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IULTCS CONGRESS

陕西科技大学
SHAANXI UNIVERSITY OF SCIENCE & TECHNOLOGY

轻工科学与工程学院
COLLEGE OF BIORESOURCES CHEMICAL & MATERIALS ENGINEERING

Multifunctional wet-white leather tanning system based on vegetable tannins and dual-functionalized zirconium phosphate nanoplatelets: Optimization, characterization, and applications

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September 9, 2025

OUTLINE

01 **Research Background**

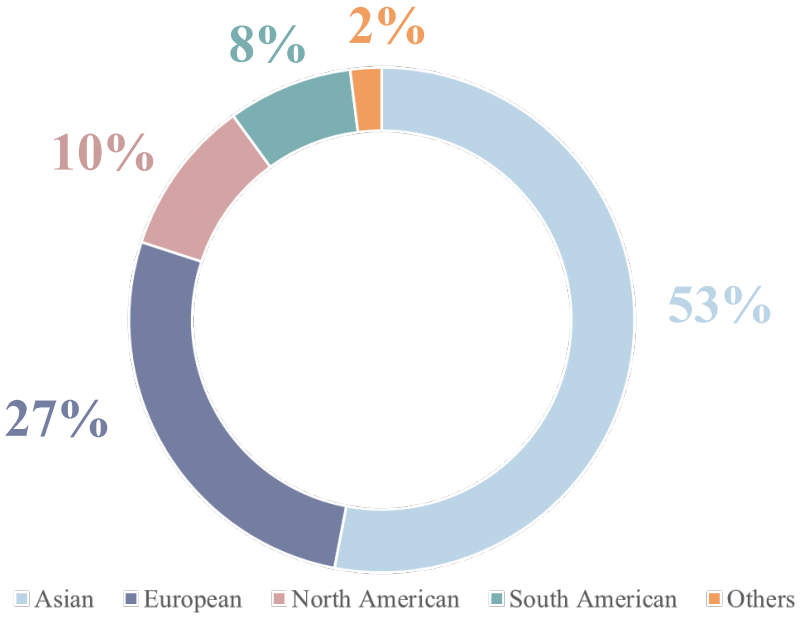
02 **Research Content**

03 **Research Conclusion**

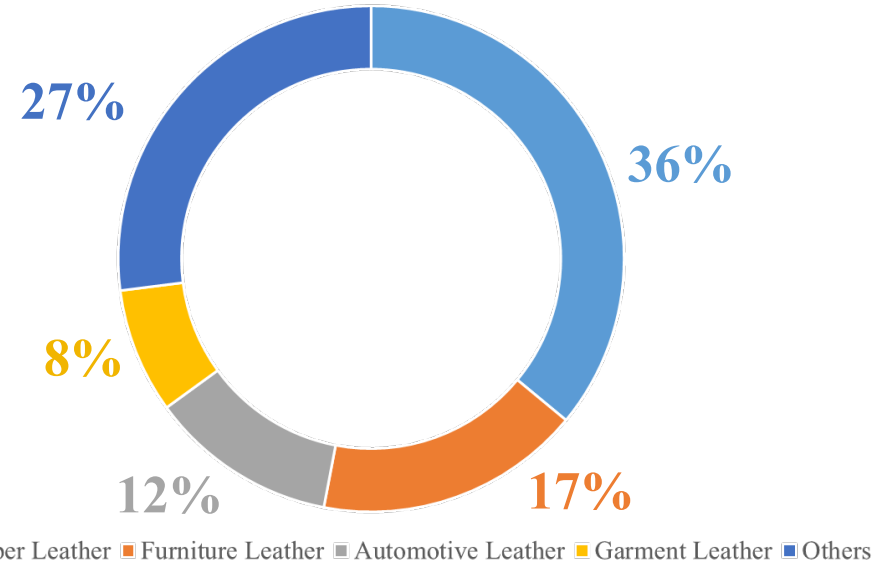
1.1 Global Leather Industry Development

- The global leather industry is indeed a cornerstone of the world economy, serving as a dynamic intersection of agriculture, technology, and fashion.

Global Distribution of Leather Production Volume



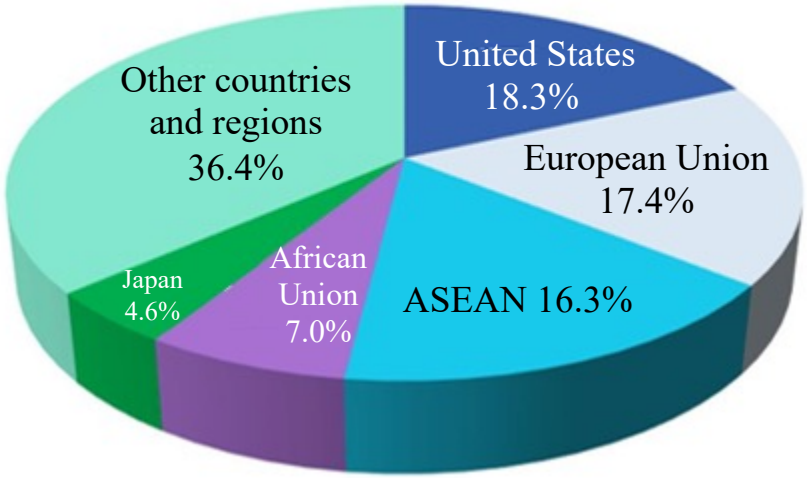
Distribution of Leather by Application



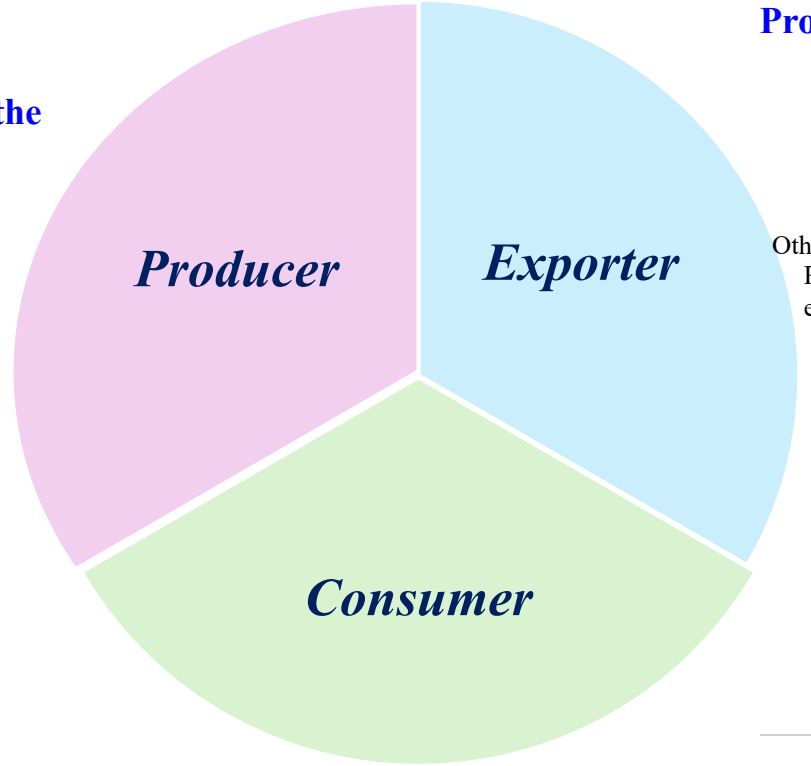
1.2 Chinese Leather Industry Development

- **Leather goods market will exceed 600 billion in 2025, with China contributing over 35% of global export as both the largest production and consumption center.**

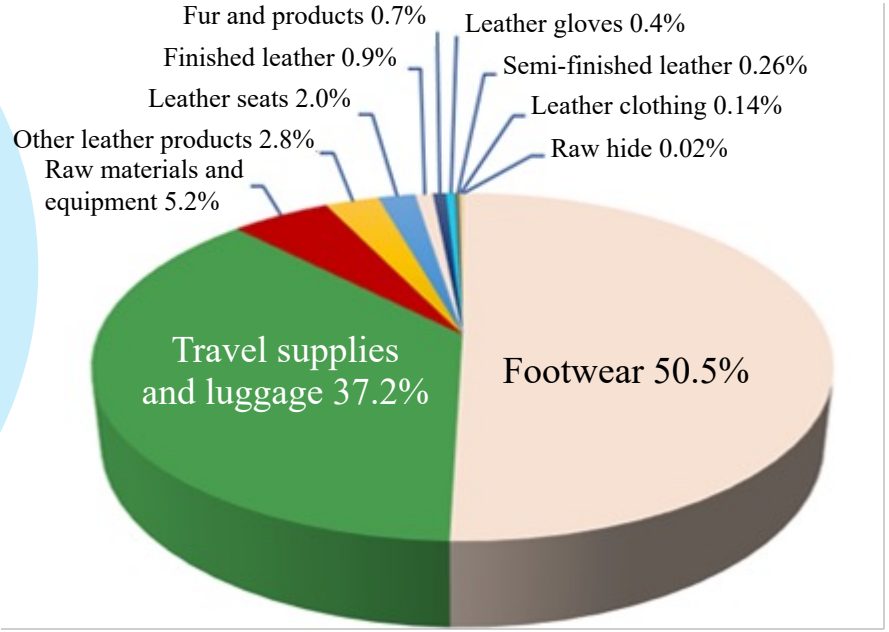
Proportion of major markets for the export value of the national leather industry in 2024



Distribution of Leather by Application



Proportion of sub industries in the export volume of the national leather industry in 2024



1.2 Chinese Leather Industry Development

➢ **Advancing research and development on cutting-edge materials and applications is critical to new productivity, quality growth, and functional & intelligent upgrading.**

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国家发展和改革委员会规章

来源： 发展改革委网站

【字体：大 中 小】打印

产业结构调整指导目录（2024年本）

（2023年12月1日经国家发展改革委第6次委务会通过 2023年12月27日国家发展改革委令第7号公布 自2024年2月1日起施行）

"Development, production and application of functional products in the leather industry" is included in the encouraged category.

皮革行业“十四五”高质量发展指导意见

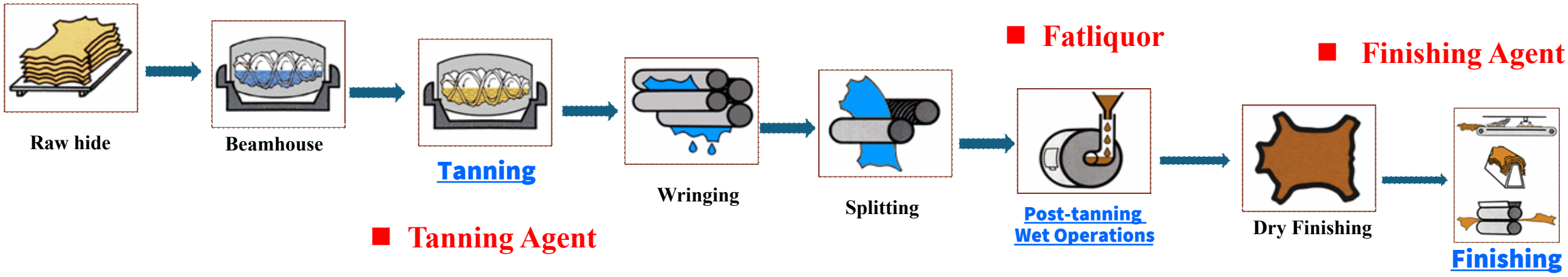
中国皮革协会

2021年8月31日

"R&D of leather materials and leather products with outstanding functions is one of the main tasks of the leather industry. "

1.3 Functions and characteristics of leather

➢ **Leather** is a material manufactured from the collagen fiber network of hides and skins, provided with **the characteristics required for the intended purpose**, and **produced by suitable chemical and physical processes**.



Exploring new high-performance, multi-functional leather chemicals and their application technologies has received considerable attention in global leather industry and academic institutions.

1.4 Advances in leather-based flexible bioelectronics

Traditional flexible electronics

Advantages

- ✓ Stable and continuous conductivity
- ✓ Excellent flexibility, stretchability and pressure resistance
- ✓ Respond to external changes

Disadvantages

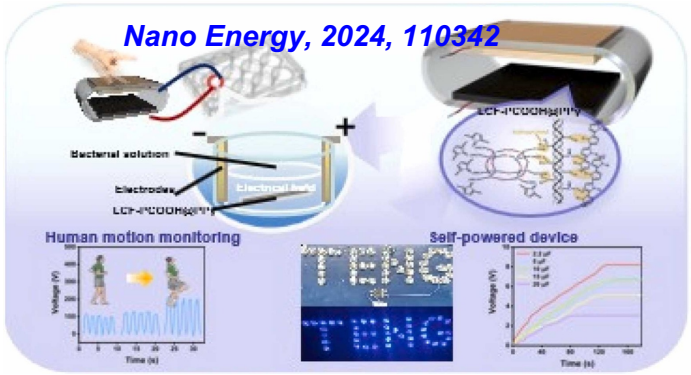
- ✓ Short service life
- ✓ Easy to cause rejection of the human body
- ✓ Easy to cause damage to the environment

Flexible e-leather

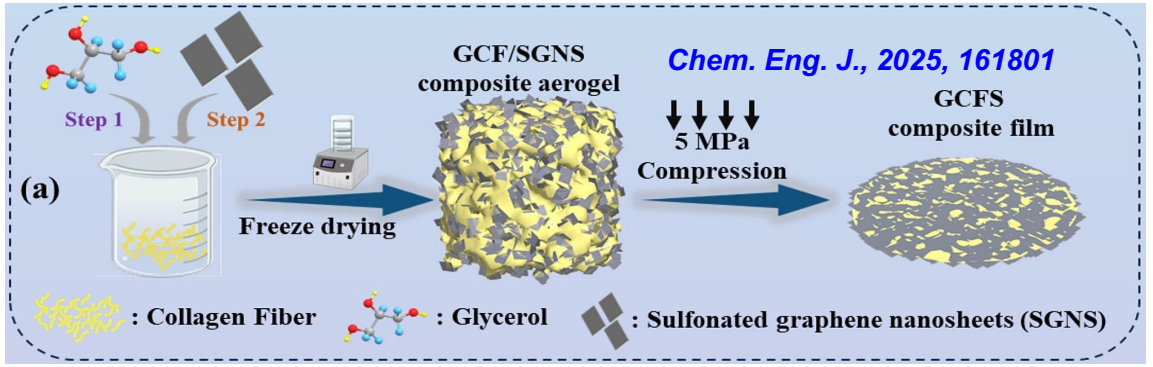
Advantages

- ✓ *Abundant biomass*
- ✓ *Reactivity*
- ✓ *Excellent biocompatibility*
- ✓ *Environmentally friendly*

J. Mater. Chem. A, 2023,11, 11773



Nano Energy, 2024, 110342



Chem. Eng. J., 2025, 161801

Owing to intrinsic renewability, degradability, cost-effectiveness, and outstanding functional properties, leather-based materials have attracted immense attention for the creation of flexible bioelectronics.

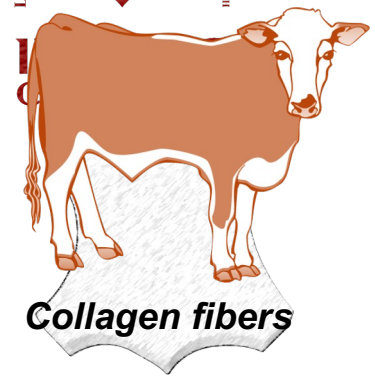
OUTLINE

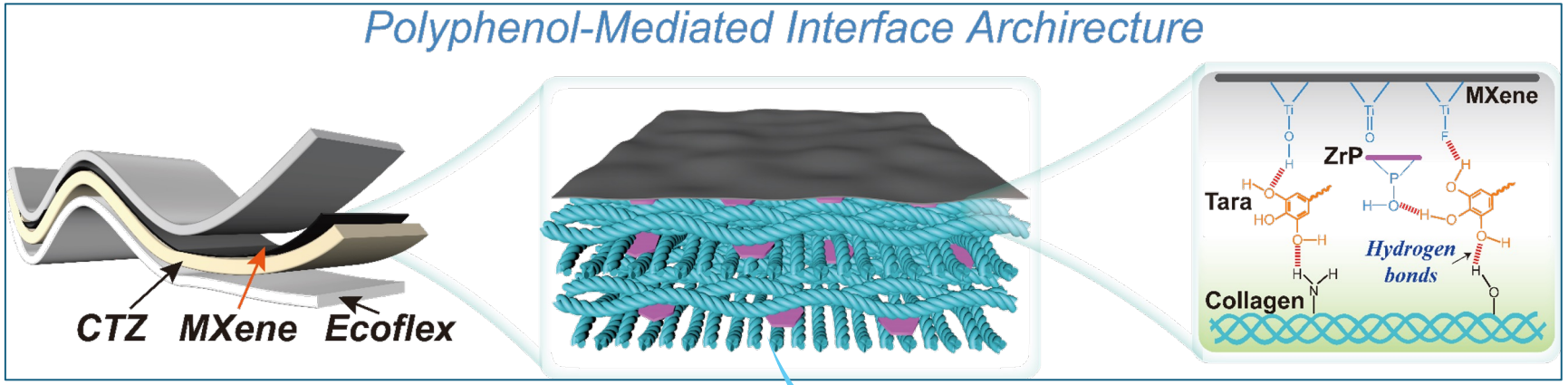
01 Research Background

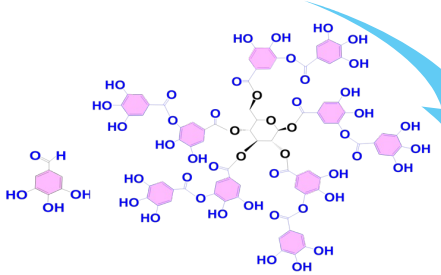
02 Research Content

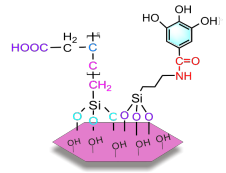
03 Research Conclusion

2.1 Design and preparation of multifunctional wet-white leather and its application of flexible electronics

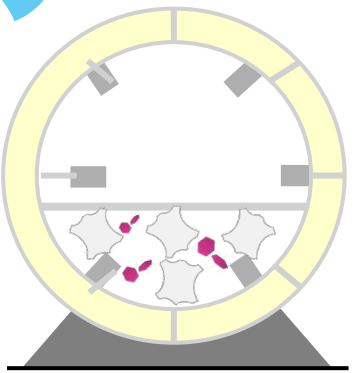


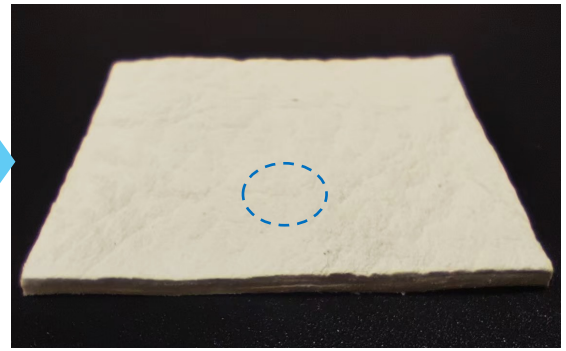






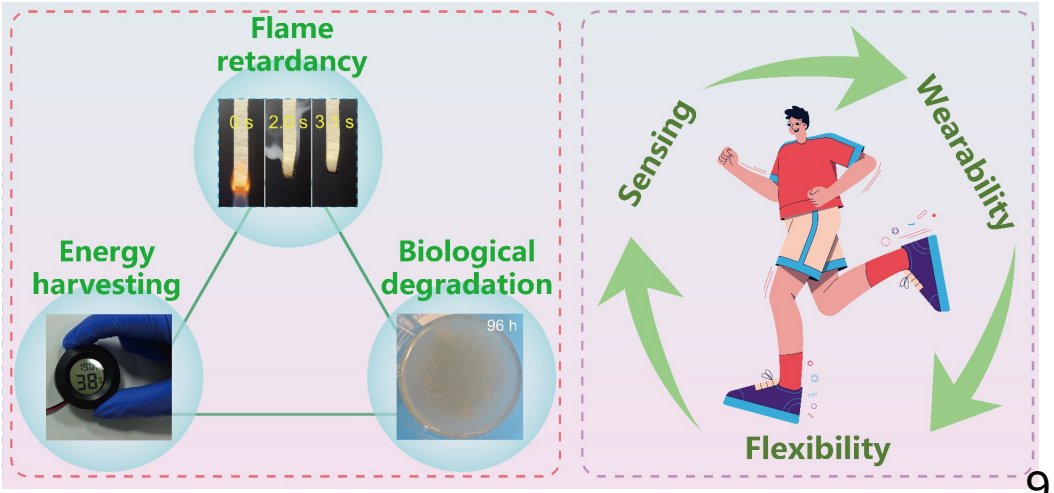
(I) Optimization of wet-white tanning system





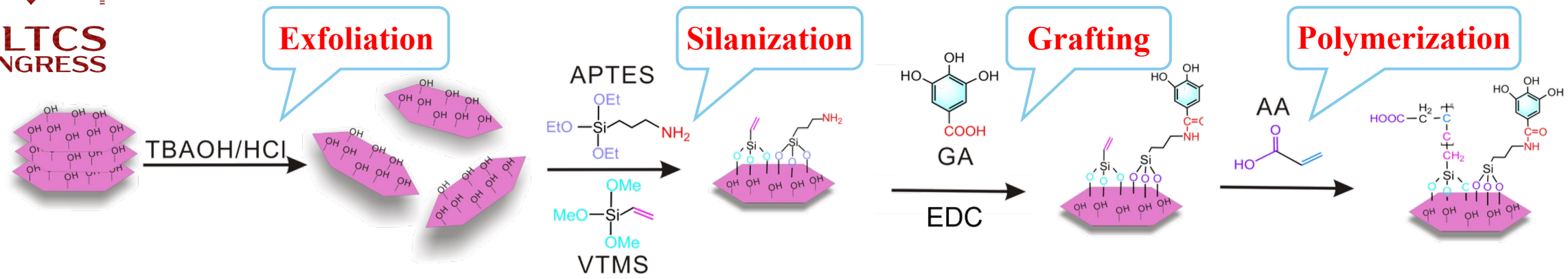
Wet-white leather matrix

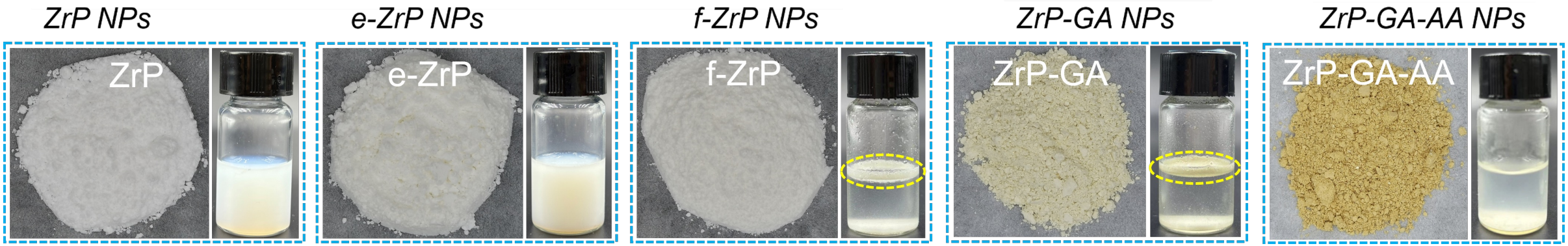
(II) Flexible electronic application of wet-white leather



2.2 Dual-functionalization of ZrP NPs with active substances

Synthesis route

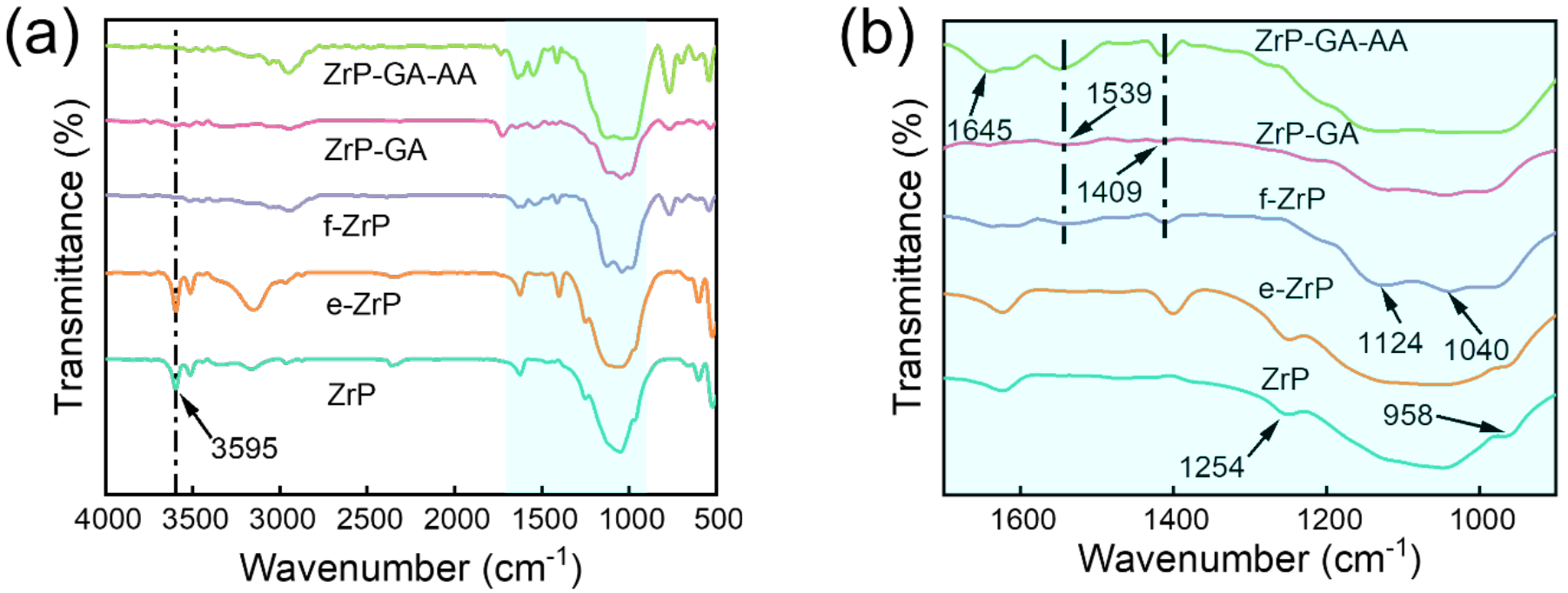




- Benefiting from excellent exfoliation and structural tunability of ZrP NPs, we propose an efficient dual-functionalization strategy to achieve functionalized ZrP NPs.

2.2 Dual-functionalization of ZrP NPs with active substances

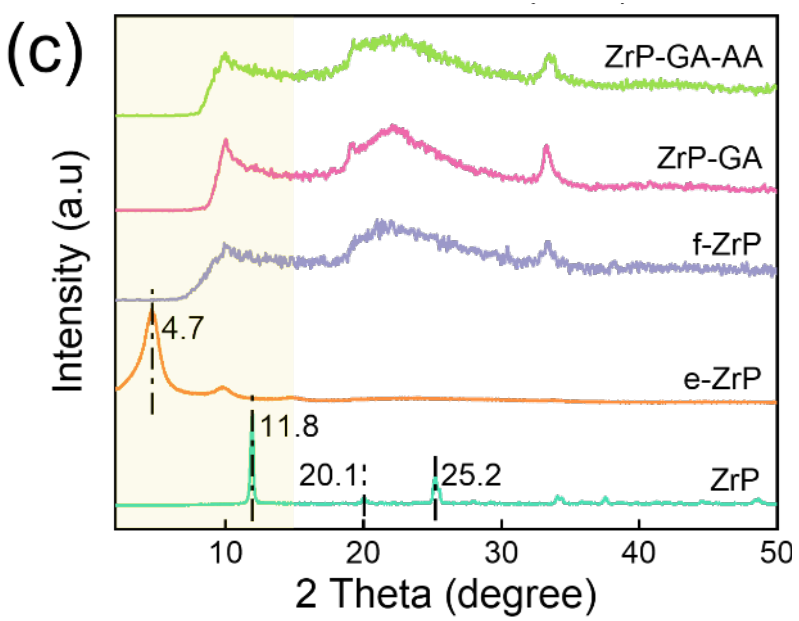
ATR-FTIR analyses



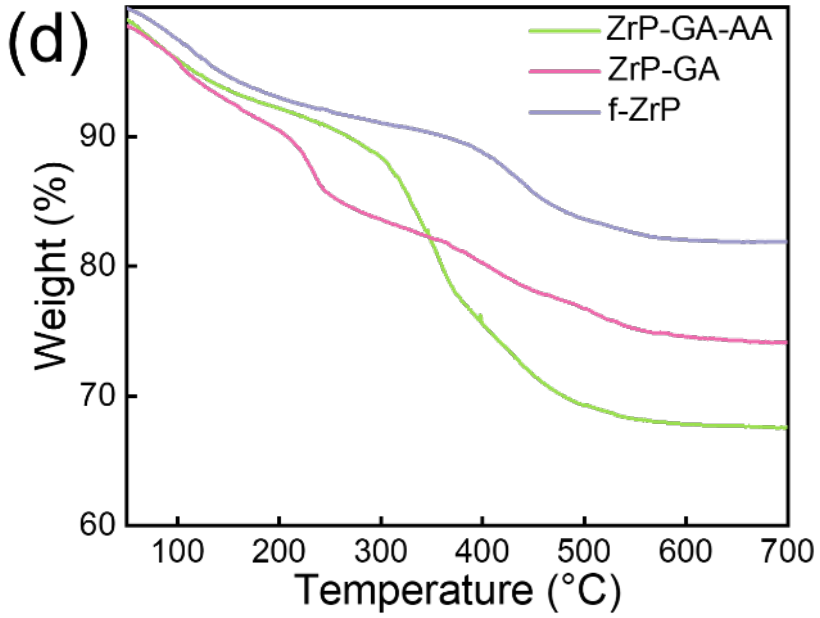
- Successful **formation of amide bond interactions** between f-ZrP NPs and gallic acid (GA) molecules is confirmed.
- Effective **surface grafting** of active acrylic acid (AA) molecules onto ZrP-GA NPs is verified.

2.2 Dual-functionalization of ZrP NPs with active substances

WAXD analyses



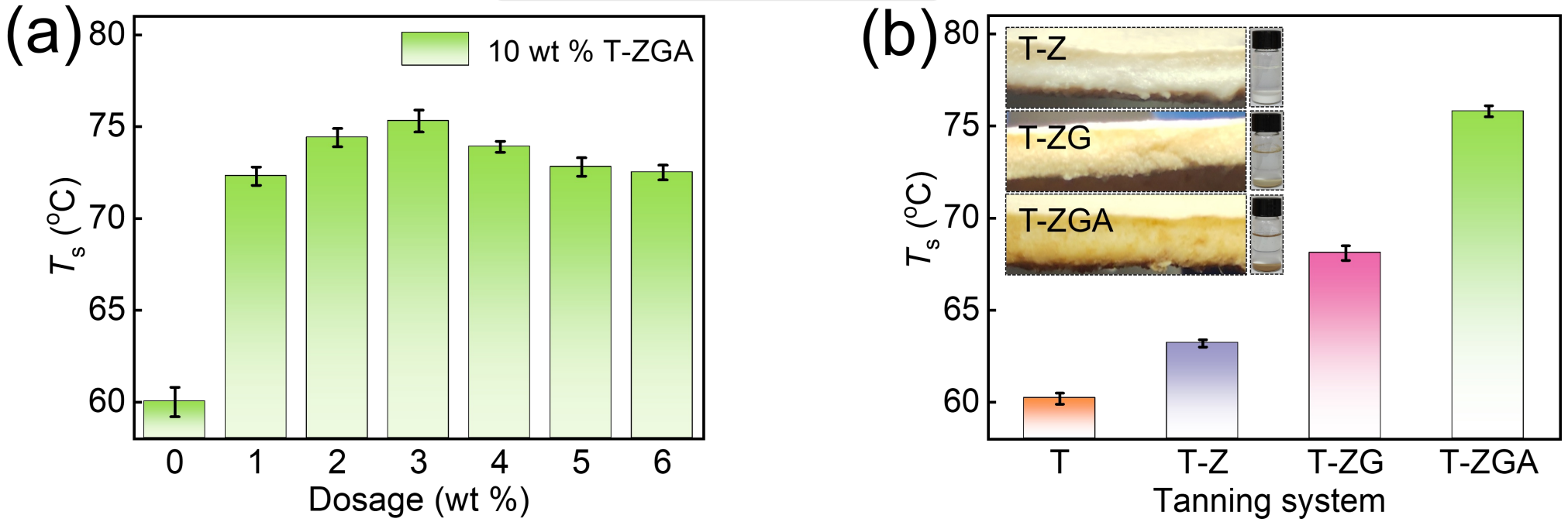
TG analyses



- **GA and AA molecules as building blocks can be successfully grafted onto the NPs surfaces via the interactions of functional groups at the surfaces and/or edges of ZrP NPs.**

2.3 Optimization of wet-white tanning system based on vegetable tannins and dual-functionalized ZrP NPs

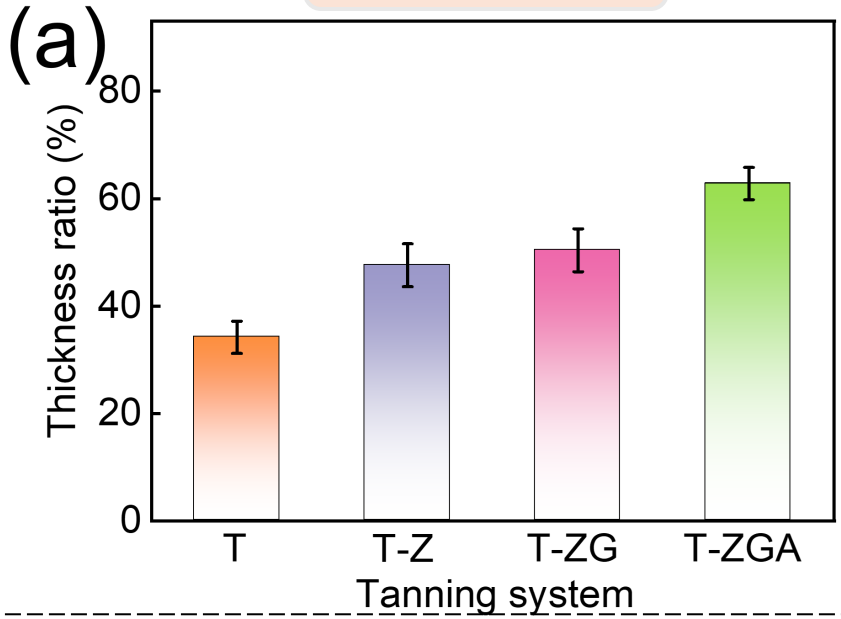
Tanning process



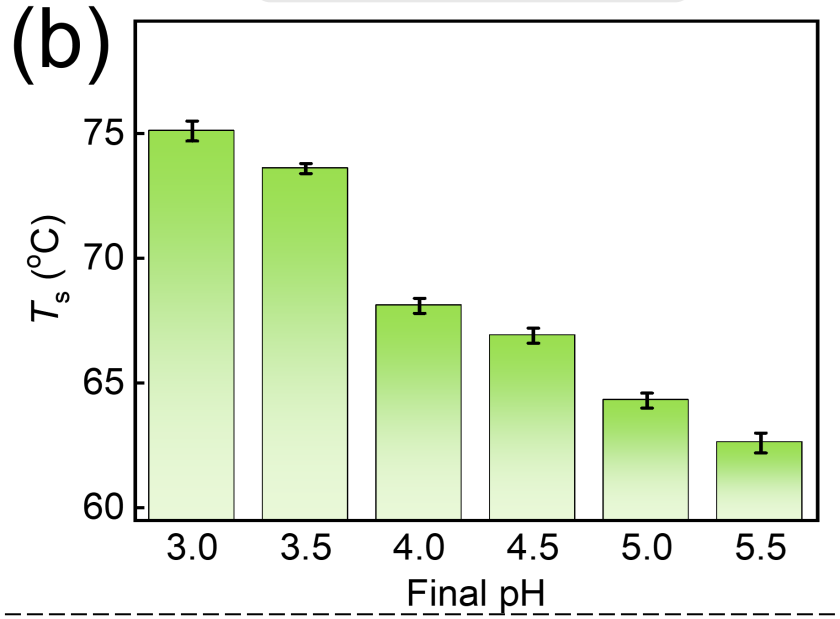
- Shrinkage temperature (T_s) reflects the **hydrothermal stability of leather**.
- **Dual-functionalized ZrP-GA-AA NPs enhances the hydrothermal stability**.
- Hydrophilic GA and AA grafting **facilitate the diffusion of ZrP NPs into the leather matrix**.

2.3 Optimization of wet-white tanning system based on vegetable tannins and dual-functionalized ZrP NPs

Thickness



pH effects

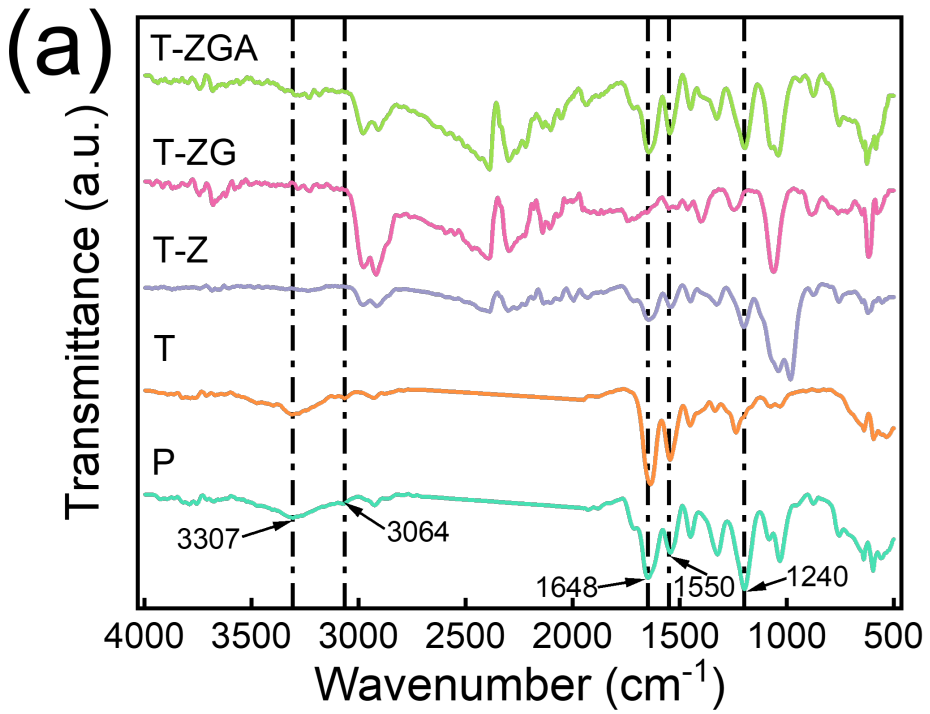


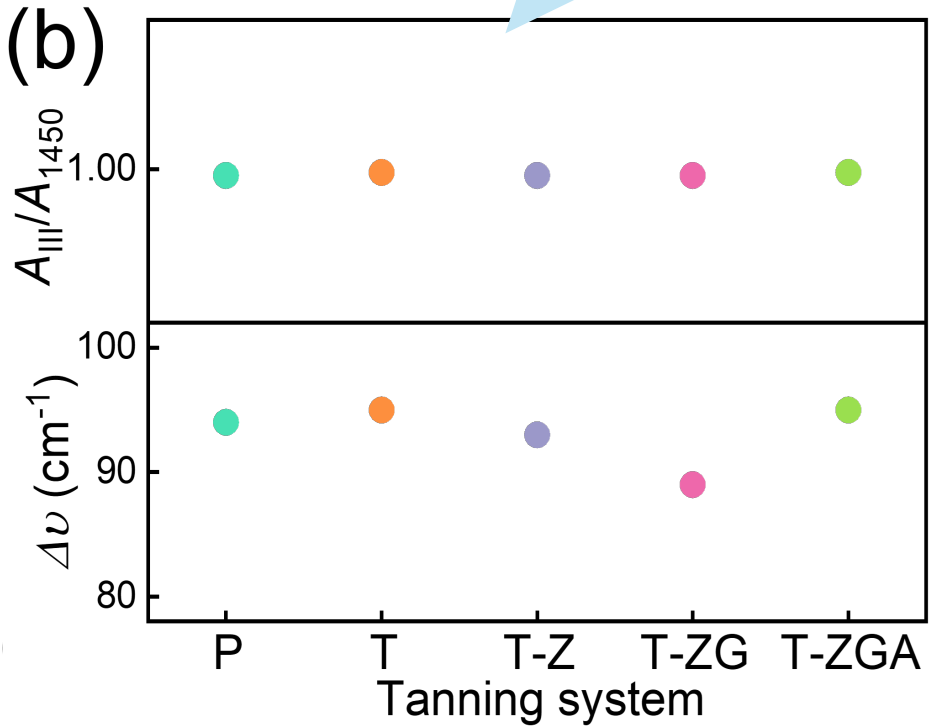
- The **enhancement of hydrothermal stability** is associated with **the filling and fixation of tanning materials within the leather**.
- Dual-functionalization of ZrP NPs can effectively **facilitate multiscale incorporations of ZrP NPs with the collagen fibers, enhancing the hydrothermal stability of the leather matrix**.

2.4 Microstructures of wet-white leather matrix

ATR-FTIR analyses

A measure of the structure integrity of collagen triple helix

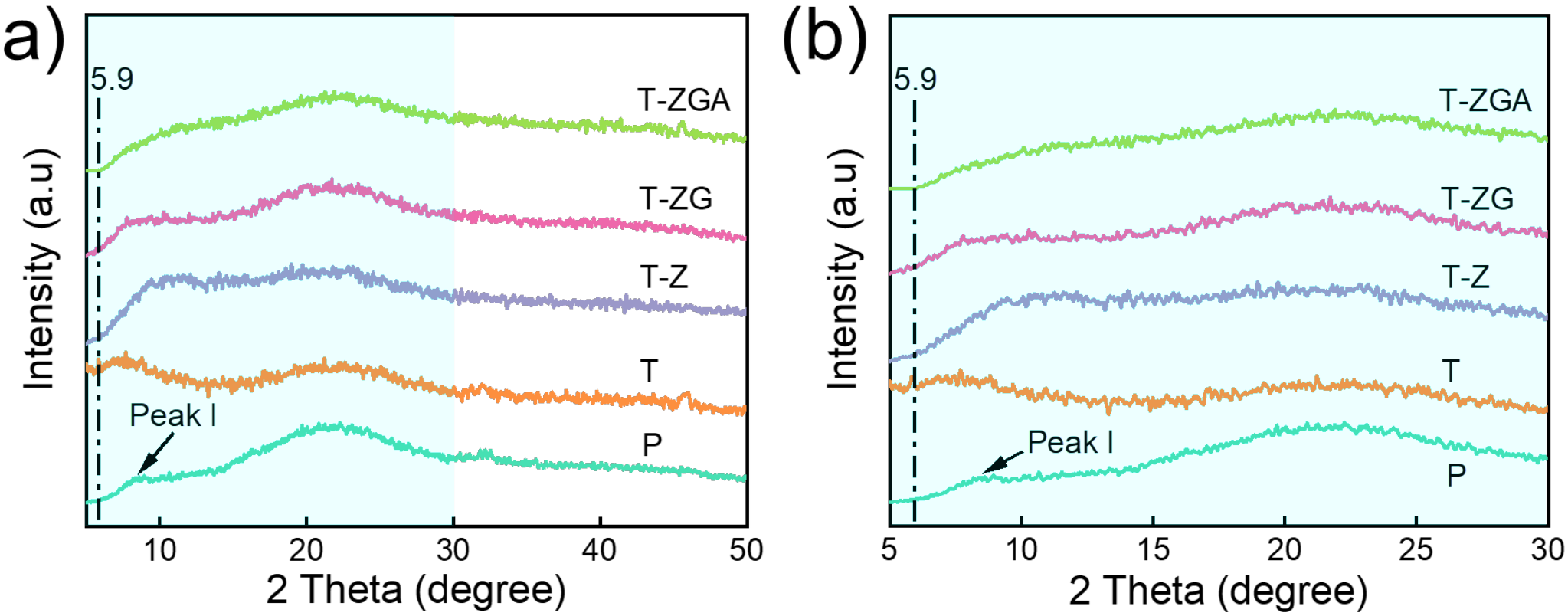




➢ All CF matrices retain triple-helical structure of type I collagen.

2.4 Microstructures of wet-white leather matrix

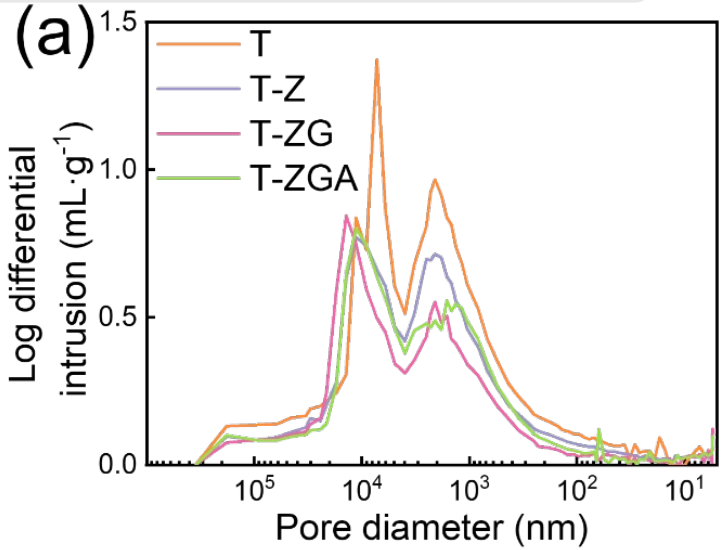
WAXD analyses



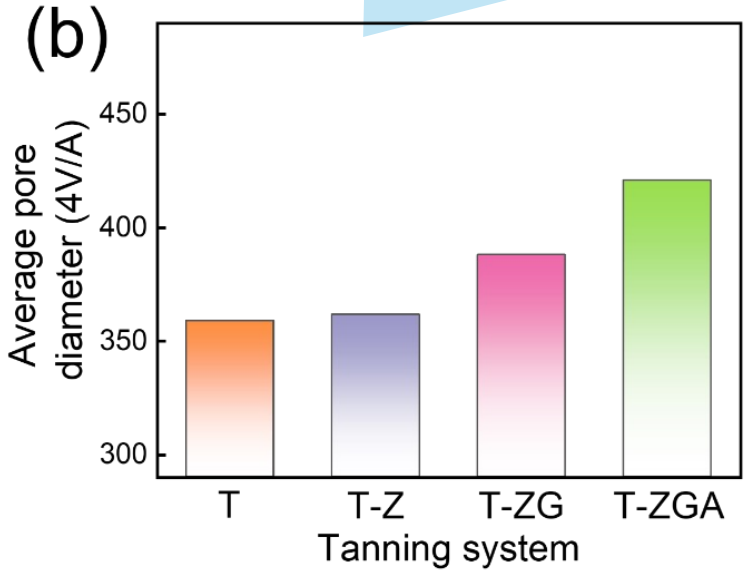
➢ **The formation of non-covalent interactions, hydrogen bonding and electrostatic interactions, between the collagens and ZrP-GA-AA NPs is further demonstrated.**

2.5 Diffusion behaviors of dual-functionalized ZrP NPs within collagen fibers

Penetration process



Mercury porosimetry determination



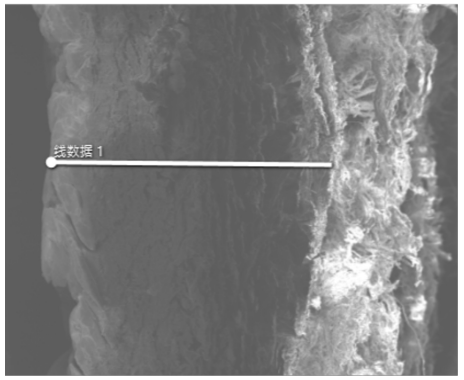
Reason for enlargement in mean pore dimensions within the CF matrices

- **Interstitial void infilling.**
- **Synergistically coupling with extensive hydrogen-bond crosslinking among collagen macromolecules.**
- **Localize surface deposition of dual-functionalized ZrP NPs onto the fibrous architecture.**

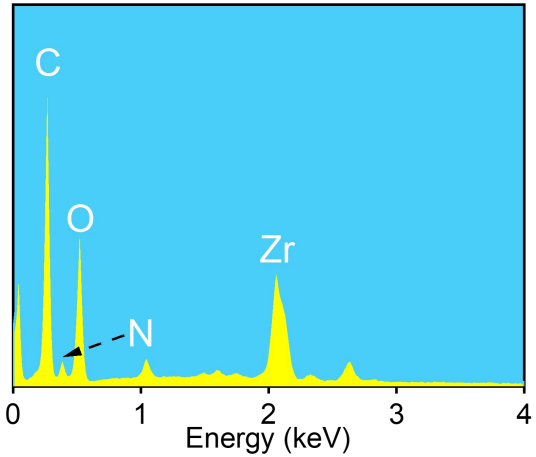
2.5 Diffusion behaviors of dual-functionalized ZrP NPs within collagen fibers

Diffusion process

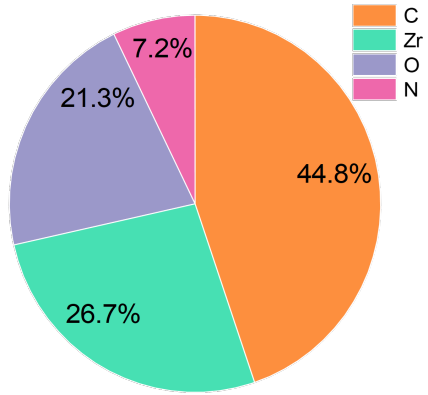
(a)



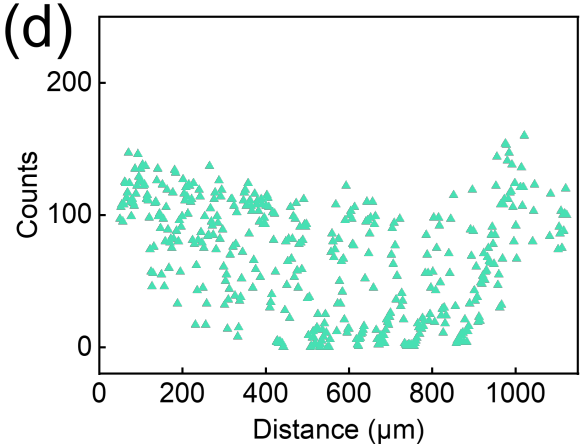
(b)



(c)



(d)

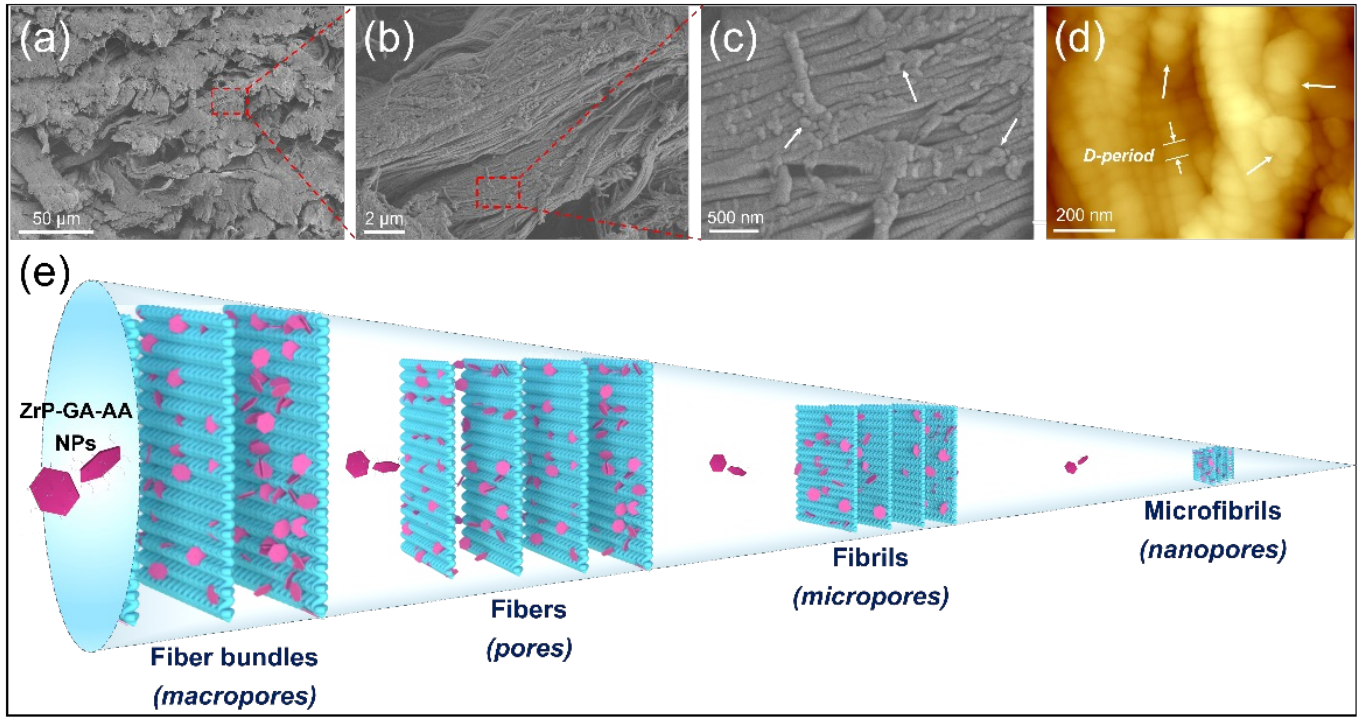


- The core challenge in the leather tanning systems lies on ensuring **sufficient penetration** and **effective binding** of nanomaterials in the **collagen microstructures**.
- The decreasing trend of Zr elements is attributed to the differences between **collagen fiber structures** in the leather matrix.

2.5 Diffusion behaviors of dual-functionalized ZrP NPs within collagen fibers

➢ **Multiscale porous microstructures** of collagen fibers provided **suitable channels** for the **diffusion-penetration** process of two-dimensional nanomaterials.

Penetration process

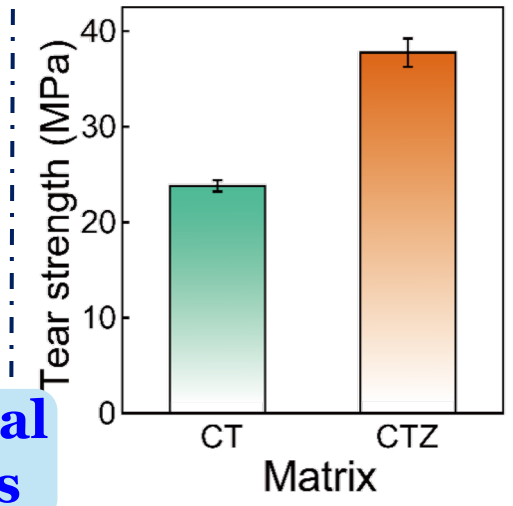


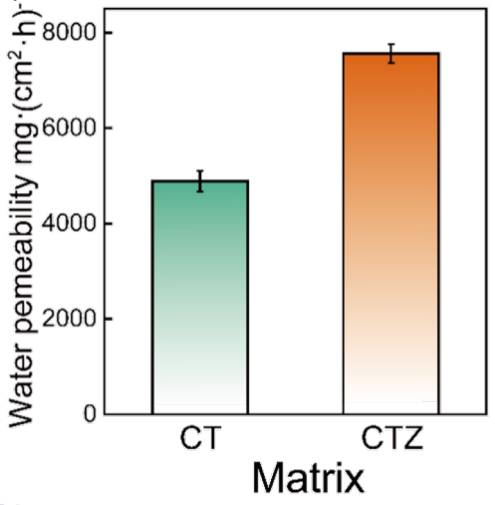
Diffusion channel of collagen fibers

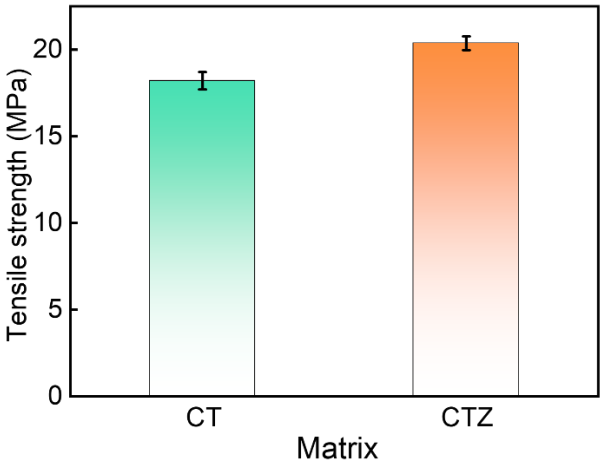
➢ Surface-engineered ZrP nanomaterials exhibit **multiscale diffusion** and **fixation** with the CF to **achieve the structural stabilization of collagen fibers via their diffusion channel**.

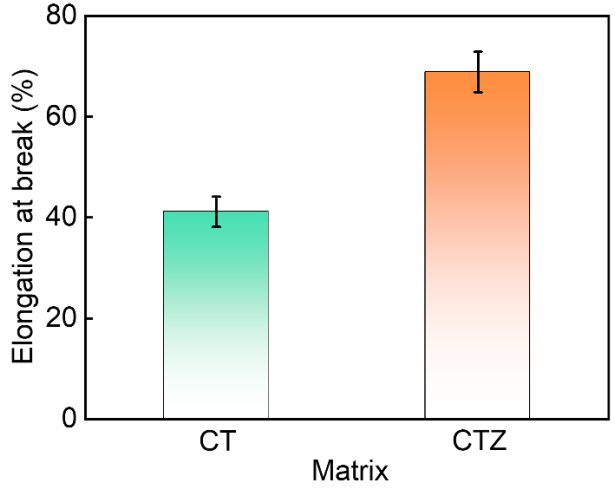
2.6 Properties of wet-white leather matrix

Mechanical properties

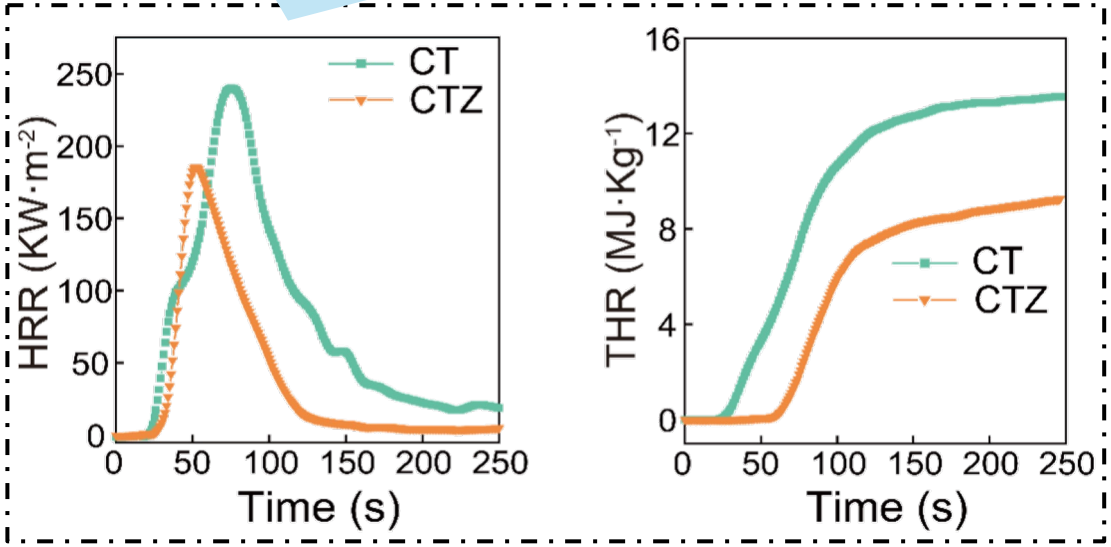






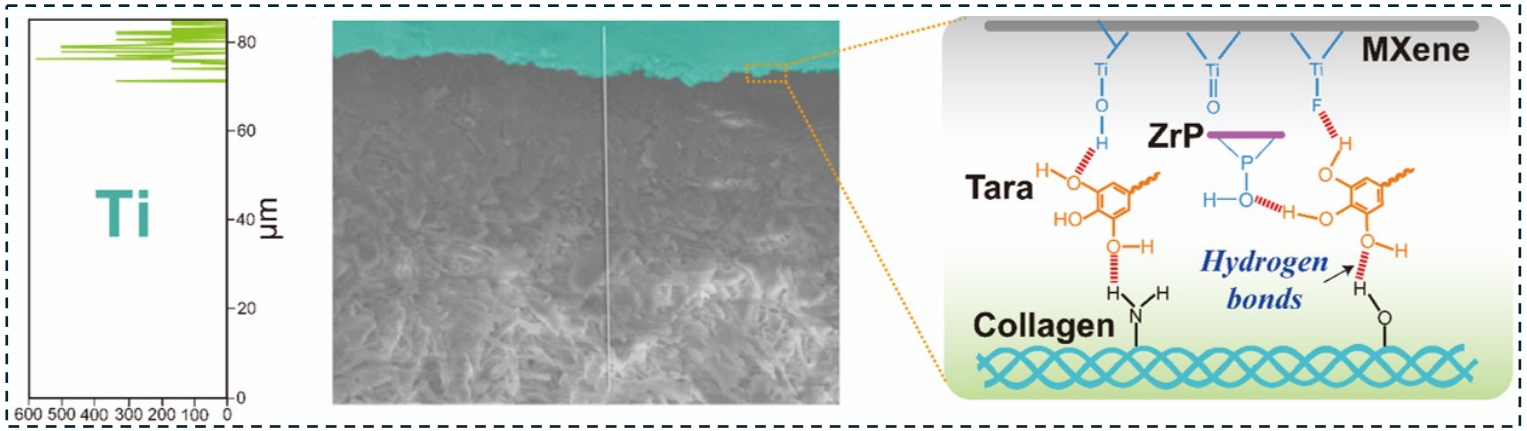


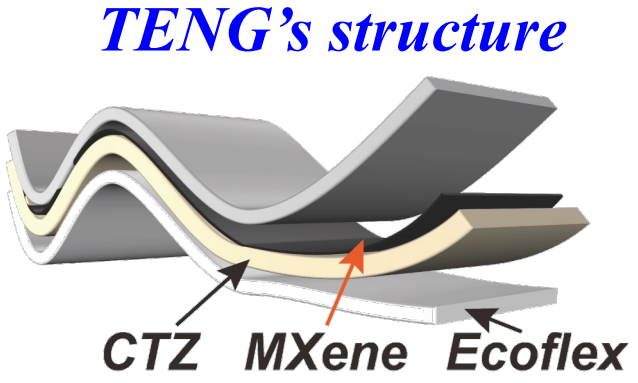
Flame-retardant properties

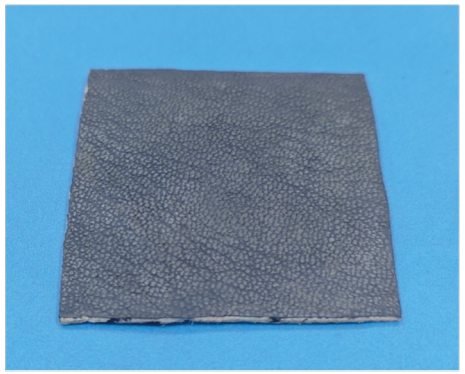


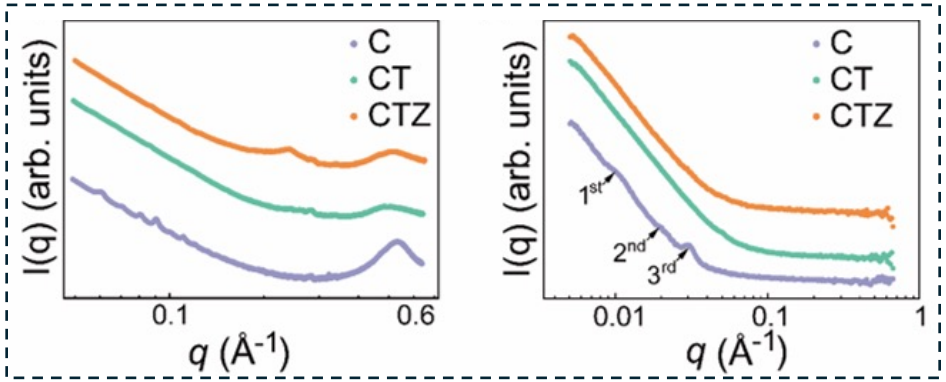
- **Dual-functionalized ZrP NPs enhance the mechanical properties and flame-retardant properties of leather matrix.**

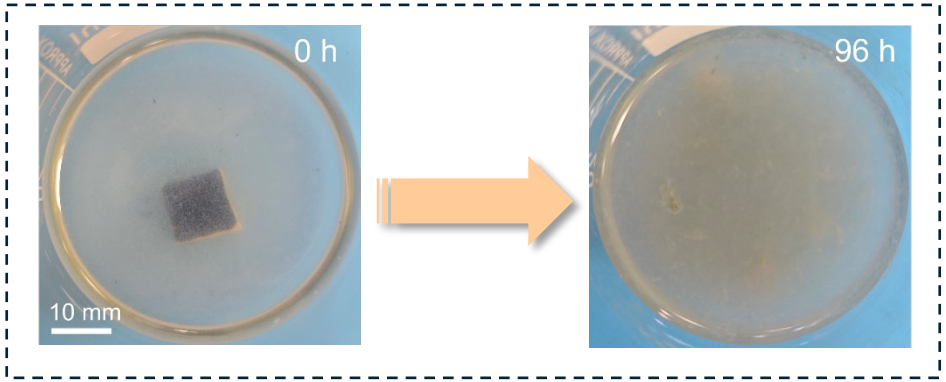
2.7 Fabrication of leather-based flexible electronic via a polyphenol-mediated strategy







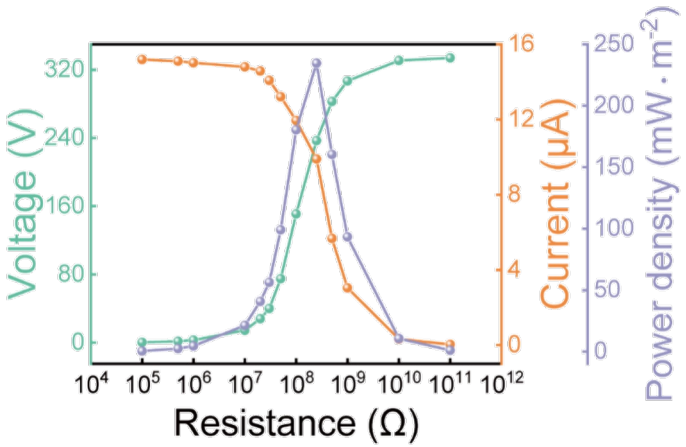




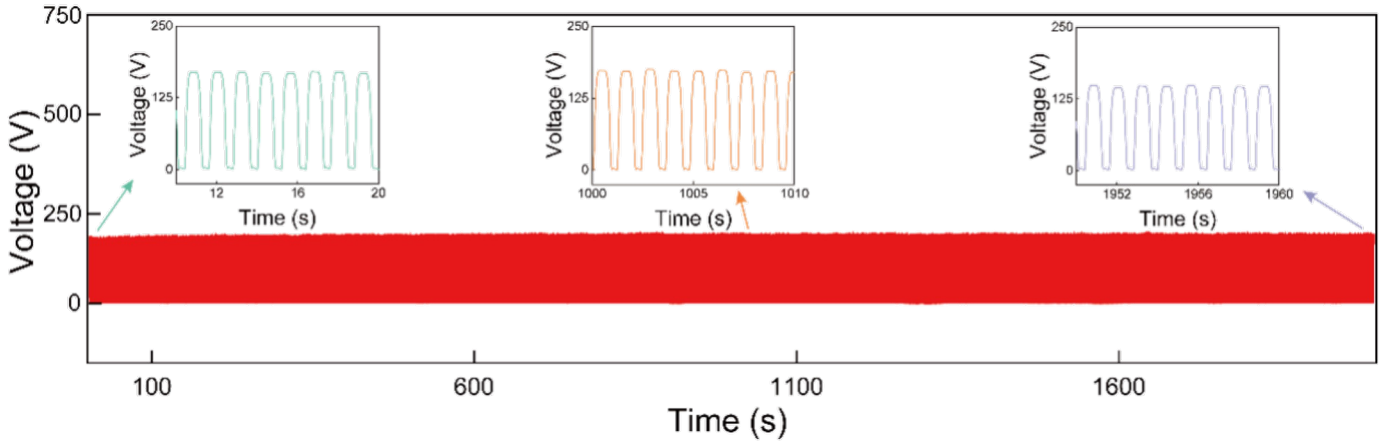
- A **biodegradable and fire-safe leather-based flexible electronic, CTZM-TENG, is achieved by coating MXene on the leather surface via a polyphenol-mediated strategy.**

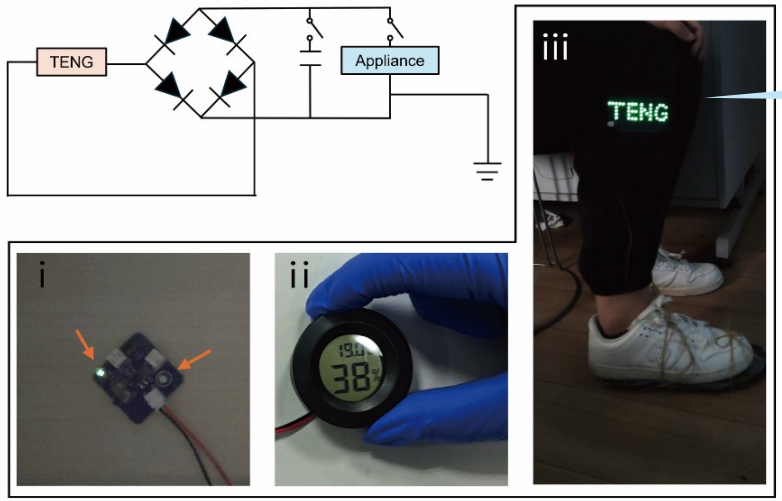
2.8 Properties of leather-based flexible electronic via a polyphenol-mediated strategy

Output performance



Cyclic stability





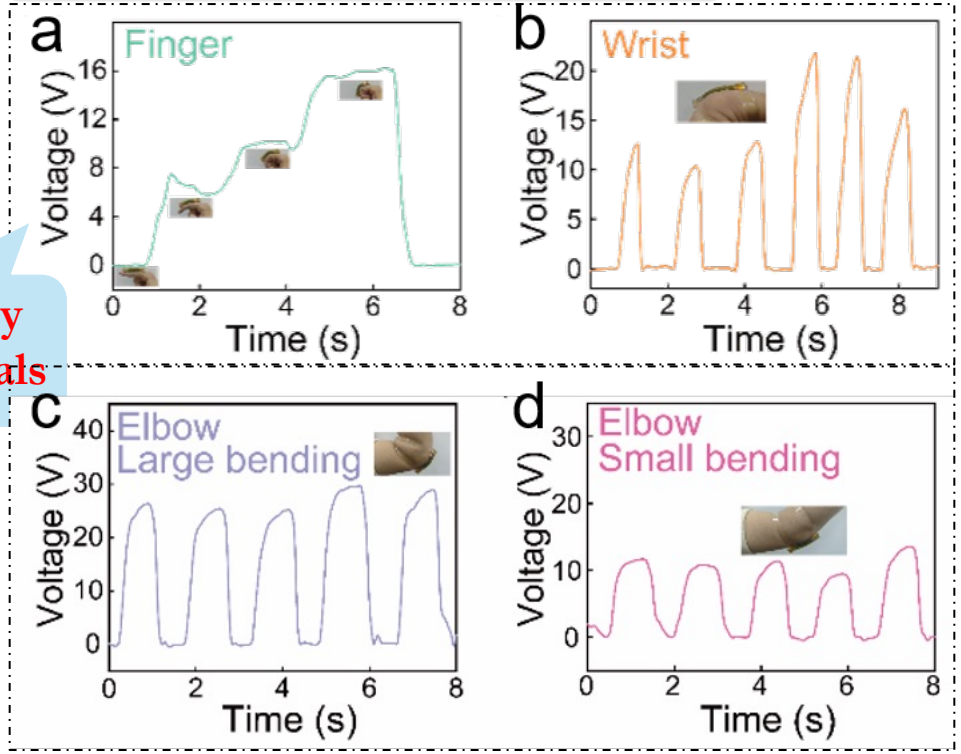
Powering application

- The CTZM-TENG exhibiting excellent output performance and cyclic stability is capable of harvesting human-body mechanical energy.

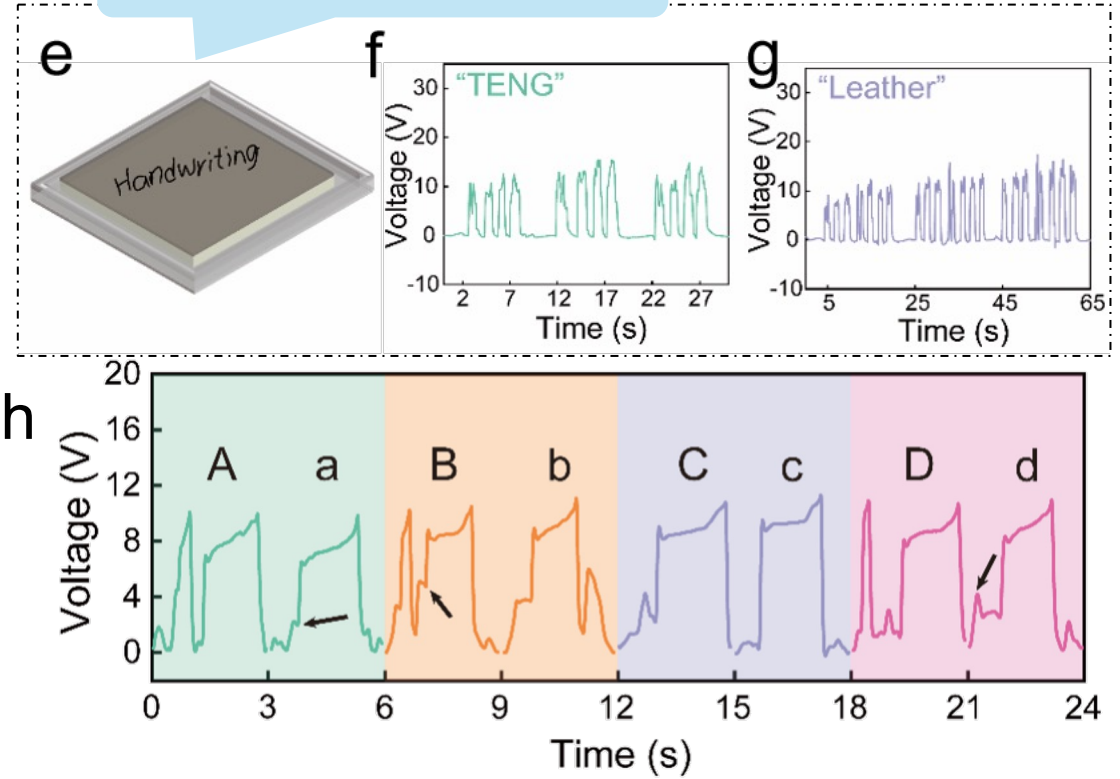
2.9 Applications of leather-based flexible electronic via a polyphenol-mediated strategy

Self-powered sensor

Human-body motion signals



Recognizing handwriting



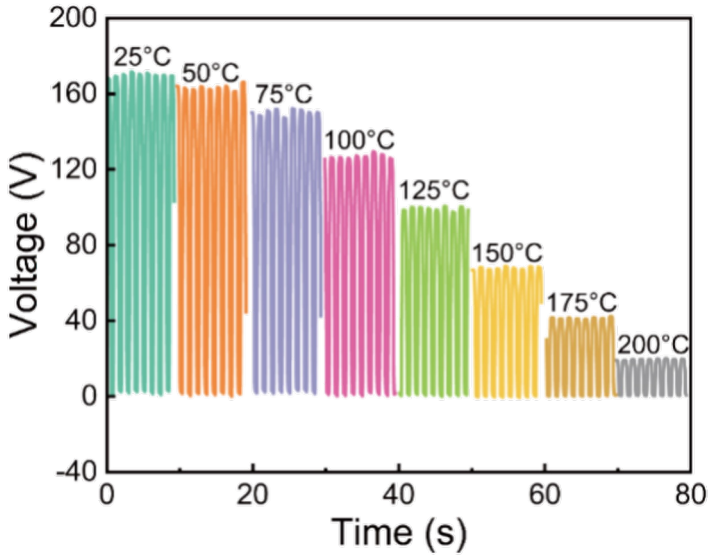
- The CTZM-TENG can be engineered as a **self-powered sensor** for **monitoring human-body motion signals** and **recognizing handwriting.**

2.9 Applications of leather-based flexible electronic via a polyphenol-mediated strategy

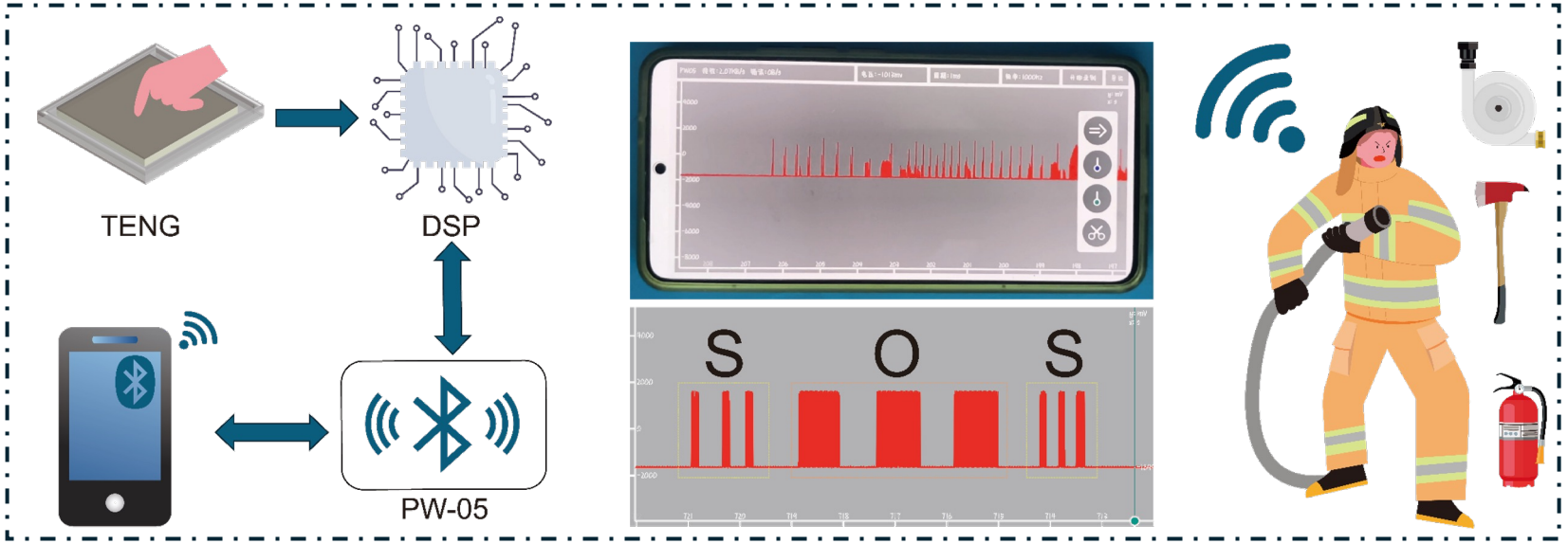
The CTZM-TENG integrates multiple advantages including:

- **Self-powering capability**
- **Rapid response characteristics**
- **Modular design**
- **Intelligent functionality**

Temperature effects



Self-powered distress signaling system



- **The CTZM-TENG showcases great potentials for advancing flexible wearable electronics in firewarning and emergency rescue applications.**

OUTLINE

01 Research Background

02 Research Content

03 Research Conclusion

3. Conclusion

1. We optimize multifunctional wet-white leather tanning system based on vegetable tannins and dual-functionalized ZrP nanomaterials.
2. Biodegradable and fire-safe leather-based flexible electronic are fabricated through polyphenol-mediated architecture.
3. MXene coating enables self-powered sensors for human motion and handwriting detection and biomechanical energy harvesting.

This work can provide not only a scalable and sustainable fabrication strategy of novel multifunctional wet-white leather but also more fundamental insight into rational design and development of next-generation biomass-based flexible wearable electronics.

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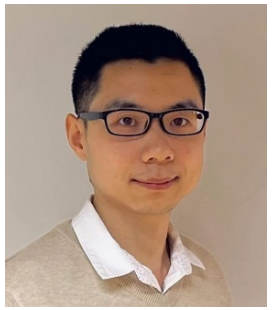

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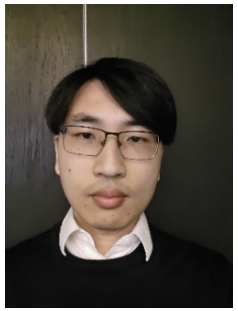

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THANKS

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