

# Lamellar-structured $\text{Al}_2\text{O}_3\text{-SiO}_2$ nanofibrous aerogels with favorable compression resilience for efficient high-temperature thermal insulation

Yuxin Ma <sup>1,†</sup>, Mengjiao Zhang <sup>1,†</sup>, Wenqiang Wang <sup>1</sup>, Hanwen Zhang <sup>1</sup>, Wenzhe Li <sup>1</sup>, Xiangxiang Gu <sup>1</sup>, Qiuxia Fu <sup>1,2,\*</sup>, Haoru Shan <sup>1,2,\*</sup>

<sup>1</sup> School of Textile and Clothing, Nantong University, Nantong 226019, China; 2315310003@stmail.ntu.edu.cn (Y.M.); 2315320005@stmail.ntu.edu.cn (M.Z.); wwq1710@163.com (W.W.); 2415310020@stmail.ntu.edu.cn (H.Z.); 2315310022@stmail.ntu.edu.cn (W.L.); 2415320003@stmail.ntu.edu.cn (X.G.); fuqx@ntu.edu.cn (Q.F.); hrshan@ntu.edu.cn (H.S.)

<sup>2</sup> National and Local Joint Engineering Research Center of Technical Fiber Composites for Safety and Health, Nantong University, Nantong 226019, China; fuqx@ntu.edu.cn (Q.F.); hrshan@ntu.edu.cn (H.S.)

\* Correspondence: fuqx@ntu.edu.cn (Q.F.); hrshan@ntu.edu.cn (H.S.)

† These authors contributed equally to this work.

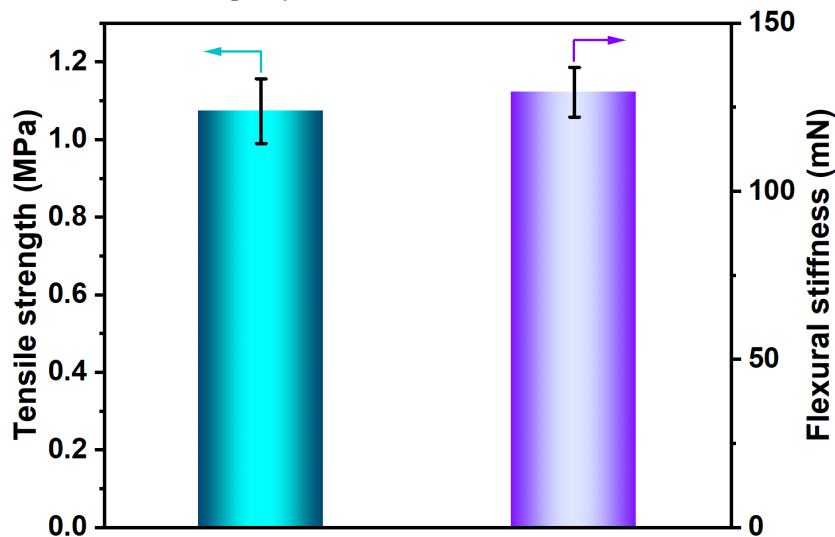


Figure S1. Tensile strength and flexural stiffness of ASO NFMs.

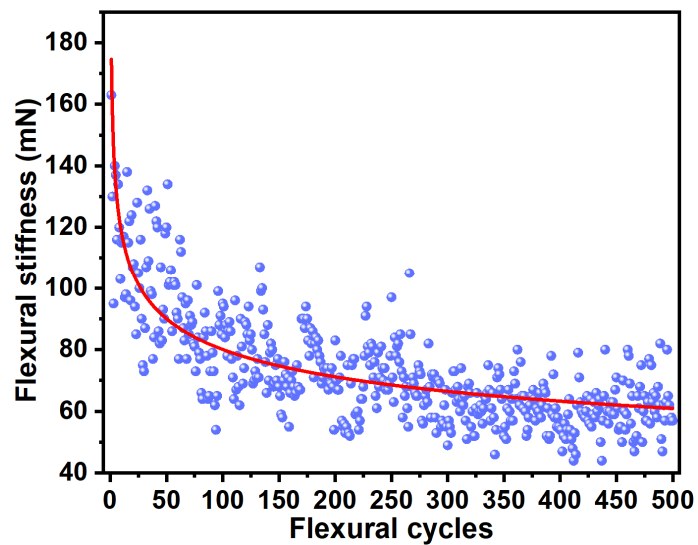


Figure S2. Flexural stiffness of ASO NFMs after 500 reciprocating bending cycles.

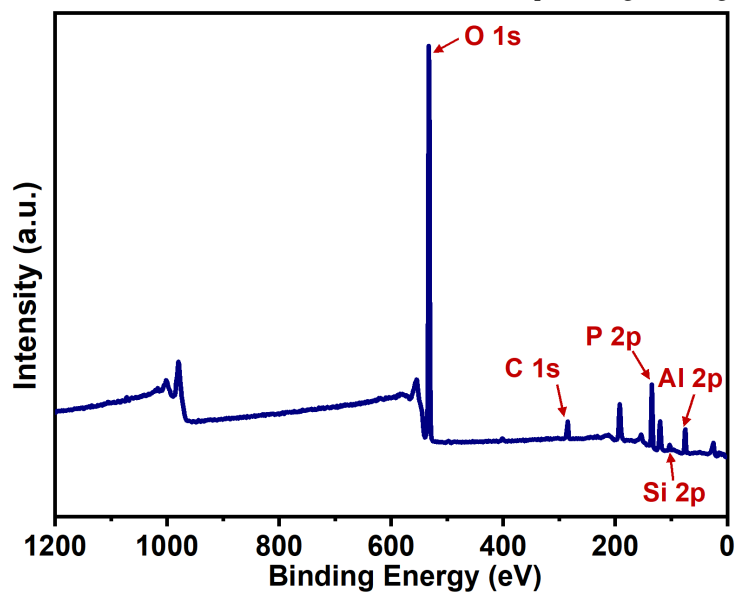


Figure S3. XPS spectra of LASO-20 NFAs.

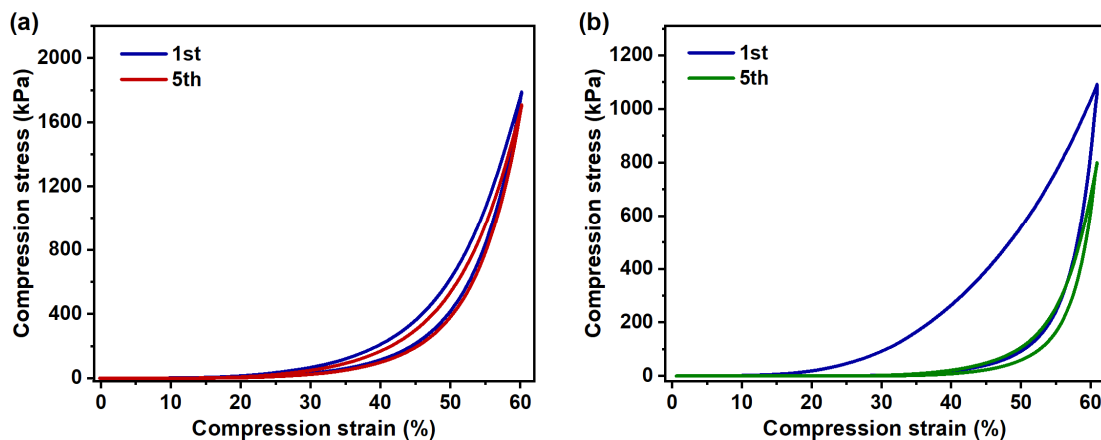


Figure S4. The cyclic compression curves of LASO-20 NFAs in (a) liquid nitrogen and (b) butane torch flames (five cycles and a compression strain of 60%).

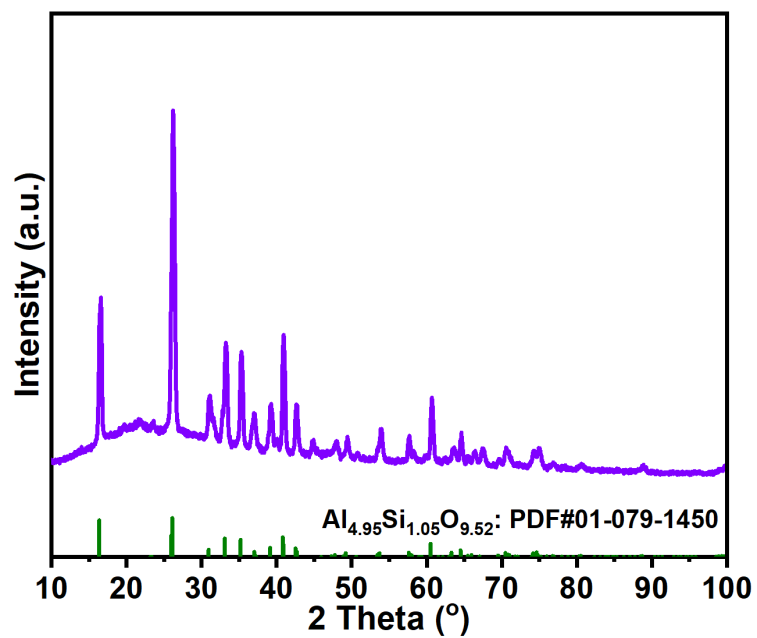


Figure S5. XRD pattern of LASO-20 NFAs after continuous calcination at 1300 °C for 24 h.

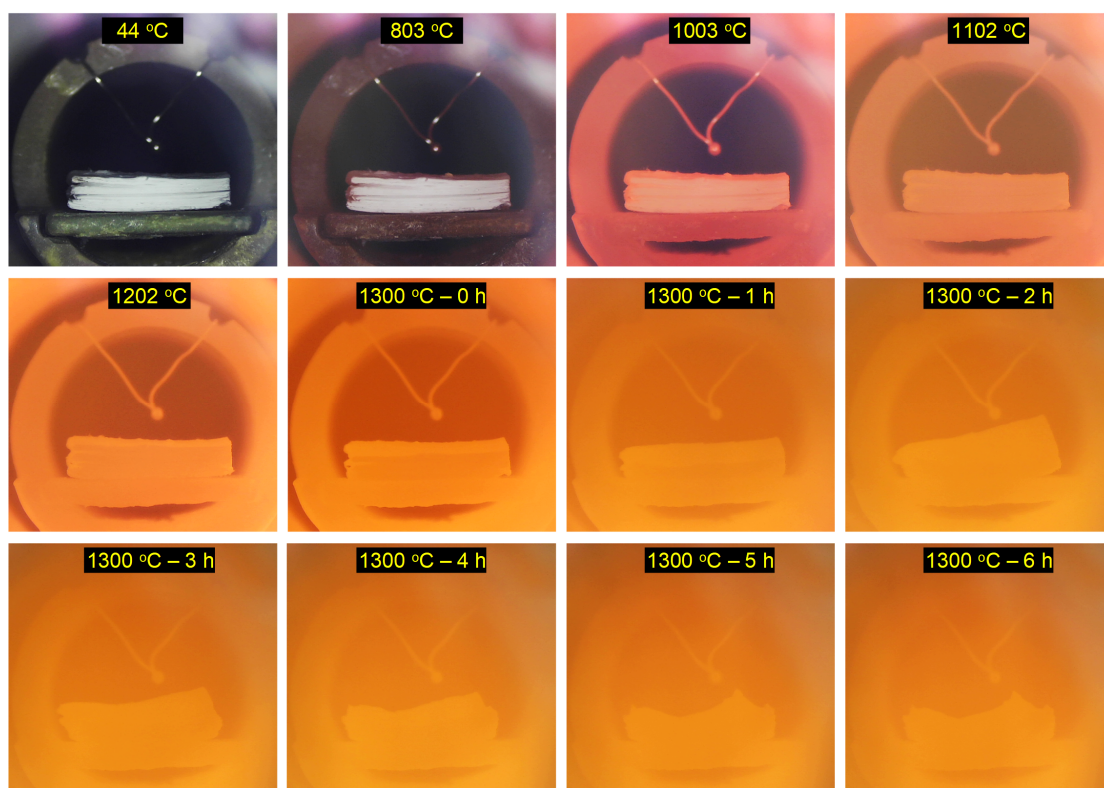


Figure S6. Sintering images of LASO-20 NFAs at different temperatures.

**Table S1.** Comparison of lamellar ceramic fiber aerogels in the literature.

| Fiber substrate                   | Binding agent                        | Thermal conductivity ( $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ ) | Compressive strength (MPa) | Spatial arrangement     | Compression durability                             | Preparation procedure    | Ref.      |
|-----------------------------------|--------------------------------------|-------------------------------------------------------------------------|----------------------------|-------------------------|----------------------------------------------------|--------------------------|-----------|
| Mullite fibers                    | Silicon resin                        | 0.083 - 0.089                                                           | 1.21 - 1.58                | Disorderly stacking     | Failure at 10 % strain                             | Vacuum filtration        | [1]       |
| Mullite and $\text{ZrO}_2$ fibers | SiC, B <sub>4</sub> C, and starch    | 0.094                                                                   | 1.06 - 1.23                | Quasi-layered structure | -                                                  | Vacuum pressing molding  | [2]       |
| Mullite fibers                    | SiC, B <sub>4</sub> C, and starch    | 0.093 - 0.165                                                           | 0.81 - 2.46                | Quasi-layered structure | -                                                  | Vacuum pressing molding  | [3]       |
| Mullite and $\text{ZrO}_2$ fibers | SiC, B <sub>4</sub> C, and starch    | 0.083-0.135                                                             | 0.91 - 1.36                | Quasi-layered structure | -                                                  | Vacuum pressing molding  | [4]       |
| Mullite fibers                    | Silica sol                           | 0.095                                                                   | 1.79                       | Disorderly stacking     | -                                                  | Vacuum filtration method | [5]       |
| Mullite and glass fibers          | Silica sol                           | -                                                                       | 2.14                       | Disorderly stacking     | -                                                  | Vacuum filtration method | [6]       |
| Mullite fiber                     | $\text{Al}_2\text{O}_3$ sol          | 0.037 - 0.217                                                           | 1.03 - 5.31                | Disorderly stacking     | -                                                  | Vacuum filtration method | [7]       |
| Alumina and glass fibers          | Silica sol                           | -                                                                       | 0.49                       | Disorderly stacking     | Failure at 7% strain                               | Vacuum filtration method | [8]       |
| ASO NFMs                          | $\text{Al}(\text{H}_2\text{PO}_4)_3$ | 0.043                                                                   | 0.055 (50% strain)         | Lamellar structure      | 500 cycles (50% strain): plastic deformation 22.1% | Face-to-face stacking    | This work |

## References:

- [1] Dong, X.; Sui, G.; Yun, Z.; Wang, M.; Guo, A.; Zhang, J.; Liu, J. Effect of temperature on the mechanical behavior of mullite fibrous ceramics with a 3D skeleton structure prepared by molding method. *Mater. Des.* **2016**, *90*, 942-948.
- [2] Zhang, R.; Hou, X.; Ye, C.; Wang, B.; Fang, D. Fabrication and properties of fibrous porous mullite–zirconia fiber networks with a quasi-layered structure. *J. Eur. Ceram. Soc.* **2016**, *36*, 3539-3544.
- [3] Zhang, R.; Ye, C.; Hou, X.; Li, S.; Wang, B. Microstructure and properties of lightweight fibrous porous mullite ceramics prepared by vacuum squeeze moulding technique. *Ceram. Int.* **2016**, *42*, 14843-14848.
- [4] Zhang, R.; Hou, X.; Ye, C.; Wang, B. Enhanced mechanical and thermal properties of anisotropic fibrous porous mullite–zirconia composites produced using sol-gel impregnation. *J. Alloys Compd.* **2017**, *699*, 511-516.
- [5] Zhu, J.; Zhu, R.; Hu, Y.; Wang, Z. Mullite fiber porous ceramic with high quality factor for high-temperature PM filtration. *J. Eur. Ceram. Soc.* **2024**, *44*, 2630-2637.
- [6] Yang, Y.; Fu, W.; Chen, X.; Chen, L.; Hou, C.; Wang, Y.; Tang, T.; Zhang, X. Fabrication of homogeneous mullite-based fiber porous ceramics with high strength and porosity. *J. Eur. Ceram. Soc.* **2022**, *42*, 7219-7227.
- [7] Yang, M.; Luo, X.; Yi, J.; Zhang, X.; Peng, Z. Fabrication of fibrous mullite-alumina ceramic with high strength and low thermal conductivity. *J. Wuhan Univ. Technol.* **2019**, *34*, 1415-1420.
- [8] Zang, W.; Guo, F.; Liu, J.; Du, H.; Hou, F.; Guo, A. Lightweight alumina based fibrous ceramics with different high temperature binder. *Ceram. Int.* **2016**, *42*, 10310-10316.