Wearable Safeguarding Leather Composite with Excellent Sensing, Thermal Management, and Electromagnetic Interference Shielding

Z.Y. Fan[1], S.H. Xuan[1], X.L. Gong[1a]

[1]CAS Key Laboratory of Mechanical Behavior and Design of Materials, Department of Modern Mechanics, University of Science and Technology of China (USTC), Hefei 230027, P. R. China.

[a]gongxl@ustc.edu.cn

Abstract. This work illustrates a "soft-toughness" coupling design method to integrate the shear stiffening gel (SSG), natural Leather, and non-woven fabrics (NWF) for preparing Leather/MXene/SSG/NWF composite with high anti-impact protecting, piezoresistive sensing, electromagnetic interference (EMI) shielding and human thermal management performance. Interestingly, the Leather/MXene/SSG/NWF (LMSN) composites could distinguish the low and high energy stimulus by exporting negative and positive resistance change, respectively. Ultimately, a soft protective vest with thermal management and impact monitoring performance is further fabricated and it shows a typical wireless impact-sensing performance. This method is expected to have broad application potential in the next-generation wearable electronic devices for human safeguarding.

Possible Sessions

9. Impact, Blast and High Strain Rate, 21. Soft matter, 24. Testing of composite materials

Introduction

With people's expectations of wearable electronic devices becoming higher and higher, flexible sensors have drawn tremendous attention in extensive fields including sensing, actuation, electronic skin, human health detection, and human-machine interaction [1, 2]. However, the stability and sensitivity of sensors under high energy impact which is very important for the practical application of electronic devices are often neglected due to the difficulty of structure designation. There is an urgent demand for wearable devices that can cope with the ubiquitous mechanical collisions in daily life and high-speed impacts in extreme situations, while sensing the impact simultaneously.

As an ancient natural material, leather with a 3D porous structure is composed of multi-level collagen fiber bundles, which enable it to be a versatile matrix for flexible electronic devices [3]. Leather fibers were modified through various functional materials, the smart leather with tunable functionalities has been developed, which demonstrated high promise for next-generation wearable electronic devices [4]. Simultaneously, leather often has been used as a natural protective device since ancient times because of its high permeability and mechanical strength, but further improvement in its protection performance is still needed [5]. Therefore, the integration of leather with multifunction plays a key role in developing high-performance wearable electronic leathers with wonderful protecting behavior.

Organisation of the Text

Fig. 1a shows the preparation process of the MXene nanosheets. Profiting from the hierarchical fiber structures of the natural leather, the Leather/MXene (LM) composites were prepared by suction filtrating MXene aqueous solution. The MXene nanosheets were evenly distributed on the fiber network of leather, which could tightly attach to the collagen fiber bundles. Subsequently, the SSG layer and NWF layer were gradually

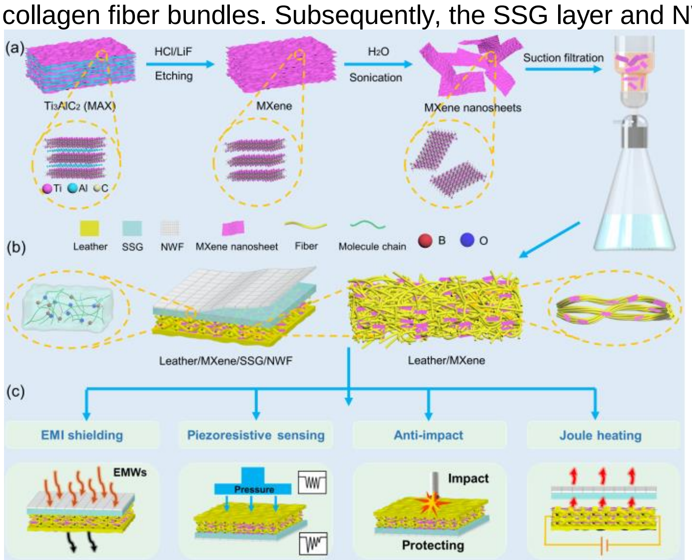

Figure 1. (a) The fabrication process of the MXene nanosheets. (b) The schematic diagrams show the preparation of the LMSN composite. (c) LMSN composite with superior properties.

assembled on the leather layer to form the laminated structure (Fig. 1b). Because of the high affinity, the SSG could be easily combined with the rough fiber surface of the leather and the porous NWF. Benefitting from the LM with excellent conductivity, the LMSN composites showed superior EMI shielding, piezoresistive sensing, and Joule heating properties (Fig. 1c).

The dynamic anti-impact performance of LMSN composite is investigated by using a drop hammer impact system (Fig. 2a). The peak force data of LM composites were firstly compared, Fig. 2b showed that different LM composites had almost the same peak force as pure leather and were lower than the reference value (reference means a control group of the impactor direct impacting the force sensor), which indicated the penetration of MXene sheets had little effect on the force-buffering performance of the leather structure. Further, the anti-impact property of the LMSN composite was studied under the impactor release height at 10-60 cm (Fig. 2c). Compared with pure leather and ten layers of Kevlar, the LMSN composite showed the best force buffering performance under the different impact energy. Then, the resistance change of the LMSN composite under drop hammer impact was investigated in Fig. 2d. After being impacted, the resistance of LMSN rose rapidly within about 1 ms, showing the unique impact-sensing performance.

To test the application potential of the LMSN composite in the field of protection, the ballistic impact performance of LMSN was tested. The LMSN also showed superior energy dissipation performance under high-velocity ballistic impact. Then, a wireless impact-sensing application was designed to catch this unique impact-sensing feature of the LMSN composite. The impact signals of LMSN could be received through a smartphone to monitor the safety status (Fig. 2e). Finally, due to the LMSN composite with low resistance, it can work as a wearable electrothermal device based on the Joule heating effect. Therefore, an electrothermal body safeguarding vest was developed based on the LMSN composite. By adjusting the supply voltage, the temperature of the electrothermal vest can easily reach 65 ℃ (Fig. 2f). The LMSN composites have shown multiple protective effects including physical impact, low-temperature damage, and electromagnetic radiation, which demonstrated broad application prospects in wearable protective devices.

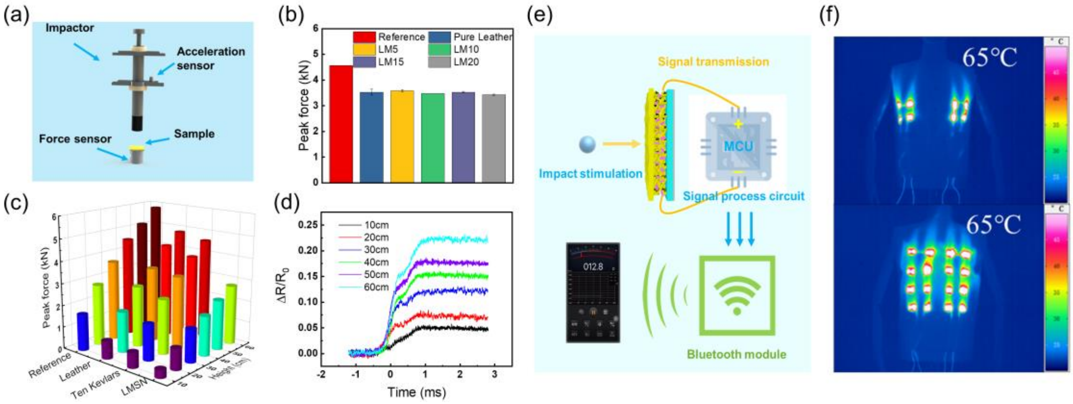

Figure 2. (a) The schematic diagram of the drop hammer testing system. (b) The peak forces of leather and LM composites at 40 cm. (c) The peak forces of diverse samples at the heights of 10-60 cm. (d) The resistance changes of the LMSN composite under different impacts. (e)The schematic diagram of the wireless sensing monitoring under high-velocity ballistic impact. (f) The body thermal management performance of the leather vest.

Conclusion

In summary, this work reported the LMSN composite integrating capabilities of piezoresistive sensing, electromagnetic interference shielding, anti-impact, and thermal management together. Eventually, a novel intelligent protective vest was designed and it showed excellent thermal management and wireless impact-sensing performances, which demonstrated the application potential of the LMSN composites for next-generation wearable electronic devices with human safeguarding.

References

[1] S. Zhao, R. Zhu: Adv. Mater. Vol 29 (2017), p. 1606151.
[2] B. Peng, F. Zhao, and Y. Ying: Small Vol 16 (2020), p. e2002681.
[3] Z. Bai, X. Wang, and X. Liu: Nano Energy Vol 120 (2024), p. 109142.
[4] Z. Ma, X. Xiang, and J. Gu, Angew. Chem. Int. Ed. Vol 61 (2022), p. e202200705.
[5] Z.Y. Fan, C.Y. Zhao, and S.H. Xuan, Compos. Pt. A-Appl. Sci. Manuf. Vol 161 (2022), p. 107078.