Electronic Supporting Information

Modular Reprogrammable 3D Mechanical Metamaterials with Unusual Hygroscopic Deformation Modes

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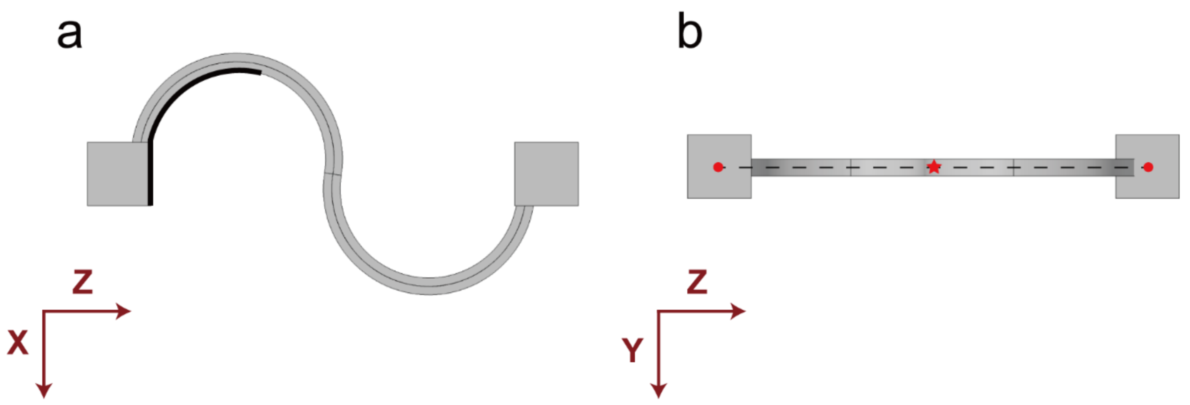

Fig. S1 Illustration of the connection between the curved strips and the cubic nodes

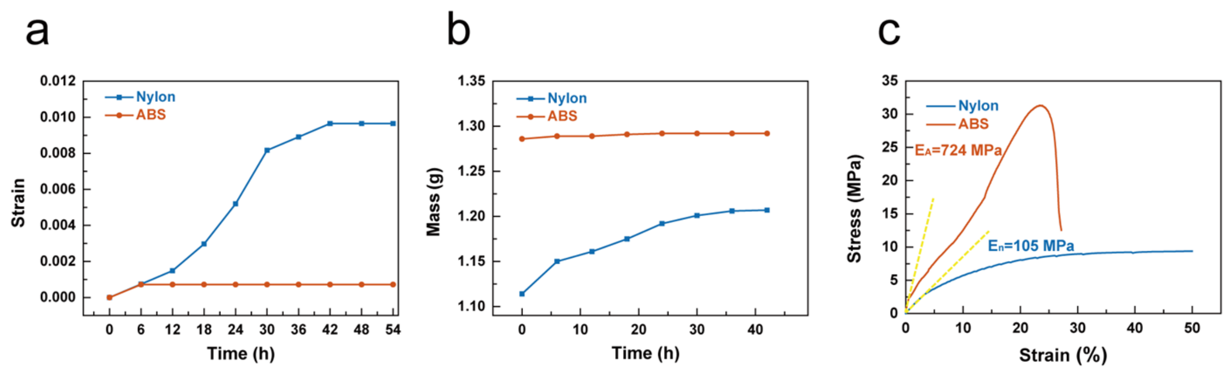

Fig. S2 Measurement of component material properties, all the tested samples were fabricated at 20% RH, 303.15 K. a) Strain-time curves of Nylon and ABS for CHE measuring at 80% RH, 303.15 K. Sample size: 110 mm×2 mm×1 mm. b) Mass-time curves of Nylon and ABS for Young's module measuring at 80% RH, 303.15 K. Sample size: 45 mm×10 mm×3 mm c) Stress-strain curves of Nylon and ABS with saturated moisture state at 80% RH, 303.15 K.

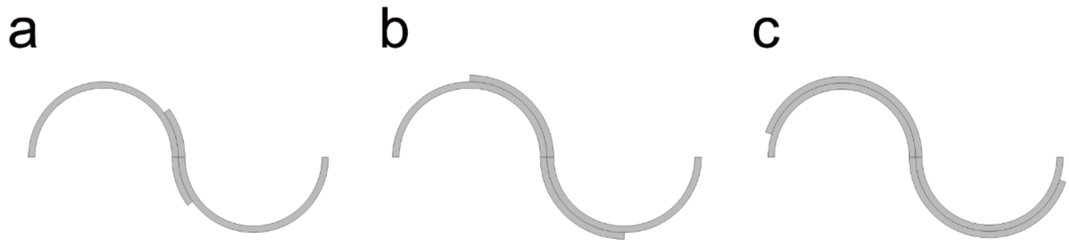

Fig. S3 The configuration of the bi-material curved strips when the radian of the inner material is kept 180° and the radian of the outer material is changed. Covered ratio (a) $\theta_2/\theta_1 = 0.2$, (b) $\theta_2/\theta_1 = 0.5$, and (c) $\theta_2/\theta_1 = 0.9$.

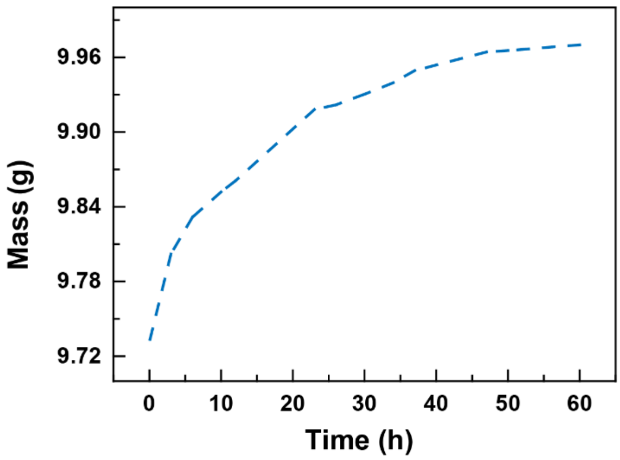

Fig. S4 Mass-time curve of a linear NHE unit cell with $\theta = 180°$ at 80% RH, 303.15 K, which is fabricated at 20% RH, 303.15 K.

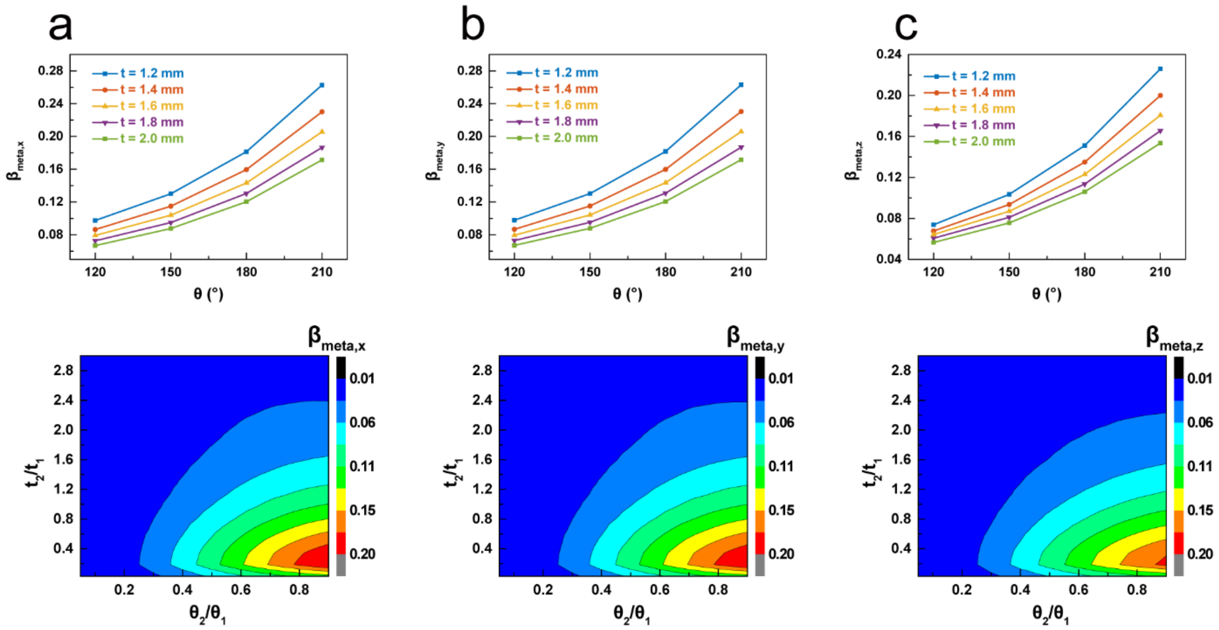

Fig. S5 Tunable hygroscopic expansion of the linear positive hygroscopic expansion structure. (a-c) The dependence of CHEs $\beta_{meta,\,x}$, $\beta_{meta,\,y}$ and $\beta_{meta,\,z}$ on total thickness t, radian θ, thickness ratio t_2/t_1 and covered ratio θ_2/θ_1.

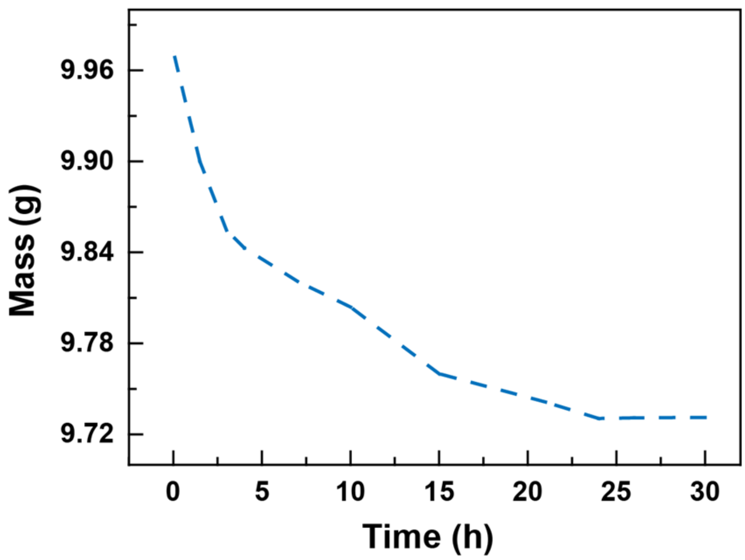

Fig. S6 Mass-time curve for a linear NHE unit cell with θ = 180° dried in the environment of 20% RH, 303.15K, which had been hygrosopic saturated at 80% RH, 303.15 K.

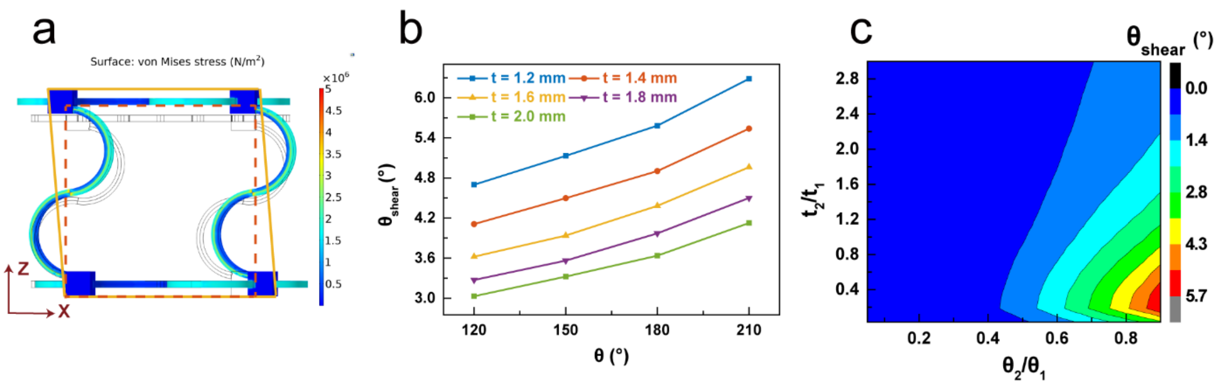

Fig. S7 Tunable hygroscopic shear deformation, with ABS and Nylon designated as outer and inner material of the curved strips, respectively. (a) Simulated hygroscopic shear deformation of the structure from the side view. (b-c) The dependence of hygroscopic shear angle θ_{shear} on total thickness t, radian θ, thickness ratio t_2/t_1 and covered ratio θ_2/θ_1.

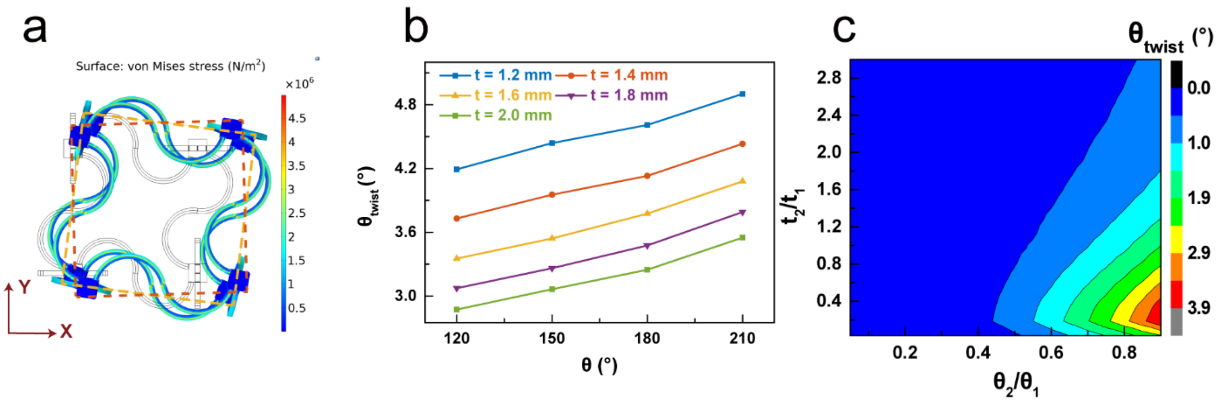

Fig. S8 Tunable hygroscopic twist deformation, with ABS and Nylon designated as outer and inner material of the curved strips, respectively. (a) Simulated hygroscopic twist deformation of the structure from the top view. (b-c) The dependence of hygroscopic twist angle θ_{twist} on total thickness t, radian θ, thickness ratio t_2/t_1 and covered ratio θ_2/θ_1.

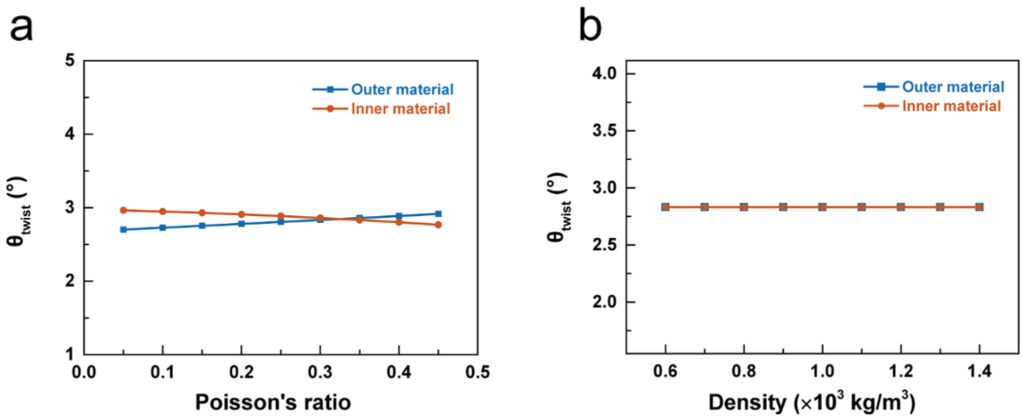

Fig. S9 The dependence of hygroscopic twist angle θ_{twist} on (a) Poisson's ratio and (b) density of outer material and inner material, with the model being the 3D array metamaterials with twist mode. Geometrical parameters: $\theta = 180°$, $t_1 = t_2 = 1$ mm, $l = 7.5$ mm, $2r\sin(\theta/2) = 25$ mm. Materials parameters: $\beta_{outer} = 0.0167$, $\beta_{inner} = 0.0017$, $E_{outer} = 105$ MPa and $E_{inner} = 724$ MPa. In addition to the variables studied, Poisson's ratio and density of outer and inner materials was set as: $v_{outer} = 0.30$, $v_{inner} = 0.35$, $\rho_{outer} = 1140$ kg/m^3, $\rho_{inner} = 1100$ kg/m^3.

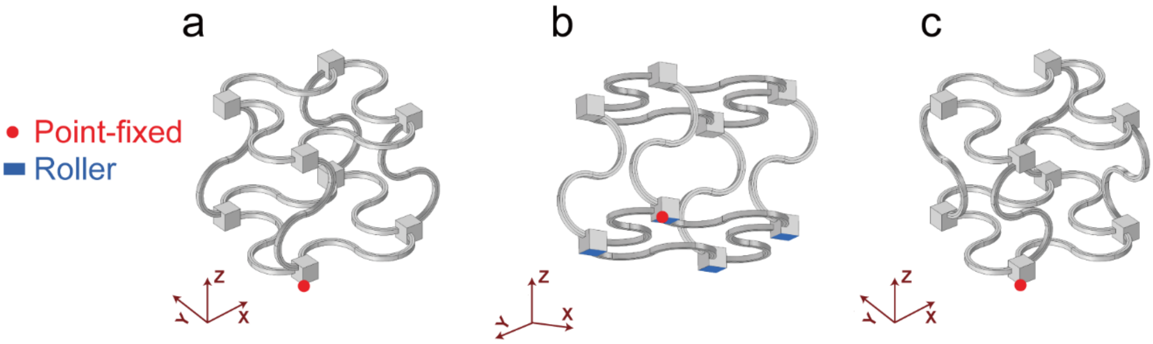

Fig. S10 Boundary conditions of simulating the hygroscopic deformation of metamaterials with (a) tunable linear expansion, (b) shear, and (c) twist deformation modes, with red and blue denoting point-fixed and roller, respectively.