

Appendix: Flexural strengthening of large-scale reinforced concrete beams using near-surface-mounted self-prestressed iron-based shape-memory alloy strips

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This appendix contains additional figures for “Flexural Strengthening of Large-Scale Reinforced Concrete Beams Using Near-Surface-Mounted Self-prestressed Iron-Based Shape-Memory Alloy Strips” by Raafat El-Hacha and Hothifa Rojob, which appears on pages 55–65 in the November–December 2018 issue of *PCI Journal*.

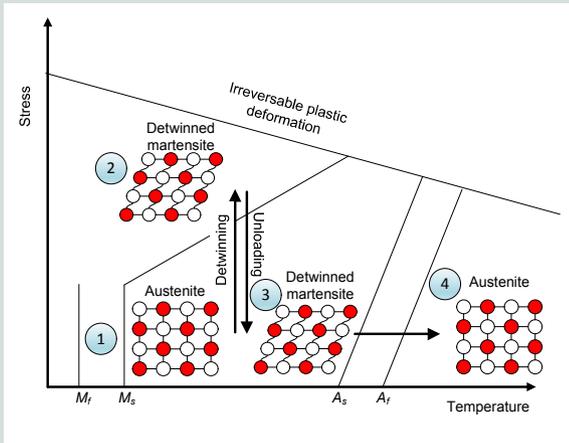


Figure A1. Phase diagram of iron-based shape-memory alloy material. Source: Adapted from Cladera et al., “Iron-Based Shape Memory Alloys for Civil Engineering Structures: An Overview,” *Construction and Building Materials*, 63 (2014): 281–293. Note: A_f = austenite finish temperature; A_s = austenite start temperature; M_f = martensite finish temperature; M_s = martensite start temperature.

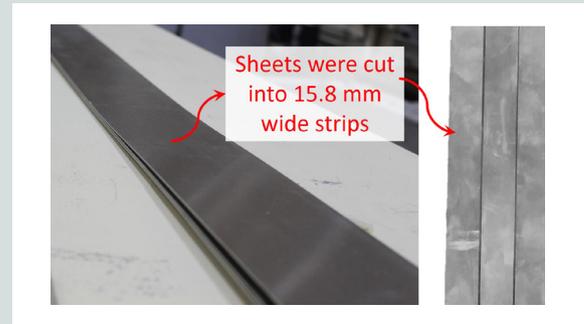


Figure A2. The iron-based shape-memory alloy sheets were cut into 15.8 mm wide strips. Note: 1 mm = 0.0394 in.

Table A1. Compressive strength of concrete

Beam	Compressive strength, MPa	
	At 28 days	At testing
B-C	46.1 ± 1.8	51.3 ± 0.6
B-SMA-0	45.8 ± 1.3	48.6 ± 0.9
B-SMA-1		
B-SMA-2		

Note: SMA = shape-memory alloy. 1 MPa = 0.145 ksi.

Table A2. Comparison between the carbon-fiber-reinforced-polymer-strengthened beams and the shape-memory-alloy-strengthened beams

Parameter	B-SMA-1	CFRP-20	SMA/CFRP*	B-SMA-2	CFRP-40	SMA/CFRP
Cracking load P_{cr} , kN	25.2	22.1	1.14	31.2	27.9	1.12
Yielding load P_y , kN	103	105.7	0.97	112.6	114.5	0.98
Ultimate load P_u , kN	127.3	141	0.90	138.9	141.7	0.98
Deflection at yield Δ_y , mm	25.6	27.7	0.92	25	28.6	0.87
Deflection at ultimate Δ_u , mm	146.5	92.5	1.58	132	79.3	1.66
Ductility index Δ_u/Δ_y	5.7	3.34	1.71	5.3	2.77	1.90
Energy dissipated,† kN-mm x 10 ³	16.5	9.9	1.66	15.9	8.7	1.84

Note: CFRP = carbon-fiber-reinforced polymer; SMA = shape-memory alloy. 1 mm = 0.0394 in.; 1 kN = 0.225 kip. *Ratio of the shape-memory alloy beam results to the carbon-fiber-reinforced polymer beam results.

†Calculated as the area under the load-deflection curve up to the failure load.

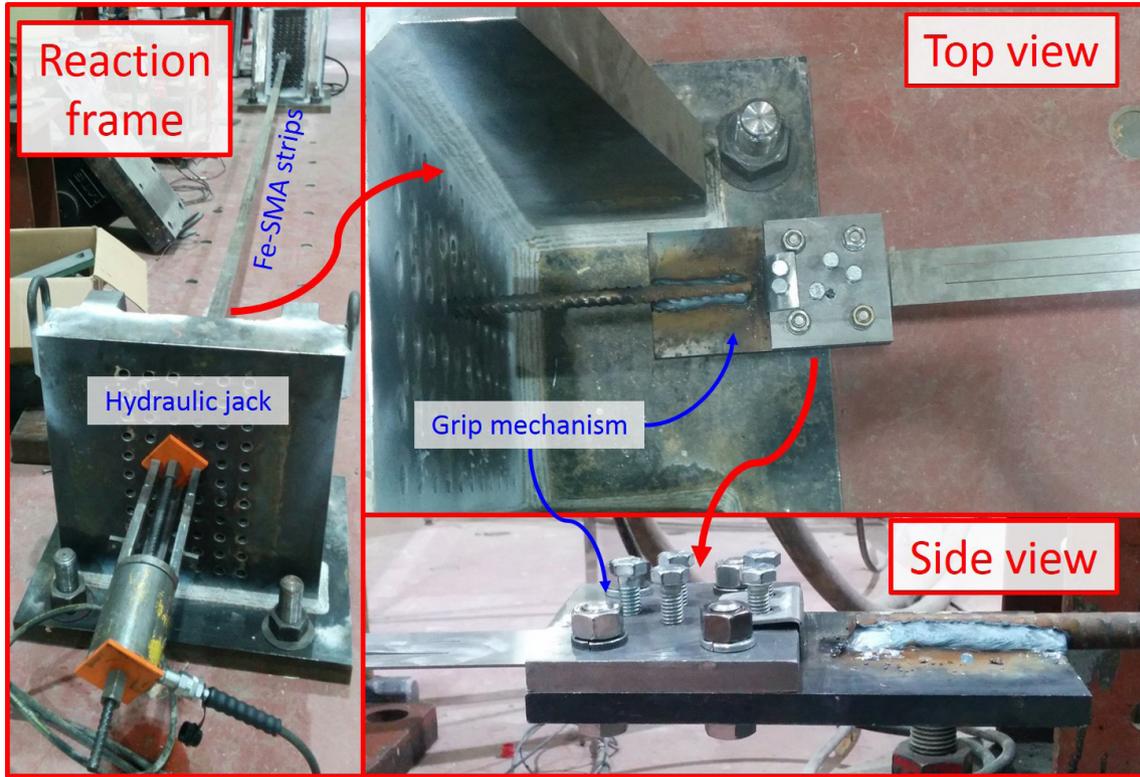


Figure A3. The reaction frame used to apply the initial strain to the Fe-SMA strips. Note: Fe-SMA = iron-based shape-memory alloy.

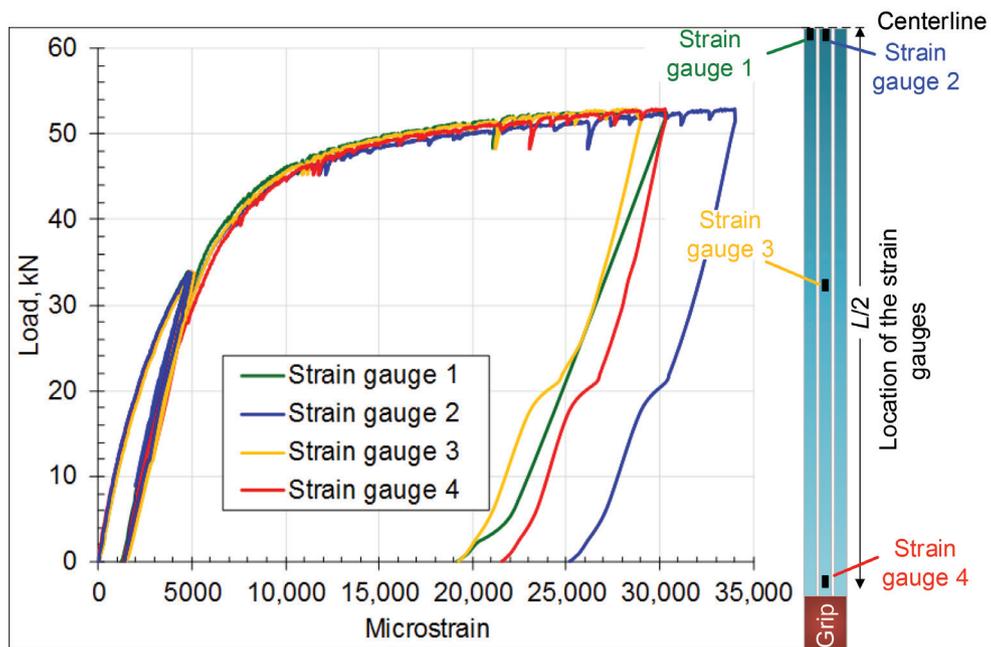


Figure A4. The application of the initial strain to the Fe-SMA strips in groups of three strips. Note: The locations of the strain gauges are shown on the side of the figure. L = length. 1 kN = 0.225 kip.

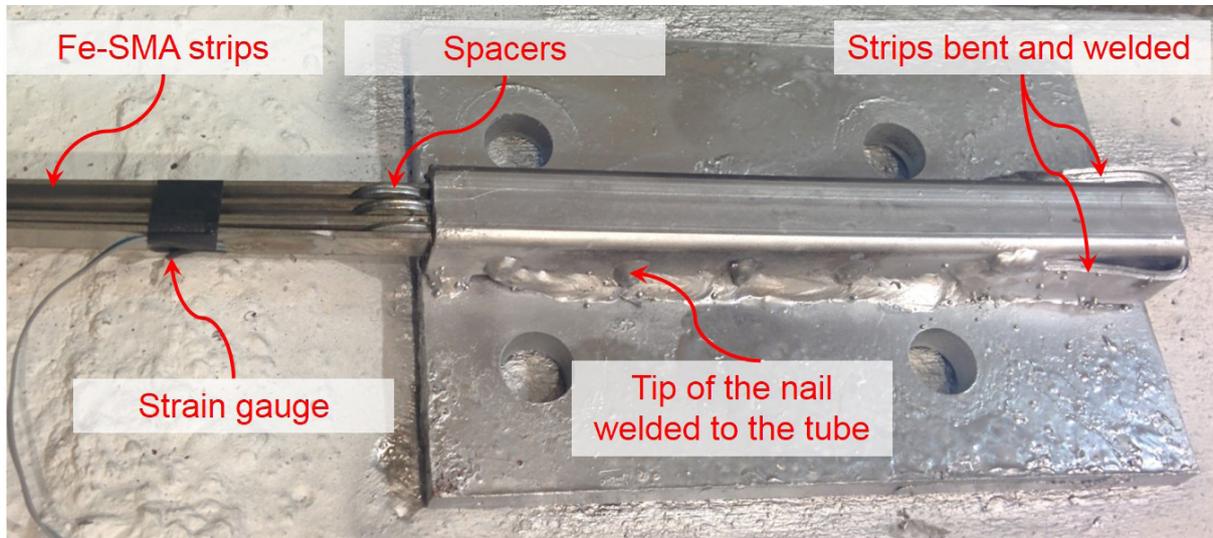


Figure A5. End anchor before being placed in the beam. Note: Fe-SMA = iron-based shape-memory alloy.

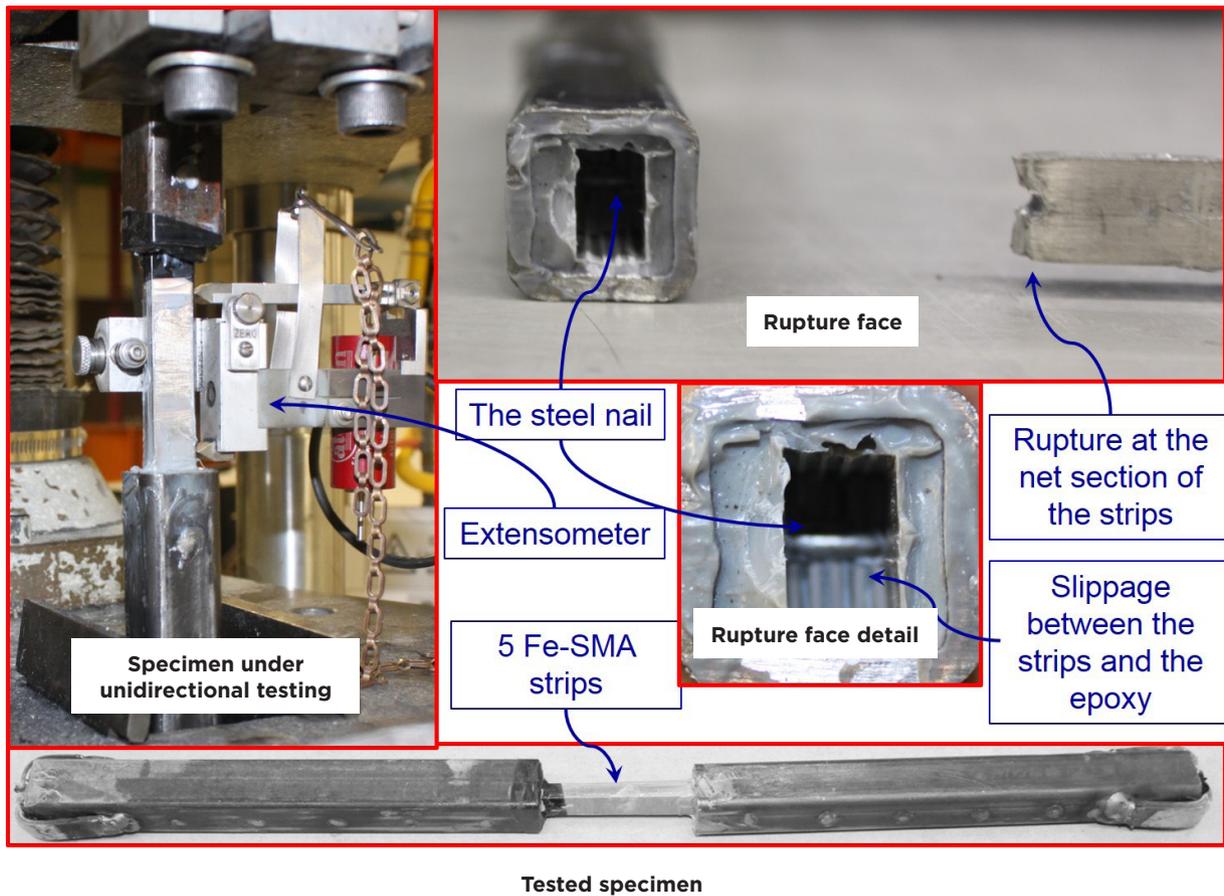


Figure A6. Testing the capacity of the end anchor. Note: Fe-SMA = iron-based shape-memory alloy.

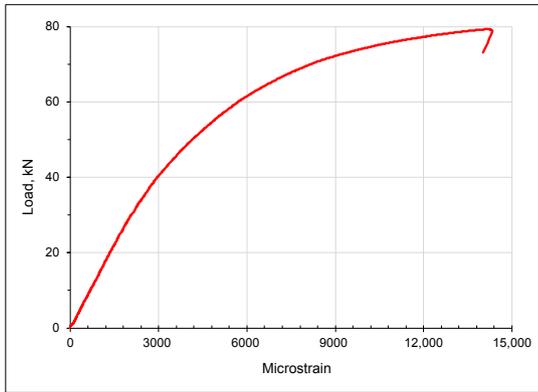


Figure A7. Load versus strain from the unidirectional tensile test of the end anchor. Note: 1 kN = 0.225 kip.



Figure A8. The end anchors connected to the beam.

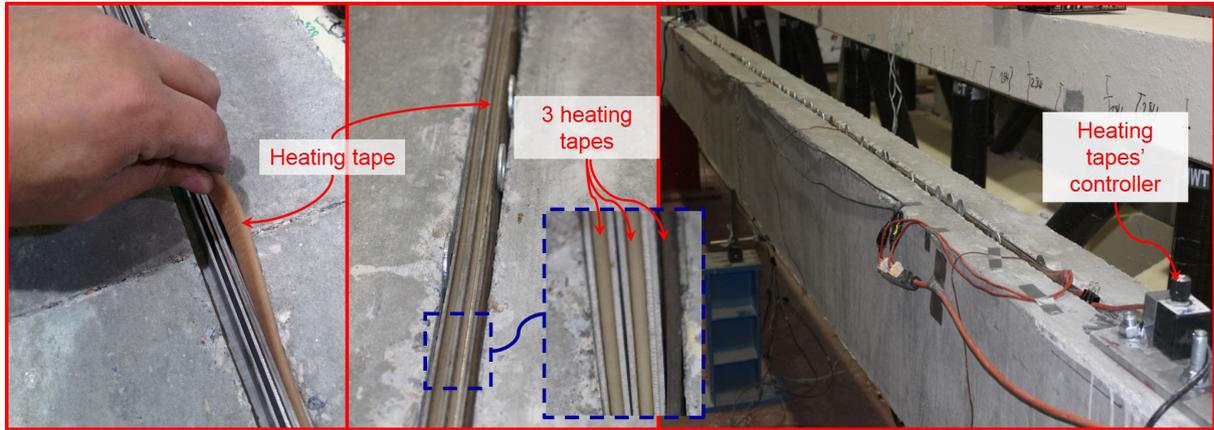
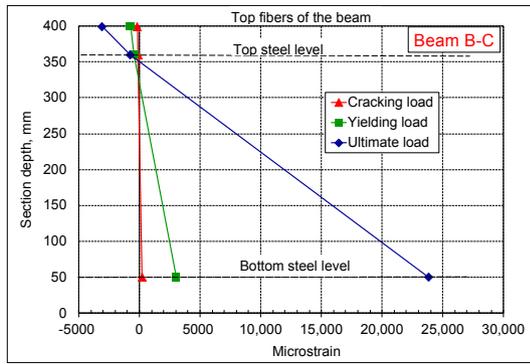


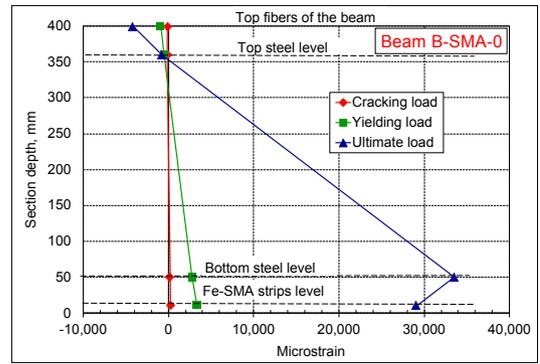
Figure A9. Inserting the heating tape between the iron-based shape-memory alloy strip.



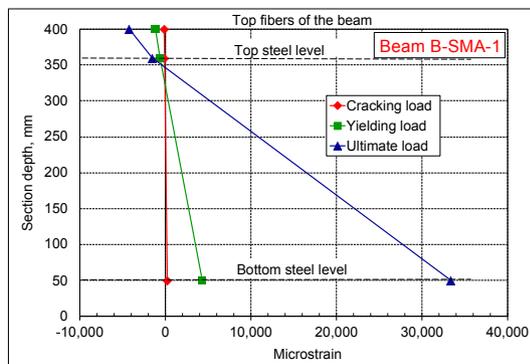
Figure A10. Filling the groove with paste adhesive.



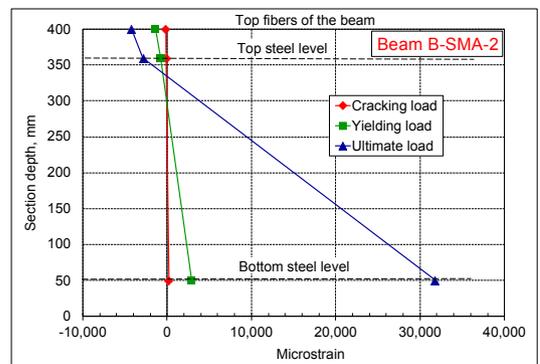
Beam B-C



Beam B-SMA-0



Beam B-SMA-1



Beam B-SMA-2

Figure A11. The strain distribution across the depth of the beams at midspan section. Note: Fe-SMA = iron-based shape-memory alloy. 1 mm = 0.0394 in.