Supporting Information

Snap-Buckling Motivated Controllable Jumping of Thermo-Responsive Hydrogel Bilayers

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Determination of elastic energy (*E*) in pulling and snapping

Determination of *E* in pulling

Assumptions are made that the as-prepared monolayer hydrogel strip is an ideal elastomer, and the pulling work (*W*) is completely converts to elastic energy (*E*). The *E* is given by:

$$E = W = \int_0^x F dx \tag{S1}$$

where *F* is external force in pulling, *x* is the elongation of the hydrogel strip.

Through the Hook's Law :

$$F = -f = kx \tag{S2}$$

where f is the counterforce generated in hydrogel during pulling, k is the stiffness coefficient of hydrogel. The E is then given by:

$$E = \int_0^x kx dx = \frac{1}{2} kx^2 \quad \text{(S3)}$$

Assuming that the hydrogel is pulled with a constant speed of v. Substituting the relation:

$$x = vt \quad \text{(S4)}$$

we obtain:

$$E = \frac{1}{2} k(vt)^2 \quad \text{(S5)}$$

which is Equation 1 in the main text.

Determination of E in snapping

During snapping, we assume that the elastic energy of a pulled hydrogel is completely converts to its kinetic energy. Thereby the E is given by:

$$E = \frac{1}{2} kx_{\max}^2 - \frac{1}{2} m_e v_s^2 \quad \text{(S6)}$$

where x_{max} is the elongation of the hydrogel strip just before snap back, m_e is the effective mass of the hydrogel strip, and equal to 1/3 of its weight,[1] v_s is the speed of

snap back. In Equation S6, the first term is the elastic energy just before the snap back of hydrogel, while the second one reflects the kinetic energy.

The v_s can be decided in following formulas (Equation S7 - Equation S12). According to Newton's Second Law:

$$F = m_e a \tag{S7}$$

where a is the accelerated speed. Substituting the relations:

$$F = -f = kx;\ a = \frac{d^2x}{dt^2} \tag{S8}$$

we obtain:

$$kx = m_e \frac{d^2x}{dt^2} \tag{S9}$$

Solving Equation S9, we obtain:

$$x = A\cos\left(\sqrt{\frac{k}{m_e}}t + \phi\right) \tag{S10}$$

where A is the amplitude, ϕ is the initial phase. To satisfy the boundary conditions in Equation S10, $A=x_{max}$, $\phi=0$. Therefore, Equation S10 is then given by:

$$x = x_{max}\cos\left(\sqrt{\frac{k}{m_e}}t\right) \tag{S11}$$

The speed of snapping (v_s) is therefore:

$$v_s = \frac{dx}{dt} = x_{max}\sqrt{\frac{k}{m_e}}sin\left(\sqrt{\frac{k}{m_e}}t\right) \quad \text{(S12)}$$

and the E (in Equation S6) is then given by:

$$E = \frac{1}{2}kx_{max}^2\left[1 - sin^2\left(\sqrt{\frac{k}{m_e}}t\right)\right] \quad \text{(S13)}$$

In the pulling-snap back process of Figure 3f in main text, the snapping started at t_0=4.63 s. As a result, the E in snapping is given by:

$$E = \frac{1}{2}kx_{max}^2\left\{1 - sin^2\left[\sqrt{\frac{k}{m_e}}\left(t - t_0\right)\right]\right\} \quad \text{(S14)}$$

which is Equation 2 in the main text.

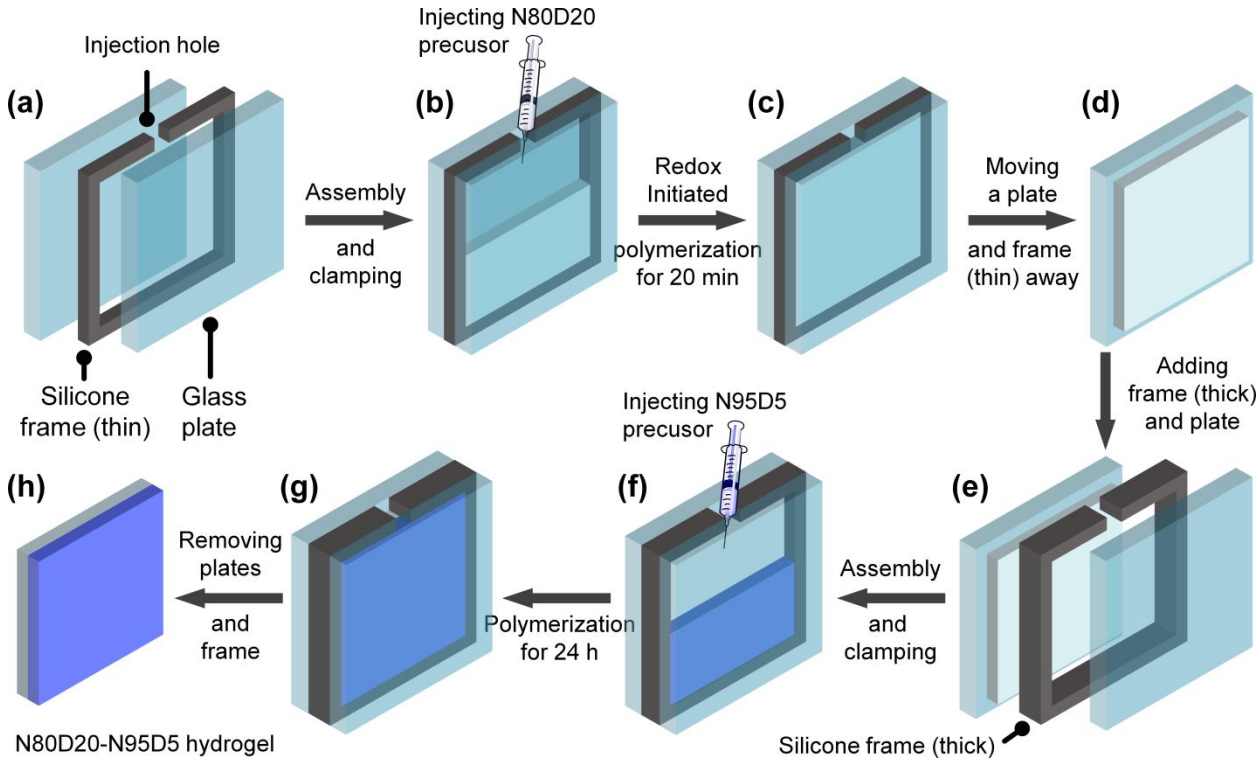

Figure S1. Schematic illustration of the fabrication of N80D20-N95D5 hydrogel. (a) The mold consists of two glass plates and a thin silicone frame. (b) The N80D20 precursor solution is injected into the assembled mold. (c) The mold is left at room temperature for initiating the polymerization for 20 min. (d) The mold is disassembled, leaving the free-standing N80D20 layer on one glass plate. (e) The thin silicone frame is replaced by a thicker one, and the mold is reassembled. (f) The N95D5 precursor solution is injected into the new space inside the reassembled mold. (g) The mold is left at room

temperature for 24 h to fully polymerization of the hydrogel bilayer. (h) The bilayer is obtained after releasing from the mold.

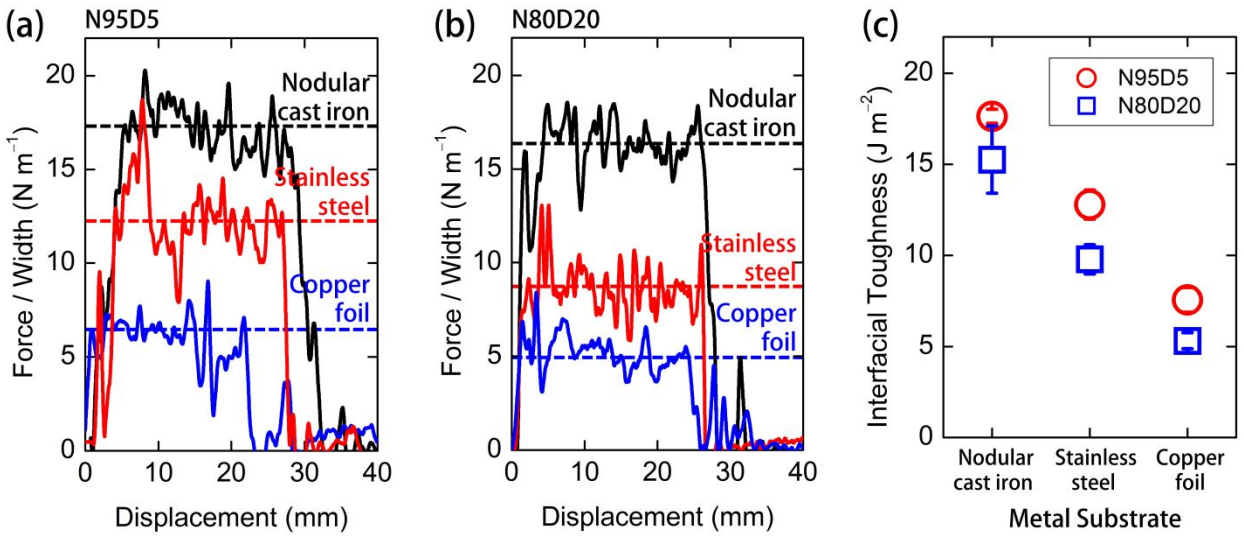

Figure S2. Typical curves of peeling force per width verses displacement for (a) N95D5 and (b) N80D20 hydrogels on flat surfaces of nodular cast iron, stainless steel and copper foil. (c) Interfacial toughness of hydrogels. Error bars indicate the standard deviation for n=3 measurements at each data point.

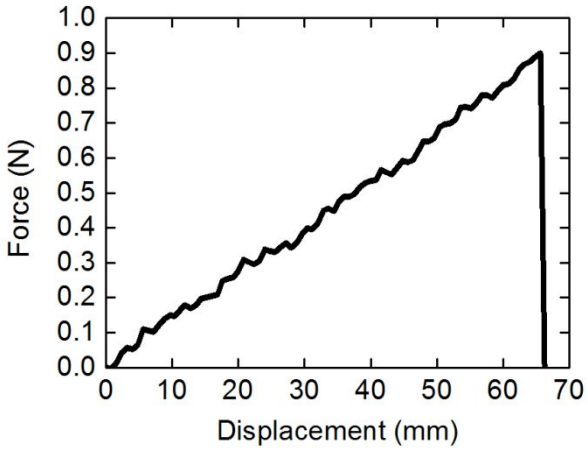

Figure S3. The tensile force-displacement curve of a N95D5 strip. The strip is 10 mm width and 1 mm thickness. In tensile, the initial crosshead distance is 40 mm, and the tensile speed is 9.61×10^{-3} m s^{-1}. The *k*, calculated as the slope from 0 to just before break of the curve, is 13.38 N m^{-1}.

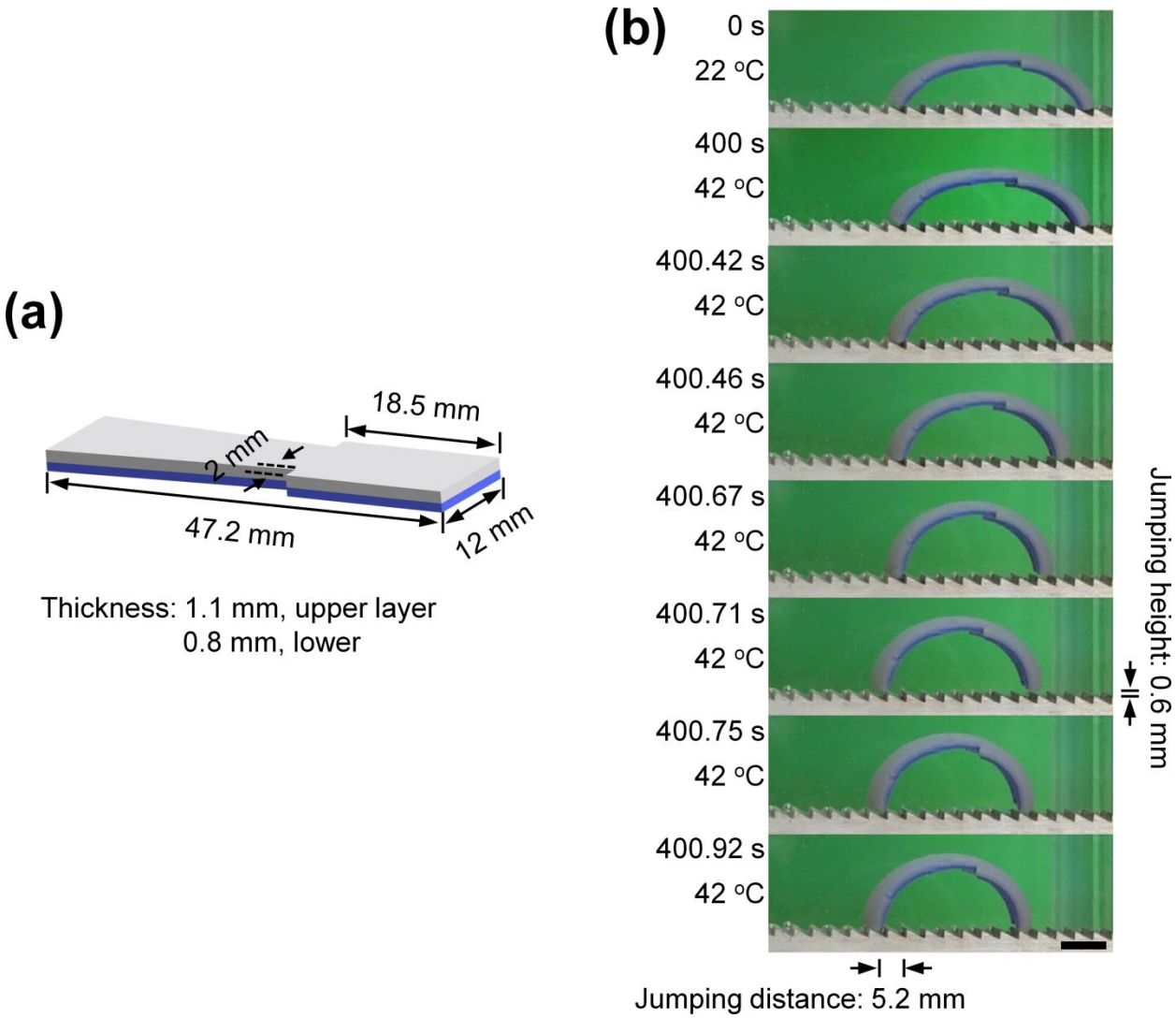

Figure S4. A jumping case with the device size different from that in Figure 4, main text. (a) Illustration denotes the size of the jumper. (b) Snapshots of the jumping cycle. Scale bar, 10 mm. Coherent process was recorded in Movie S5.

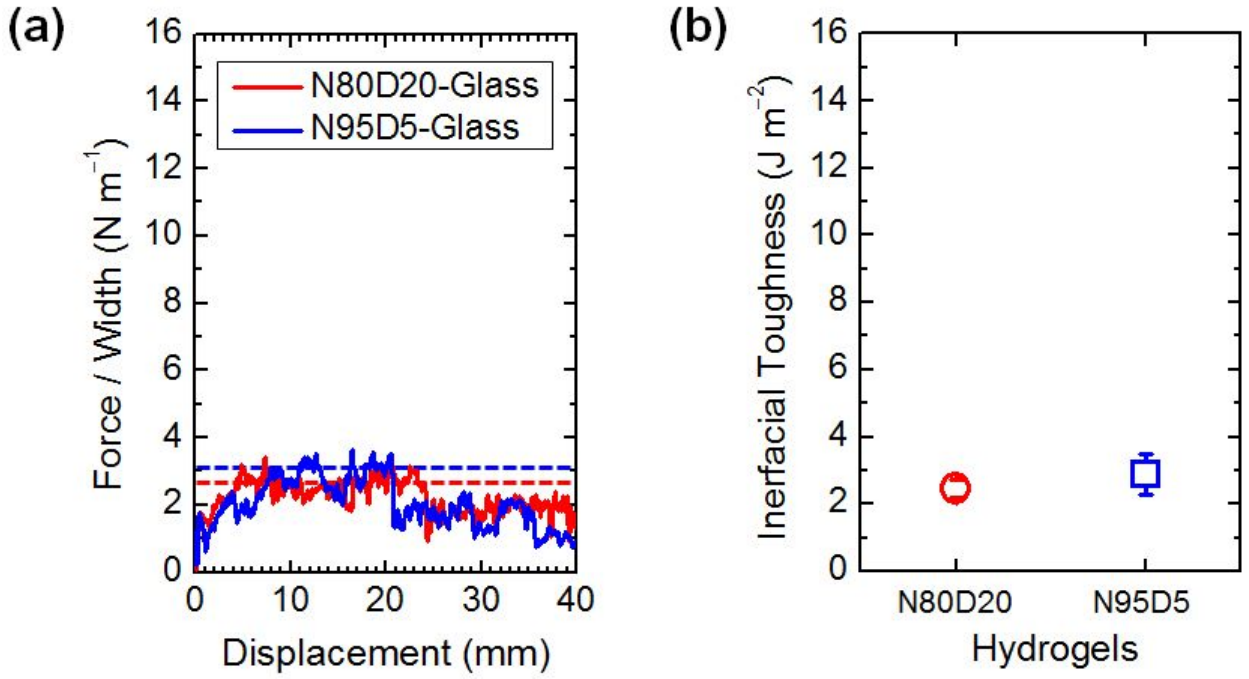

Figure S5. Gel-glass substrate adhesion. (a) Representative curves of peeling force per width verses displacement of N80D20 and N95D5 hydrogels adhesion to glass substrate. (b) Interfacial toughness of hydrogels. Error bars indicate the standard deviation for n=3 measurements at each data point. The hydrogels were pre-equilibrated in water of 47 °C before 90° peeling-off tests.

REFERENCES

(1) Rodríguez, E. E.; Gesnouin, G. A. Effective Mass of an Oscillating Spring. *Physics Teacher* **2007**, *45*, 100-103.