, optical displays, data transfer, and communication in complex textiles [43].

Sustainability in textiles with nanoparticles

Nanotechnology presents an opportunity to create eco-friendly textiles that benefit both consumers and the environment by addressing textile waste and its environmental impacts. Nanoparticles can reinforce textile fibers, improving durability and reducing the need for frequent replacement, thereby reducing waste generation and conserving resources. Nanotechnology also allows for precise application of coatings, reducing excess material usage during production, Additionally, innovative nanomaterial synthesis processes enhance energy efficiency and minimize environmental impact in textile manufacturing. Researchers are developing eco-friendly nanoparticles derived from natural sources that can degrade safely in the environment, minimizing potential hazards associated with traditional nanoparticles [1,4].

Current challenges and future perspectives

The integration of nanotechnology in the textile industry has ushered in a new era of innovative and high-performance fabrics. However, these advancements come with environmental challenges that necessitate a careful and responsible approach to ensure sustainable practices. Nanoparticles used in textiles can pose potential environmental challenges at various stages of their lifecycle [1,21]. Some key concerns include potential toxicity and Pollution during manufacturing, difficulties in end-of-life disposal, and increased resource consumption in nanoparticle production. To ensure environmental sustainability, responsible practices must be adopted throughout the entire lifecycle of nanoparticle-treated textiles. This includes prioritizing eco-friendly nanoparticles, employing environmentally friendly manufacturing processes, conducting thorough life cycle assessment and fostering collaboration and research on sustainable nanotechnology.

Conclusion

Nanotechnology has revolutionized the textile industry by providing opportunities for value addition and the development of innovative fabrics. Nanocoatings have provided fabrics with enhanced functionalities, nanofibers have improved strength and comfort, nanosensors have given rise to smart textiles, and nanoparticles have contributed to the development of eco-friendly and sustainable textiles. Moreover, the integration of nanotechnology has paved the way for advancements in wearable electronics and other cutting-edge applications. As the textile industry continues to leverage nanotechnology for progress, environmental sustainability must remain a primary concern. By incorporating responsible practices, using eco-friendly nanoparticles, promoting efficient manufacturing, and adopting circular economy principles, we can create textiles with nanotechnology that are both high-performing and environmentally friendly. Collaboration, research, and adherence to regulations will be key in shaping a sustainable future for nanotechnology in textiles.

References

1. Shah MA, Pirzada BM, Price G, Shibiru AL, Qurashi A (2022) Applications of nanotechnology in smart textile industry: A critical review. Journal of Advanced Research 38: 55-75.
2. Parvinzadeh Gashti M, Pakdel E, Alimohammadi F (2016) Nanotechnology-based coating techniques for smart textiles. In: Active Coatings for Smart Textiles pp: 243-268.
3. Joshi M, Adak B (2019) Advances in nanotechnology based functional, smart and intelligent textiles: A review. In: Comprehensive Nanoscience and Nanotechnology, pp. 253-290.
4. Sarvalkar PD, Barawkar SD, Karvekar OS, Patil PD, Prasad SR, et al. (2023) A review on multifunctional nanotechnological aspects in modern textile. The Journal of The Textile Institute 114(3): 470-487.
5. Nadi A, Boukhriss A, Bentis A, Jabrane E, Gmouh S (2018) Evolution in the surface modification of textiles: A review. Textile Progress 50(2): 67-108.
6. Hassan BS, Islam GMN, Haque ANMA (2019) Applications of nanotechnology in textiles: A review. Adv Res Text Eng 4(2): 1038.
7. Malik S, Muhammad K, Waheed Y (2023) Nanotechnology: A revolution in modern industry. Molecules 28(2): 661.
8. Pereira C, Pereira AM, Freire C, Pinto TV, Costa RS, et al. (2020) Nanoengineered textiles: from advanced functional nanomaterials to groundbreaking high-performance clothing. In: Mustansar Hussain C (Ed.), Handbook of Functionalized Nanomaterials for Industrial Applications, Amsterdam, Netherlands, pp. 611-714.
9. Yetisen AK, Qu H, Manbachi A, Butt H, Dokmeci MR, et al. (2016) Nanotechnology in textiles. ACS Nano 10(3): 3042-3068.
10. Damuluri R, Kiran K, Chakravarthy DP (2017) Review studies on application of nanotechnology in textiles. IJTFT 7(6): 2250 - 2378.
11. El-Atab N, Qaiser N, Badghaish H, Shaikh SF, Hussain MM (2020) Flexible nanoporous template for the design and development of reusable anti-COVID-19 hydrophobic face masks. ACS Nano 14(6): 7659-7665.
12. Fouda A, Saad E, Salem SS, Shaheen TI (2018) *In-Vitro* cytotoxicity, antibacterial and UV protection properties of the biosynthesized Zinc oxide nanoparticles for medical textile applications. Microb Pathog 125: 252-261.
13. Klasen HJ (2000) Historical review of the use of silver in the treatment of burns I. Early uses. Burns 26(2): 117-130.
14. Gulrajani ML (2013) The use of nanotechnology in the finishing of technical textiles. Advances in the Dyeing and Finishing of Technical Textiles, pp: 280-308.
15. Haque M (2018) Nano Fabrics in the 21st century: a review. Asian Journal of Nanoscience and Materials 2(2): 131-148.
16. Aithal PS (2016) Nanotechnology innovations & business opportunities: A review. International Journal of Management, IT and Engineering 6 (1): 182-204.
17. Perera S, Wijesekara D, Thiripuranathar G, Menaa F (2022) The use of nanoparticles to enhance performance in the textile industry-A concise review. Current Nanoscience 18(3): 319-335.
18. Liu Y, Tang J, Wang R, Lu H, Li L, et al. (2007) Artificial lotus leaf structures from assembling carbon nanotubes and their applications in hydrophobic textiles. J Mater Chem 17(11): 1071-1079.
19. Zahid M, Mazzon G, Athanassiou A, Bayer IS (2019) Environmentally benign non-wettable textile treatments: A review of recent state-of-the-art. Adv Colloid Interface Sci 270: 216-250.

20. Shyr TW, Lien CH, Lin AJ (2010) Coexisting antistatic and water-repellent properties of polyester fabric. Text Res J 81(3): 254-263.
21. El-Khatib EM (2012) Antimicrobial and self-cleaning textiles using nanotechnology. Res J Text Apparel 16(3): 156-174.
22. Yeo SY, Lee HJ, Jeong SH (2003) Preparation of nanocomposite fibers for permanent antibacterial effect. J Mater Sci 38(10): 2143-2150.
23. Rehman S, Asiri SM, Khan FA, Jermy BR, Khan H, et al. (2019) Biocompatible tin oxide nanoparticles: Synthesis, antibacterial anticandidal and cytotoxic activities. Chemistry Select 4(14): 4013-4017.
24. Jyothirmai S, Panda S (2021) Nanotechnology and its applications in textiles-A review. IJARIIE 7(2): 243-249.
25. Kostic MM, Milanovic JZ, Baljak MV, Mihajlovski K, Kramar AD (2014) Preparation and characterization of silver-loaded hemp fibers with antimicrobial activity. Fibers and Polymers 15(1): 57-64.
26. Talebian S, Wallace GG, Schroeder A, Stellacci F, Conde J (2020) Nanotechnology based disinfectants and sensors for SARS-CoV-2. Nat Nanotechnol 15(8): 618-621.
27. Yang H, Zhu S, Pan N (2004) Studying the mechanisms of titanium dioxide as ultraviolet-blocking additive for films and fabrics by an improved scheme. J Appl Polym Sci 92(5): 3201-3211.
28. Wasim M, Khan M R, Mushtaq M, Naeem A, Han M, Wei Q (2020) Surface modification of bacterial cellulose by copper and zinc oxide sputter coating for UV-resistance/antistatic/antibacterial characteristics. Coatings 10(4): 364.
29. Wang R, Xin JH, Tao XM, Daoud WA (2004) ZnO nanorods grown on cotton fabrics at low temperature. Chem Phys Lett 398(1-3): 250-255.
30. Yu J, Pang Z, Zheng C, Zhou T, Zhang J, et al. (2019) Cotton fabric finished by PANI/TiO_2 with multi-functions of conductivity, anti-ultraviolet and photocatalysis activity. Appl Surf Sci 470: 84-90.
31. Dhineshbabu NR, Bose S (2019) UV resistant and fire-retardant properties in fabrics coated with polymer-based nanocomposites derived from sustainable and natural resources for protective clothing application. Compos B Eng 172: 555-563.
32. Saleemi S, Naveed T, Riaz T, Memon H, Awan JA, et al. (2020) Surface functionalization of cotton and PC fabrics using SiO_2 and ZnO Nanoparticles for Durable Flame-Retardant Properties: Coatings 10(2): 124.
33. Coyle S, Wu Y, Lau KT, Rossi DD, Wallace G, et al. (2007) Smart nanotextiles: A review of materials and applications. MRS Bulletin 32: 434-442.
34. Kim H, Ahn JH (2017) Graphene for flexible and wearable device applications. Carbon 120: 244-257.
35. Suzuki K, Yataka K, Okumiya Y, Sakakibara S, Sako K, et al. (2016) Rapid response, widely stretchable sensor of aligned MWCNT/elastomer composites for human motion detection. ACS Sensors 1(6): 817-825.
36. Naikoo GA, Awan T, Hassan IU, Salim H, Arshad F, et al. (2021) Nanomaterials-based sensors for respiratory viral detection: A review. IEEE Sens J 21(16): 17643-17656.
37. Li X, Sun P, Fan L, Zhu M, Wang K, et al. (2012) Multifunctional graphene woven fabrics. Sci Rep 2(1): 395.
38. Shateri Khalilabad M, Yazdanshenas ME (2013) Fabricating electroconductive cotton textiles using graphene. Carbohydr Polym 96(1): 190-195.
39. Trovato V, Teblum E, Kostikov Y, Pedrana A, Re V, et al. (2020) Sol-gel approach to incorporate millimeter-long carbon nanotubes into fabrics for the development of electrical-conductive textiles. Mater Chem Phys 240: 122218.
40. Jost K, Perez CR, McDonough JK, Presser V, Heon M, et al. (2011) Carbon coated textiles for flexible energy storage. Energy Environ Sci 4(12): 5060-5067.
41. Gauvreau B, Schicker K, Guo N, Dubois C, Wingfield R, et al. (2008) Coloron- demand photonic textiles. The Textile J 125:70-81.
42. Gauvreau B, Guo N, Schicker K, Stoeffler K, Boismenu F, et al. (2008) Color changing and color-tunable photonic bandgap fiber textiles. Opt Express 16(20): 15677-15693.
43. Wong YWH, Yuen CWM, Leung MYS, Ku SKA, Lam HLI (2006) Selected applications of nanotechnology in textiles. Autex Research Journal 6(1): 1-8.