Electronic Supplementary Information (ESI)

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Experimental details

Fabrication of edible superhydrophobic mixed waxes powder

The wax-in-ethanol solutions of carnauba wax (purchased from Shanghai Macklin Biochemical Co. Ltd., China.) and beeswax (purchased from Solarbio Science & Technology Co. Ltd., China.) were prepared using methods reported by our group before, with modifications.[1, 2] In detail, 2 g of carnauba wax and beeswax were added into flasks with 200 ml of ethanol (purchased from Rionlon, China.), separately. Then wax-in-ethanol solutions of carnauba wax and beeswax were heated to dissolve waxes. After dissolve, the solutions were cooled at room temperature for precipitation of edible superhydrophobic waxes particles. Furthermore, the waxes particles suspensions were ultrasonicated for 2h, aiming even separation and distribution.

Two solutions were then mixed at carnauba wax: beeswax ratio of 4:1, 3:1, 2:1, 1:1 and pure beeswax. The emulsions were then loaded into the spray gun (W-71, Dongcheng, China) with the spray pressure set at around 20 psi. During spray, the nozzle of the spray gun was held at a distance around 20 cm from the spray substrate (parafilm (PF), nitrile butadiene rubber (NBR) and polyethylene (PE) film).

Water jetting test and underwater stability test of the coating

The water jetting test was performed by setting the water flow at ~ 5 m/s (12.5 kPa according to equation below) and 20 cm above the 45 °C tilted samples. The CA and SA recordings of each sample were measured three times and averaged for result.

$$V = \sqrt{\frac{2P}{\rho}}$$

where V, P and ρ represent water velocity (m/s), pressure (kPa) and density (kg/m^3) separately. The water flow mimicked the water splash within the container itself, as the water impact of liquid food packaging mainly occurs within water environment of the container.

Characterisation

SEM images of the membrane surface and cross section were acquired from the emission scanning electron microscope (FESEM, QUANTA FEG 650, FEI, USA.). FTIR spectra results were recorded from Fourier Transform Infrared Spectroscopy (FTIR, Thermo Scientific Nicolet iS10). The mechanical properties of the 3:1 mixed waxes coating coated parafilm (30 × 5 mm^2) were characterized at 15 °C through electronic universal testing machine (EZ Test EZ-LX) at speed of 0.1% / min with loading cell of 18 N. Thickness of the coated parafilm were previously measured in triplicate by digital micrometre. The water contact angle (WCA) was measured through JC2000D system (Zhongchen Digital Equipment Co., Ltd., Shanghai, China). The roll-off angle (WRA) was measured using the DSA100 contact angle meter. 5 µl water droplets was applied to all WCA and WRA tests. WCA and WRA recordings of each sample were measured three times and averaged for result.

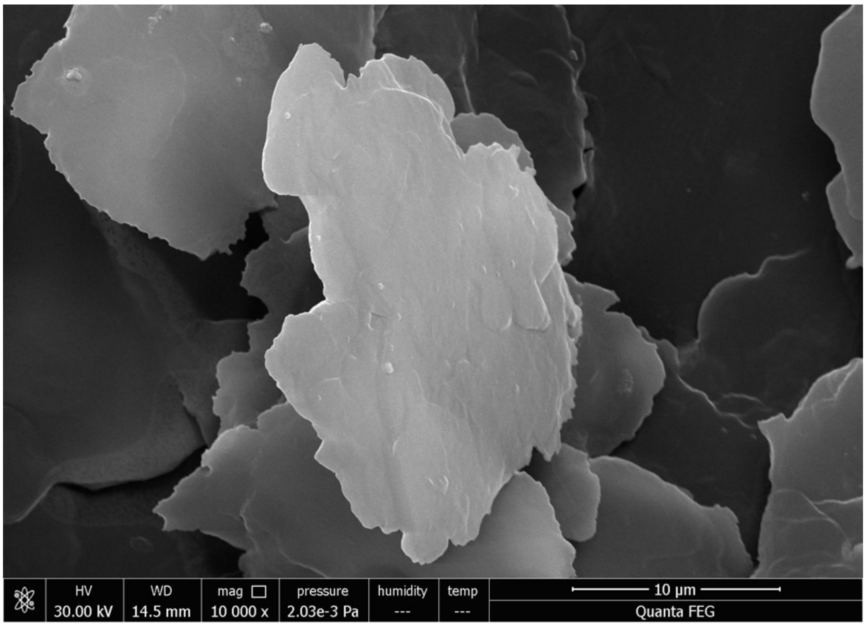

Fig S1: SEM image of beeswax flakes.

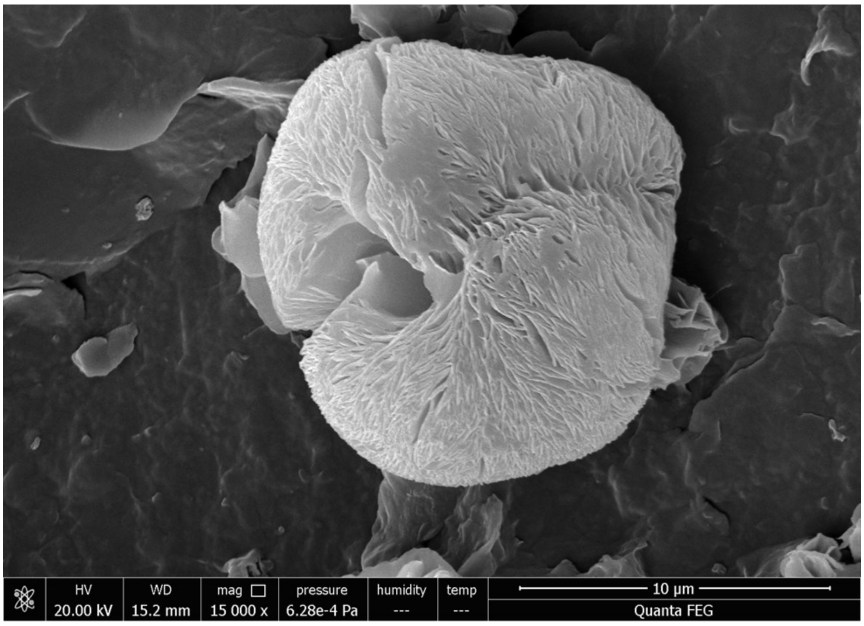

Fig S2: SEM image of carnauba wax spheres.

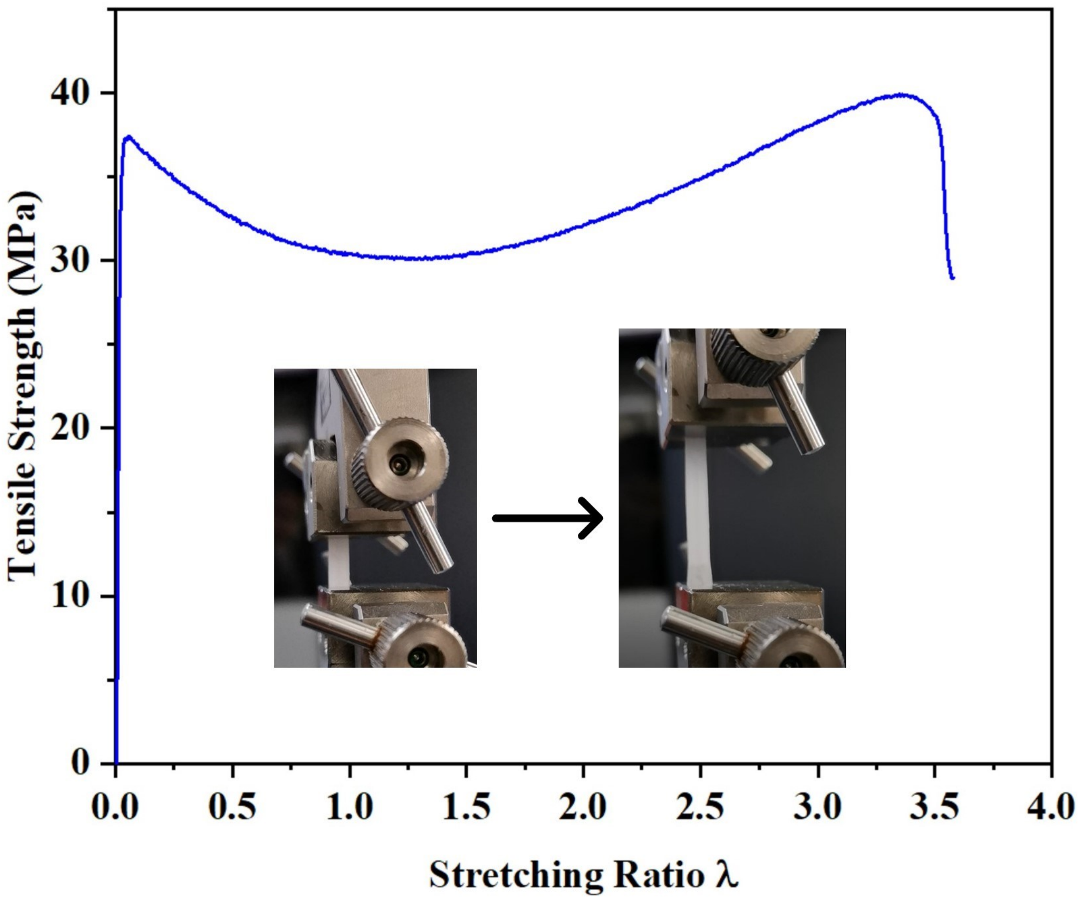

Fig S3: Stretching mechanical test of 3:1 mixed waxes coating coated parafilm.

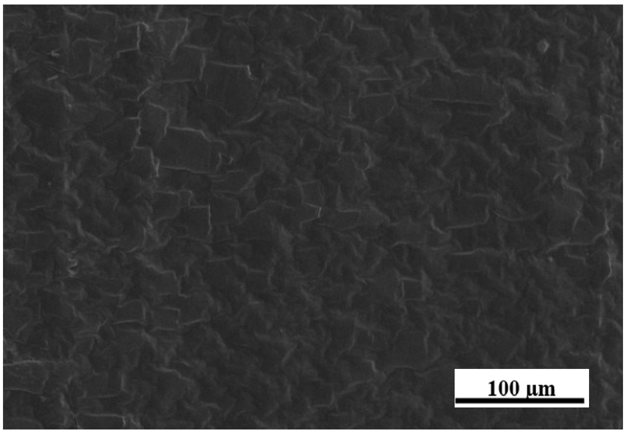

Fig S4: SEM image of parafilm before stretching.

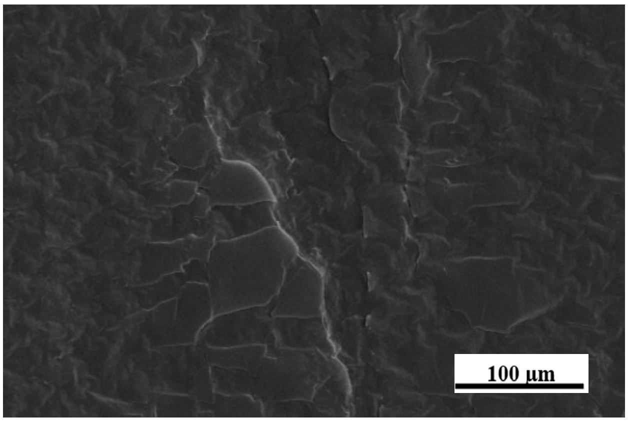

Fig S5: SEM image of parafilm after stretching.

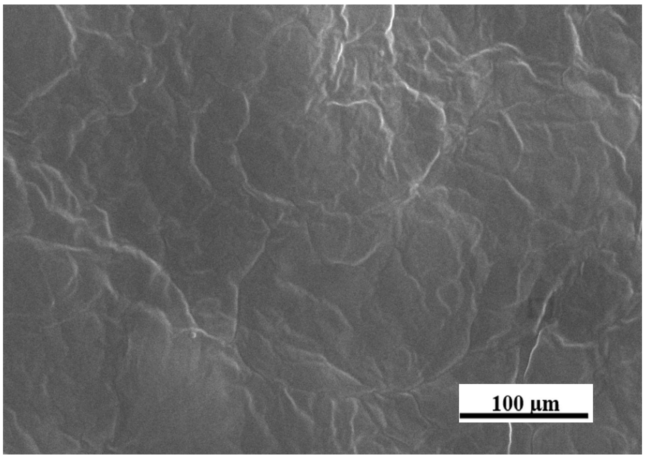

Fig S6: SEM image of pure beeswax base layer after heating/before stretching.

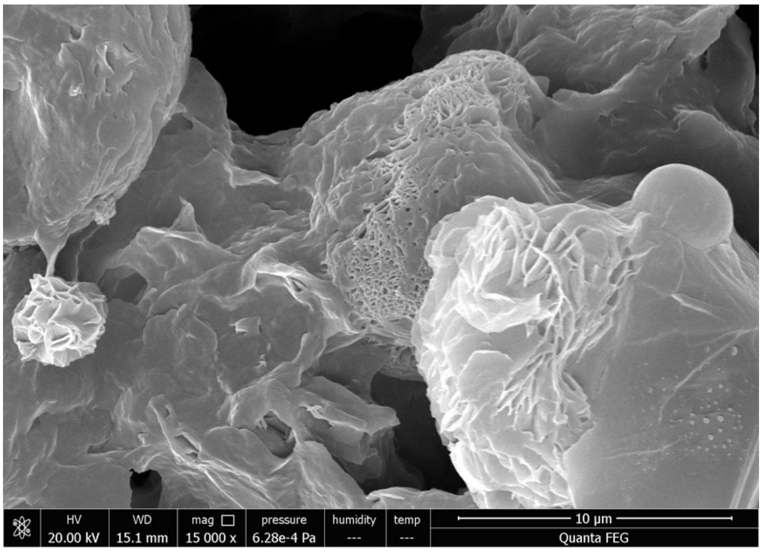

Fig S7: Mixing ratio of 1:1 SEM image of carnauba wax and beeswax mixed coating.

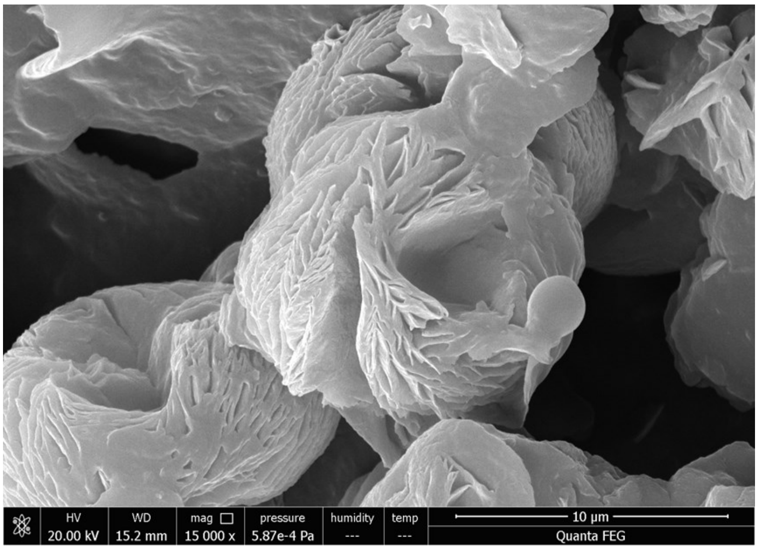

FIG. S8: Mixing ratio of 2:1 SEM image of carnauba wax and beeswax mixed coating.

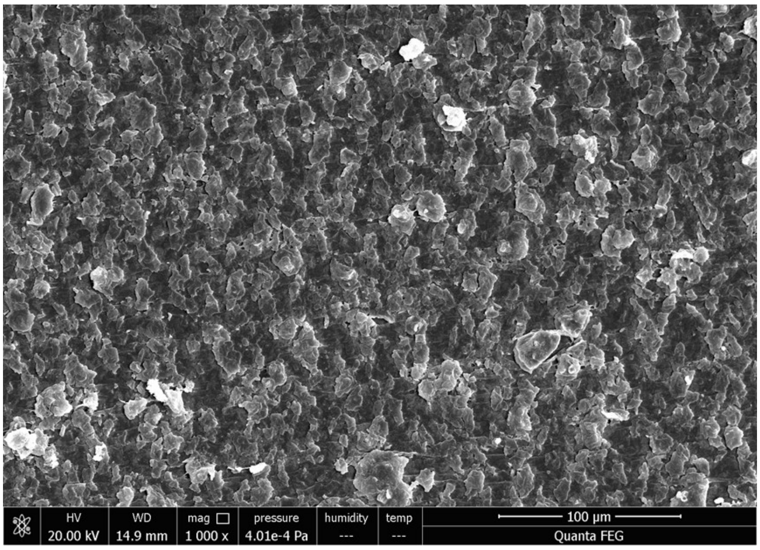

Fig S9: SEM image of 4:1 mixed waxes coating after 8 cycles of abrasion and stretching.

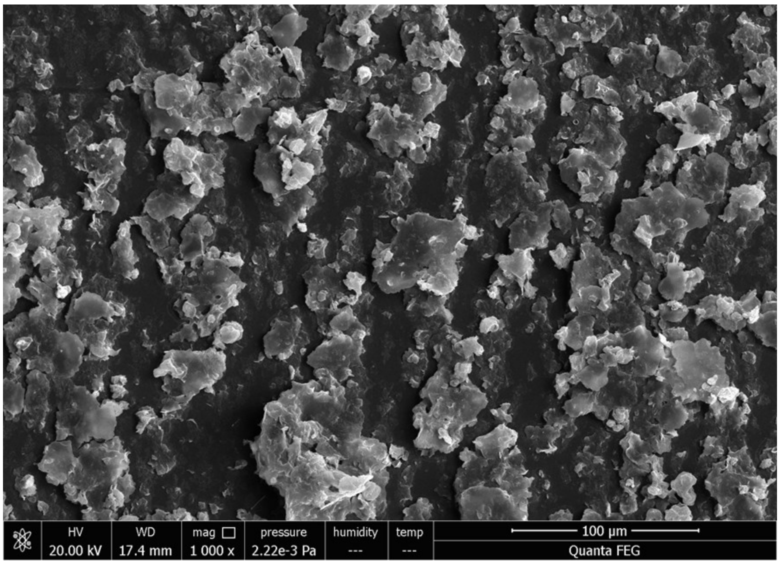

Fig S10: SEM image of 3:1 mixed waxes coating after 14 cycles of abrasion and stretching.

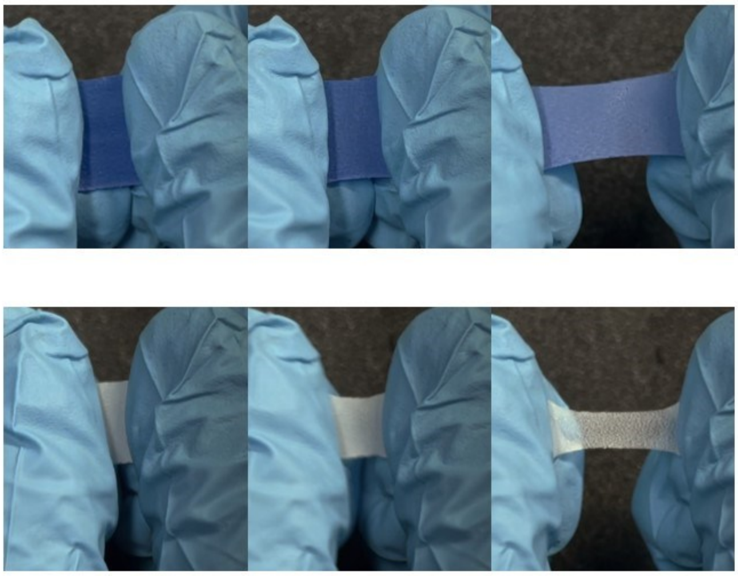

Fig S11: Images of 3:1 mixed waxes coating on NBR and 4:1 mixed waxes coating PE substrates.

Fig S12: Images of 3:1 mixed waxes coating on PF substrates sealing liquid with silver mirror effect at the water facing surface.

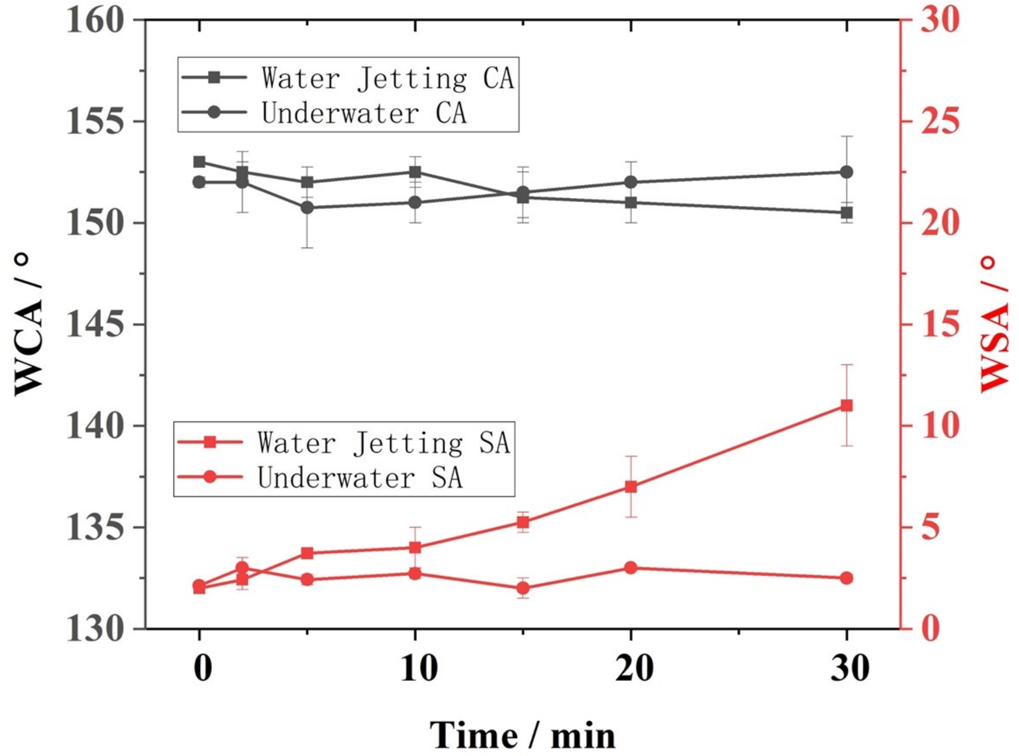

Fig. S13 Water jetting stability test and under water stability test of 3:1 mixed waxes coating on PF substrates.

References

1. D. Wang, Z. Guo and W. Liu, *Research (Wash D C)*, 2019, **2019**, 1649427.

2. D. Wang, J. Huang and Z. Guo, *Chemical Engineering Journal*, 2020, **400**.