NASA
Engineering Directorate
Materials Science Division
Kennedy Space Center, Florida

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SUBJECT: Properties of Refractory Concrete in Tension and Compression

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1. FOREWORD

Refractory concrete on the LC-39A Flame Deflector has been damaged during multiple Space Shuttle launches (e.g. STS-124, STS-126, STS-119, and STS-125, STS-127). These events have prompted a better understanding of the system via an analytical model of the Flame Deflector assembly to include the Fondu Fyre refractory concrete. This model requires test data inputs of the refractory concrete's mechanical properties, which include stress versus strain curves in tension and compression, modulus of elasticity, and Poisson's ratio. Sections of Fondu Fyre refractory concrete removed from the LC-39A Flame Deflector were provided for this testing.

2. PROCEDURE AND RESULTS

2.1. Compression testing of ten specimens was performed per ASTM C 39. Specimens were prepared using a 3 inch inner-diameter core drill. The specimen height was determined by the thickness of the Fondu Fyre refractory concrete sections provided for testing. The sections of Fondu Fyre provided for compression testing are shown in Figure 1.

2.1.1. All test specimens were dried in an oven at 230ºF for 18 hours prior to testing. The rate of loading was 14000 lbf/min, which corresponds to the specification value of 35 psi/sec ±10%. Neoprene end caps were used for the first specimen, but this test gave excessive deflection in the load versus displacement curve. All subsequent testing was performed with Masonite, 0.125 inches thick, between the specimen and the bearing surfaces.

2.1.2. Three of the ten specimens were submerged in tap water for 8 days. These specimens are labeled 'wet' in Table 1.

2.1.3. Four compression test specimens were instrumented with Vishay strain gages (part number: C2A-06-20CLW-350) to precisely measure the compressive strain in the axial (i.e. longitudinal) and diametric (i.e. radial) directions. All four strain gages were wired in a quarter Wheatstone bridge configuration. Two gages were bonded longitudinally and two gages were bonded in a radial direction. Each set of strain gages were bonded180° apart and averaged to negate bending.

2.2. Tensile testing was performed with two sets of specimens prepared from material removed from the north side of the LC-39A Flame Deflector. This testing was not in accordance with a test standard since there is no known specification for directly testing concrete in tension. Tensile properties of refractory concrete have previously been measured from the modulus of resilience or splitting tensile methods.

2.2.1. Dogbone specimens were cut from thin sections of refractory concrete with a water-jet cutter. The testing rate was 0.005 in/min. Strain was measured using an extensometer with a 2.0 inch gage length.

2.2.2. Bar specimens were prepared for tensile testing. Nine 1 inch x 1 inch x 6 inch bars were bonding to aluminum discs using Loctite® 1C Epoxi-Patch® adhesive. Screws were tapped into the ends of the disks and mounted to the Universal Testers using fastener testing fixtures. The testing rate was 0.010 in/min. Strain was measured using an extensometer with a 2.0 inch gage length.

3. <u>RESULTS</u>

3.1. Results of compression testing are included in Table 1. Curves of the load versus displacement are shown in Figure 3, with failed specimens shown in Figure 4.

3.1.1. The compression strength of the three specimens from the SSME-side of the Flame Deflector averaged 5803 psi, four specimens from the SRB-side averaged 3635 psi, and the three wet specimens from the SRB-side averaged 3479 psi.

3.1.2. Stress versus strain curves and photos of the compression specimens instrumented with strain gages are included in Figures 5-8. The ratio of axial strain to the diametric strain, or Poisson's ration, was calculated for each specimen and included in Table 2.

3.2. Tensile test results are included in Table 3.

3.2.1. The two dogbone specimens averaged 253 psi. Stress versus strain curves are shown in Figure 9. Pictures of the failed specimens are shown in Figure 10.

3.2.2. The nine bar specimens averaged 432 psi. Stress versus strain curves are shown in Figure 11. Pictures of the failed specimens are shown in Figure 12-14.

Table 1. Results of Compression Tests.

Specimen label	Diameter (in)	Height (in)	Comp. load (lbf)	Compressive stress (psi)
10	2.90	6.00	44080	6674
6	2.91	3.10	26897	4044
2	2.90	4.80	26490	4011
1	2.91	4.95	12293	1848
4	2.91	3.25	30850	4638
8	2.90	3.90	38990	5903
9	2.90	3.80	31908	4831
3-wet	2.90	3.50	28708	4346
7-wet	2.90	2.78	21482	3252
5-wet	2.90	3.35	18743	2838

Table 2. Results of Moduli Measurements from Compression Tests.

Specimen label	Axial Modulus (psi^6)	Diametric Modulus (psi^6)	Poisson's Ratio
1	17.46	1.95	0.111
2	14.17	2.57	0.182
4	11.59	3.02	0.260
6	21.34	1.45	0.068

Table 3. Results of Tensile Tests.

Specimen label	Width (in)	Thickness (in)	Modulus (psi^6)	Tensile load (lbf)	Tensile stress (psi)
B	1.49	0.31	1.54	124	272
C	1.49	0.19	1.97	65	235
1	1.08	1.07	2.86	359	310
2	1.06	1.13	3.17	497	415
8	1.03	1.09	3.52	516	460
4	0.90	1.08	2.45	465	478
3	1.03	1.08	2.66	718	645
7	0.85	1.04	5.83	455	515
9	0.89	1.02	3.84	296	326
6	0.76	1.02	4.21	343	443
10	1.09	1.10	1.47	354	295

EQUIPMENT:

Instron 4507 Universal Testing Machine (M68413) 11/13/2009

500 kg Load Cell (M68416) 11/13/2009

Instron 5889 Universal Testing Machine (5889Q S/N Q5246) 5/12/2010

60,000 kg Load Cell (5889Q S/N 52050) 5/12/2010

RELATED DOCUMENTATION:

ASTM C 39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

PRIMARY INVESTIGATOR: ______________________ NASA Kennedy Space Center 2009.11.13 09:53:12 -05'00'

Jeff Sampson/NE-L2-T

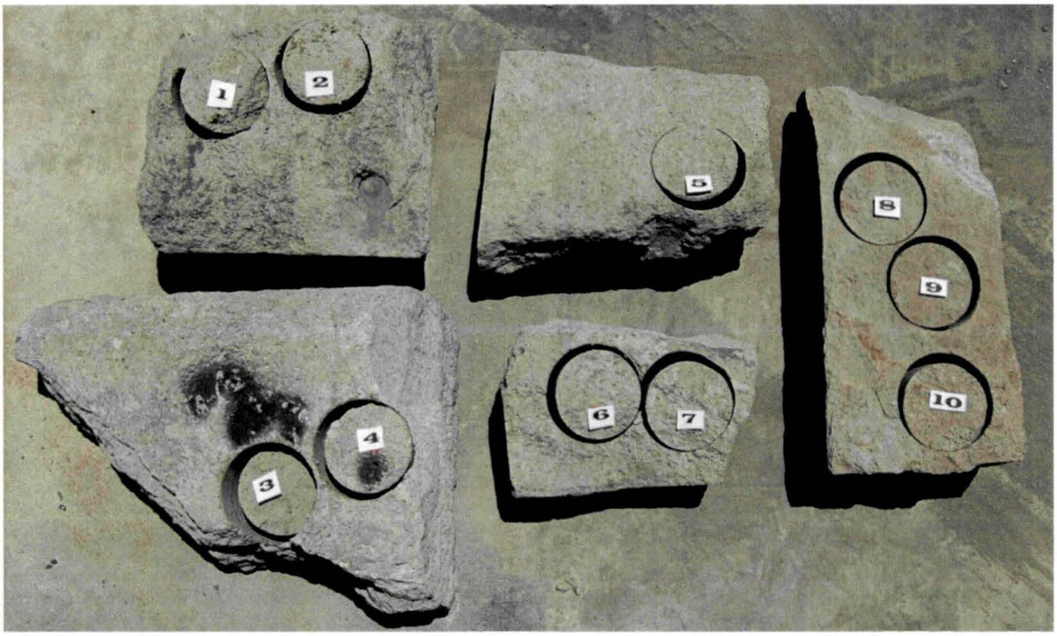

Figure 1. Four Sections of Fondu Fyre removed from SRB Flame Deflector (left and center) and One Section Removed from SSME Flame Deflector (right).

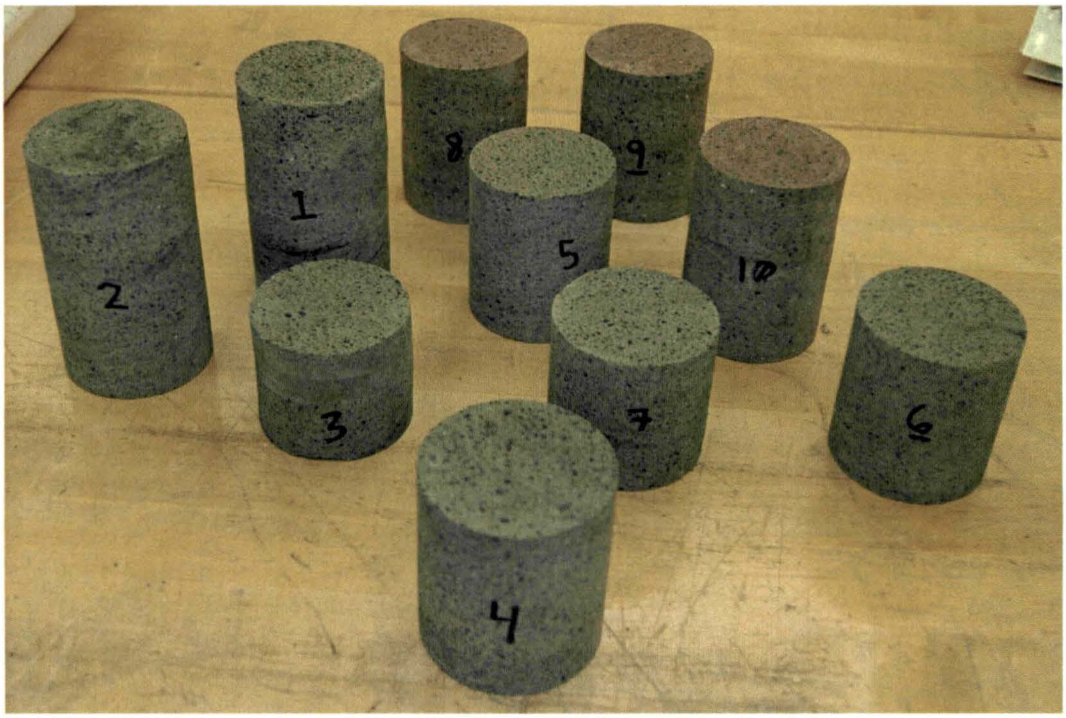

Figure 2. Compressive Strength Specimens.

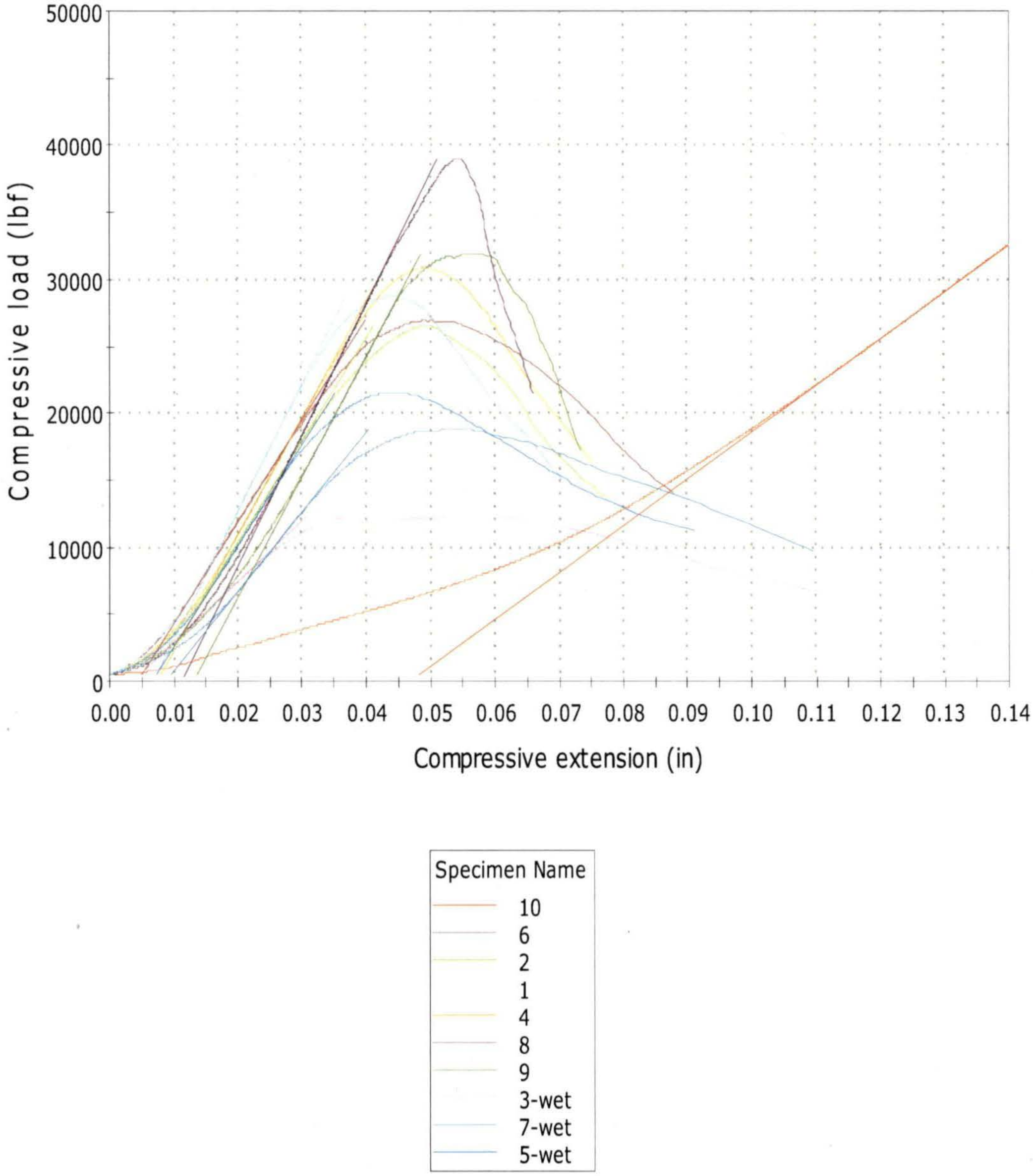

Figure 3. Load vs. Extension Curves for Compression Specimens.

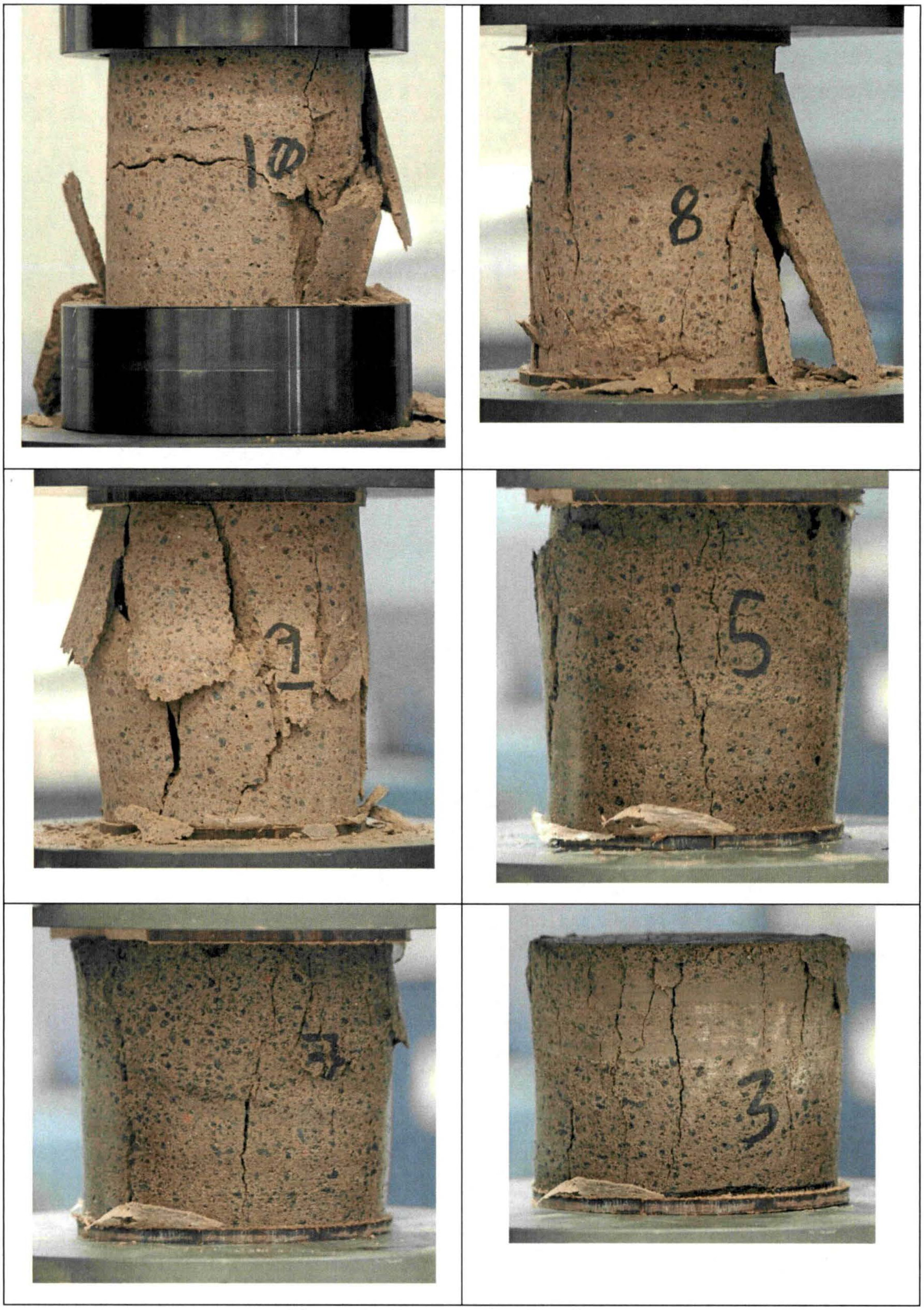

Figure 4. Compression Specimens.

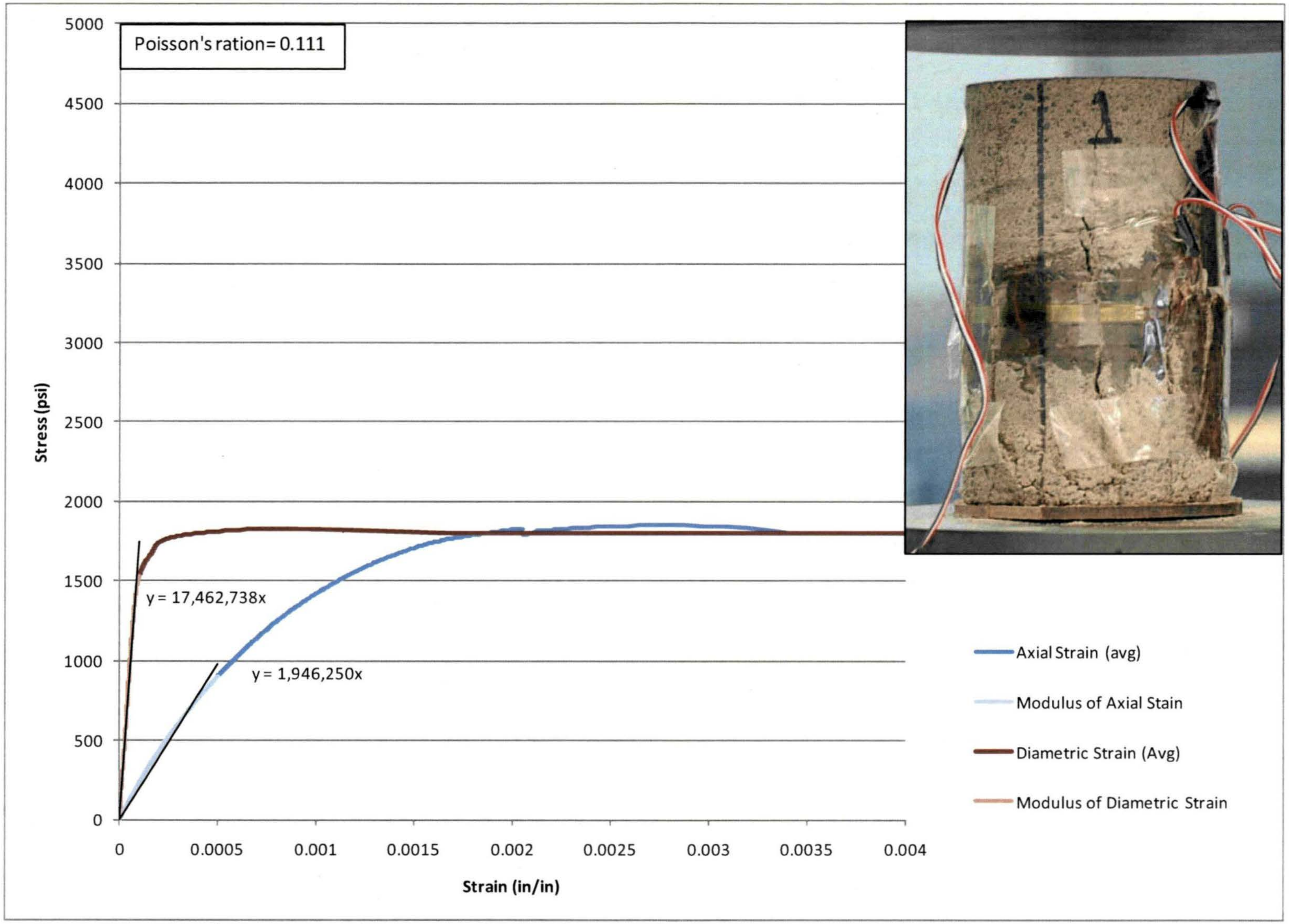

Figure 5. Stress vs. Strain Curves from Specimen 1 Loaded to Failure in Compression.

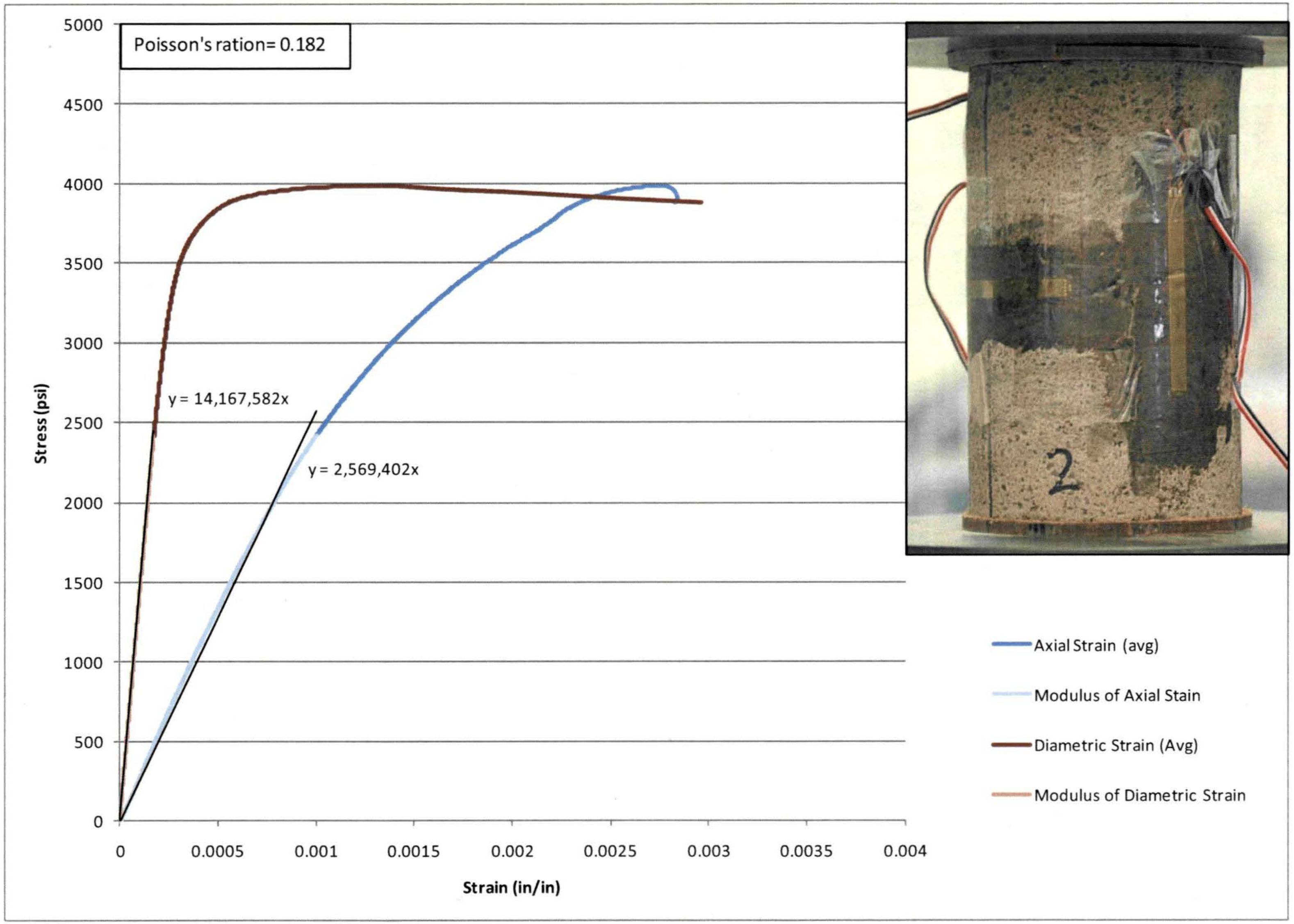

Figure 6. Stress vs. Strain Curves from Specimen 2 Loaded to Failure in Compression.

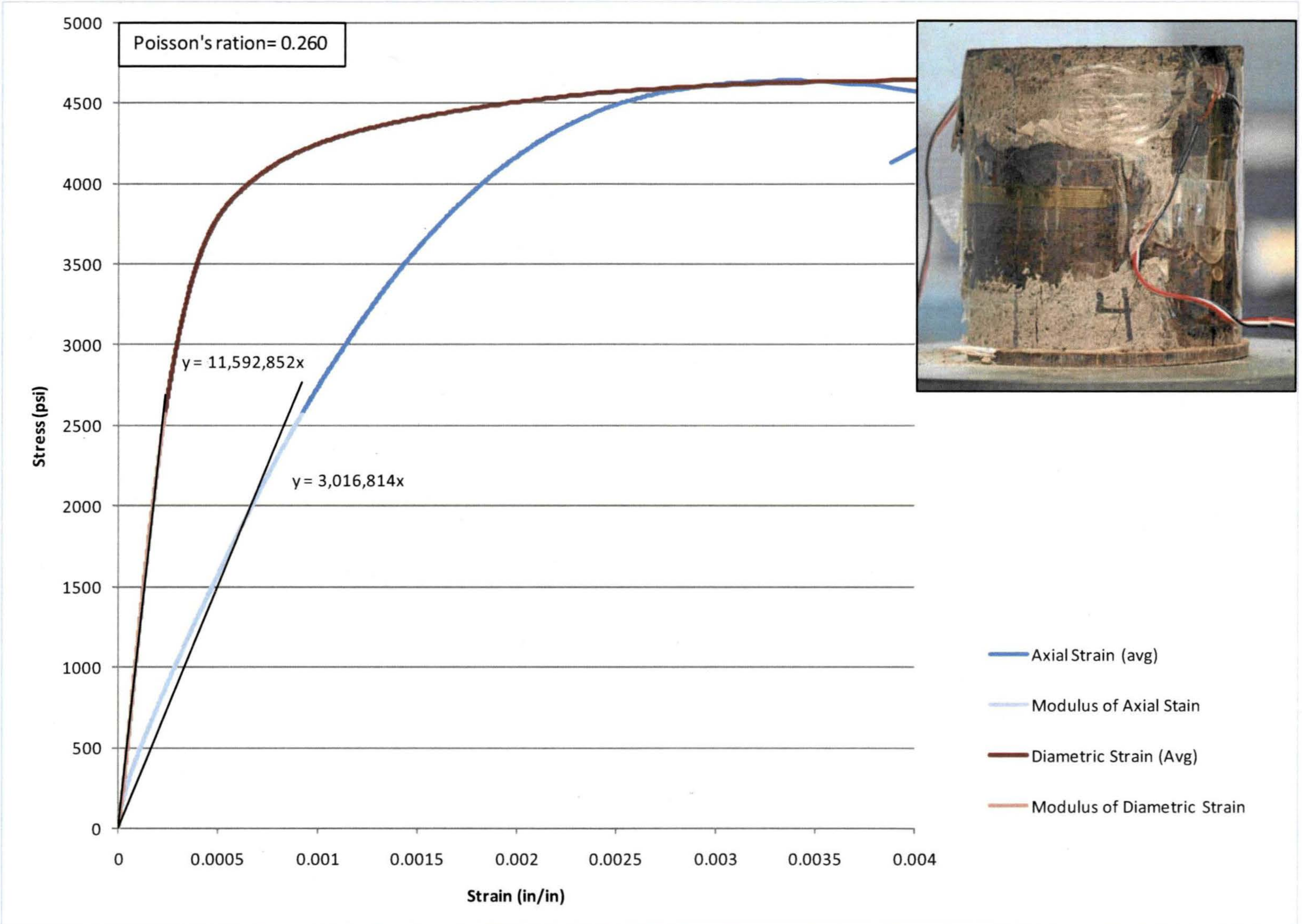

Figure 7. Stress vs. Strain Curves from Specimen 4 Loaded to Failure in Compression.

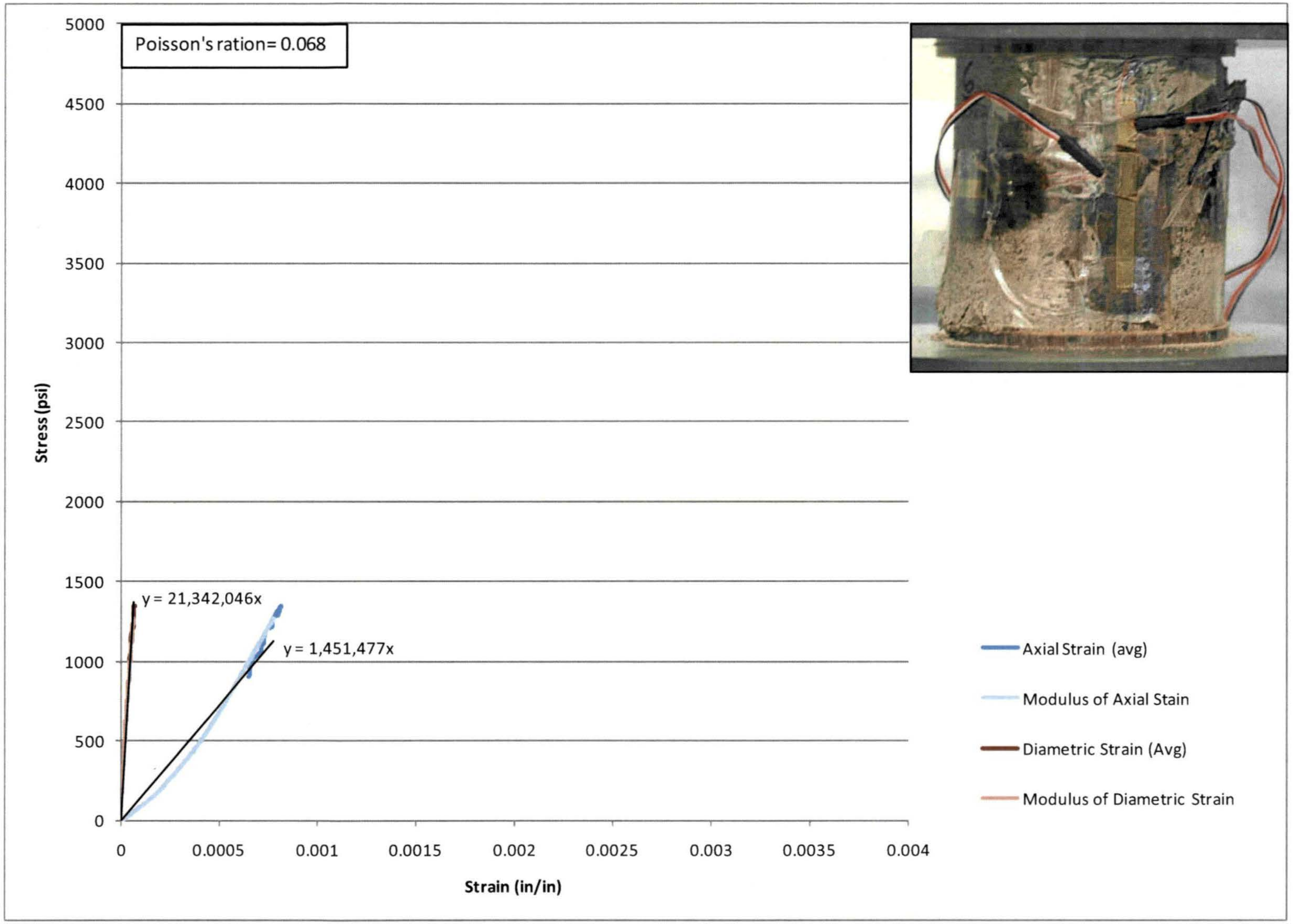

Figure 8. Stress vs. Strain Curves from Specimen 6 Loaded to Failure in Compression.

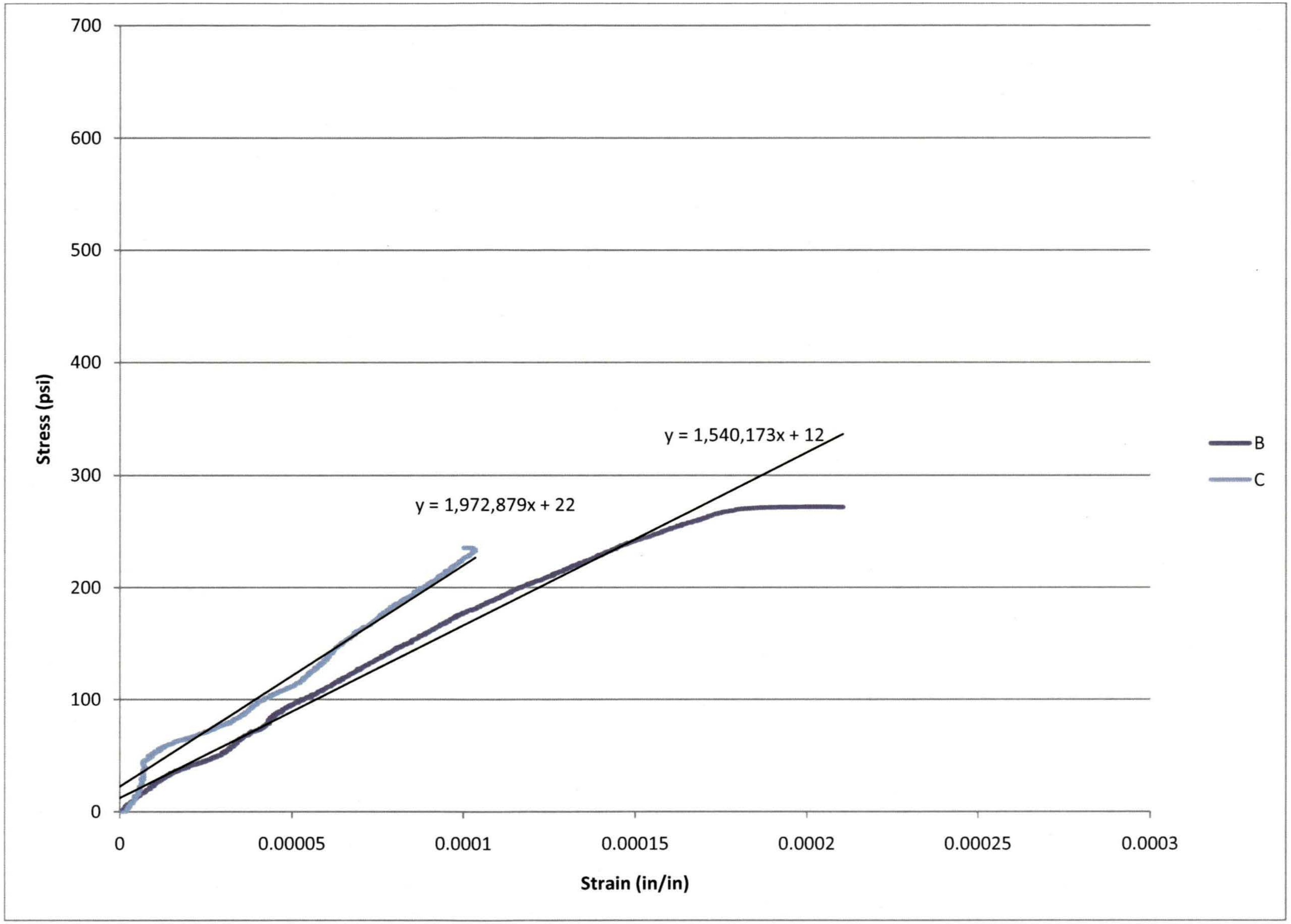

Figure 9. Stress vs. Strain Curves for Dogbone Specimens Loaded to Failure in Tension.

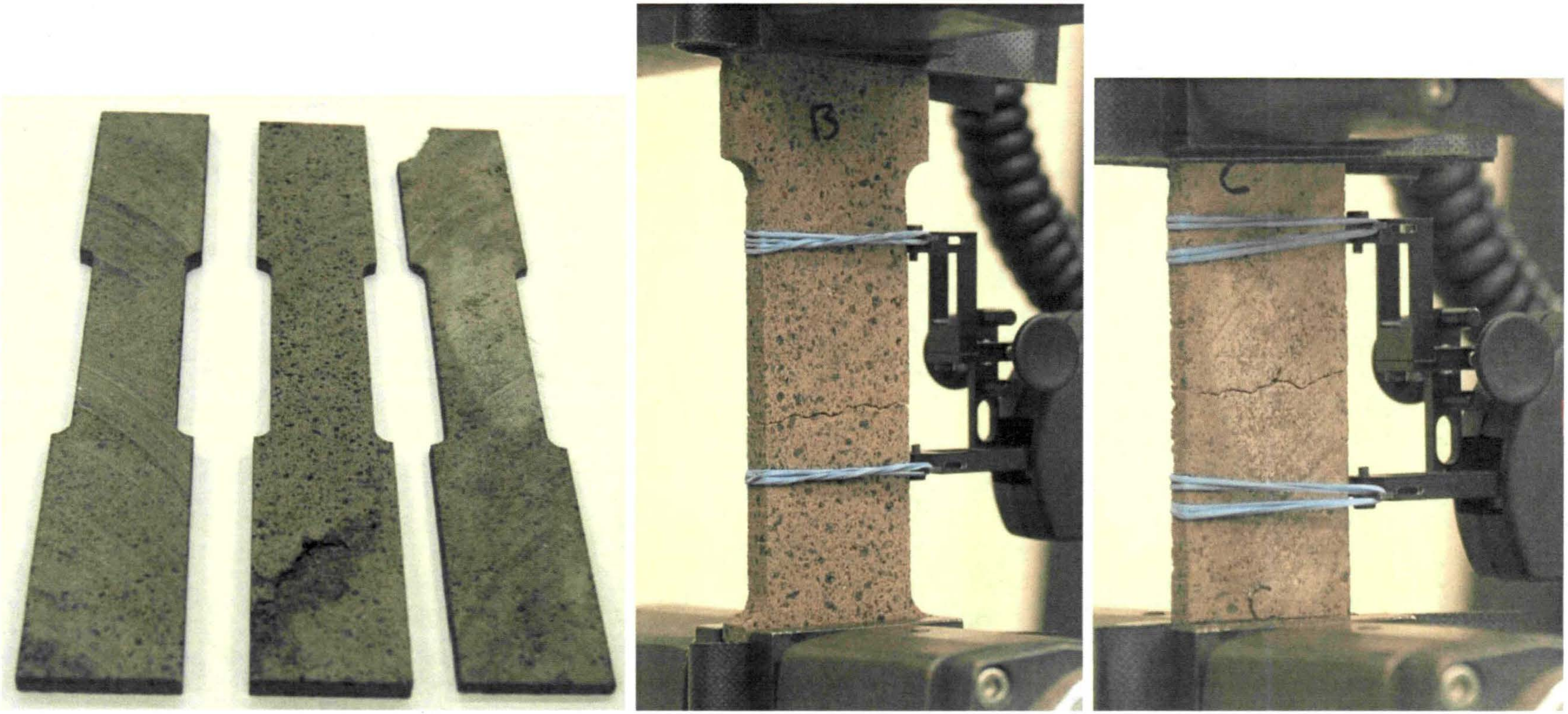

Figure 10. Dogbone Specimens.

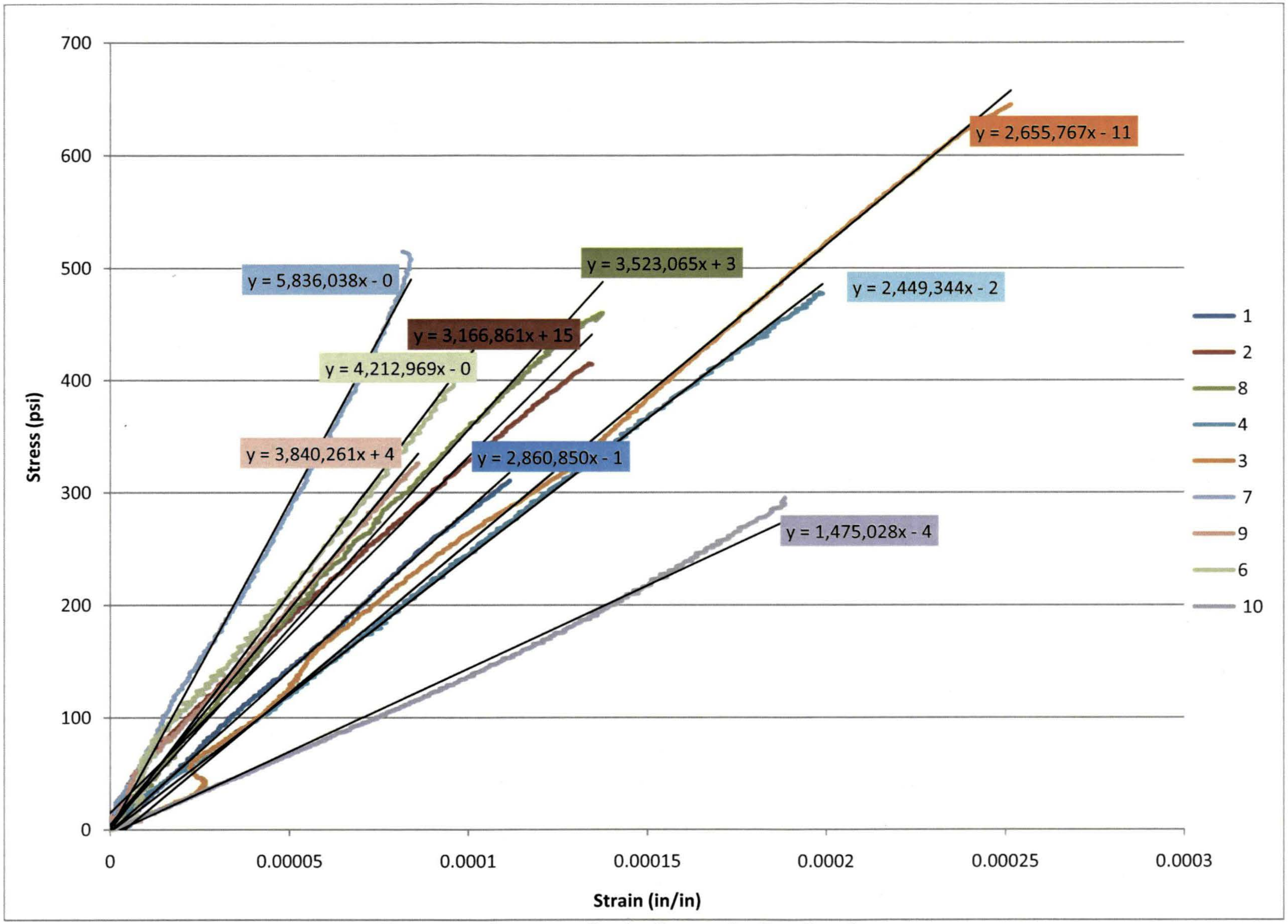

Figure 11. Stress vs. Strain Curves for Bar Specimens.

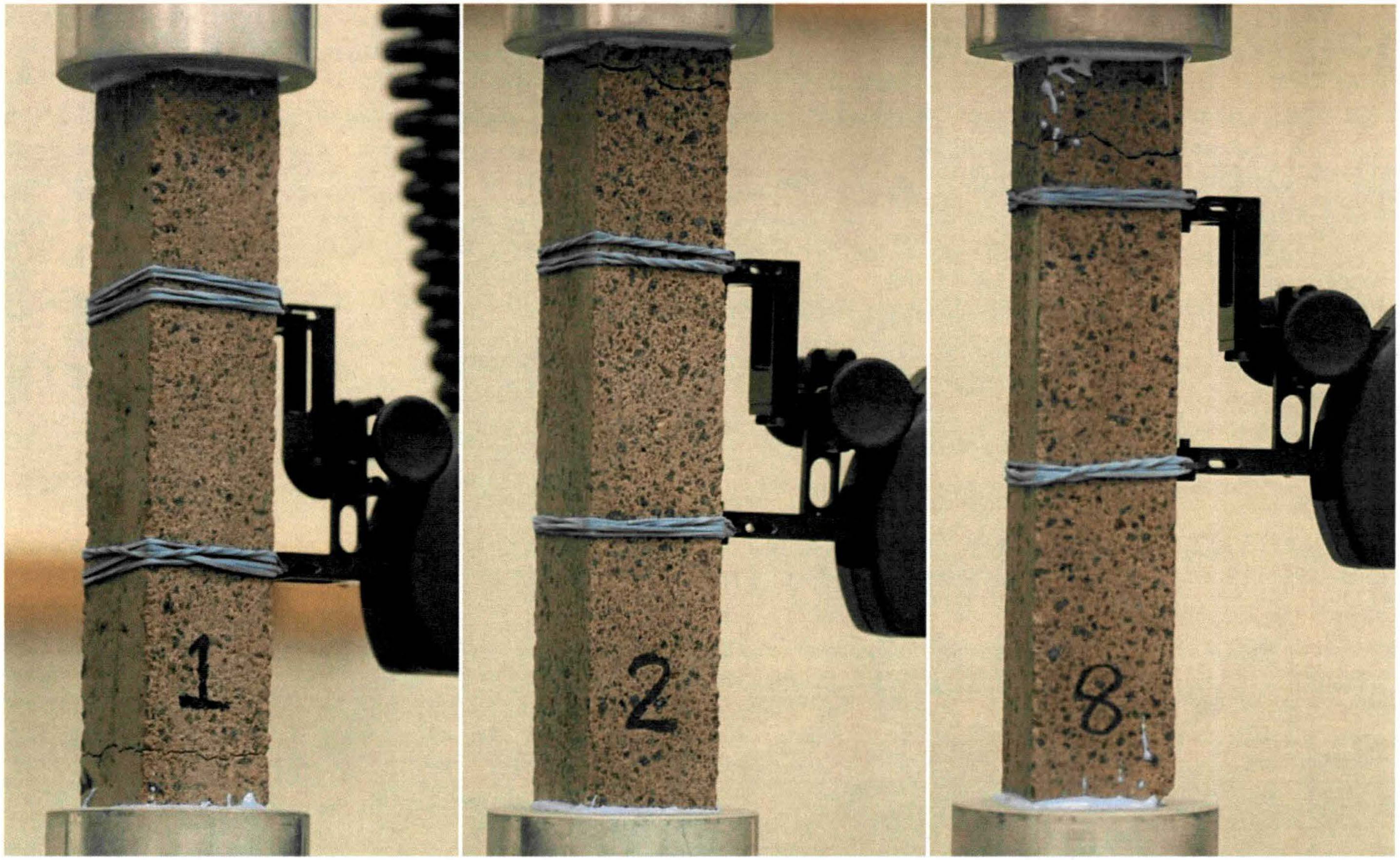

Figure 12. Bar Specimens Loaded to Failure in Tension.

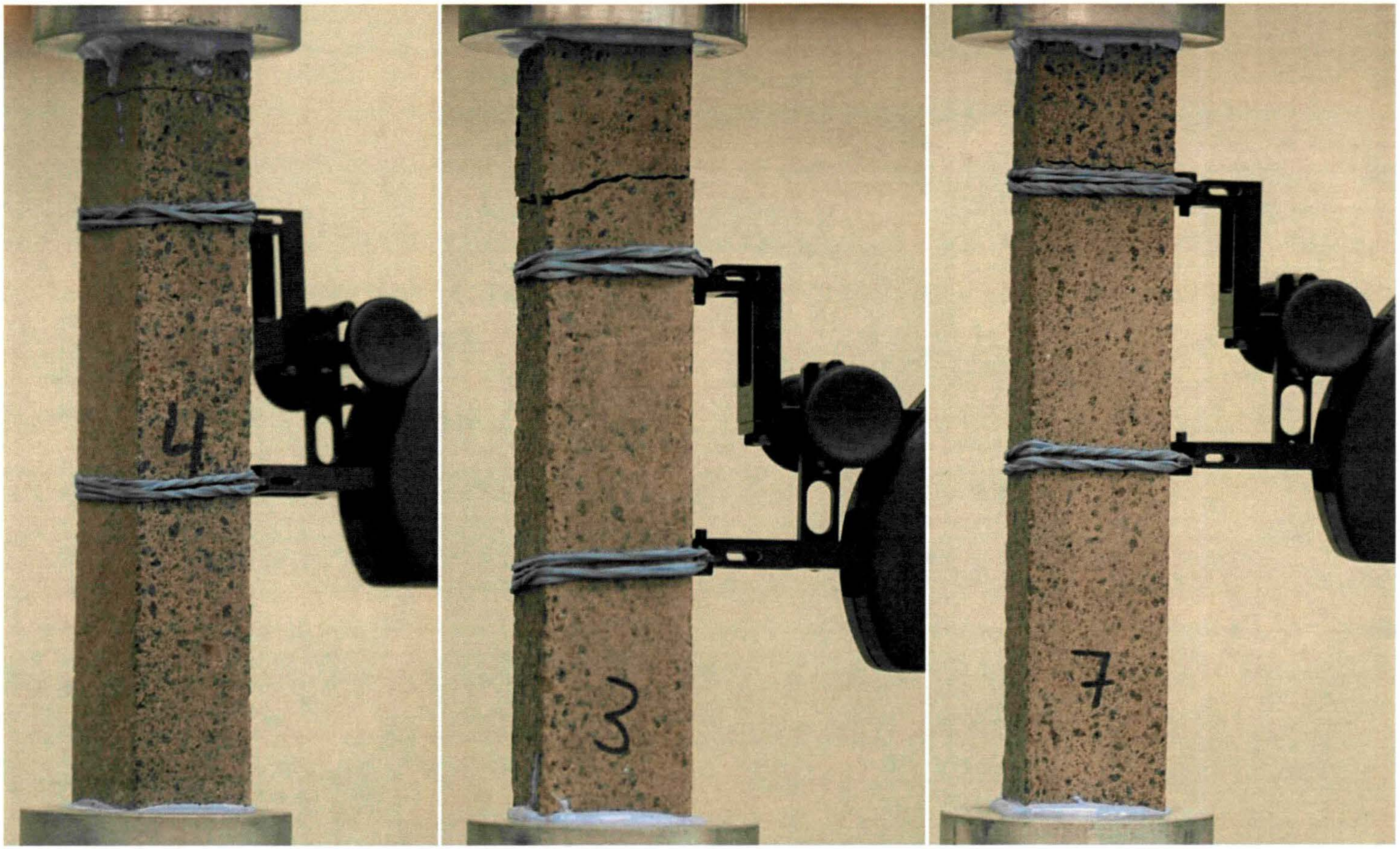

Figure 13. Bar Specimens Loaded to Failure in Tension.

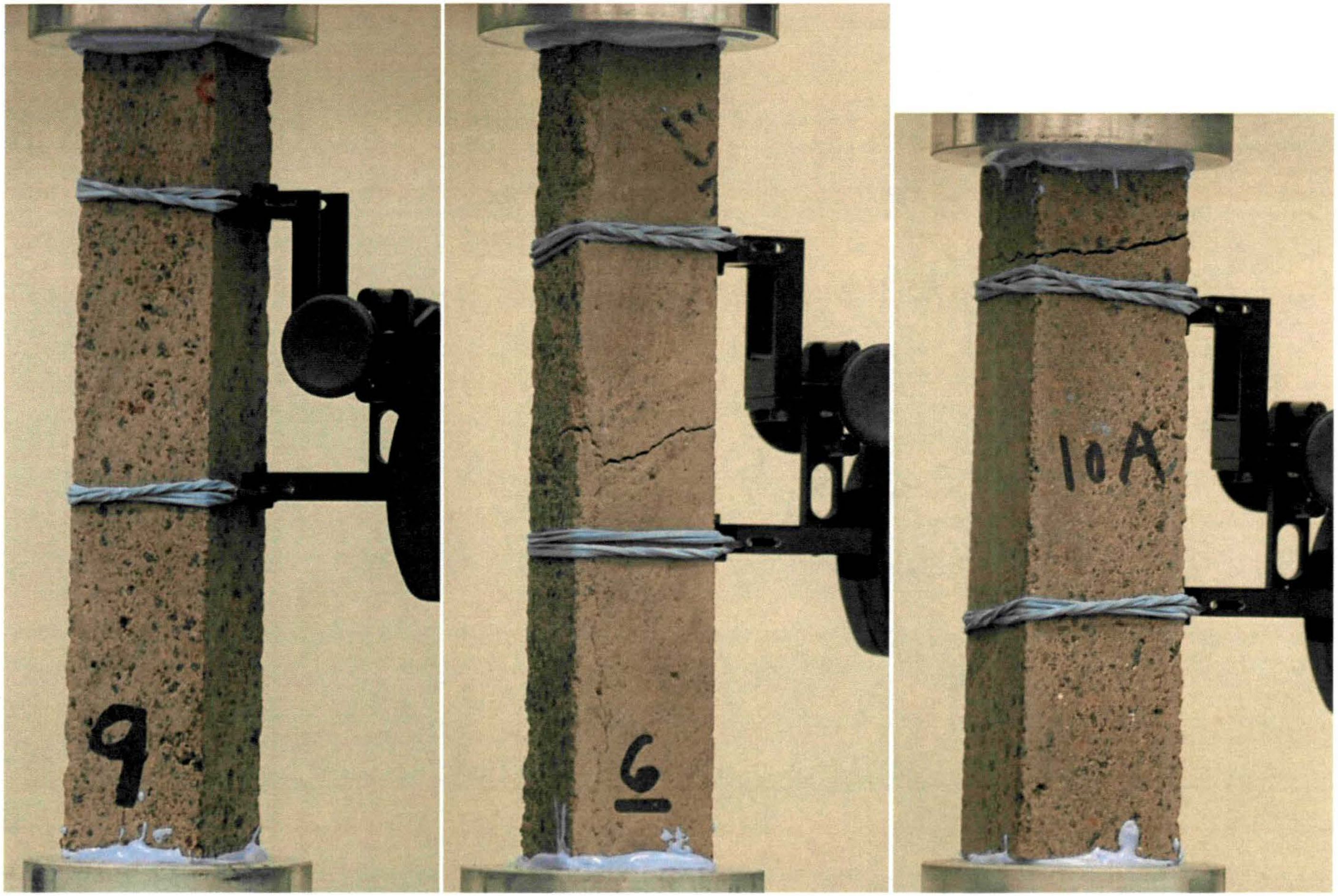

Figure 14. Bar Specimens Loaded to Failure in Tension.