

*Research article*

## **A photothermal soft actuator based on graphene/PDMS composite materials reinforced by carbon fiber skeleton**

**Jincong Chen<sup>1,2,3</sup>, Xiaodong Zhao<sup>1,2,3</sup> and Haiyan Zhao<sup>1,2,3,\*</sup>**

<sup>1</sup> Department of Mechanical Engineering, Tsinghua University, Beijing 100084, PR China

<sup>2</sup> State Key Laboratory of Tribology in Advanced Equipment, Tsinghua University, Beijing 100084, PR China

<sup>3</sup> State Key Laboratory of Clean and Efficient Turbomachinery Power Equipment, Department of Mechanical Engineering, Tsinghua University, Beijing, 100084, PR China

\* **Correspondence:** Email: [hyzhao@tsinghua.edu.cn](mailto:hyzhao@tsinghua.edu.cn); Tel: +86-10-6278-4578; Fax: +86-10-6278-4578.

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## **Supplementary**

## Details in the manufacturing process of actuators



**Figure S1.** Optical images of carbon fiber skeleton laid on PDMS layer.

## Details of finite element calculation

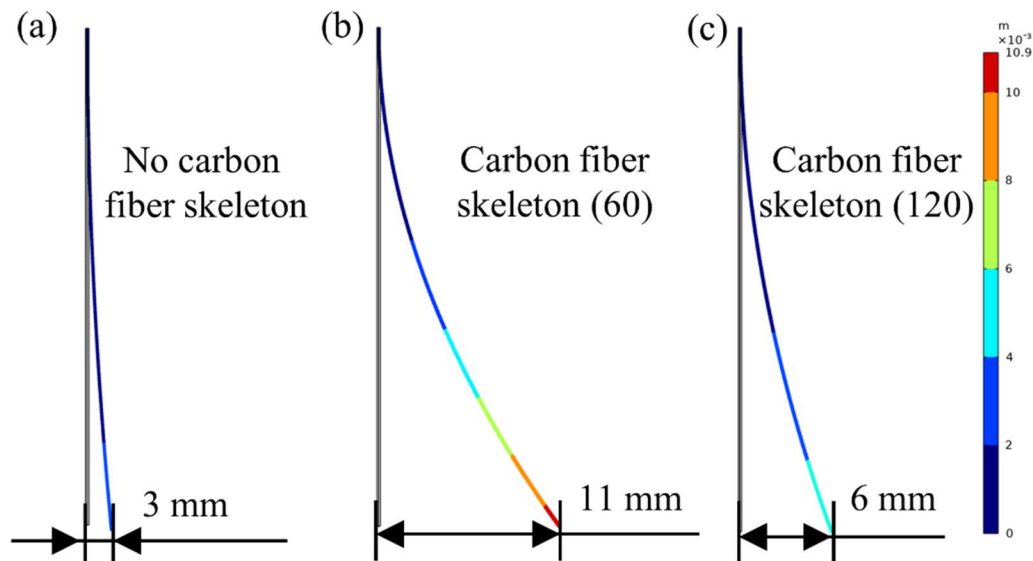
Firstly, calculate the volume fraction of carbon fiber and PDMS by the ratio of cross-sectional areas. Then, the material parameter results are calculated based on the orthogonal anisotropic material model and the fiber-reinforced composite material model [1], as shown in Table S1.

**Table S1.** Calculated material parameters.

Material parameters		No carbon fiber	Carbon fiber skeleton (60)	Carbon fiber skeleton (120)
Elastic modulus	E11	1.07 MPa	572 MPa	1145 MPa
	E22		1.56 MPa	0.75 MPa
	E33		1.56 MPa	0.75 MPa
Coefficient of thermal expansion	$\alpha_{11}$	$2.91 \times 10^{-4} \text{ }^{\circ}\text{C}^{-1}$	$7.17 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$	$5.57 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$
	$\alpha_{22}$		$2.90 \times 10^{-4} \text{ }^{\circ}\text{C}^{-1}$	$2.90 \times 10^{-4} \text{ }^{\circ}\text{C}^{-1}$
	$\alpha_{33}$		$2.90 \times 10^{-4} \text{ }^{\circ}\text{C}^{-1}$	$2.90 \times 10^{-4} \text{ }^{\circ}\text{C}^{-1}$

A finite element model of the actuator is constructed in COMSOL Multiphysics, with one layer PDMS and the other layer composite material, measuring 30 mm in length and 0.1 mm in thickness,

corresponding to the experiments. The laser is loaded onto the actuator in the form of a temperature field, with a maximum temperature of 130 °C, corresponding to the experiments. The calculated displacement field is shown in Figure S2.



**Figure S2.** Finite element calculation results of actuator displacement.

## References

1. Wang J, Cui J, Nie Y (2009) The two-scale analysis model for mechanics parameter computation of fiber-reinforced composite materials. *J Numer Methods Comput Appl* 30: 30–40. <https://doi.org/10.12288/szjs.2009.1.30>



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