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Advances in the Application of Shape-Memory Materials in Smart Wearable Systems

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ABSTRACT
Shape-memory materials are capable of returning to a predetermined shape or generating a restoring stress in response to external stimuli such as thermal, electrical, optical or magnetic forces. Combining advantages such as light weight, flexibility, programmable response and structural reconfigurability, they have gradually become a vital material foundation for smart wearable systems. This paper follows the main thread of 'Materials and Structural Fundamentals—Typical Wearable Applications—Key Issues and Development Trends', systematically reviews research progress in shape memory materials across areas such as wearable sports assistance and rehabilitation, thermal management and thermotherapy, flexible sensing and haptic interaction, and functional and medical apparel. It focuses on summarising the adaptation pathways, representative configurations and performance characteristics of different material systems and fabrication methods, whilst discussing the major challenges currently faced in terms of response speed, thermal safety, cycling stability, textile processing compatibility and system integration. It also offers a outlook on future trends in multifunctional synergy, closed-loop control, personalised design and mass production.

KEYWORDS
Shape memory materials; Smart wearables; Sports assistance; Thermal management; Flexible sensing

1 Introduction

With the rapid development of smart materials, flexible electronics and advanced textile processing technologies, traditional clothing and fabric systems are gradually evolving from passive carriers for coverage and protection into comprehensive wearable platforms capable of sensing, responding, regulating and interacting. Shape-memory materials are capable of returning to a predetermined shape or generating restorative stress in response to external stimuli such as thermal, electrical, optical or magnetic forces.

Combining characteristics such as light weight, programmability and soft deformability, they are demonstrating increasingly significant application potential in fields including smart textiles, soft actuation, functional clothing, rehabilitation aids and human-machine interaction [1-7].

In recent years, research in this field has gradually shifted from single materials or devices towards structural design, performance evaluation and application synthesis for smart wearable systems.

On the one hand, existing reviews have systematically examined the differences in drive modes, wearable forms and application scenarios of shape memory alloy textiles based on structures such as knitted, woven and corded fabrics, pointing out that textile structural design has become a key factor influencing output displacement, recovery force, compliance and human body adaptability [8].

On the other hand, a review of research on rehabilitation soft robotics indicates that SMAs offer both high energy density and good structural compliance in upper limb, lower limb and hand functional assistance systems; however, their thermal hysteresis, cooling efficiency and control accuracy remain significant bottlenecks constraining clinical translation [9].

In the field of thermo-responsive textiles, relevant research further indicates that the synergistic design of shape-memory fibres and fabric pore structures holds promise for advancing wearable systems from passive protection towards active regulation in areas such as thermal and moisture management, adaptive thermal regulation, and functional clothing [10].

2 Fundamental Materials and Structures for Smart Wearable Systems

2.1 Shape-Memory Composite Fabrication and Integration with Textile Structures

Research by Zhang et al. demonstrates that mirror-symmetric layups can effectively mitigate the internal stress interference caused by the self-curling of conventional weft-knitted fabrics, enabling the reinforced composites to maintain high shape retention rates and stable recovery behaviour under both tensile and U-bend loading conditions; specifically, specimens oriented at 0° typically exhibit faster recovery rates, whilst those oriented at 90°, with higher ply counts and higher loop densities, are more conducive to achieving greater recovery forces.

2.2 Wearable Soft Actuators and Artificial Muscles

Guan et al. utilised conjugate electrospinning technology to prepare continuous SMPU nanofibre yarns, establishing a structure–property relationship between the microstructure and macroscopic properties by controlling the twist angle on the nanofibre surface.

The optimised yarns retained near-complete recovery performance after multiple thermomechanical cycles and could be further woven into fabric-scale structures capable of rapid and stable deformation under heating conditions. Fu Chiyu, on the other hand, utilised NiTi wires as the core and polyimide fibres as the outer sheath to prepare shape-memory alloy composite yarns via a friction spinning process, and further constructed fabric actuators with shape-programmable properties. This demonstrates that yarn-level compositing and fabric-level reconfiguration are important technical pathways for realising flexible artificial muscles and wearable actuators.

2.3 Fundamentals of Drive Mechanisms, Thermal Management and Wearability

Jin Guanxiu conducted research on the weaving and wearability of shape-memory polyurethane core-spun yarn fabrics, pointing out that by appropriately controlling the warping, sizing and weaving tensions, it is possible to effectively mitigate dimensional instability caused by cold stretching of the core yarns, enabling the fabric to retain good shape retention, recovery and surface smoothness even after desizing. In their research on comfort-oriented functional fibres, Guo Lixing et al. further noted that shape-memory fibres can achieve pressure distribution through morphological changes in response to body temperature.

These fibres demonstrate potential for improving pressure comfort in applications such as smart cushions and intimate apparel, and exhibit development trends towards intelligence, multifunctional integration and green sustainability.

3 Typical Applications of Shape Memory Materials in Smart Wearable Systems

3.1 Wearable Sports Assistance and Rehabilitation Equipment

In the field of lumbar and lower limb assistance, Lee et al. developed an SMA lumbar exoskeleton designed for lifting and lowering tasks, with a total weight of only 2.9 kg. The system identifies changes in trunk posture via an inertial measurement unit and utilises SMA heating to generate assistive torque around the pelvis.

In the field of upper limb assistance and bionic drive, Park et al. proposed an upper limb soft exosuit based on ‘textile muscles’. This device utilises fabric woven from SMA springs as the core actuator unit, which is further encapsulated as flexible textile muscles and integrated into a foldable exosuit. Lee and Park, meanwhile, incorporated knitted SMA into the design of a rehabilitation ex-glove for patients with hemiplegia. Based on 3D hand scans and joint range-of-motion (ROM) analysis, they achieved customised structural configuration.

3.2 Wearable Sensing and Haptic Interaction Systems

In addition to motion assistance, shape-memory materials also offer new avenues for perception and feedback in wearable systems.

On the one hand, shape-memory textile actuators can be directly utilised for haptic feedback and immersive interaction; on the other hand, novel material systems combining conductive networks, self-healing structures and multi-stimulus response mechanisms further expand the application boundaries of flexible sensors in low-temperature, underwater and complex environments.

3.3 Functional Wearable Clothing and Medical Garments

At the mechanism level, smart textile systems incorporating shape-memory layers can form an adjustable air layer through morphological changes induced by heat or cold, thereby dynamically altering thermal resistance. The shape-memory smart textile system developed by Wang et al. demonstrated that the fabric exhibits optimal thermal insulation performance when the spacing between adjacent alloy wires is 2 cm, achieving an approximately 14% improvement in thermal and humidity comfort compared to traditional three-layer insulation systems; Wang Lijun further validated this conclusion from a design mechanism perspective, noting that the 2 cm spacing scheme offers a superior balance between air layer thickness, thermal protection effectiveness and wear comfort.

4 Conclusion

Significant progress has been made in the application of shape-memory materials in smart wearable systems, particularly in areas such as textile actuation, physiological monitoring, energy storage and actuation, and 4D printing integration.

Shape-memory alloy fibres have been woven into spiral yarns and used in continuous weaving processes; a fabric weighing just 10 grams is capable of lifting objects weighing 10–15 kilograms.

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References

[1] Yao Lianzhen, Yang Wenfang, Qiao Yanli. Research Progress on Smart Fibres and Their Textiles [J]. Printing and Dyeing, 2012 (12): 43–46.
[2] Zhang Xiying, Fang Donggen, Shen Lei, He Yijun. Research and Development of Smart Fibres and Smart Textiles [J]. Textile Bulletin, 2015 (6): 103–106.
[3] Wang Wenli, Wang Yan, Qu Honggang. Research and Application of Shape-Memory Functional Textiles [J]. Functional Materials, 2009.
[4] Yao Y, Jin Z, Meng R, Gao H. Research Progress on Polyurethane Materials in the Field of Novel Smart Textiles and Apparel [J]. Modern Textile Technology, 2025, 33 (5): 10-21.
[5] Wang Y, Yu X, Liu R, Zhi C, Liu Y, Fan W, Meng J. Shape memory active thermal-moisture management textiles [J]. Composites Part A: Applied Science and Manufacturing, 2022, 160: 107037.
[6] Tan Xin, Zhang Hongyue, Zhao Yuchan, et al. Applications of shape memory alloys in assistive devices and rehabilitation equipment [J]. Chinese Journal of Tissue Engineering, 2025, 29 (10): 2113-2123.
[7] Li J, Lin J H, Qi Y, et al. Shape Memory Smart Textile Composites Open a New Era of Human Limb Function Rehabilitation: Principles, Design and Applications [J]. Article in press, 2025.
[8] Lee S M. Advances in shape memory alloy textiles for wearable applications: A critical review [J]. Journal of Industrial Textiles, 2025, 55: 1-19.
[9] Shami Z, Arslan T, Lomax P. Wearable soft robots: Case study of using shape memory alloys in rehabilitation [J]. Bioengineering, 2025, 12 (3): 276.
[10] Liu K, Yuan B, Pan T, et al. Thermal responsive shape memory textiles for self-adaptive applications: A review[J]. Sensors and Actuators A: Physical, 2025: 116935.