International Journal of Applied Home Science
(An International Double Blind Peer Reviewed / Refereed Research Journal of Home Science)
Volume 13 (1 & 2), January & February (2026) : 67-70
Received : 23.12.2025; Revised : 08.01.2026; Accepted : 23.01.2026

REVIEW PAPER
ISSN : 2394-1413 (Print)
DOI: https://doi-ds.org/doilink/03.2026-67922997/IJAHS/13.1&2/67-70

Emerging Smart and Functional Fibres: Technological Developments and Applications in the Textile Industry

ANNU*[1], NISHA ARYA[2], SOMLATA[3], MINAKSHI SHARMA[4] AND DIVYA[5]
[1,3,4,5]Ph.D Scholar and [2]Associate Professor
Department of Apparel and Textile Science, I.C. College of Community Science
C.C.S. Haryana Agricultural University, Hisar (Haryana) India

*Corresponding Author

ABSTRACT

Recent advancements in material science and fibre engineering have transformed the textile industry, shifting from conventional fibres toward multifunctional and intelligent materials. Smart and functional fibres integrate sensing, actuation, conductivity and responsiveness to environmental stimuli enabling applications ranging from wearable electronics to medical monitoring and adaptive clothing. This review examines the technological developments driving these innovations, focusing on nano-technology, conductive polymers, phase change materials, shape memory fibres and bio-functional coatings. It further explores the integration of these fibres into smart textiles, their manufacturing techniques (electro-spinning, melt-spinning, coating, and in-situ polymerization) and their potential applications in health care, defense, sports and fashion. The paper also highlights challenges in washability, comfort, energy management, recyclability and scalability. Finally, emerging trends such as self-powered fabrics, fibre-based sensors and biocompatible smart fibres are discussed as future directions for research and commercialization.

Keywords: Smart fibres, Functional textiles, Nano-technology, Wearable electronics, Responsive materials, Textile innovation

INTRODUCTION

The global textile and apparel industry has evolved from a focus on aesthetics and comfort to incorporating functionality and intelligence. Smart and functional fibres represent the foundation of this transformation, integrating electrical, thermal, mechanical and chemical properties that allow fabrics to sense, respond and adapt to external stimuli (Coyle *et al.,* 2021). The rise of Industry 4.0, Internet of Things (IoT) and wearable technology has accelerated the development of smart fibres that bridge the gap between electronics and traditional textiles (Stoppa and Chiolerio, 2014).

Functional fibres can be defined as fibres possessing additional engineered properties beyond basic mechanical performance such as conductivity, thermoregulation, self-cleaning, antimicrobial activity and responsiveness (Zhou *et al.,* 2020). Smart fibres, a subset of functional fibres, can interact dynamically with the environment through embedded sensors or responsive materials (Mattila, 2018).

This review synthesizes progress in material innovation, manufacturing processes and applications of emerging smart and functional fibres. It also identifies current challenges and proposes directions for future research in achieving sustainable, durable and user-friendly smart textiles.

Classification of Smart and Functional Fibres

Smart and functional fibres are typically classified based on their response mechanism or embedded functionality (Table 1):

Technological Developments in Smart Fibre Manufacturing:

Nanotechnology and Surface Functionalization:

Nanotechnology has revolutionized fibre design by

How to cite this Article: Annu, Arya, Nisha, Somlata, Sharma, Minakshi and Divya (2026). Emerging Smart and Functional Fibres: Technological Developments and Applications in the Textile Industry. *Internat. J. Appl. Home Sci.,* **13** (1 & 2) : 67-70.

Table 1 : Classification of Smart and Functional Fibres

Type	Functionality	Example Materials
Conductive fibres	Electrical conductivity, sensing, heating	Silver-coated fibres, carbon nanotubes (CNTs), graphene, PEDOT:PSS
Phase change fibres	Thermal regulation via latent heat	Paraffin microcapsules, polyethylene glycol (PEG)
Shape memory fibres	Deformation and recovery with stimuli	Polyurethane, NiTi alloys
Photochromic and thermochromic fibres	Color change under light/heat	Leuco dyes, spiropyrans
Antimicrobial and self-cleaning fibres	Inhibit bacteria, degrade pollutants	TiO_2, ZnO nanoparticles, chitosan
Biofunctional fibres	Drug release, wound healing	Silk fibroin, alginate, collagen

(Source: Adapted from De Rossi *et al.*, 2020; Mattila, 2018)

enabling the incorporation of nanoparticles (Ag, TiO, ZnO, CNTs) to impart conductivity, UV protection or antibacterial properties. Surface modification via plasma treatment, sol-gel coating or layer-by-layer deposition improves nanoparticle adhesion and durability (Zhou *et al.,* 2020).

For example, silver nanoparticles (AgNPs) provide antimicrobial activity and conductivity but raise concerns about leaching and cytotoxicity (Balasubramaniam et al., 2021). Graphene oxide (GO) and carbon nanotubes (CNTs) offer high conductivity and flexibility, making them ideal for wearable sensors (Cheng *et al.*, 2022) (Fig. 1).

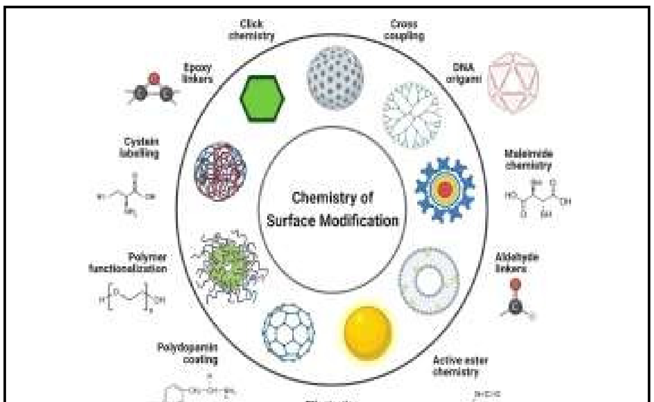

Fig. 1 : Nanomaterial surface modification

Conductive Polymers:

Polymers such as polypyrrole (PPy), polyaniline (PANI), and poly (3,4-ethylenedioxythiophene) (PEDOT:PSS) have emerged as flexible alternatives to metallic coatings. Their intrinsic conductivity and processability enable the fabrication of stretchable fibres through in-situ polymerization or coating (Bose *et al.*, 2020). Hybrid composites combining polymers and metal nanowires enhance conductivity while retaining comfort (Fig. 2).

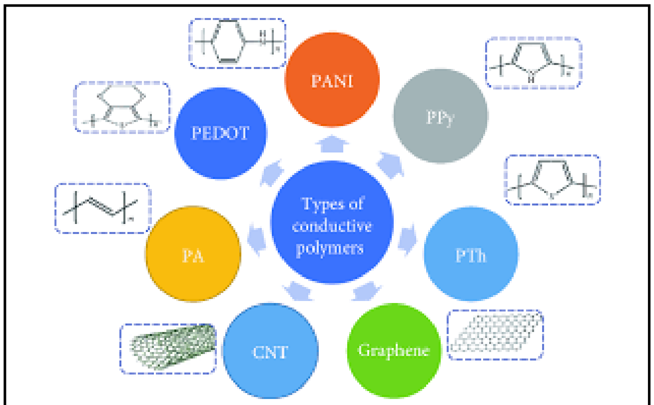

Fig. 2 : Types of conductive polymers

Phase Change and Thermal Regulation Fibres:

Phase change materials (PCMs) embedded in microcapsules within fibres store and release heat, maintaining thermal comfort. Integration into polyester or nylon fibres through melt spinning or coating offers applications in sportswear and protective clothing (Huang et al., 2019). Recent advances include bio-based PCMs and nanocapsule stabilization for improved durability (Fig. 3).

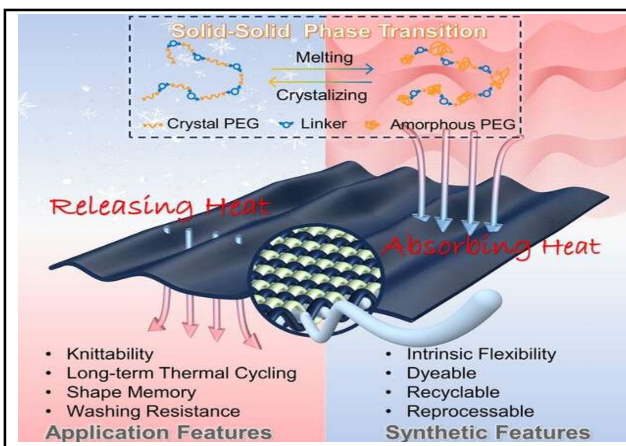

Fig. 3 : Phase change fibres for thermal regulation

Shape Memory and Responsive Fibres:

Shape memory polymers (SMPs) can change configuration under heat or light and revert upon cooling, enabling adaptive garments and medical compression textiles (Liu *et al.*, 2021). Electrospinning of SMP fibres allows precise control of microstructure and responsiveness (Fig. 4).

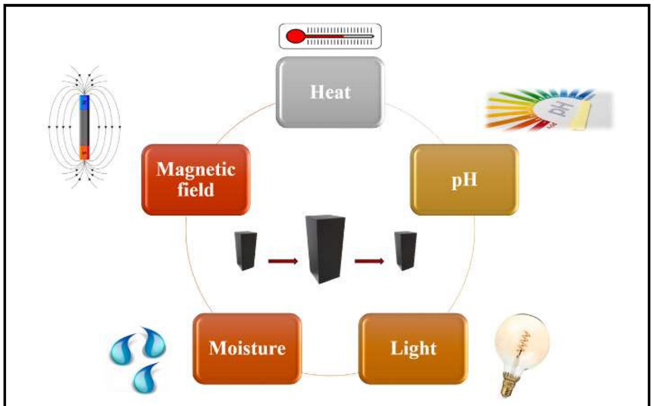

Fig. 4 : Shape memory materials

Electrospinning for Smart Fibre Production:

Electrospinning enables the production of nanofibres with high surface area, facilitating sensor integration and functionalization. Hybrid nanofibres incorporating metal oxides (ZnO, TiO_2) or conductive polymers have shown improved performance in energy storage and sensing applications (Wang *et al.*, 2022) (Fig. 5).

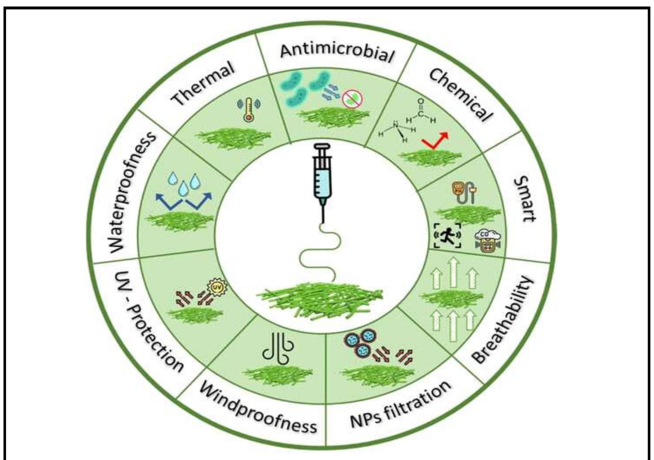

Fig. 5 : Use of electrospinning for sustainable production of nanofibres

Applications of Smart and Functional Fibres:

Healthcare and Medical Textiles:

Smart fibres play an essential role in health monitoring, drug delivery and therapeutic clothing. Conductive and piezoelectric fibres enable real-time biosignal monitoring (heart rate, respiration) (Stoppa and Chiolerio, 2014). Antibacterial and biofunctional fibres aid wound healing and infection prevention (Cheng *et al.,* 2022) (Fig. 6).

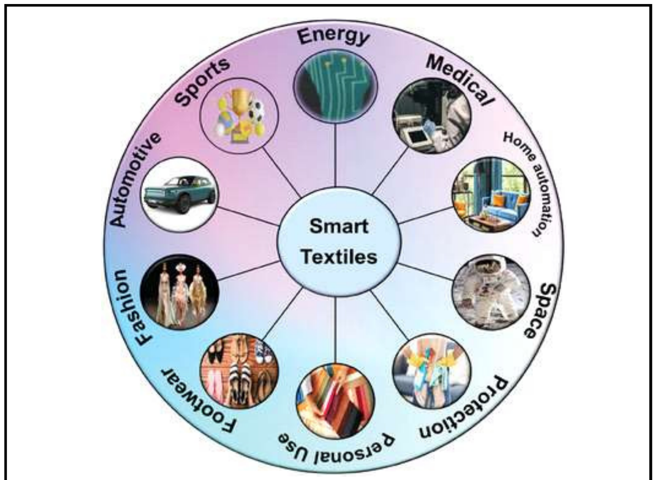

Fig. 6 : Various applications of smart textiles

Sports and Performance Apparel:

Phase change and moisture management fibres maintain optimal body temperature and comfort. Embedded sensors monitor motion and performance, while stretchable conductive fibres allow integration into garments without compromising flexibility (Mattila, 2018).

Defense and Protective Textiles:

Military applications include camouflage textiles, chemical/biological protection and temperature-adaptive uniforms. Shape-memory alloys and conductive composites provide thermal management and adaptive insulation (De Rossi *et al.*, 2020).

Environmental and Energy Applications:

Textiles incorporating photovoltaic fibres or triboelectric nanogenerators (TENGs) can harvest energy from motion or sunlight (Zhang *et al.,* 2022). Self-cleaning fibres with TiO_2 nanocoatings decompose pollutants, reducing washing needs.

Fashion and Aesthetic Design:

Photochromic and electroluminescent fibres offer color-changing and light-emitting effects for fashion innovation, merging artistic design with functionality

(Huang *et al.,* 2019).

Challenges and Limitations:

Despite rapid progress, several challenges hinder large-scale adoption:

- ***Durability and washability:*** Functional coatings often degrade during laundering (Bose *et al.,* 2020).
- ***Energy management****:* Powering smart fibres remains complex; self-powered systems are emerging but not yet mainstream (Zhang *et al.*, 2022).
- ***Comfort and wearability***: Integration of electronics may compromise flexibility and breathability.
- ***Scalability and cost:*** High production costs of nanomaterials and conductive polymers limit mass-market viability (Mattila, 2018).
- **Environmental impact**: Nanoparticle release and end-of-life recyclability pose ecological challenges (Balasubramaniam *et al.*, 2021).

Future Trends and Research Directions:

1. ***Self-powered and energy-harvesting fibres*****:** Integration of piezoelectric and triboelectric materials to generate electricity from body motion (Zhang *et al.,* 2022).
2. ***Biocompatible and biodegradable smart fibres***: Use of silk, chitosan and cellulose for sustainable and safe wearables.
3. ***AI-integrated smart textiles*****:** Incorporation of data analytics and IoT for predictive health monitoring.
4. ***3D printing of functional fibres*** : Direct fabrication of multi-material fibres enabling localized conductivity and flexibility.
5. ***Circular design and recyclability***: Research into easily separable or recyclable conductive materials.

Conclusion:

Emerging smart and functional fibres are reshaping the textile industry, combining comfort and intelligence in unprecedented ways. From conductive and shape-memory fibres to self-cleaning and bio-functional materials, technological innovations are enabling textiles that sense, adapt and interact with users and the environment. Future advancements will depend on addressing challenges of durability, sustainability and scalability while embracing cross-disciplinary integration of materials science, nanotechnology and digital systems. The next generation of smart fibres promises a convergence of fashion, function and technology a hallmark of truly intelligent textiles.

REFERENCES

Balasubramaniam, N., Lim, S. and Lee, J. (2021). Nanotechnology applications in smart textiles: A review of materials and methods. *J. Textile Sci. & Technol.*, **37**(4) : 112-125.

Bose, S., Venkatraman, P. and Kim, H. (2020). Conductive polymer-based fibres for wearable electronics. *Advanced Materials Technologies*, **5**(9) : 2000362.

Cheng, H., Wang, Y. and Li, S. (2022). Graphene-based smart fibres for health monitoring applications. *Composites Sci. & Technol.*, **228**, 109692.

Coyle, S., Wu, Y. and Lau, K. (2021). Smart textiles for wearable sensing: Current status and future prospects. *Sensors & Actuators A: Physical*, **329**, 112773.

De Rossi, D., Carpi, F. and Scilingo, E. (2020). Functional and adaptive materials for smart textiles. *Materials Today*, **35** : 78-92.

Huang, L., Jiang, P. and Li, F. (2019). Phase change fibres for thermal regulation in textiles. *Textile Res. J.*, **89**(3) : 326-340.

Liu, X., Gao, Q. and Zhao, Y. (2021). Shape-memory polymer fibres and their textile applications. *Polymer Reviews*, **61**(4), 557-584.

Mattila, H. (2018). *Intelligent Textiles and Clothing for Ballistic and NBC Protection*. Woodhead Publishing.

Stoppa, M. and Chiolerio, A. (2014). Wearable electronics and smart textiles: A critical review. *Sensors*, **14**(7) : 11957-11992.

Wang, T., Xu, Y. and Chen, L. (2022). Electrospun nanofibres in multifunctional smart textiles. *J. Industrial Textiles*, **52**(2) : 145-165.

Zhang, Z., Zhang, Q. and Lin, Z. (2022). Fibre-based energy harvesting for self-powered smart textiles. *Nano Energy*, **99**, 107446.

Zhou, Y., Li, M. and He, J. (2020). Recent advances in nanotechnology for smart and functional textiles. *Advanced Functional Materials*, **30**(26), 2000188.

****