

Supporting Information

Shape Memory Properties of Polystyrene-*block*-Poly(ethylene-co-butylene)-*block*-Polystyrene (SEBS) ABA Triblock Copolymer Thermoplastic Elastomers

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Keywords: Shape memory polymer, dynamic mechanical analysis (DMA), polystyrene-*block*-poly(ethylene-co-butylene)-*block*-polystyrene (SEBS), chain pull-out, triblock copolymer, thermoplastic, microphase separation

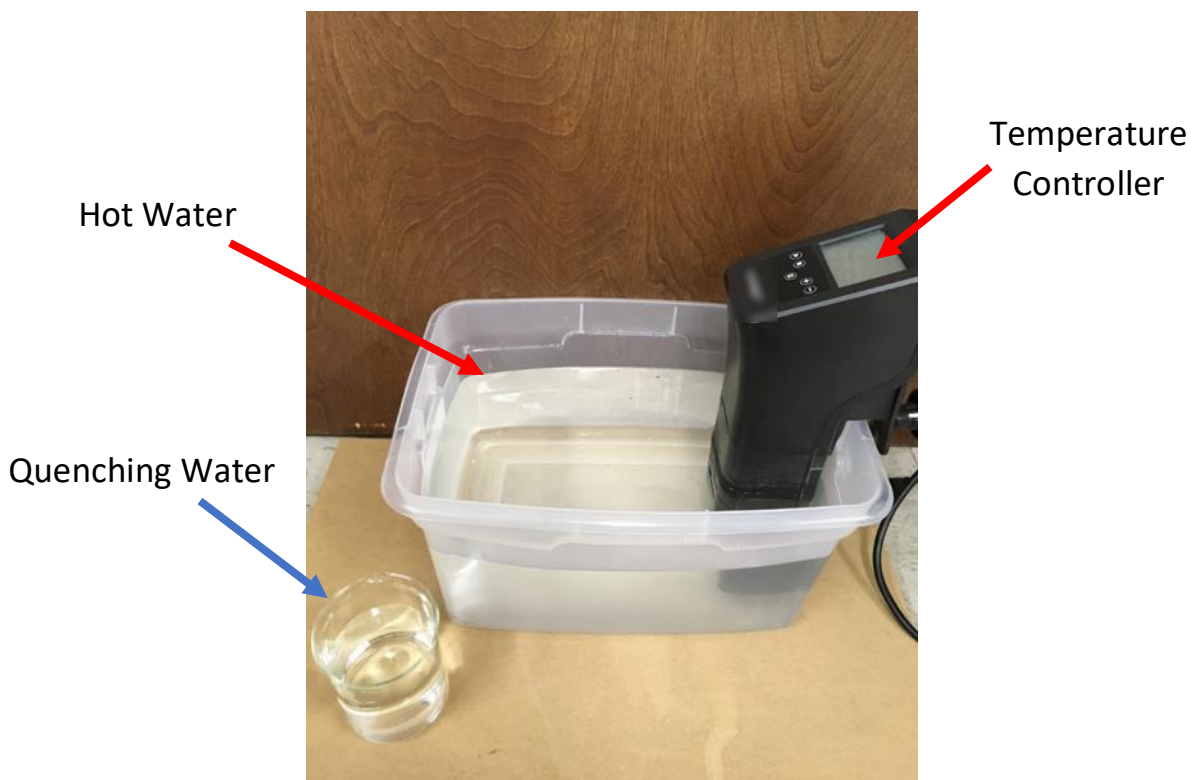


Figure S1: Water bath setup used for shape memory cycling.

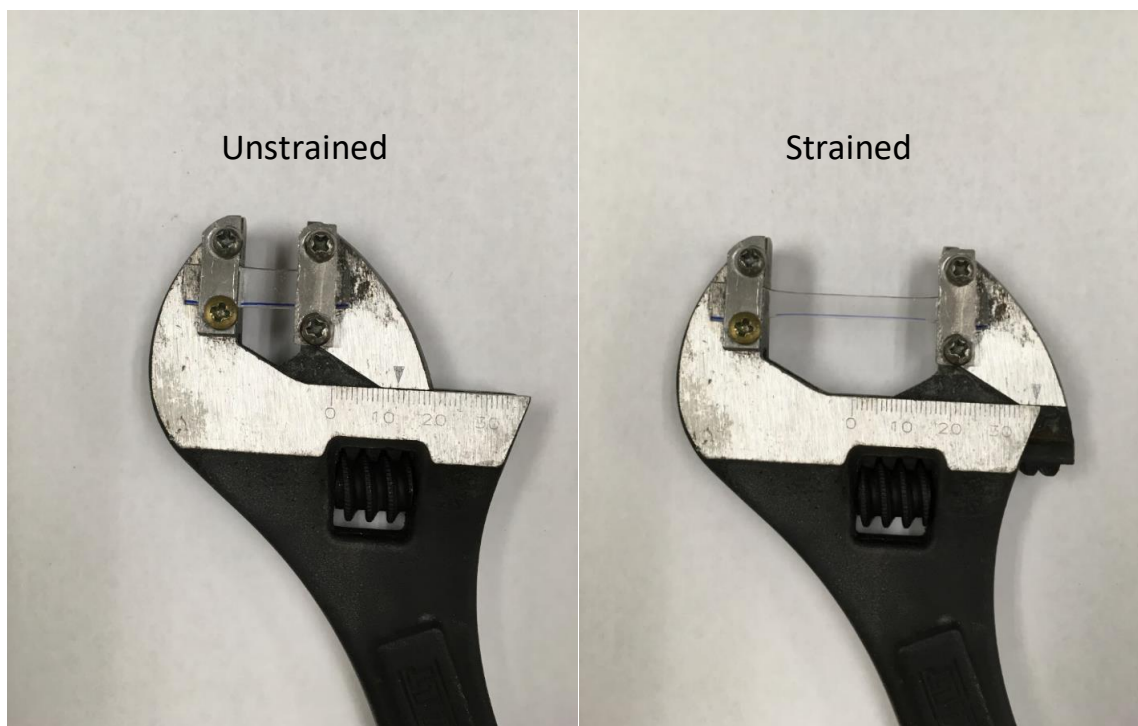


Figure S2: Modified wrench used to strain SEBS samples inside a hot water bath.

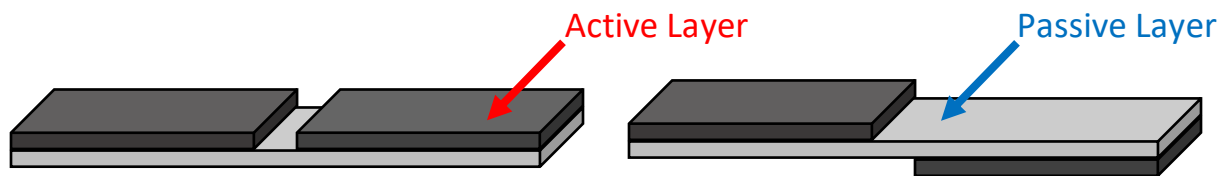


Figure S3: Bilayer hinge assembly schematics.

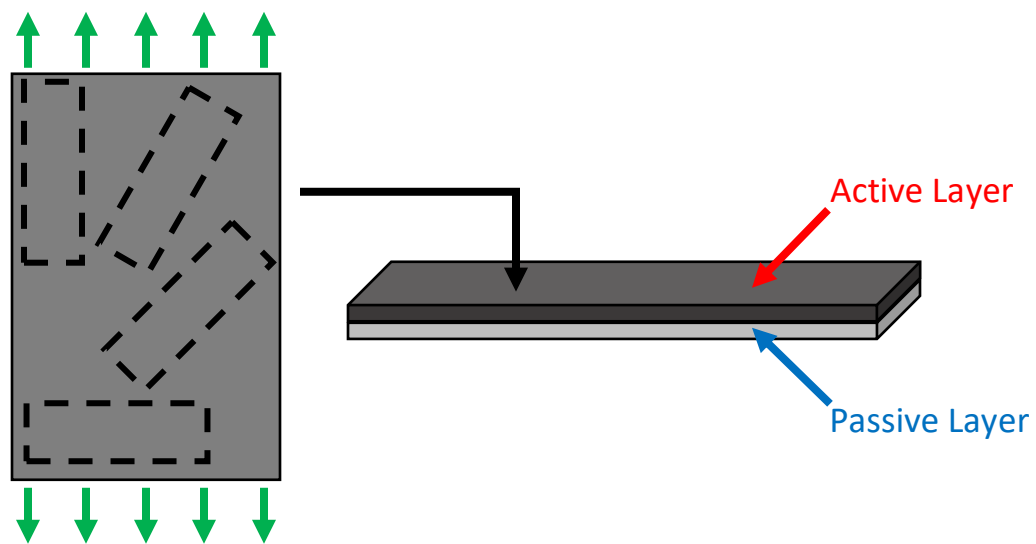


Figure S4: Schematics of bilayers with directional active layer recovery.

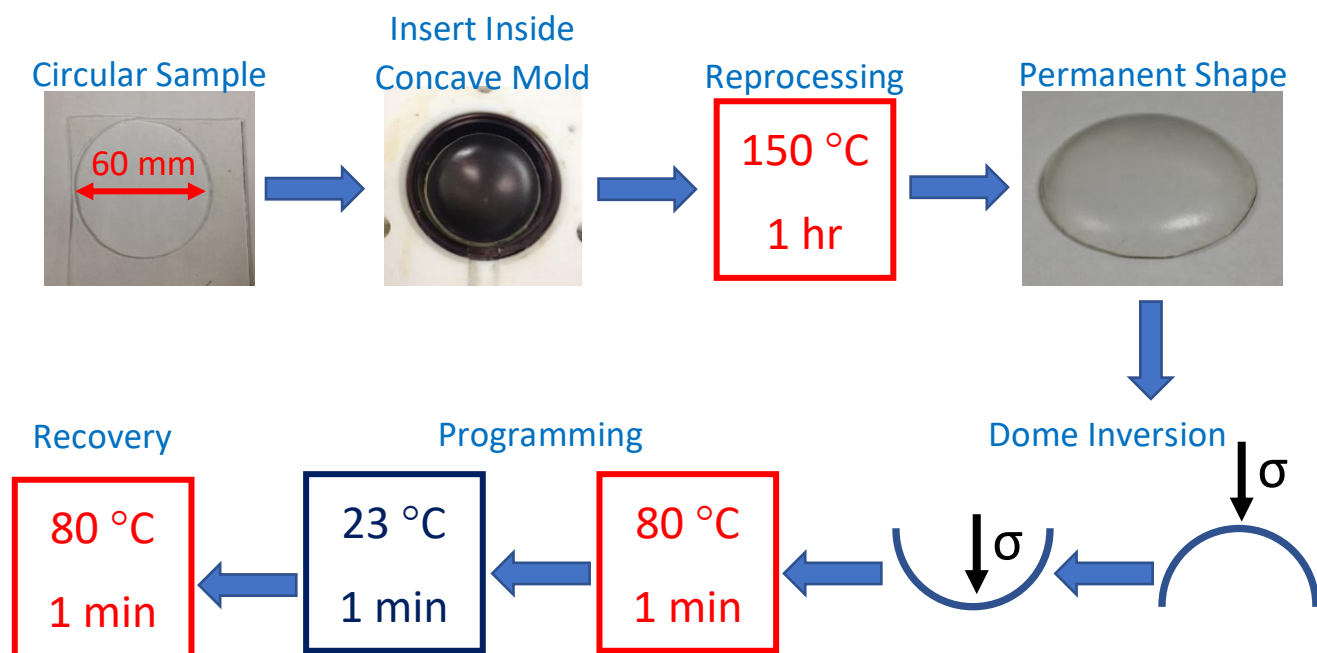


Figure S5: Dome shape processing schematics.

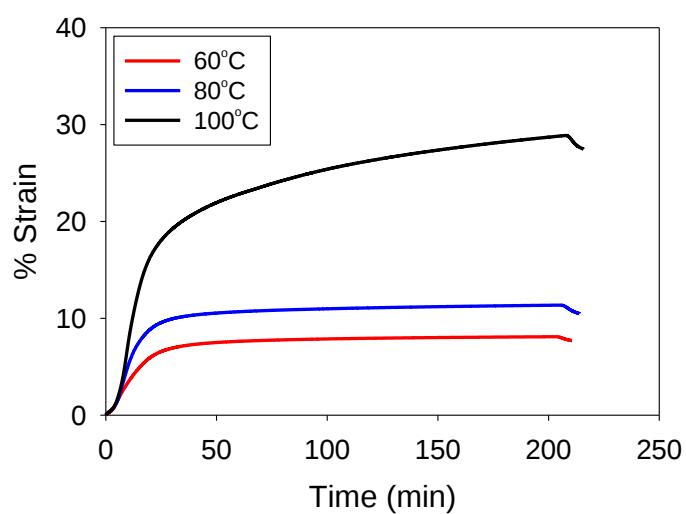


Figure S6: Gravimetric creep measurements of G1650 SEBS.

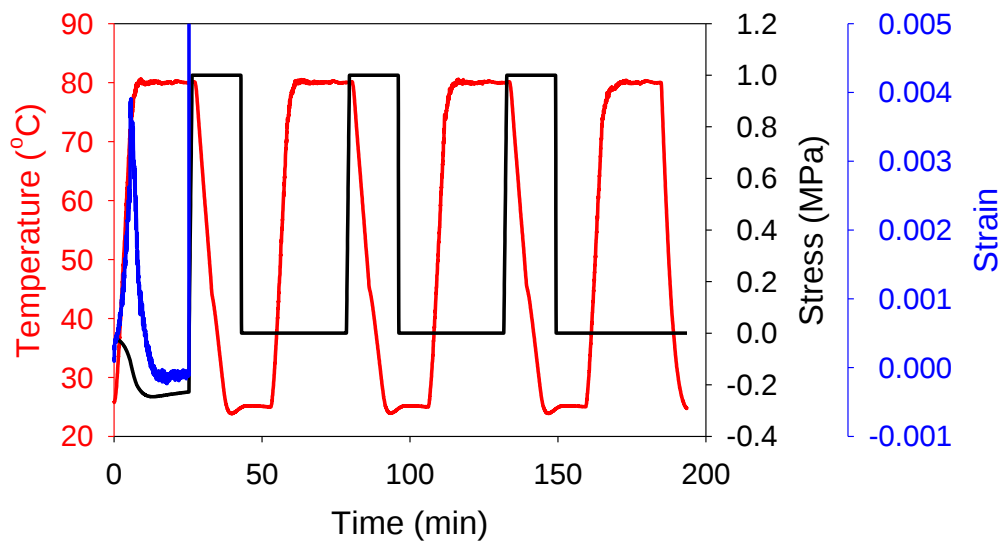


Figure S7: Replicate of Figure 2 in the manuscript with reduced strain axis scale.

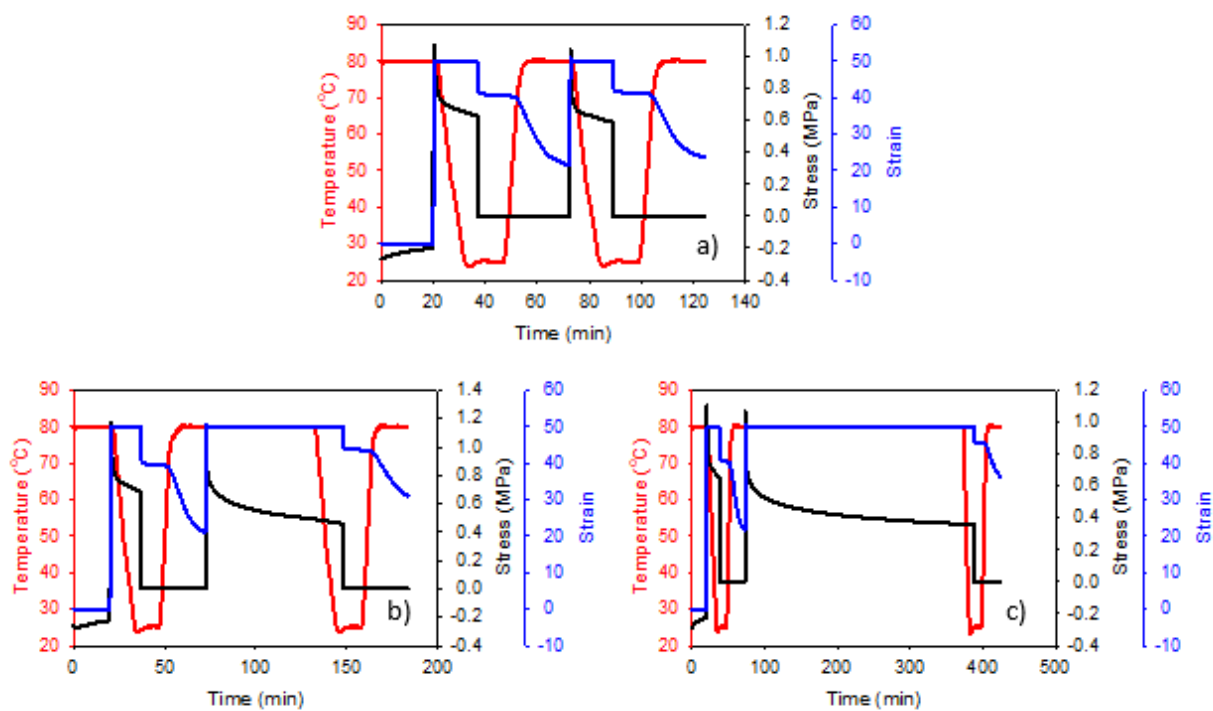


Figure S8: G1650 SEBS shape memory DMA data of 50% strain with second cycle annealing times of a) 15, b) 75, and c) 315 minutes.

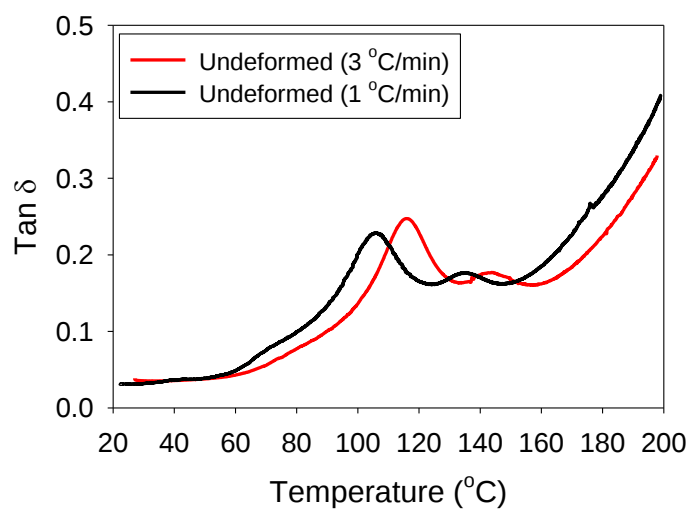


Figure S9: Temperature sweeps of undeformed samples performed at different heating rates.

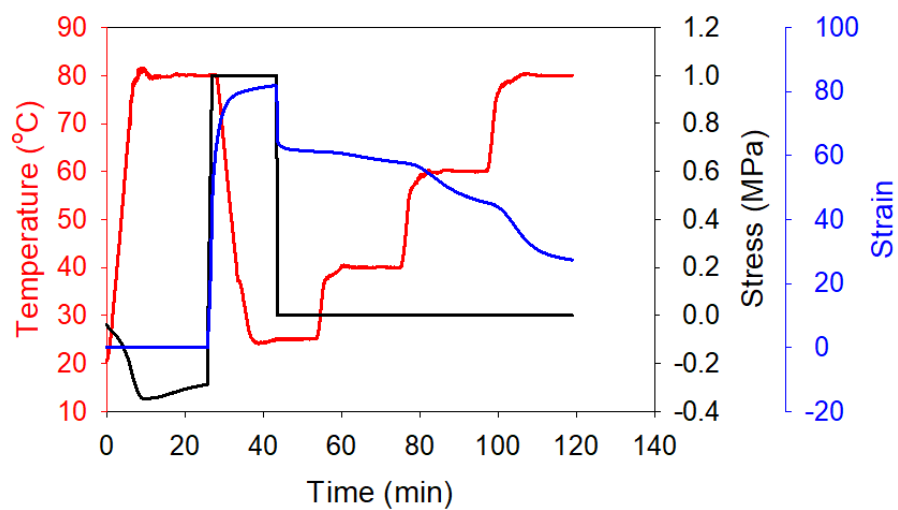


Figure S10: Step heating of shape memory programmed G1650 SEBS.

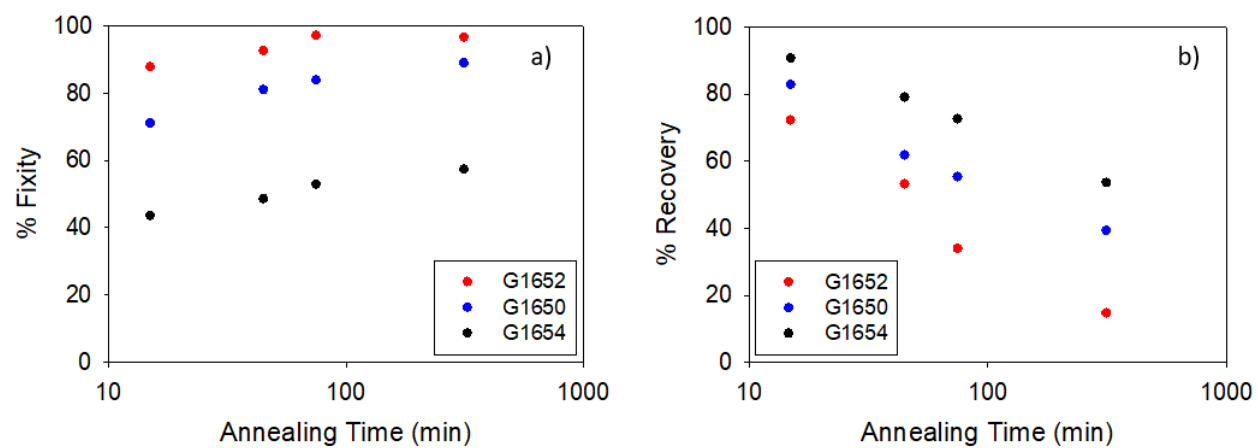


Figure S11: a) Fixity and b) recovery of G1652, G1650 and G1654 SEBS with various second cycle annealing times obtained using a programming temperature of 80 °C and an applied strain of 100%.

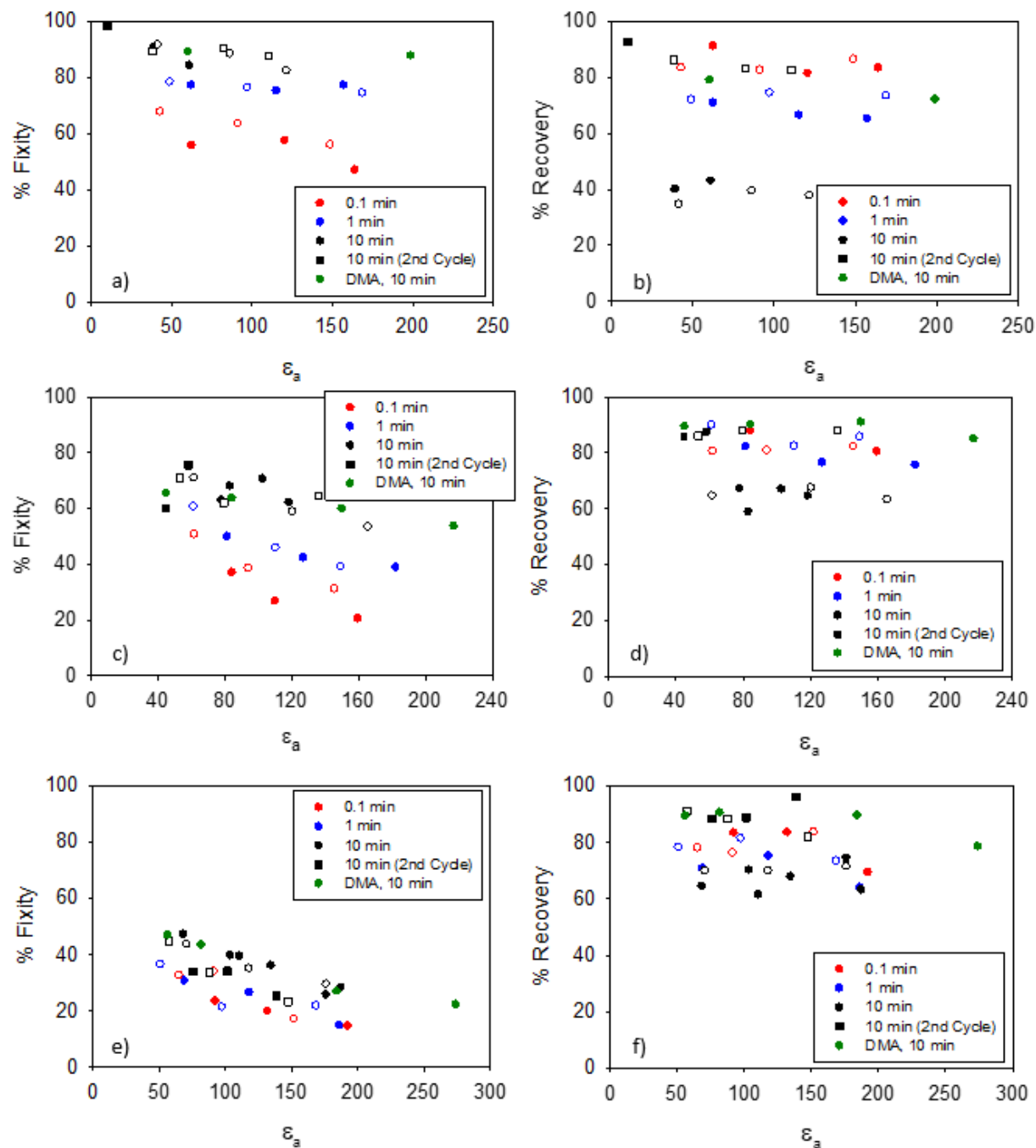


Figure S12: Fixity and recovery of a-b) G1652, c-d) G1650, and e-f) G1654 SEBS obtained using the water bath shape memory testing method. Open and closed symbols correspond to data taken with l_i values of 5 and 10 mm, respectively.

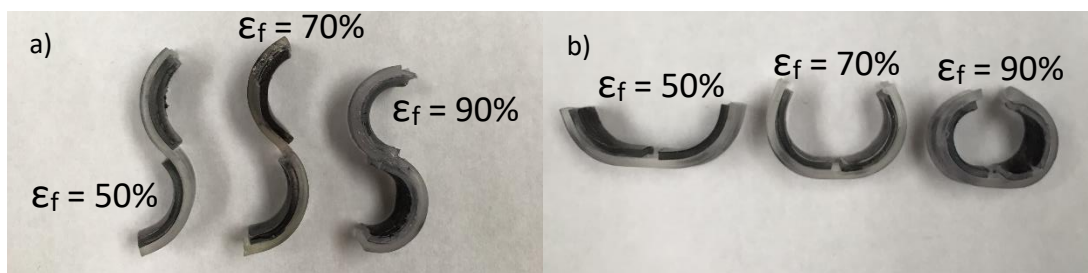


Figure S13: SEBS bilayer hinges constructed by adhering the active layers on a) opposite sides and b) on the same side of the passive layer. The annotated fixed strains correspond to the strain fixed within the active layer prior to recovery.

Table S1: Summary of programming temperatures and applied stresses used for G1650 SEBS DMA shape memory cycling. These values correspond to Figure 3 in the manuscript.

Applied Stress (MPa)	Programming Temperature (°C)				
	40	60	80	90	100
	1.3	1.0	0.7	0.6	0.1
	1.5	1.3	1.0	0.8	0.2
	1.8	1.5	1.15	0.9	
	2.0	1.8	1.3		

Table S2: Second cycle fixity and recovery values of G1650, G1652, and G1654 SEBS corresponding to Figures 3 and 7 in the manuscript.

G1652			G1654		
Programming Temperature (°C)					
80			80		
ϵ_a	% Fixity	% Recovery	ϵ_a	% Fixity	% Recovery
60.2	89.1	79.0	56.2	46.9	89.5
198.7	87.7	72.1	81.8	43.5	90.6
			184.0	27.0	89.5
			273.8	22.3	78.6
G1650					
Programming Temperature (°C)					
40			60		
ϵ_a	% Fixity	% Recovery	ϵ_a	% Fixity	% Recovery
35.0	8.8	52.6	40.1	36.4	82.4
61.7	9.8	55.0	58.0	36.5	84.9
140.8	6.9	50.7	91.6	32.2	80.1
213.4	6.5	39.6	333.8	16.8	70.4
80			90		
ϵ_a	% Fixity	% Recovery	ϵ_a	% Fixity	% Recovery
45.0	65.5	89.5	64.5	79.0	88.0
84.3	63.7	90.2	99.1	80.8	89.0
150.0	60.0	91.0	150.6	78.7	87.2
216.8	53.7	85.0			
100					
ϵ_a	% Fixity	% Recovery			
23.8	85.3	44.7			
34.6	84.4	72.6			

Table S3: First cycle fixity and recovery values of G1650, G1652, and G1654 SEBS corresponding to Figures 3 and 7 in the manuscript.

G1652			G1654		
Programming Temperature (°C)					
80			80		
ε _a	% Fixity	% Recovery	ε _a	% Fixity	% Recovery
50.4	92.5	47.6	54.0	67.7	39.1
114.6	91.0	54.9	78.5	64.2	39.9
			165.4	45.6	43.8
			230.0	40.3	39.4
G1650					
Programming Temperature (°C)					
40			60		
ε _a	% Fixity	% Recovery	ε _a	% Fixity	% Recovery
33.2	43.3	6.9	38.3	59.0	33.2
56.6	40.3	7.9	54.0	55.6	40.0
120.4	30.0	9.7	82.5	50.2	40.6
176.9	25.8	8.8	274.9	32.8	33.3
80			90		
ε _a	% Fixity	% Recovery	ε _a	% Fixity	% Recovery
43.0	76.7	51.5	58.0	84.8	58.7
77.5	73.0	58.1	85.6	84.7	65.2
130.1	66.9	59.1	123.8	82.6	64.0
175.8	67.0	56.4			
100					
ε _a	% Fixity	% Recovery			
18.7	95.0	8.2			
28.1	91.8	32.9			

Table S4: Third cycle fixity and recovery values of G1650, G1652, and G1654 SEBS corresponding to Figures 3 and 7 in the manuscript.

G1652			G1654		
Programming Temperature (°C)					
80			80		
ϵ_a	% Fixity	% Recovery	ϵ_a	% Fixity	% Recovery
68.9	89.7	89.4	57.3	45.6	99.7
N/A	N/A	N/A	83.9	41.9	99.1
			195.9	24.3	98.1
			304.0	19.5	88.6
G1650					
Programming Temperature (°C)					
40			60		
ϵ_a	% Fixity	% Recovery	ϵ_a	% Fixity	% Recovery
36.0	7.8	94.1	41.0	34.6	96.4
64.8	7.7	78.3	60.1	34.8	97.1
154.5	5.5	58.5	95.3	29.1	97.4
236.8	4.7	58.4	372.4	14.4	77.6
80			90		
ϵ_a	% Fixity	% Recovery	ϵ_a	% Fixity	% Recovery
47.0	65.5	98.9	68.4	78.8	97.1
89.5	62.6	98.2	123.1	80.6	88.3
167.1	52.1	93.9	N/A	N/A	N/A
252.6	50.1	90.0			
100					
ϵ_a	% Fixity	% Recovery			
28.5	85.1	55.0			
51.1	84.1	80.8			

Table S5: Second cycle fixity and recovery values of G1650 SEBS corresponding to Figure 5b-c in the manuscript.

% Applied Strain					
50			100		
Annealing Time (min)	% Fixity	% Recovery	Annealing Time (min)	% Fixity	% Recovery
15	68.7	89.1	15	71.0	82.8
45	76.0	66.2	45	80.9	61.7
75	77.9	55.8	75	83.8	55.3
315	84.1	39.0	315	88.9	39.2
150					
Annealing Time (min)	% Fixity	% Recovery			
15	67.7	84.8			
45	83.3	63.4			
75	84.0	60.9			
315	N/A	N/A			

Table S6: First cycle fixity and recovery values of G1650 SEBS corresponding to Figure 5b-c in the manuscript.

% Applied Strain					
50			100		
Annealing Time (min)	% Fixity	% Recovery	Annealing Time (min)	% Fixity	% Recovery
15	80.9	47.0	15	79.1	50.8
45	80.4	45.8	45	78.6	52.7
75	78.7	46.7	75	78.9	52.9
315	80.9	45.7	315	80.7	52.2
150					
Annealing Time (min)	% Fixity	% Recovery			
15	75.9	55.1			
45	77.1	55.4			
75	76.0	56.2			
315	76.3	53.6			

Table S7: Fixity and recovery values of G1652 SEBS corresponding to Figure 8a-b in the manuscript.

*Corresponds to l_i values of 10 mm. Red values correspond to the second cycle.

Annealing Time (min)					
0.1			1		
ϵ_a	% Fixity	% Recovery	ϵ_a	% Fixity	% Recovery
62.5	55.8	91.2	62.4	77.2	70.9
120.5	57.5	81.5	115.1	75.2	66.6
164.0	47.1	83.3	157.0	77.3	65.3
42.9*	67.8	83.5	49.1*	78.4	72.1
91.2*	63.5	82.6	97.2*	76.4	74.4
148.6*	56.1	86.5	168.6*	74.4	73.4
10					
ϵ_a	% Fixity	% Recovery			
39.1	90.8	40.1			
61.1	84.3	43.1			
41.6*	91.7	34.8			
86.2*	88.4	39.5			
121.5*	82.4	37.8			
10.3	98.4	92.5			
38.46*	89.2	86.6			
82.5*	90.4	83.0			
110.4*	87.7	82.7			

Table S8: Fixity and recovery values of G1650 SEBS corresponding to Figure 8c-d in the manuscript.

*Corresponds to l_i values of 10 mm. Red values correspond to the second cycle.

Annealing Time (min)					
0.1			1		
ϵ_a	% Fixity	% Recovery	ϵ_a	% Fixity	% Recovery
84.3	37.1	87.9	81.3	50.0	82.2
110.1	26.9	82.5	126.8	42.5	76.5
159.5	20.6	80.5	182.2	39.0	75.7
61.7*	50.8	80.7	61.2*	60.8	89.9
94.0*	38.6	81.0	110.3*	46.0	82.5
145.8*	31.2	82.4	149.2*	39.3	85.8
10					
ϵ_a	% Fixity	% Recovery			
77.8	63.0	67.2			
118.3	62.3	64.7			
83.0	68.1	58.9			
102.6	70.7	67.0			
61.5*	71.1	64.6			
120.3*	58.9	67.5			
165.4*	53.5	63.4			
44.7	60.0	85.9			
58.1	75.5	87.6			
53.2*	71.1	86.2			
79.5*	62.0	88.2			
136.1*	64.5	87.9			

Table S9: Fixity and recovery values of G1654 SEBS corresponding to Figure 8e-f in the manuscript.

*Corresponds to l_i values of 10 mm. Red values correspond to the second cycle.

Annealing Time (min)					
0.1			1		
ϵ_a	% Fixity	% Recovery	ϵ_a	% Fixity	% Recovery
92.3	23.6	83.4	68.9	30.7	70.8
131.9	19.9	83.6	117.9	26.5	75.2
192.2	14.7	69.5	186.0	148.6	64.0
65.1*	32.7	78.1	50.9*	36.5	78.4
91.1*	34.0	76.4	97.2*	21.4	81.4
151.7*	17.2	83.7	168.4*	21.8	73.5
10					
ϵ_a	% Fixity	% Recovery			
68.4	47.3	64.5			
103.5	39.7	70.2			
110.5	39.5	61.5			
134.4	36.2	67.9			
176.0	25.8	75.5			
187.2	28.3	63.2			
70.6*	43.7	70.0			
117.7*	35.1	70.0			
176.0*	29.6	71.5			
75.8	34.1	88.4			
101.4	34.1	88.7			
138.6	25.3	96.1			
57.2*	44.9	91.2			
87.7*	33.6	88.4			
147.5*	23.2	82.1			

Table S10: Second cycle fixity and recovery values of G1650, G1652, and G1654 SEBS corresponding to Figure S11 in the Supporting Information.

SEBS Molecular Weight					
G1652			G1654		
Annealing Time (min)	% Fixity	% Recovery	Annealing Time (min)	% Fixity	% Recovery
15	86.1	81.3	15	41.8	91.3
45	92.5	53.1	45	48.5	79.0
75	97.1	33.9	75	52.8	72.4
315	96.5	14.6	315	57.3	53.5
G1650					
Annealing Time (min)	% Fixity	% Recovery			
15	71.0	82.8			
45	80.9	61.7			
75	83.8	55.3			
315	88.9	39.2			

Table S11: First cycle fixity and recovery values of G1650, G1652, and G1654 SEBS corresponding to Figure S11 in the Supporting Information.

SEBS Molecular Weight					
G1652			G1654		
Annealing Time (min)	% Fixity	% Recovery	Annealing Time (min)	% Fixity	% Recovery
15	92.7	49.2	15	53.5	48.3
45	90.4	52.4	45	53.7	50.1
75	93.7	54.4	75	53.7	47.5
315	86.5	55.3	315	54.0	47.5
G1650					
Annealing Time (min)	% Fixity	% Recovery			
15	79.1	50.8			
45	78.6	52.7			
75	78.9	52.9			
315	80.7	52.2			