DEPARTMENT OF TRANSPORTATION

Development of a Rock Strength Database

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June 2018

Research Project
Final Report 2018-19

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Rock strength and elastic behavior are important for foundations such as spread footings resting on rock and drilled shafts socketed into rock. In addition to traditional rock quality information, stiffness and failure parameters are helpful for design. MnDOT has previously used a low-capacity load frame for routine rock testing but this apparatus does not generate sufficient force for testing hard rock.

The report provides a comprehensive suite of results from 134 specimens tested under uniaxial compression and 33 specimens tested under triaxial compression on a wide variety of rock, including hard rock, which frequently is of interest for high-capacity foundation systems. Thus, an economic benefit is realized if the strength of the rock is measured, as opposed to correlated with an index parameter, due to the potential to reduce foundation size and construction time. Information from the testing was used to expand the MnDOT database of rock properties and allow for improved designs based on accurate measurements of Young's modulus, uniaxial compressive strength, and friction angle.

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DEVELOPMENT OF A ROCK STRENGTH DATABASE

FINAL REPORT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Rock strength and elastic behavior are important for foundations, such as spread footings resting on rock and drilled shafts socketed into rock. In addition to traditional rock quality information, stiffness (Young's modulus) and failure parameters (uniaxial compressive strength and friction angle) are helpful for design. The Minnesota Department of Transportation (MnDOT) has previously used a low-force load frame for routine rock testing, but this apparatus does not have sufficient capacity for testing hard rock.

This report provides a comprehensive suite of results from uniaxial compression tests (134 specimens) and triaxial compression tests (33 specimens) on a wide variety of rock, including hard rock, which frequently is of interest for high-capacity foundation systems. Thus, an economic benefit is realized if the strength of the rock is measured, as opposed to correlated with an index parameter, due to the potential to reduce foundation size and construction time. Information from the testing was used to expand the MnDOT database of rock properties and allow for improved designs based on accurate measurements of Young's modulus, uniaxial compressive strength, and friction angle.

CHAPTER 1: INTRODUCTION

1.1 MOTIVATION

Understanding the failure response of rock to various stress states is of fundamental importance in a number of applications in geoengineering. For example, in foundation design or the excavation of a tunnel, an evaluation of strength is needed to prevent or promote failure, and a greater understanding of rock failure can lead to safer designs and improve constructability.

Failure criteria have been widely studied for rock (Jaeger and Cook 1979) by testing a right circular cylinder subjected to uniaxial compression or conventional triaxial compression (Figure 1.1). The results are typically analyzed using the Mohr-Coulomb failure criterion, which is depicted in Figure 1.2a using the principal stress plane σ_I, σ_{III} (compression positive). The failure surface has slope N and intercept C_0 = uniaxial compressive strength on the σ_I – axis; the intersection of the failure surface with the hydrostatic axis is denoted V_0, the theoretical isotropic tensile strength. The uniaxial tensile strength T_0 predicted from Mohr-Coulomb is not measured in experiments and a tension cut-off is often implemented. The Mohr-Coulomb failure criterion on a Mohr diagram is shown in Figure 1.2b, where the parameters V_0, T_0, and T = uniaxial tensile strength are indicated; the intercept on the shear stress axis is c and the slope is $\tan \phi$, where c = cohesion and ϕ = friction angle are material parameters related to C_0 and N. The circle with principal stresses $-\sigma_{III} = T$ and $\sigma_I = \sigma^*$ forms the tension cut-off part of the failure envelope.

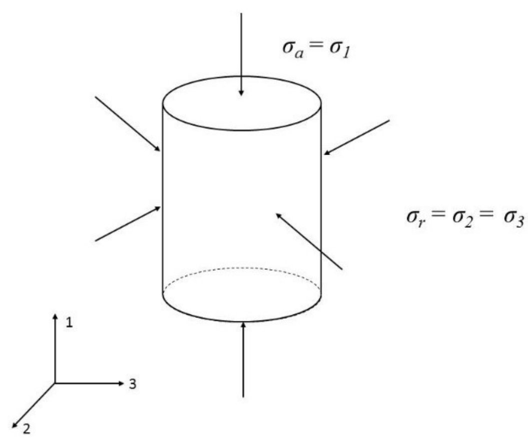

Figure 1.1 Axisymmetric stress state in conventional triaxial testing.

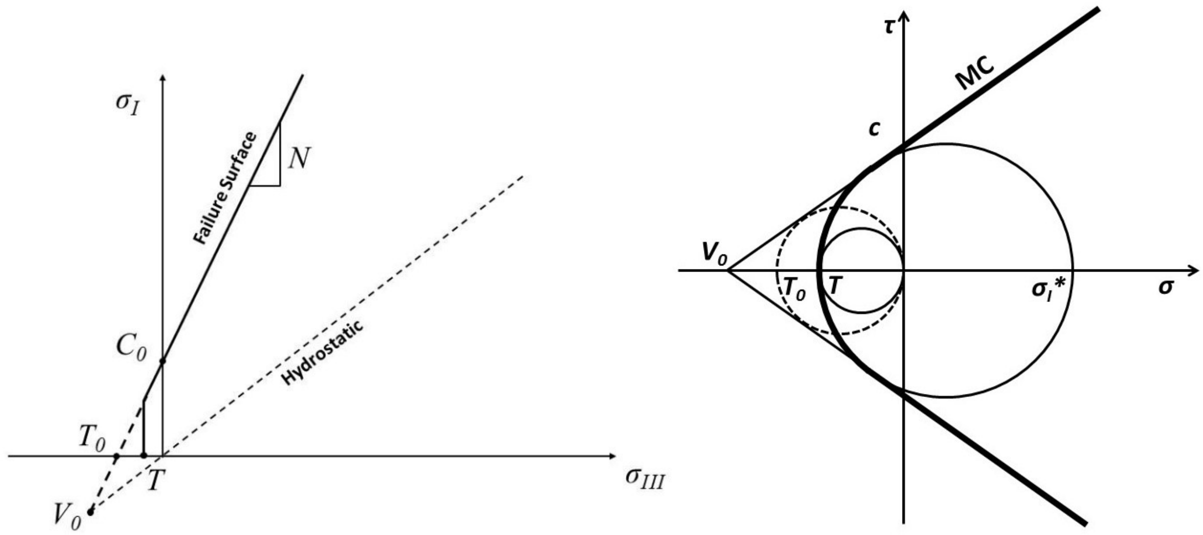

Figure 1.2 (a) Mohr-Coulomb (MC) failure surface with tension cut-off on principal stress plane, major stress = σ_I and minor stress = σ_{III}. (b) Mohr-Coulomb (MC) failure surface with tension cut-off on the Mohr plane, shear stress = τ and normal stress = σ.

1.2 OBJECTIVE

The main focus of this work is to determine the strength and stiffness parameters of rock associated with transportation projects in Minnesota. Uniaxial and triaxial compression tests were performed on rock provided by the Minnesota Department of Transportation (MnDOT). Rock strength and stiffness relations were determined for various projects related to the rock formations. Test data were added to the geology/rock database, where data are aggregated to improve the general understanding of Minnesota geology and rock behavior.

CHAPTER 2: BACKGROUND

2.1 STRESS INVARIANTS

Using a Cartesian coordinate system, the Cauchy stress tensor σ_{ij} gives the state of stress in terms of normal stresses (*i* = *j*) and shear stresses (*i* ≠ *j*) acting on an element (compression positive):

$$\sigma_{ij} = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{yz} & \sigma_{zz} \end{bmatrix} \quad (1)$$

For any given stress state, a coordinate system exists such that no shear stresses act on three perpendicular faces of the element. The three orthogonal axes of this coordinate system (x_I, x_{II}, x_{III}) are the principal axes, and the three corresponding normal stresses are stress invariants called the major σ_I, intermediate σ_{II}, and minor σ_{III} principal stresses ($\sigma_I \geq \sigma_{II} \geq \sigma_{III}$).

$$\sigma_p = \begin{bmatrix} \sigma_I & 0 & 0 \\ 0 & \sigma_{II} & 0 \\ 0 & 0 & \sigma_{III} \end{bmatrix} \quad (2)$$

Note that σ_1, σ_2, σ_3 can also represent the principal stresses with no regard to order with six permutations:

$$\sigma_1 \geq \sigma_2 \geq \sigma_3 \quad (3a)$$

$$\sigma_1 \geq \sigma_3 \geq \sigma_2 \quad (3b)$$

$$\sigma_2 \geq \sigma_1 \geq \sigma_3 \quad (3c)$$

$$\sigma_2 \geq \sigma_3 \geq \sigma_1 \quad (3d)$$

$$\sigma_3 \geq \sigma_1 \geq \sigma_2 \quad (3e)$$

$$\sigma_3 \geq \sigma_2 \geq \sigma_1 \quad (3f)$$

This coordinate system is useful when constructing a failure surface, *e.g.* Mohr-Coulomb, where a six-sided pyramid appears, as shown in Figure 2.1. The plane normal to the hydrostatic axis is called the π-plane, with coordinate axes $\sigma'_1, \sigma'_2, \sigma'_3$.

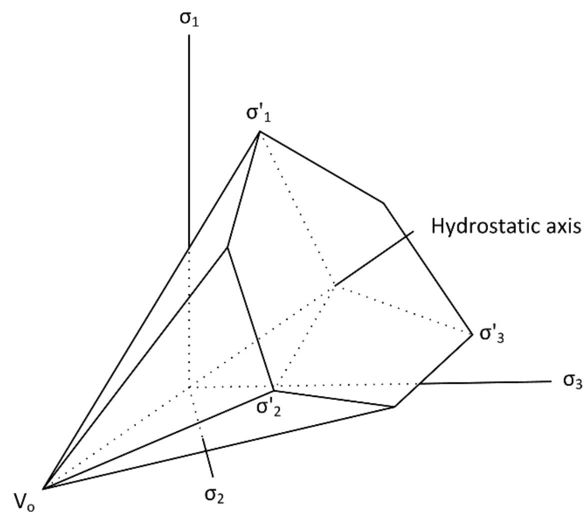

Figure 2.1 Six-sided pyramidal failure surface in principal stress space $\sigma_1, \sigma_2, \sigma_3$ with no regard to order (Meyer and Labuz 2013).

2.2 FAILURE CRITERIA

Failure of rock and other geomaterials has been a topic of concern dating back to the classic experiments of Von Karman (1911). Over the years, numerous studies have been conducted to describe failure under various stress states and statistical analyses and fitting methods have been applied (Murrell, 1965; Carter *et al*., 1991; Pincus, 2000; Pariseau, 2007).

The simplest failure criterion for geomaterials was proposed by Coulomb. Failure occurs when the shear stress τ on a plane is equal to the sum of a constant *c* and a pressure-dependent component produced by the normal stress σ on the plane multiplied by *tan* ϕ:

$$\tau = c + \sigma \tan\varphi \qquad (4)$$

where *c* = cohesion and ϕ = friction angle. Coulomb's criterion is linear on a Mohr diagram and is usually referred to as the Mohr-Coulomb failure criterion.

The Mohr-Coulomb failure criterion (MC) is a linear failure envelope that is a best fitted line, such that the failure envelope is tangent to the Mohr circles. The failure criterion can be written in terms of the major and minor principal stresses, a parameter *N*, and the uniaxial compressive strength C_0:

$$\sigma_I = N\sigma_{III} + C_0 \tag{5}$$

$$N = \frac{1+\sin\phi}{1-\sin\phi} \tag{6}$$

Note that there is no dependence of the intermediate principal stress. The Mohr-Coulomb criterion is popular, as the friction angle and uniaxial compressive strength can be determined from a few lab tests. MC has been shown to be a reasonable approximation for a limited range of stress states, as typical failure envelopes appear nonlinear with increasing stresses (Figure 2.2).

A drawback of MC is the overestimation of the uniaxial tensile strength *T*, often times by greater than an order of magnitude; T_0 is the theoretical uniaxial tensile strength predicted from MC. Paul (1960) suggested including a tension cut-off to improve the accuracy of the prediction, as shown in Figure 1.2 and described by

$$\sigma_I = N\sigma_{III} + C_0 \text{ for } \sigma_I > \sigma_I^* \tag{7}$$

$$-\sigma_{III} = T \text{ for } \sigma_I \le \sigma_I^* \tag{8}$$

$$\sigma_I^* = C_0 - NT \tag{9}$$

Mohr defined a failure criterion that is characterized by a group of Mohr circles described by principal stresses. The family of Mohr circles forms an envelope, where the normal and shear stresses at failure are found by the tangency of the envelope to the Mohr circles (Figure 2.2). Mohr's criterion can be linear or nonlinear. An example of the latter is the parabolic function proposed by Fairhurst (1964):

$$\tau^2 = (m-1)^2 T (T+\sigma) \tag{9}$$

where T = uniaxial tensile strength, $m = (\eta + 1)^{1/2}$, and $\eta = C_0/T$.

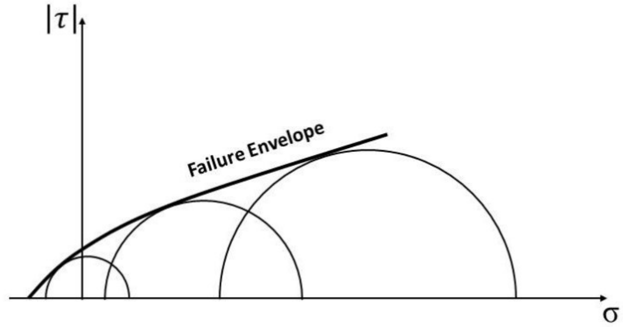

Figure 2.2 Family of Mohr circles with corresponding failure envelope.

CHAPTER 3: EXPERIMENTAL TECHNIQUES

3.1 SYSTEM DESCRIPTION

Tests were performed using the MTS 815 Rock Mechanics Test System load frame (Figure 3.1) with the MTS 286 confining pressure and pore pressure intensifiers with the following components.

- MTS Model 315.04 Load Frame: 4,600 kN (1,000,000 lb) compression, 2,300 kN (500,000 lb) tension, 100 mm (4.0 in.) stroke.
- Test space height with adapter plates: maximum 1160 mm (45.7 in.), minimum 1060 mm (41.7 in.); test space width, 686 mm (27 in.).
- Stiffness = 10.5 GN/m (6.0 x 10^7 lb/in.).
- LVDT stroke and differential pressure transducer for force measurements and syringe pump for volume change measurements.

3.2 EQUIPMENT SET-UP

Prior to testing rock specimens provided by the Minnesota Department of Transportation, the one million pound load frame was evaluated for system stiffness in axial and lateral displacement/strain measurements. To account for system response, a specimen was fabricated from a hardened aluminum alloy (6061) with the following geometry and material properties.

- Diameter D = 50.0 mm.
- Length L = 100.0 mm.
- Young's modulus E = 69.0 GPa.
- Poisson's ratio ν = 0.33.

The response of the specimen can be then determined.

3.2.1 Stroke

During compression testing, the axial displacement measured by the stroke – displacement of the actuator – contains both specimen and machine displacements. To evaluate machine stiffness, the aluminum specimen was tested using the same configuration (platens) that was used to test the rock specimens. Knowing the displacement of the aluminum specimen, system displacement was calculated and this information was used for all other tests. Results from the stroke calibration are presented in Figure 3.2.

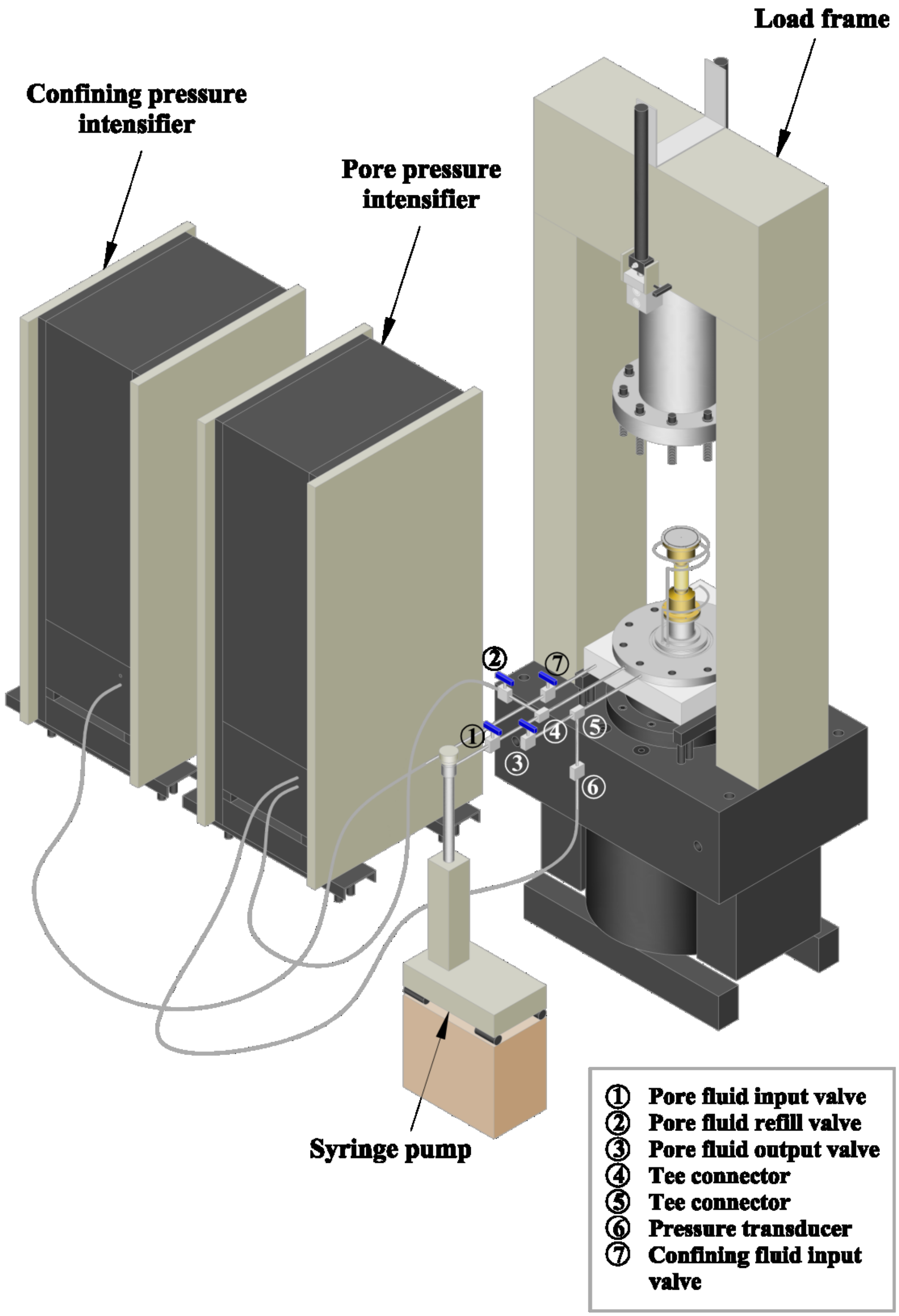

Figure 3.1 MTS 815 Rock Mechanics Test System.

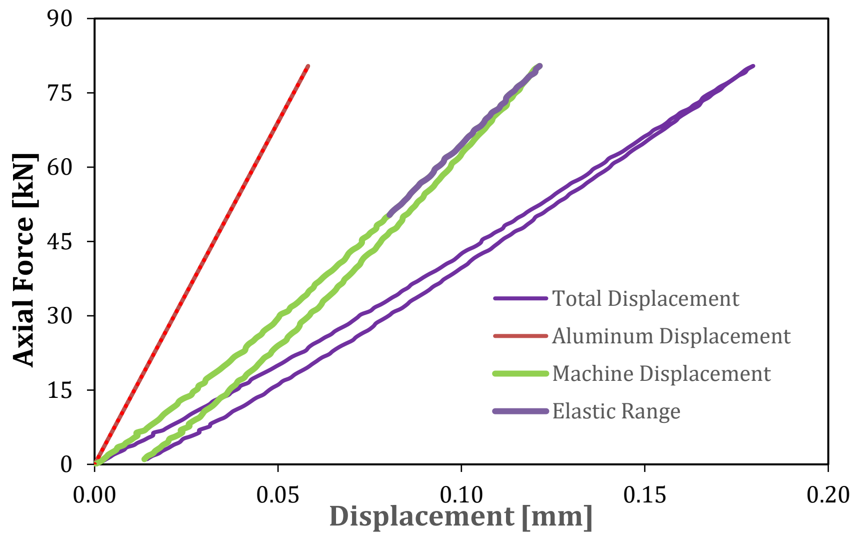

Figure 3.2 Calibration results for the one million pound load frame, MTS Model 315.04.

3.2.2 Axial Strain

To measure axial strain, a strain-gage based transducer called an extensometer was used. The axial extensometer measures the axial deformation on opposite sides (diametrically opposed) of the specimen. The axial extensometer consists of two sensor units, which measure the axial displacement over a gage length of 50.0 mm. Two contact points made of hardened steel contact the specimen and are held in-place by a spring assembly. Axial strain is calculated from the displacement measurement and used to determine Young's modulus. Again, the aluminum (6061, E = 69.0 GPa) specimen was used to calibrate the axial extensometer. The setup is shown in Figure 3.3 and results are shown in Figure 3.4. The axial strain is accurately measured with the extensometers, as E = 69.0 GPa was determined.

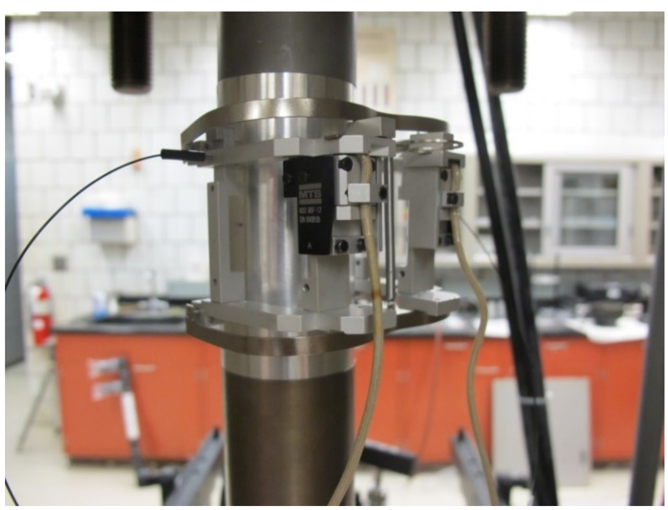

Figure 3.3 Axial extensometer setup.

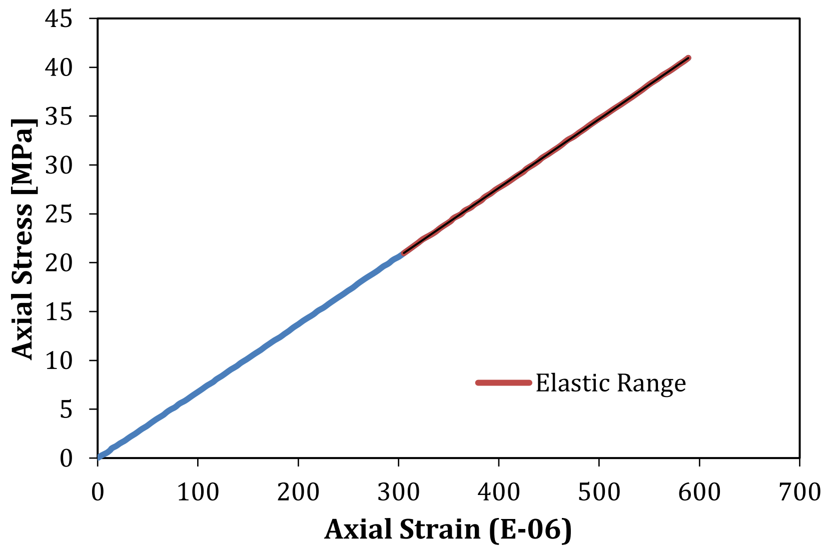

Figure 3.4 Axial extensometer calibration for MTS Model 315.04.

3.2.3 Lateral Strain

To measure lateral strain, another type of strain-gage based extensometer was used. The extensometer responds to the change in circumference at the center of the specimen. The circumferential extensometer uses a roller chain placed around the specimen and the extensometer is attached to the ends of the chain. Tension in the chain is provided through a spring assembly. Lateral strain is calculated from this measurement. The aluminum specimen was used to calibrate the circumferential extensometer. The setup is shown in Figure 3.5 and results are shown in Figure 3.6. The initial loading of the specimen shows some additional displacement probably due to adjustment and slip of the chain, but the successive load-unload cycles are repeatable. Some hysteresis was observed due to frictional losses with the chair arrangement.

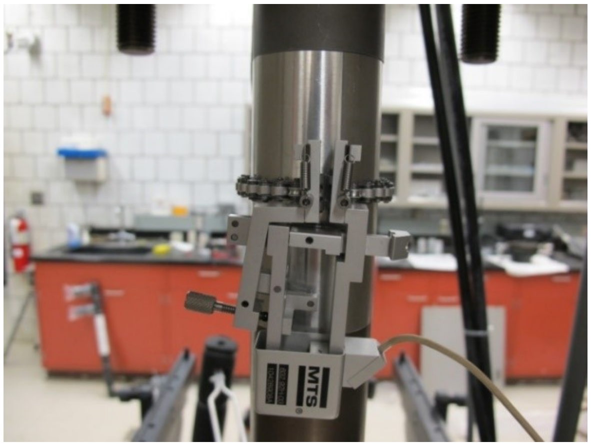

Figure 3.5 Circumferential extensometer setup.

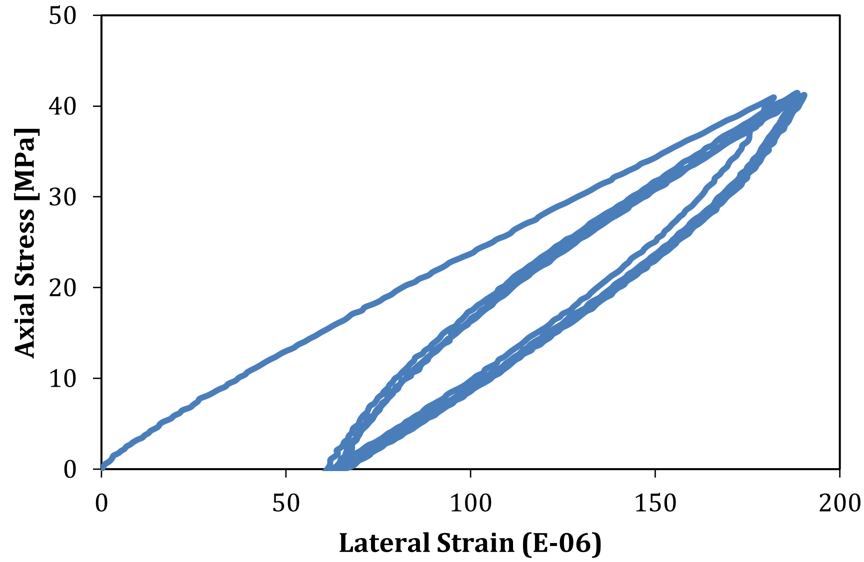

Figure 3.6 Circumferential extensometer calibration for MTS Model 315.04.

3.3 PREPARATION OF SPECIMENS

All cores received were organized by elevation and cataloged for testing. Core length dictated which core could be tested under uniaxial and triaxial compression, as the 2:1 length:diameter (L:D) ratio was not strictly enforced; *i.e.* L:D < 2 for a few UCS tests. The specimens were prepared in accordance to ASTM standards: Standard Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock, ASTM D2845; Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens, ASTM D2938; Standard Test Method for Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression, ASTM D3148; Standard Test Method for Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements, ASTM D2664.

Each specimen was cut using a “wet” saw equipped with a 250 mm (10 in.) diamond saw blade (Figure 3.7). To prevent the specimen from breaking during the cutting process, the maximum depth of each cut was approximately one-third the specimen diameter. Once the maximum depth of the cut was achieved, the specimen was rotated and another cut was made; this was repeated until the specimen was cut completely. Each specimen was cut to achieve (i) a length-to-diameter ratio = 2.0 (typically L = 100 mm and D = 50 mm) or (ii) if L < 100m, the maximum ratio from the core.

Specimens were ground using a surface grinder and water with a rust inhibitor as a coolant (Figure 3.6). Each specimen was ground flat within a tolerance of 0.05 mm (0.002 in.) and perpendicular to the axis of the cylinder. A specimen was prepared by first placing it on the magnetic chuck and clamping it to a precision v-block, which ensured that the specimen would be ground perpendicular to the longitudinal axis. A maximum step of 0.0125 mm (0.0005 in.) was used. The cylinder was ground in steps until the entire surface made contact with the grinding wheel; once this occurred, the wheel was lowered by 0.0025 mm (0.0001 in.) and the specimen was reground.

With the one end completed, the specimen was then flipped and the grinding process was repeated. Once both ends of the specimen were ground, the flatness of each end was measured on a surface table with a dial indicator (Figure 3.8). If the surface tolerance was not within the limits, the specimen was reground. A stearic acid lubricant was used to reduce frictional constraint in the compression tests.

Figure 3.7 (a) Table saw and (b) surface grinder.

Figure 3.8 Core on surface table with dial indicator.

3.4 PROCEDURE FOR UNIAXIAL COMPRESSION TESTS

3.4.1 Specimen Characteristic

Prior to testing, several specimen dimensions were measured to the nearest 0.01 mm (0.0004 in.) using a digital caliper. Diameter was measured in three locations along the length of the specimen and the average was recorded. Length was also measured in three locations and the average length was recorded. Specimen mass was measured to 0.01 g. P-wave velocity was also measured from the P-wave travel time through the length of the specimen; travel time was measured to the nearest 0.1 µs and wave velocity was calculated knowing the average specimen length. Finally, stearic acid was applied to reduce friction between the specimen and platens during testing.

3.4.2 Stroke Control

Following accepted standards, uniaxial compression tests were completed within 5-10 min. Loading of the specimen can be controlled using two methods. Stroke control is a method in which the rate of the actuator displacement is controlled; an LVDT measures actuator movement. For hard rock such as the specimens provided from TH 53, the rate was 1-3 microns/s.

3.4.3 Circumferential Control

The second method that can be used to control loading is circumferential displacement control. Using this method, loading is controlled by the rate at which the circumference of the specimen increases. Circumference change is measured using a strain gage based extensometer attached around the center of the specimen. The extensometer measures the circumferential extension. The rate used for the TH 53 rock specimens was 0.2-0.4 microns/s.

In order to perform tests under closed-loop control, tuning of the system is needed. The purpose of tuning is to optimize test performance by minimizing the system error. The extensometer was tuned using specimen #3 (SB-12 184.9-185.2 ft.). During tuning, the specimen prematurely failed under an axial force of approximately 150 kN (axial stress = 74 MPa). No data acquisition was running, so an exact value is not available. Figure 3.9 shows the configuration that was used for tuning and testing.

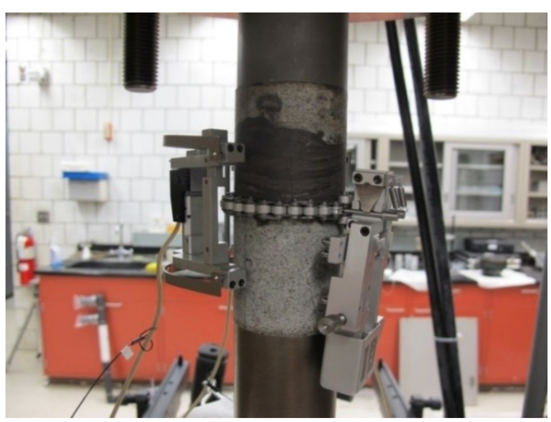

Figure 3.9 Axial extensometer shown on left and circumferential extensometer on right.

3.4.4 Rock Properties

Uniaxial compressive strength (UCS) and Young's modulus (E) were determined using the following methods. To calculate UCS, peak load is divided by the original cross sectional area; strictly speaking, the current area at peak load should be used but because the displacements are very small, the original area provides an accurate value. Young's modulus is determined from the slope of the axial stress-strain plot at the range corresponding to 30-50% of the UCS (Figure 3.10). Axial strain is calculated using the axial extensometer or the corrected axial displacement from the stroke. Rock strength parameters, specimen properties, and axial stress-strain plots can be found in Appendix B.

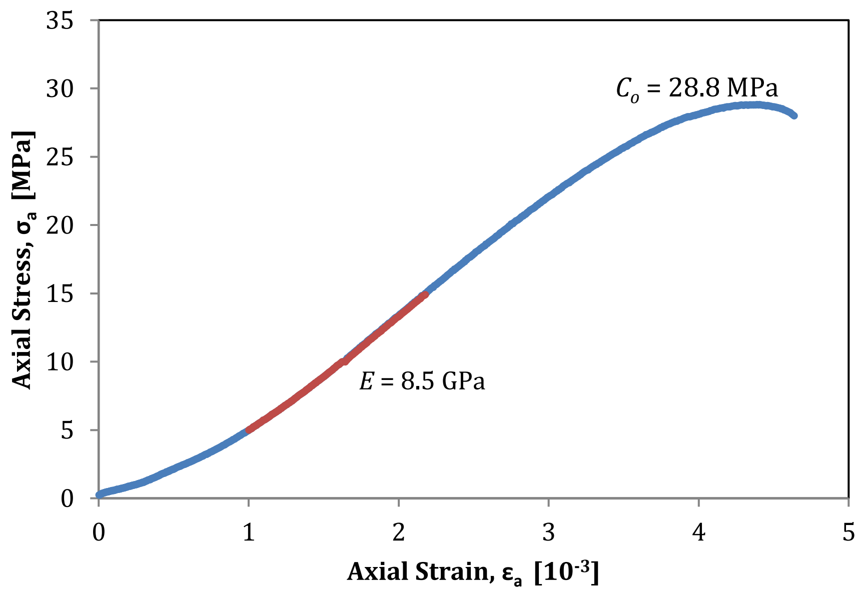

Figure 3.10 Mechanical response of a uniaxially stressed sandstone specimen.

CHAPTER 4: UNIAXIAL COMPRESSION TESTING

4.1 INTRODUCTION

Rock cores were received from MnDOT from the TH 53 project, which requires relocation of the highway from its existing alignment due to the expiration of a 1960 easement and the subsequent planned expansion of the United Taconite Thunderbird Mine. The cores were cataloged for testing by borehole and depth (Table 4.1). Prior to uniaxial compression tests, specimens were prepared in accordance with accepted standards. Each specimen was wet cut on a wet saw using diamond saw blade. Specimens were cut to a ratio of 2:1 (length:diameter) with a tolerance of 5 mm (0.20 in.). After cutting, cores were wet ground using a surface grinder with an aluminum oxide grinding wheel.

Prior to testing, several specimen dimensions were measured to the nearest 0.01 mm (0.0004 in.) using a digital caliper. Diameter was measured in three locations along the length of the specimen and the average was recorded. Length was also measured in three locations and the average length was recorded. Specimen mass was measured to 0.01 gram. P-wave velocity was also measured from the P-wave travel time through the length of the specimen; travel time was measured to the nearest 0.1 µs and wave velocity was calculated knowing the average specimen length.

Following accepted standards, uniaxial compression tests were completed within 5-10 min. Stroke control was used, where the rate of the actuator displacement is controlled; an LVDT measures actuator movement. For hard rock, such as the specimens provided from TH 53, the rate was 1-3 microns/s. Rock strength parameters and specimen properties for 134 specimens are recorded in Tables 4.2-4.4 in SI units (Tables 4.4-4.6) and the same results in English units (Tables 4.5-4.7). Axial stress-strain plots for each specimen can be found in Appendix B.

Table 4.1 Rock boring metadata and locations

Point ID	Unique Number	Hole Depth	Elevation	CC North (Y)	CC East (X)	UTM_N	UTM_E
DBA-01	81523	234	1559.9	197077.9	482606.1	5262630.8	536110.5
DBA-01a	81524	781.6	1558.1	197073.8	482555.3	5262629.5	536095
DBA-02	81526	80	1557.4	197065.2	482543.7	5262626.8	536091.5
DBA-03	81528	180	1557.2	197040.4	482551.2	5262619.3	536093.8
DBA-04	81530	120	1558.3	197102.8	482522.3	5262638.2	536084.9
DBA-05A	81533	112	1493.9	196858.1	481370.0	5262561.2	535734.4
DBA-06	81535	252	1488.5	196917.1	481335.4	5262579.1	535723.7
IDH-02	81542	773	1564.6	197155.2	482695.5	5262654.6	536137.6
IDH-08	81552	473.3	1611.7	195884.0	484312.9	5262270.8	536633.0
IDH-09	81555	323	1610.7	195666.7	484523.7	5262205.0	536697.7
IDH-10	81557	277	1588.0	196116.9	483871.6	5262340.8	536498.1
IDH-11	81558	417	1597.7	196332.6	483931.4	5262406.6	536515.9
SD-12	79226	237	1317.7	196968.0	481762.9	5262595.5	535853.8
SD-13	79227	228	1317.5	196915.4	481774.5	5262579.5	535857.5
SD-14	79228	237	1316.4	196944.2	481685.5	5262588.1	535830.3

4.2 RESULTS

Table 4.2 Specimen dimensions, mass, density, UCS, and Young's modulus in SI units (specimen 1 – 50)

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]	
1	SD-12	163.5	163.8	50.63	103.77	2013.29	629.77	3.01	4633	**164.1**	**68.0**	
2	SD-12	172.8	173.1	50.83	106.55	2029.22	645.00	2.98	5822	**213.2**	**60.5**	
3	SD-12	184.9	185.2	50.92	105.31	2036.42	653.92	3.05	4744	**N/A**	**N/A**	**Specimen failed during tuning of circumferential control**
4	SD-14	164.2	164.5	50.51	101.41	2003.75	680.07	3.35	5122	**140.0**	**84.4**	
5	SD-14	174.0	174.3	50.56	107.75	2007.72	720.39	3.33	5671	**113.3**	**85.6**	
6	SD-13	169.8	170.1	50.70	101.45	2018.86	565.31	2.76	4299	**110.3**	**55.4**	
7	SD-13	179.0	179.3	50.72	102.78	2020.45	639.25	3.08	4111	**111.4**	**55.6**	
8	SD-12	188.3	188.7	50.89	104.49	2034.02	716.25	3.37	4318	**88.6**	**27.8**	
9	SD-14	186.2	186.5	50.38	107.17	1993.45	672.15	3.15	4871	**133.3**	**46.2**	
10	SD-14	189.1	189.4	50.42	101.42	1996.62	620.12	3.06	5071	**99.6**	**45.9**	
11	SD-13	183.9	184.2	50.68	100.34	2017.27	627.48	3.10	4216	**56.8**	**20.3**	
12	SD-13	190.7	191.0	50.70	108.24	2018.86	669.8	3.07	3838	**45.7**	**15.4**	
13	DBA-01-01	36.5	37.2	50.80	103.43	2026.83	682.24	3.25	5472	**150.2**	**60.3**	
14	DBA-02-01	19.6	20.2	50.49	105.68	2002.17	654.19	3.09	5562	**222.6**	**65.0**	
15	DBA-02-02	70.8	71.4	50.17	103.72	1976.87	711.31	3.47	4736	**189.3**	**45.5**	
16	DBA-02-03	53.1	53.9	50.42	104.38	1996.62	678.39	3.26	4209	**99.0**	**28.1**	
17	DBA-03-01	33.1	33.7	50.76	103.95	2023.64	652.26	3.10	4747	**89.4**	**38.6**	
18	DBA-03-02	63.5	64.0	50.51	104.17	2003.75	712.57	3.41	4150	**207.8**	**33.3**	
19	DBA-03-03	68.1	68.8	50.54	104.08	2006.14	713.18	3.42	4355	**223.5**	**40.0**	
20	DBA-03-04	77.5	78.2	50.34	104.25	1990.29	709.4	3.42	4533	**103.5**	**28.7**	
21	DBA-03-05	83.5	84.2	50.37	104.26	1992.66	660.96	3.18	4418	**35.3**	**15.4**	
22	DBA-03-06	95.4	96.0	50.21	104.08	1980.02	654.92	3.18	5393	**167.0**	**57.8**	
23	DBA-03-07	102.1	102.8	50.37	103.89	1992.66	623.91	3.01	5556	**336.0**	**69.5**	
24	DBA-03-08	126.7	127.2	50.37	104.35	1992.66	631.92	3.04	4876	**100.8**	**26.4**	
25	DBA-03-09	158.2	158.9	50.17	103.42	1976.87	650.56	3.18	5530	**240.6**	**50.4**	
26	DBA-04-01	65.3	65.8	50.37	103.10	1992.66	719.96	3.50	5181	**165.1**	**49.1**	
27	DBA-04-02	74.5	75.4	50.44	104.64	1998.20	683.84	3.27	4219	**170.9**	**34.4**	
28	DBA-04-03	84.5	85.1	50.41	103.22	1995.83	663.91	3.22	4064	**139.9**	**25.2**	
29	DBA-04-04	94.9	95.7	50.55	105.95	2006.93	692.77	3.26	5986	**183.1**	**69.5**	
30	DBA-04-05	104.4	104.9	50.56	95.11	2007.72	575.55	3.01	4662	**128.0**	**45.0**	
31	DBA-05A-01	19.6	20.1	50.59	105.92	2010.11	596.56	2.80	4729	**87.2**	**35.9**	
32	DBA-05A-02	40.2	41.0	50.62	103.18	2012.49	675.16	3.25	5159	**97.0**	**36.0**	
33	DBA-05A-03	49.2	49.9	50.46	105.10	1999.79	726.64	3.46	5474	**117.8**	**55.5**	
34	DBA-05A-04	58.9	59.4	50.48	102.53	2001.38	582.52	2.84	5231	**95.4**	**38.8**	
35	DBA-05A-05	61.7	62.2	50.49	103.90	2002.17	617.69	2.97	5440	**158.3**	**49.1**	
36	DBA-05A-06	70.0	70.5	50.35	102.93	1991.08	563.41	2.75	4657	**102.8**	**33.7**	
37	DBA-05A-07	78.0	78.6	50.37	103.72	1992.66	654.57	3.17	5186	**186.7**	**49.7**	
38	DBA-05A-08	100.8	101.5	50.55	101.92	2006.93	664.49	3.25	5096	**173.8**	**50.1**	
39	DBA-06-01	29.3	29.9	50.53	105.68	2005.34	659.03	3.11	4782	**35.2**	**8.8**	**Existing axial fractures**
40	DBA-06-02	50.2	50.8	50.59	103.76	2010.11	702.33	3.37	5461	**176.3**	**63.4**	
41	DBA-06-03	58.1	58.8	50.50	105.06	2002.96	769.64	3.66	5559	**158.6**	**62.1**	
42	DBA-06-04	77.8	78.5	50.49	104.72	2002.17	611.8	2.92	5454	**59.4**	**29.0**	
43	DBA-01a-01	48.0	48.6	50.58	103.77	2009.31	613.85	2.94	5520	**128.8**	**39.6**	
44	DBA-01a-02	102.8	103.4	50.55	107.58	2006.93	N/A	N/A	N/A	**N/A**	**N/A**	**Specimen fractured during preparation**
45	DBA-01a-03	156.3	156.8	50.34	101.11	1990.29	554.34	2.75	4956	**22.0**	**10.4**	
46	DBA-01a-04	196.9	197.4	50.64	104.78	2014.08	619.05	2.93	5789	**102.0**	**39.9**	
47	DBA-01a-05	253.4	254.2	50.70	106.25	2018.86	749.06	3.49	5682	**262.6**	**56.9**	
48	DBA-01a-06	300.5	301.0	50.57	104.69	2008.52	649.32	3.09	6584	**231.0**	**56.4**	
49	DBA-01a-07	356.0	356.7	50.49	104.54	2002.17	557.68	2.66	4526	**152.0**	**29.5**	
50	DBA-01a-08	364.2	370.0	50.50	106.89	2002.96	561.00	2.62	5426	**40.3**	**20.3**	**One end intially highly fractured**

Table 4.3 Specimen dimensions, mass, density, UCS, and Young's modulus in SI units (specimen 51-107)

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]	
51	DBA-01a-09	367.7	368.3	50.44	105.78	1998.20	570.13	2.70	3186	**14.0**	**4.6**	
52	DBA-01a-10	370.3	371.0	50.50	103.95	2002.96	622.21	2.99	3713	**56.9**	**15.9**	
53	DBA-01a-11	372.9	373.6	50.51	106.74	2003.75	578.60	2.71	4942	**127.1**	**25.2**	
54	DBA-01a-12	389.0	389.9	50.57	104.55	2008.52	616.36	2.94	3556	**50.1**	**14.1**	
55	DBA-01a-13	395.0	395.6	50.56	104.11	2007.72	551.93	2.64	4607	**55.1**	**21.9**	
56	DBA-01a-14	401.8	402.5	50.57	105.19	2008.52	582.86	2.76	5844	**320.1**	**58.2**	
57	DBA-01a-15	452.9	453.8	50.20	105.64	1979.23	751.17	3.59	5649	**53.8**	**14.9**	
58	DBA-01a-16	490.4	491.3	49.46	105.84	1921.31	603.21	2.97	5266	**179.0**	**53.2**	
59	DBA-01a-17	549.3	550.1	50.49	104.88	2002.17	699.02	3.33	5434	**123.0**	**45.1**	
60	DBA-01a-18	600.6	601.4	50.17	105.46	1976.87	709.95	3.41	5992	**221.2**	**63.1**	
61	DBA-01a-19	651.8	652.4	50.19	106.28	1978.45	662.10	3.15	5594	**178.0**	**56.9**	
62	DBA-01a-20	703.2	703.9	50.37	105.56	1992.66	597.42	2.84	5441	**150.1**	**50.7**	
63	DBA-01a-21	755.0	755.8	50.59	105.28	2010.11	594.37	2.81	5013	**167.5**	**54.2**	
64	DBA-06-05	108.0	108.6	50.49	105.73	2002.17	630.08	2.98	4387	**73.3**	**18.5**	
65	DBA-06-06	151.6	152.4	50.17	105.60	1976.87	706.53	3.38	5708	**266.9**	**76.4**	
66	DBA-06-07	187.6	188.2	50.48	103.74	2001.38	643.89	3.10	5460	**303.2**	**83.5**	
67	DBA-06-08	248.0	248.7	50.50	104.90	2002.96	632.19	3.01	5828	**355.2**	**77.3**	
68	IDH-02-01	248.2	249.0	50.55	104.69	2006.93	657.64	3.13	5598	**229.8**	**58.8**	
69	IDH-02-02	293.4	294.4	50.61	104.80	2011.70	631.06	2.99	5402	**102.3**	**38.4**	
70	IDH-02-03	346.8	347.6	50.59	105.97	2010.11	591.70	2.78	4839	**98.8**	**40.3**	
71	IDH-02-04	361.9	362.5	50.56	105.23	2007.72	635.51	3.01	4176	**22.7**	**9.2**	**Chip missing from end of specimen**
72	IDH-02-05	373.5	374.2	50.55	104.03	2006.93	634.10	3.04	4112	**102.0**	**25.0**	
73	IDH-02-06	408.0	408.8	50.12	105.66	1972.93	611.47	2.93	5363	**226.2**	**58.1**	
74	IDH-08-01	96.0	97.0	50.53	104.10	2005.34	557.11	2.67	5816	**103.2**	**40.2**	**Core sample in poor condition**
75	IDH-08-02	222.6	223.2	50.58	105.19	2009.31	726.40	3.44	5340	**62.1**	**27.2**	
76	IDH-08-04	167.0	167.6	50.60	104.95	2010.90	702.25	3.33	6102	**228.7**	**65.6**	
77	IDH-08-05	321.7	322.2	49.98	103.76	1961.92	662.13	3.25	5670	**379.1**	**79.0**	
78	IDH-08-06	378.1	378.7	50.51	104.47	2003.75	576.12	2.75	5470	**158.2**	**51.3**	
79	IDH-08-07	418.5	419.0	50.55	104.47	2006.93	618.62	2.95	5557	**126.6**	**47.7**	
80	IDH-09-01	161.2	161.8	50.29	104.24	1986.34	654.10	3.16	4964	**92.2**	**34.4**	
81	IDH-09-02	286.1	286.6	50.55	104.90	2006.93	656.25	3.12	5550	**170.1**	**51.2**	
82	IDH-09-03	247.0	247.8	50.70	104.97	2018.86	624.99	2.95	5768	**107.5**	**43.0**	
83	IDH-09-04	137.8	138.2	50.10	89.40	1971.36	476.39	2.70	4448	**49.3**	**18.9**	**Core in poor condition resulting in spec. length**
84	IDH-09-05	191.7	192.2	50.28	105.61	1985.55	692.74	3.30	5102	**125.2**	**46.7**	
85	IDH-09-06	96.1	96.7	50.48	104.34	2001.38	607.59	2.91	4992	**137.3**	**51.1**	
86	IDH-09-07	41.9	42.4	50.70	104.81	2018.86	699.23	3.30	5347	**369.0**	**67.2**	
87	IDH-02-07	436.0	437.1	50.53	104.87	2005.34	732.08	3.48	6062	**185.6**	**27.3**	
88	IDH-02-08	464.0	464.7	50.55	104.59	2006.93	639.55	3.05	5534	**170.0**	**24.3**	
89	IDH-02-09	489.3	490.2	50.54	104.11	2006.14	597.19	2.86	5628	**161.8**	**25.0**	
90	IDH-02-10	568.4	569.2	50.74	104.67	2022.04	786.74	3.72	4961	**109.3**	**21.9**	
91	IDH-02-11	634.5	635.1	50.58	104.05	2009.31	593.29	2.84	5100	**65.4**	**14.5**	
92	IDH-02-12	708.5	709.1	50.37	105.46	1992.66	652.87	3.11	5353	**41.6**	**10.3**	**Ends visibly fractured prior to testing**
93	IDH-02-13	764.0	764.8	50.50	104.09	2002.96	561.23	2.69	5566	**97.6**	**17.7**	
94	IDH-10-01	244.2	245.0	50.56	104.68	2007.72	615.6	2.93	5424	**204.0**	**26.3**	
95	IDH-10-02	253.6	254.7	50.32	105.01	1988.71	633.38	3.03	5304	**87.6**	**12.6**	
96	IDH-11-01	56.2	56.9	50.32	105.44	1988.71	605.94	2.89	5699	**190.5**	**23.2**	
97	IDH-11-02	135.1	135.7	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**	**N/A**	**Specimen fractured during preparation**
98	IDH-11-03	196.7	197.5	50.34	104.9	1990.29	640.23	3.07	5960	**215.4**	**28.1**	
99	IDH-11-04	212.1	212.9	50.36	103.98	1991.87	655.19	3.16	5908	**223.8**	**28.4**	
100	IDH-11-05	232.9	233.8	50.44	103.99	1998.20	659.07	3.17	5445	**135.5**	**21.2**	
101	IDH-11-06	240.6	241.5	50.60	105.51	2010.90	671.20	3.16	5024	**41.9**	**8.5**	
102	IDH-11-07	248.0	248.7	50.36	104.41	1991.87	687.06	3.30	4350	**78.8**	**13.7**	
103	IDH-11-08	275.3	276.3	50.53	105.40	2005.34	711.85	3.37	4925	**81.8**	**15.5**	
104	IDH-11-09	292.1	292.1	50.21	104.73	1980.02	611.00	2.95	4173	**95.3**	**14.1**	
105	IDH-11-10	358.8	359.5	50.44	105.18	1998.20	623.78	2.97	5507	**132.9**	**21.6**	
106	IDH-11-11	412.6	413.2	50.45	105.17	1999.00	574.14	2.73	4759	**139.9**	**21.4**	
107	IDH-11-12	224.0	224.9	50.5	106.27	2002.96	683.77	3.21	5623	**168.4**	**20.5**	

Table 4.4 Specimen dimensions, mass, density, UCS, and Young’s modulus in SI units (specimen 108-134)

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]	
108	DBA-07-01	22.2	23.0	50.27	102.07	1984.76	602.92	2.98	4619	109.1	14.5	
109	DBA-07-02	27.6	28.3	50.34	101.07	1990.29	605.17	3.01	5183	102.0	18.2	
110	DBA-07-03	46.9	47.4	50.47	100.62	2000.58	569.39	2.83	6845	144.9	26.3	
111	DBA-07-04	59.8	60.4	50.5	101.08	2002.96	587.31	2.90	6357	255.7	29.3	
112	DBA-08-01	32.3	32.8	50.45	102.56	1999.00	569.53	2.78	1906	57.8	3.6	
113	DBA-08-02	40.9	41.5	50.55	101.45	2006.93	565.44	2.78	7246	425.1	61.4	
114	DBA-08-03	44.6	45.4	50.49	100.23	2002.17	558.66	2.78	7480	293.2	54.8	
115	DBA-08-04	56.1	56.7	50.32	101.30	1988.71	630.75	3.13	6845	378.1	60.5	
116	DBA-09-01	15.1	15.8	50.40	100.30	1995.04	600.19	3.00	4438	91.8	16.7	
117	DBA-09-02	31.1	31.6	50.49	100.71	2002.17	531.22	2.63	6031	75.5	19.6	
118	DBA-09-03	44.0	44.6	50.52	100.13	2004.55	566.75	2.82	7309	266.0	57.8	
119	DBA-09-04	49.9	50.6	50.57	99.53	2008.52	535.92	2.68	5753	108.3	30.0	
120	DBA-01	168.5	169.3	50.43	99.65	1997.41	625.12	3.14	5137	107.4	53.8	
121	DBA-01A	405.3	406.0	50.5	100.94	2002.96	595.89	2.95	3838	15.6	4.5	
122	DBA-01A	383.9	384.5	50.63	100.73	2013.29	587.76	2.90	3178	31.3	6.9	
123	IDH-01	371.0	371.7	50.32	80.54	1988.71	446.88	2.79	3183	9.3	1.2	**Short length due to fraturing during preparation**
124	IDH-02	364.5	365.0	50.61	101.14	2011.70	609.43	3.00	4359	140.6	27.8	
125	IDH-06	189.0	189.6	50.04	103.49	1966.64	582.87	2.86	3644	16.2	8.4	
126	IDH-07	76.0	76.6	50.39	100.83	1994.25	597.62	2.97	5016	155.6	35.0	
127	IDH-07	362.0	362.6	50.13	102.38	1973.72	512.55	2.54	4612	27.2	8.5	
128	IDH-09	78.9	79.5	50.52	103.75	2004.55	610.2	2.93	5608	241.6	46.7	
129	IDH-09	237.0	237.6	50.68	101.33	2017.27	556.27	2.72	5333	97.1	22.0	
130	IDH-10	124.0	124.6	50.46	101.95	1999.79	574.16	2.82	5511	162.8	28.9	
131	IDH-10	200.8	200.1	50.58	103.37	2009.31	587.26	2.83	5743	267.4	47.1	
132	IDH-11	118.1	118.9	50.36	101.88	1991.87	623.66	3.07	5145	125.4	35.8	
133	IDH-11	358.7	386.3	50.52	101.90	2004.55	538.06	2.63	3287	22.8	5.6	
134	IDH-11	386.5	387.2	50.54	102.01	2006.14	550.07	2.69	3435	19.3	4.6	

Table 4.5 Specimen dimensions, mass, density, UCS, and Young's modulus in US customary (specimen 1 – 50)

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Weight	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[in]	[in]	[in^2]	[lb]	[lb/ft^3]	[ft/s]	[ksi]	[ksi]	
1	SD-12	163.5	163.8	1.99	4.09	3.12	1.39	188.18	15199	**23.8**	**9,860**	
2	SD-12	172.8	173.1	2.00	4.19	3.15	1.42	186.23	19102	**30.9**	**8,773**	
3	SD-12	184.9	185.2	2.00	4.15	3.16	1.44	190.36	15563	**N/A**	**N/A**	**Specimen failed during tuning of circumferential control**
4	SD-14	164.2	164.5	1.99	3.99	3.11	1.50	208.93	16804	**20.3**	**12,243**	
5	SD-14	174.0	174.3	1.99	4.24	3.11	1.59	207.89	18606	**16.4**	**12,415**	
6	SD-13	169.8	170.1	2.00	3.99	3.13	1.25	172.31	14103	**16.0**	**8,039**	
7	SD-13	179.0	179.3	2.00	4.05	3.13	1.41	192.17	13488	**16.2**	**8,066**	
8	SD-12	188.3	188.7	2.00	4.11	3.15	1.58	210.38	14166	**12.8**	**4,025**	
9	SD-14	186.2	186.5	1.98	4.22	3.09	1.48	196.41	15982	**19.3**	**6,704**	
10	SD-14	189.1	189.4	1.99	3.99	3.09	1.37	191.18	16637	**14.5**	**6,653**	
11	SD-13	183.9	184.2	2.00	3.95	3.13	1.38	193.53	13832	**8.2**	**2,949**	
12	SD-13	190.7	191.0	2.00	4.26	3.13	1.48	191.35	12593	**6.6**	**2,228**	
13	DBA-01-01	36.5	37.2	2.00	4.07	3.14	1.50	203.17	17954	**21.8**	**8,739**	
14	DBA-02-01	19.6	20.2	1.99	4.16	3.10	1.44	193.01	18248	**32.3**	**9,430**	
15	DBA-02-02	70.8	71.4	1.98	4.08	3.06	1.57	216.57	15538	**27.5**	**6,593**	
16	DBA-02-03	53.1	53.9	1.99	4.11	3.09	1.50	203.21	13809	**14.4**	**4,080**	
17	DBA-03-01	33.1	33.7	2.00	4.09	3.14	1.44	193.57	15573	**13.0**	**5,598**	
18	DBA-03-02	63.5	64.0	1.99	4.10	3.11	1.57	213.12	13616	**30.1**	**4,825**	
19	DBA-03-03	68.1	68.8	1.99	4.10	3.11	1.57	213.23	14287	**32.4**	**5,802**	
20	DBA-03-04	77.5	78.2	1.98	4.10	3.08	1.56	213.44	14871	**15.0**	**4,158**	
21	DBA-03-05	83.5	84.2	1.98	4.10	3.09	1.46	198.61	14494	**5.1**	**2,239**	
22	DBA-03-06	95.4	96.0	1.98	4.10	3.07	1.44	198.39	17693	**24.2**	**8,383**	
23	DBA-03-07	102.1	102.8	1.98	4.09	3.09	1.38	188.14	18227	**48.7**	**10,079**	
24	DBA-03-08	126.7	127.2	1.98	4.11	3.09	1.39	189.72	15998	**14.6**	**3,828**	
25	DBA-03-09	158.2	158.9	1.98	4.07	3.06	1.43	198.65	18145	**34.9**	**7,303**	
26	DBA-04-01	65.3	65.8	1.98	4.06	3.09	1.59	218.77	16998	**23.9**	**7,124**	
27	DBA-04-02	74.5	75.4	1.99	4.12	3.10	1.51	204.17	13843	**24.8**	**4,986**	
28	DBA-04-03	84.5	85.1	1.98	4.06	3.09	1.46	201.19	13333	**20.3**	**3,661**	
29	DBA-04-04	94.9	95.7	1.99	4.17	3.11	1.53	203.39	19639	**26.6**	**10,086**	
30	DBA-04-05	104.4	104.9	1.99	3.74	3.11	1.27	188.16	15296	**18.6**	**6,528**	
31	DBA-05A-01	19.6	20.1	1.99	4.17	3.12	1.32	174.92	15514	**12.7**	**5,203**	
32	DBA-05A-02	40.2	41.0	1.99	4.06	3.12	1.49	202.98	16926	**14.1**	**5,226**	
33	DBA-05A-03	49.2	49.9	1.99	4.14	3.10	1.60	215.83	17959	**17.1**	**8,050**	
34	DBA-05A-04	58.9	59.4	1.99	4.04	3.10	1.28	177.22	17162	**13.8**	**5,632**	
35	DBA-05A-05	61.7	62.2	1.99	4.09	3.10	1.36	185.37	17847	**23.0**	**7,118**	
36	DBA-05A-06	70.0	70.5	1.98	4.05	3.09	1.24	171.62	15280	**14.9**	**4,883**	
37	DBA-05A-07	78.0	78.6	1.98	4.08	3.09	1.44	197.71	17014	**27.1**	**7,214**	
38	DBA-05A-08	100.8	101.5	1.99	4.01	3.11	1.46	202.80	16719	**25.2**	**7,261**	
39	DBA-06-01	29.3	29.9	1.99	4.16	3.11	1.45	194.13	15689	**5.1**	**1,272**	**Existing axial fractures**
40	DBA-06-02	50.2	50.8	1.99	4.09	3.12	1.55	210.22	17917	**25.6**	**9,190**	
41	DBA-06-03	58.1	58.8	1.99	4.14	3.10	1.70	228.33	18237	**23.0**	**9,005**	
42	DBA-06-04	77.8	78.5	1.99	4.12	3.10	1.35	182.16	17894	**8.6**	**4,206**	
43	DBA-01a-01	48.0	48.6	1.99	4.09	3.11	1.35	183.79	18109	**18.7**	**5,745**	
44	DBA-01a-02	102.8	103.4	1.99	4.24	3.11	N/A	N/A	N/A	**N/A**	**N/A**	**Specimen fractured during preparation**
45	DBA-01a-03	156.3	156.8	1.98	3.98	3.08	1.22	171.97	16261	**3.2**	**1,513**	
46	DBA-01a-04	196.9	197.4	1.99	4.13	3.12	1.36	183.13	18993	**14.8**	**5,780**	
47	DBA-01a-05	253.4	254.2	2.00	4.18	3.13	1.65	218.00	18641	**38.1**	**8,248**	
48	DBA-01a-06	300.5	301.0	1.99	4.12	3.11	1.43	192.78	21602	**33.5**	**8,180**	
49	DBA-01a-07	356.0	356.7	1.99	4.12	3.10	1.23	166.33	14848	**22.0**	**4,284**	
50	DBA-01a-08	364.2	370.0	1.99	4.21	3.10	1.24	163.58	17801	**5.8**	**2,950**	**One end intially very fractured**

Table 4.6 Specimen dimensions, mass, density, UCS, and Young's modulus in US customary (specimen 51 – 107)

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Weight	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[in]	[in]	[in^2]	[lb]	[lb/ft^3]	[ft/s]	[ksi]	[ksi]	
51	DBA-01a-09	367.7	368.3	1.99	4.16	3.10	1.26	168.39	10453	**2.0**	**661**	
52	DBA-01a-10	370.3	371.0	1.99	4.09	3.10	1.37	186.56	12180	**8.3**	**2,302**	
53	DBA-01a-11	372.9	373.6	1.99	4.20	3.11	1.28	168.88	16213	**18.4**	**3,656**	
54	DBA-01a-12	389.0	389.9	1.99	4.12	3.11	1.36	183.24	11667	**7.3**	**2,048**	
55	DBA-01a-13	395.0	395.6	1.99	4.10	3.11	1.22	164.84	15114	**8.0**	**3,172**	
56	DBA-01a-14	401.8	402.5	1.99	4.14	3.11	1.28	172.22	19173	**46.4**	**8,443**	
57	DBA-01a-15	452.9	453.8	1.98	4.16	3.07	1.66	224.28	18534	**7.8**	**2,158**	
58	DBA-01a-16	490.4	491.3	1.95	4.17	2.98	1.33	185.18	17276	**26.0**	**7,709**	
59	DBA-01a-17	549.3	550.1	1.99	4.13	3.10	1.54	207.81	17829	**17.8**	**6,541**	
60	DBA-01a-18	600.6	601.4	1.98	4.15	3.06	1.57	212.59	19659	**32.1**	**9,146**	
61	DBA-01a-19	651.8	652.4	1.98	4.18	3.07	1.46	196.57	18352	**25.8**	**8,245**	
62	DBA-01a-20	703.2	703.9	1.98	4.16	3.09	1.32	177.31	17852	**21.8**	**7,359**	
63	DBA-01a-21	755.0	755.8	1.99	4.14	3.12	1.31	175.34	16448	**24.3**	**7,858**	
64	DBA-06-05	108.0	108.6	1.99	4.16	3.10	1.39	185.81	14394	**10.6**	**2,688**	
65	DBA-06-06	151.6	152.4	1.98	4.16	3.06	1.56	211.28	18727	**38.7**	**11,081**	
66	DBA-06-07	187.6	188.2	1.99	4.08	3.10	1.42	193.60	17913	**44.0**	**12,109**	
67	DBA-06-08	248.0	248.7	1.99	4.13	3.10	1.39	187.84	19120	**51.5**	**11,204**	
68	IDH-02-01	248.2	249.0	1.99	4.12	3.11	1.45	195.40	18367	**33.3**	**8,525**	
69	IDH-02-02	293.4	294.4	1.99	4.13	3.12	1.39	186.86	17723	**14.8**	**5,564**	
70	IDH-02-03	346.8	347.6	1.99	4.17	3.12	1.30	173.41	15875	**14.3**	**5,842**	
71	IDH-02-04	361.9	362.5	1.99	4.14	3.11	1.40	187.78	13700	**3.3**	**1,339**	**Chip missing from end of specimen**
72	IDH-02-05	373.5	374.2	1.99	4.10	3.11	1.40	189.60	13490	**14.8**	**3,622**	
73	IDH-02-06	408.0	408.8	1.97	4.16	3.06	1.35	183.12	17597	**32.8**	**8,424**	
74	IDH-08-01	96.0	97.0	1.99	4.10	3.11	1.23	166.60	19080	**15.0**	**5,825**	**Core sample in poor condition**
75	IDH-08-02	222.6	223.2	1.99	4.14	3.11	1.60	214.55	17518	**9.0**	**3,944**	
76	IDH-08-04	167.0	167.6	1.99	4.13	3.12	1.55	207.73	20019	**33.2**	**9,512**	
77	IDH-08-05	321.7	322.2	1.97	4.09	3.04	1.46	203.05	18602	**55.0**	**11,455**	
78	IDH-08-06	378.1	378.7	1.99	4.11	3.11	1.27	171.81	17945	**22.9**	**7,435**	
79	IDH-08-07	418.5	419.0	1.99	4.11	3.11	1.36	184.20	18231	**18.4**	**6,912**	
80	IDH-09-01	161.2	161.8	1.98	4.10	3.08	1.44	197.21	16285	**13.4**	**4,992**	
81	IDH-09-02	286.1	286.6	1.99	4.13	3.11	1.45	194.60	18210	**24.7**	**7,420**	
82	IDH-09-03	247.0	247.8	2.00	4.13	3.13	1.38	184.11	18923	**15.6**	**6,240**	
83	IDH-09-04	137.8	138.2	1.97	3.52	3.06	1.05	168.75	14592	**7.1**	**2,738**	**Core in poor condition resulting in spec. length**
84	IDH-09-05	191.7	192.2	1.98	4.16	3.08	1.53	206.24	16739	**18.2**	**6,776**	
85	IDH-09-06	96.1	96.7	1.99	4.11	3.10	1.34	181.64	16379	**19.9**	**7,409**	
86	IDH-09-07	41.9	42.4	2.00	4.13	3.13	1.54	206.30	17544	**53.5**	**9,748**	
87	IDH-02-07	436.0	437.1	1.99	4.13	3.11	1.61	217.32	19888	**26.9**	**3,955**	
88	IDH-02-08	464.0	464.7	1.99	4.12	3.11	1.41	190.21	18156	**24.7**	**3,530**	
89	IDH-02-09	489.3	490.2	1.99	4.10	3.11	1.32	178.50	18463	**23.5**	**3,619**	
90	IDH-02-10	568.4	569.2	2.00	4.12	3.13	1.73	232.06	16275	**15.9**	**3,179**	
91	IDH-02-11	634.5	635.1	1.99	4.10	3.11	1.31	177.16	16734	**9.5**	**2,109**	
92	IDH-02-12	708.5	709.1	1.98	4.15	3.09	1.44	193.95	17563	**6.0**	**1,497**	**Ends visibly fractured prior to testing**
93	IDH-02-13	764.0	764.8	1.99	4.10	3.10	1.24	168.05	18262	**14.2**	**2,567**	
94	IDH-10-01	244.2	245.0	1.99	4.12	3.11	1.36	182.86	17795	**29.6**	**3,820**	
95	IDH-10-02	253.6	254.7	1.98	4.13	3.08	1.40	189.34	17400	**12.7**	**1,825**	
96	IDH-11-01	56.2	56.9	1.98	4.15	3.08	1.34	180.40	18699	**27.6**	**3,365**	
97	IDH-11-02	135.1	135.7	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**	**N/A**	**Specimen fractured during preparation**
98	IDH-11-03	196.7	197.5	1.98	4.13	3.08	1.41	191.44	19555	**31.2**	**4,076**	
99	IDH-11-04	212.1	212.9	1.98	4.09	3.09	1.44	197.48	19383	**32.5**	**4,119**	
100	IDH-11-05	232.9	233.8	1.99	4.09	3.10	1.45	198.01	17863	**19.7**	**3,070**	
101	IDH-11-06	240.6	241.5	1.99	4.15	3.12	1.48	197.49	16484	**6.1**	**1,227**	
102	IDH-11-07	248.0	248.7	1.98	4.11	3.09	1.51	206.24	14273	**11.4**	**1,984**	
103	IDH-11-08	275.3	276.3	1.99	4.15	3.11	1.57	210.25	16159	**11.9**	**2,251**	
104	IDH-11-09	292.1	292.1	1.98	4.12	3.07	1.35	183.94	13689	**13.8**	**2,045**	
105	IDH-11-10	358.8	359.5	1.99	4.14	3.10	1.38	185.28	18067	**19.3**	**3,139**	
106	IDH-11-11	412.6	413.2	1.99	4.14	3.10	1.27	170.49	15613	**20.3**	**3,104**	
107	IDH-11-12	224.0	224.9	1.99	4.18	3.10	1.51	200.54	18447	**24.4**	**2,967**	

Table 4.7 Specimen dimensions, mass, density, UCS, and Young's modulus in US customary (specimen 108-134)

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Weight	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[in]	[in]	[in^2]	[lb]	[lb/ft^3]	[ft/s]	[ksi]	[ksi]	
108	DBA-07-01	22.2	23.0	1.98	4.02	3.08	1.33	185.79	15153	15.8	2,103	
109	DBA-07-02	27.6	28.3	1.98	3.98	3.08	1.33	187.81	17005	14.8	2,640	
110	DBA-07-03	46.9	47.4	1.99	3.96	3.10	1.26	176.58	22457	21.0	3,814	
111	DBA-07-04	59.8	60.4	1.99	3.98	3.10	1.29	181.10	20857	37.1	4,250	
112	DBA-08-01	32.3	32.8	1.99	4.04	3.10	1.26	173.42	6254	8.4	522	
113	DBA-08-02	40.9	41.5	1.99	3.99	3.11	1.25	173.37	23774	61.7	8,905	
114	DBA-08-03	44.6	45.4	1.99	3.95	3.10	1.23	173.79	24540	42.5	7,948	
115	DBA-08-04	56.1	56.7	1.98	3.99	3.08	1.39	195.46	22456	54.8	8,775	
116	DBA-09-01	15.1	15.8	1.98	3.95	3.09	1.32	187.25	14561	13.3	2,422	
117	DBA-09-02	31.1	31.6	1.99	3.96	3.10	1.17	164.47	19785	10.9	2,843	
118	DBA-09-03	44.0	44.6	1.99	3.94	3.11	1.25	176.27	23979	38.6	8,383	
119	DBA-09-04	49.9	50.6	1.99	3.92	3.11	1.18	167.36	18875	15.7	4,351	
120	DBA-01	168.5	169.3	1.99	3.92	3.10	1.38	196.06	16852	1.3	7,796	
121	DBA-01A	405.3	406.0	1.99	3.97	3.10	1.31	184.00	12592	2.3	648	
122	DBA-01A	383.9	384.5	1.99	3.97	3.12	1.30	180.93	10425	4.5	994	
123	IDH-01	371.0	371.7	1.98	3.17	3.08	0.99	174.18	10444	1.4	177	**Short length due to fraturing during preparation**
124	IDH-02	364.5	365.0	1.99	3.98	3.12	1.34	186.99	14303	20.4	4,026	
125	IDH-06	189.0	189.6	1.97	4.07	3.05	1.29	178.78	11955	2.4	1,217	
126	IDH-07	76.0	76.6	1.98	3.97	3.09	1.32	185.54	16458	22.6	5,072	
127	IDH-07	362.0	362.6	1.97	4.03	3.06	1.13	158.35	15130	3.9	1,233	
128	IDH-09	78.9	79.5	1.99	4.08	3.11	1.35	183.17	18399	35.0	6,772	
129	IDH-09	237.0	237.6	2.00	3.99	3.13	1.23	169.89	17497	14.1	3,195	
130	IDH-10	124.0	124.6	1.99	4.01	3.10	1.27	175.81	18080	23.6	4,186	
131	IDH-10	200.8	200.1	1.99	4.07	3.11	1.29	176.51	18841	38.8	6,834	
132	IDH-11	118.1	118.9	1.98	4.01	3.09	1.37	191.86	16881	18.2	5,189	
133	IDH-11	358.7	386.3	1.99	4.01	3.11	1.19	164.44	10784	3.3	805	
134	IDH-11	386.5	387.2	1.99	4.02	3.11	1.21	167.80	11269	2.8	660	

4.3 CLASSIFICATION

As stated by Deere and Miller (1966): “In classifying rock for engineering purposes, it is desirable to have a relatively simple system of classification with a small number of categories. The classification should be based on significant physical properties so that the system has wide application and is not limited to a specific problem. An optimum classification system should also provide good reproducibility, and the classification should not be a function of the background and experience of the person making the classification.”

Figure 4.1 is a summary of the data plotted in the Deere and Miller (1966) system of engineering classification using two mechanical properties: uniaxial compressive strength and Young’s modulus. The description uses both the strength class (A, B, C, D, or E) and the modulus ratio = E/UCS, with H = High Modulus Ratio, L = Low Modulus Ratio, and no suffix (or M) for an Average Modulus Ratio. Thus, a rock can be classified as BH for high strength and high modulus ratio. Most of the tested rock is in the very high (A) to medium (C) strength range with an average modulus ratio.

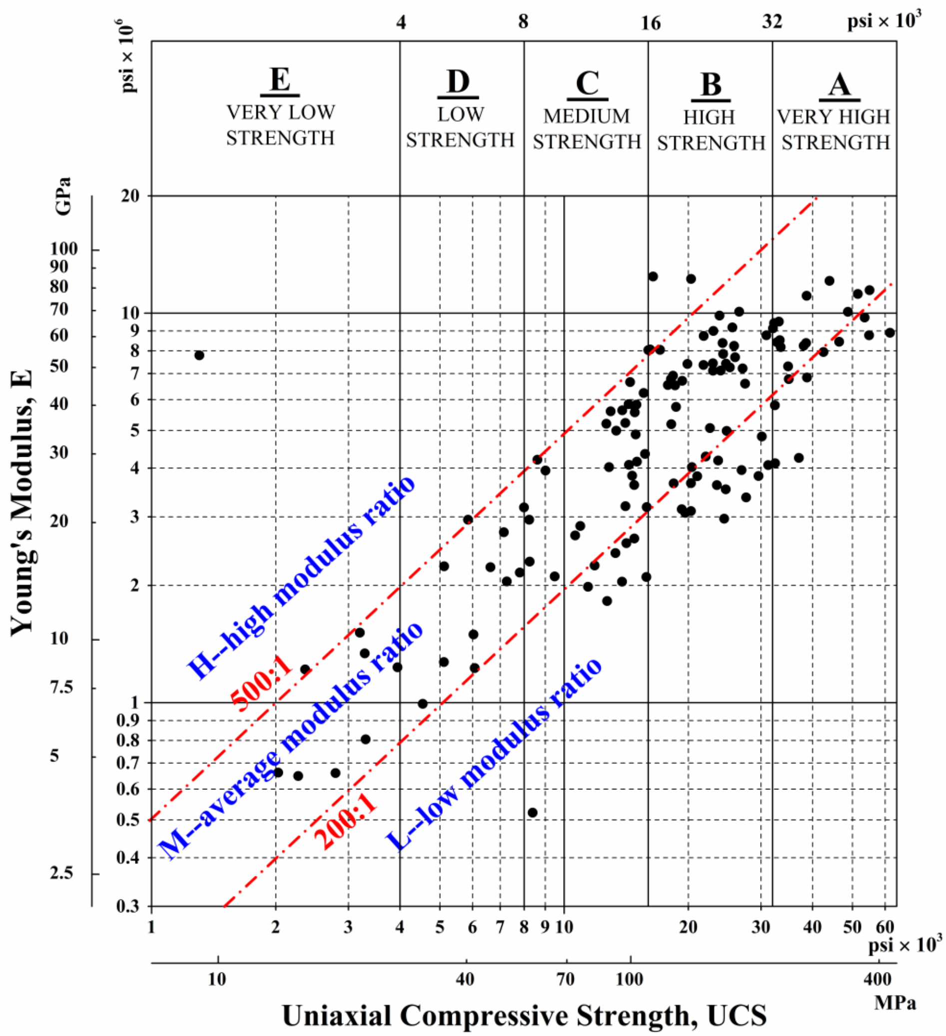

Figure 4.1 Deere and Miller (1966) classification of tested rocks.

CHAPTER 5: TRIAXIAL COMPRESSION TESTING

5.1 INTRODUCTION

Thirty-three (33) triaxial compression tests were performed on rock supplied by MnDOT. All specimens tested included axial displacement measurements to determine axial strain. Prior to testing, triaxial compression specimens were measured for volume, mass, density, and P-wave velocity (Tables 5.1-5.4).

Triaxial compression testing was performed on St. Peter Sandstone, where specimens were machined from a block provided by MnDOT. Due to the St. Peter Sandstone being a soft, friable rock, obtaining “good” core samples for triaxial testing was challenging. The irregular shaped block was placed in a wood box and filled with sand in order to provide confinement while coring. Coring was performed dry with a saw-tooth barrel, and compressed air was used to blow the cuttings from the borehole. The ends of the cores were then sawed by hand to make the ends flat and parallel. Results for the St. Peter Sandstone are in Table 5.1; stress-strain curves are in Appendix C and photos of the specimens and coring process are presented in Appendix F.

The results from triaxial compression testing for SP2782-334 are reported in Table 5.3 and for SP804-81 in Table 5.4. Failure was determined from the peak load and the original cross-sectional area of the specimens. The axial stress-axial strain diagrams of the specimens from SP2782-334 and SP804-81 are included in Appendices B and C respectively. Photographs of the specimens before testing and after testing are shown in Appendices D and E for SP2782-334 and SP804-81 respectively. Axial displacement is determined from a measure of stroke displacement that contains system displacement. This machine displacement is determined by testing an aluminum specimen within the same configuration as that used for the rock specimens. Knowing the displacement of the aluminum (from known material properties and geometry), a system correction was calculated and applied to all other tests. The displacements reported are associated with the specimens (the correction was applied).

5.2 RESULTS

5.2.1 SP2782-334 Results

From Figure 5.1, an estimate of friction angle for group A is 48.7 degrees with an R-squared of 0.93. Group B cannot yield a realistic friction angle due to the specimens not being of the similar material. From Figure 5.2, an estimate of friction angle for group B is 35.1 degrees with an R-squared of 0.98. Group A from Figure 5.2 cannot yield a realistic friction angle due to the specimens not being of the same material.

Table 5.1 Labeling, depth, and stratigraphy for each sample

Sample ID	Hole ID	Depth from [ft]	Depth to [ft]	Member	Formation
x1	T06	74.4	74.825	Magnolia	Platteville
x2	T06	84.0	84.425	Hidden Falls	Platteville
x3	T06	85.9	86.325	Mifflin	Platteville
x4	T06	95.8	96.225	Mifflin	Platteville
x5	T06	99.0	99.425	Pecatonica	Platteville
x6	T06	100.6	101.025	N/A	Glenwood Shale

Table 5.2 Specimen dimensions, mass, density, P-wave velocity, minor and major principal stresses

Sample ID	D [mm]	L [mm]	M [g]	Density [g/cm^3]	P-wave [m/s]	σ_3 [MPa]	σ_1 [MPa]
x1	44.83	91.95	372.1	2.564	4123	5.0	174.5
x2	44.65	93.15	355.5	2.437	3833	10.0	181.2
x3	44.70	96.35	395.5	2.616	4700	20.0	274.4
x4	44.70	94.25	387.3	2.619	4736	5.0	220.4
x5	44.68	95.4	390.4	2.610	5021	10.0	231.2
x6	44.40	94.9	336.0	2.287	2166	20.0	100.0

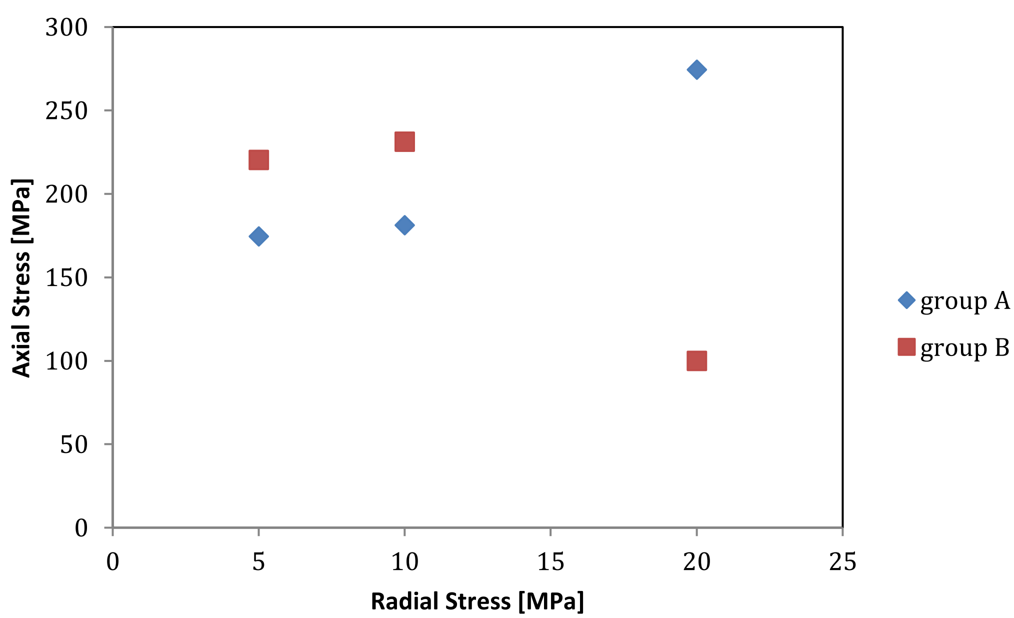

Figure 5.1 Principal stress plot of test specimens divided into groups by depth. Samples x1, x2, x3 belong to group A and samples x4, x5, x6 belong to group B.

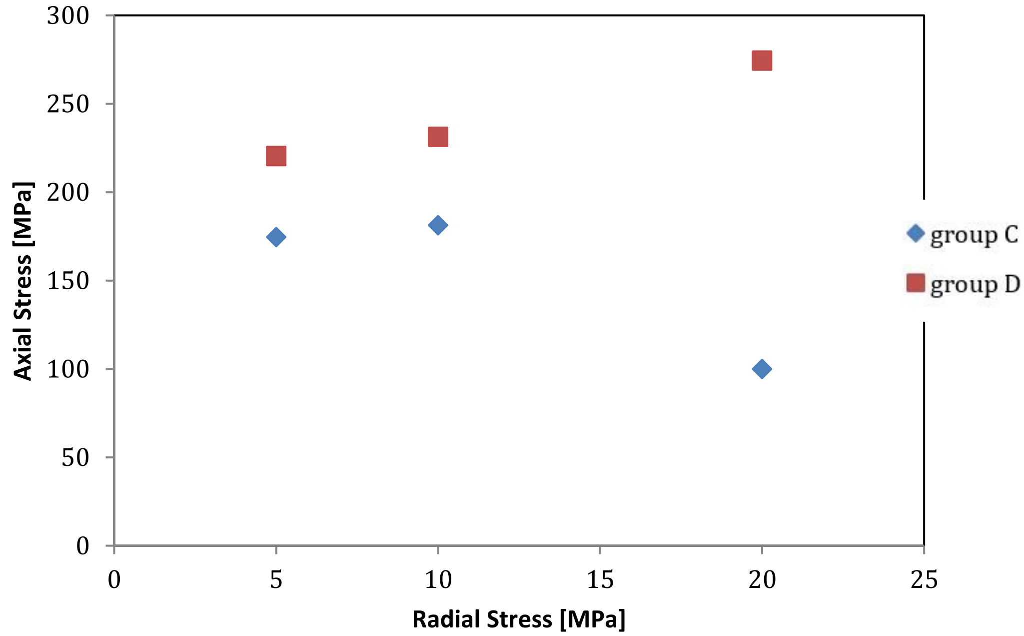

Figure 5.2 Principal stress plot of test specimens divided into groups based on similar P-wave velocities and densities. Samples x1, x2, and x6 belong to group C while samples x3, x4, x5 belong to group D.

5.2.2 SP804-81 Results

Table 5.3 Labeling, depth and stratigraphy for each sample

Sample ID	Unique#	Depth from [ft]	Depth to [ft]	Stratigraphy
7	80240	40.3	40.7	Cretaceous Sediments
8	80240	62.0	62.4	Cretaceous Sediments
9	80240	69.1	69.5	Cretaceous Sediments
10	80241	40.5	40.9	Cretaceous Sediments
11	80241	41.1	41.5	Cretaceous Sediments
12	80241	42.45	42.85	Cretaceous Sediments
13	80241	43.1	43.5	Cretaceous Sediments
14	80241	43.9	44.3	Cretaceous Sediments
15	80241	44.8	45.2	Cretaceous Sediments
16	80241	46.8	47.2	Cretaceous Sediments
17	80241	47.3	47.7	Cretaceous Sediments
18	80241	61.2	61.6	Cretaceous Sediments
19	80241	68.9	69.3	Cretaceous Sediments
20	80241	73.6	74.0	Cretaceous Sediments
21	80242	87.0	87.4	Cretaceous Sediments
22	80243	70.3	70.7	Cretaceous Sediments

23	80243	72.6	73.0	Cretaceous Sediments
24	80243	76.7	77.1	Cretaceous Sediments
25	80243	77.3	77.8	Cretaceous Sediments
26	80243	77.9	78.3	Cretaceous Sediments
27	80243	78.5	78.9	Cretaceous Sediments
28	80243	79.5	79.9	Cretaceous Sediments
29	80243	80.0	80.4	Cretaceous Sediments

Table 5.4 Specimen dimensions, mass, density, P-wave velocity, minor and major principal stresses, and friction angles.

Triaxial Group	Sample ID	Diameter	Length	Mass	Density	P-wave	σ3	σ1	Friction Angle
-	-	[mm]	[mm]	[g]	[g/cm^3]	[m/s]	[MPa]	[MPa]	[deg]
1	9	44.0	93.4	300.7	2.12	2245	5.0	50.4	25.5
1	19	44.2	95.0	311.2	2.13	2273	2.5	40.4	
1	22	44.1	91.7	297.1	2.12	2215	10.0	60.0	
2	12	44.2	96.2	294.2	1.99	2069	2.5	34.9	34.4
2	13	44.3	95.1	293	2.00	2366	5.0	52.5	
2	14	44.3	96.1	299	2.02	2403	10.0	63.6	
3	7	43.7	69.7	220.8	2.11	2099	2.5	30.0	52.1
3	10	43.7	93.4	306.6	2.19	2359	2.5	54.2	
3	18	44.0	88.2	277.2	2.07	1991	5.0	51.3	
4	8	44.6	64.4	202	2.01	1328	10.0	64.3	18.9
4	11	44.3	59.2	185.7	2.04	2368	2.5	48.9	
4	15	44.1	89.5	284.7	2.08	2096	5.0	57.4	
5	20	44.3	81.1	246.3	1.97	1191	2.5	33.7	19.2
5	23	44.2	68.9	208.3	1.97	1298	7.5	45.9	
5	24	44.2	89.1	269.5	1.97	1700	5.0	38.7	
5	25	43.3	93.7	266.7	1.93	2002	10.0	47.8	
6	26	43.4	96.4	281	1.97	1890	2.5	25.9	28.6
6	27	43.8	94.9	283.2	1.98	2086	5.0	41.0	
6	28	44.2	95.3	281.2	1.92	2032	10.0	47.1	
6	29	44.1	66.4	205.1	2.02	2082	7.5	48.3	
7	16	43.4	90.1	273.2	2.05	1713	2.5	26.5	N/A
7	17	42.5	91.0	243.6	1.89	1628	0.0	21.6	
7	21	45.3	90.9	282.7	1.93	1416	0.0	24.3	

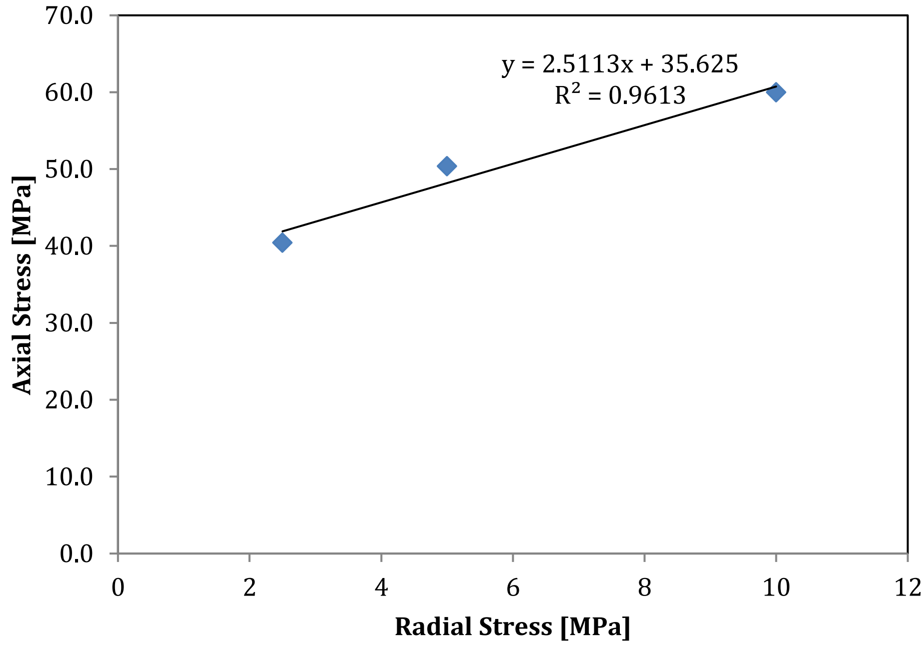

Figure 5.3 Principal stress plot for triaxial group 1 (specimens 19, 9, 22).

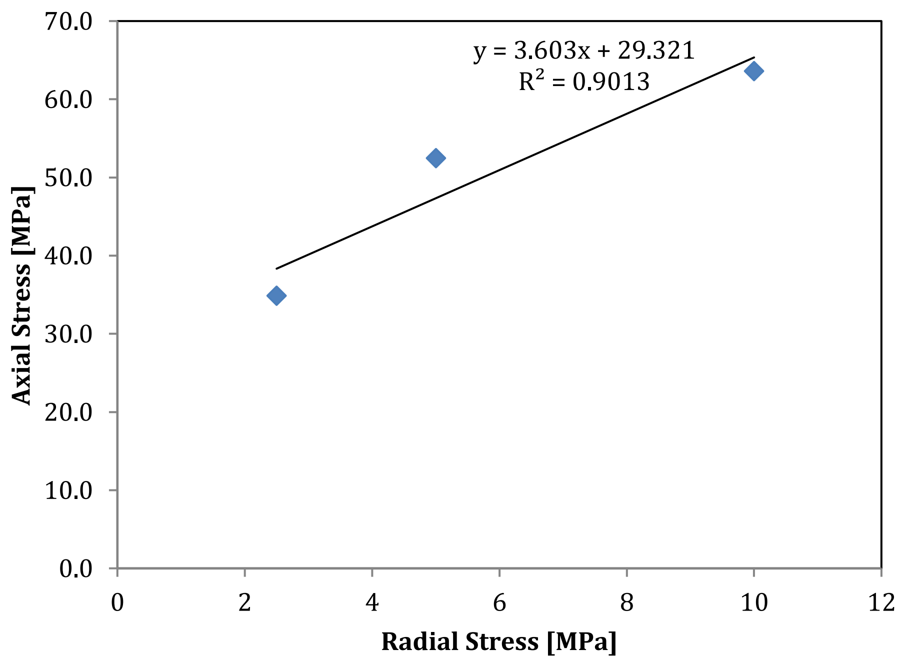

Figure 5.4 Principal stress plot for triaxial group 2 (specimens 12, 13, 14).

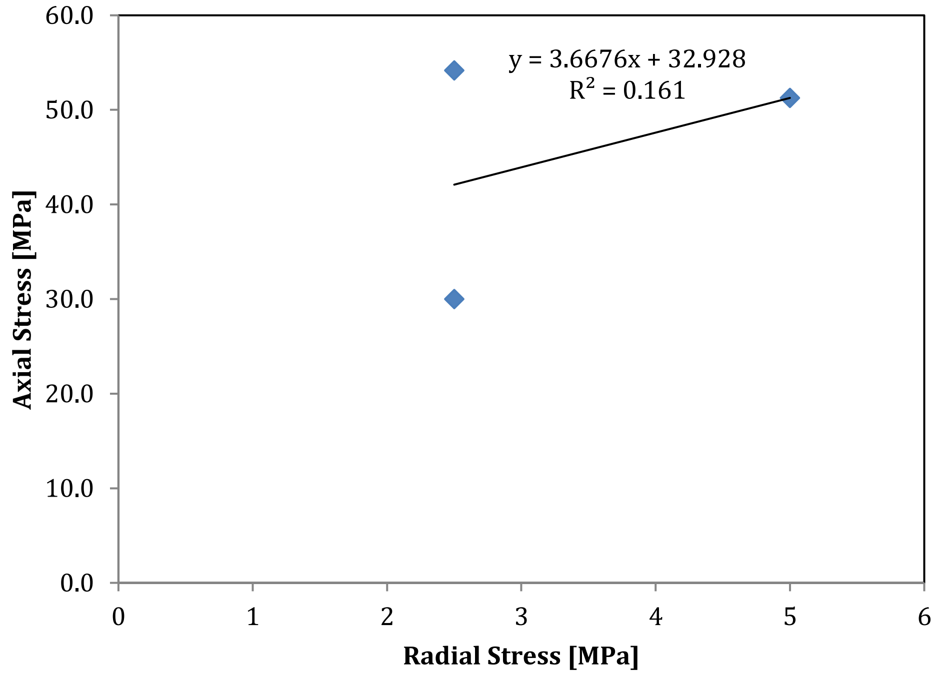

Figure 5.5 Principal stress plot for triaxial group 3 (specimens 7, 10, 18).

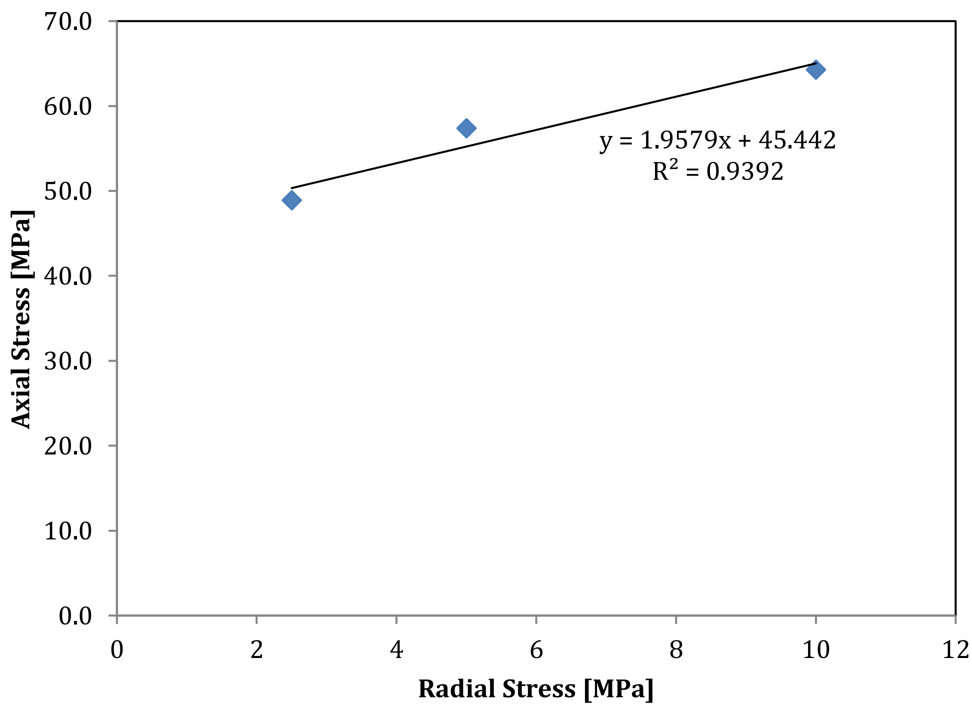

Figure 5.6 Principal stress plot for triaxial group 4 (specimens 11, 15, 8).

CHAPTER 6: CONCLUSIONS

A bridge project in northern Minnesota provided an opportunity to expand the rock strength database and examine in greater detail the mechanical properties of rock. A high-capacity, computer-controlled, servo-hydraulic load frame can apply up to one million pounds of force on a rock specimen, and do so in a controlled manner, so the failure of brittle materials such as rock can be studied and classified.

In classifying rock for engineering purposes, it is desirable to have a simple system of classification with only a few categories. The classification for intact rock should be based on physical properties such as strength and stiffness. Also the classification should not be a function of the background and experience of the person classifying the rock.

The classification system due to Deere and Miller (1966), which depends on uniaxial compressive strength (UCS) and Young's modulus (E), was applied to the measured data. The description uses both the strength class (A, B, C, D, or E) and the modulus ratio = E/UCS, with H = High Modulus Ratio, L = Low Modulus Ratio, and no suffix (or M) for an Average Modulus Ratio. Thus, a rock can be classified as BH for high strength and high modulus ratio. Most of the tested rock is in the very high (A) to medium (C) strength range with an average modulus ratio.

Often when rock is tested, engineers apply force until the rock breaks, which for high-strength rock usually happens violently. But with the computer-controlled load frame, the force placed on the rock can be applied at a constant rate up to a maximum force. Then the force can be reduced gradually, to preserve the rock specimen for further study. By observing the way the rock fails and by recording the maximum force, researchers can determine if natural features in the rock are contributing to the failure process. These planes of weakness are important for design of the bridge foundation. Additionally, by preventing the rock from breaking apart violently when it fails, engineers can study the effects of the applied force after the experiment is completed.

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APPENDIX A: AXIAL STRESS - AXIAL STRAIN PLOTS AND SPECIMEN PHOTOS

Specimen 1

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
1	SD-12	163.5	163.8	50.63	103.77	629.77	3.01	2013.29	4633	**164.1**	**67.98**

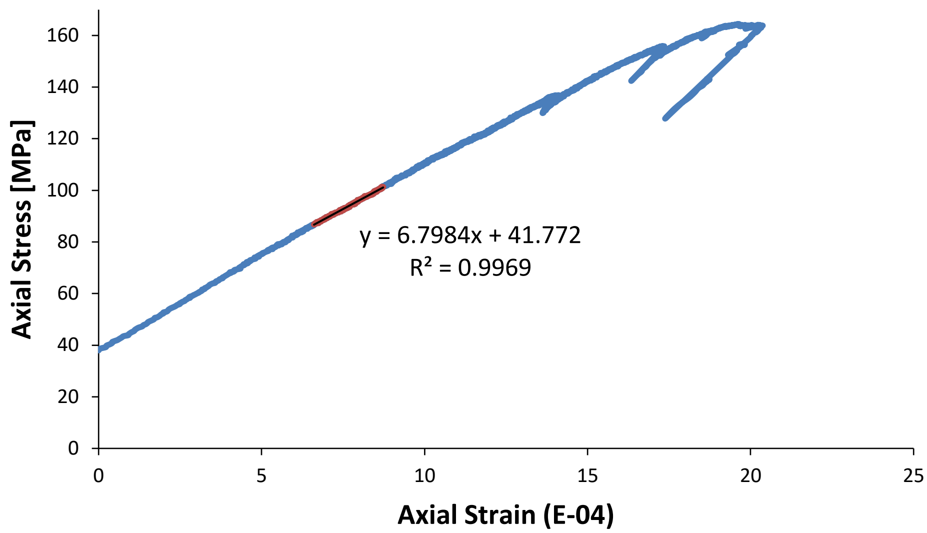

Figure A.1 Specimen 1: Young's modulus calculation

Figure A.2 Specimen 1: Before USC test and After UCS test

Specimen 2

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
2	SD-12	172.8	173.1	50.83	106.55	645.00	2.98	2029.22	5822	**213.2**	**60.49**

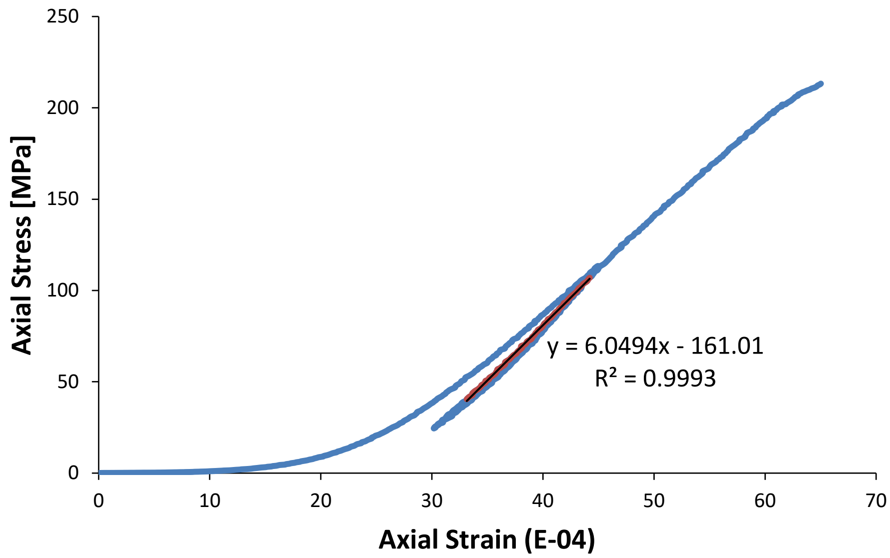

Figure A.3 Specimen 2: Young's modulus calculation

Figure A.4 Specimen 2: Before USC test and After UCS test

Specimen 3

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]	
3	SD-12	184.9	185.2	50.92	105.31	653.92	3.05	2036.42	4744	**N/A**	**N/A**	**Specimen failed during tuning of circumferential control**

Figure A.5 Specimen 3: Before tuning and After tuning

Specimen 4

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
4	SD-14	164.2	164.5	50.51	101.41	680.07	3.35	2003.75	5122	**140.0**	**84.41**

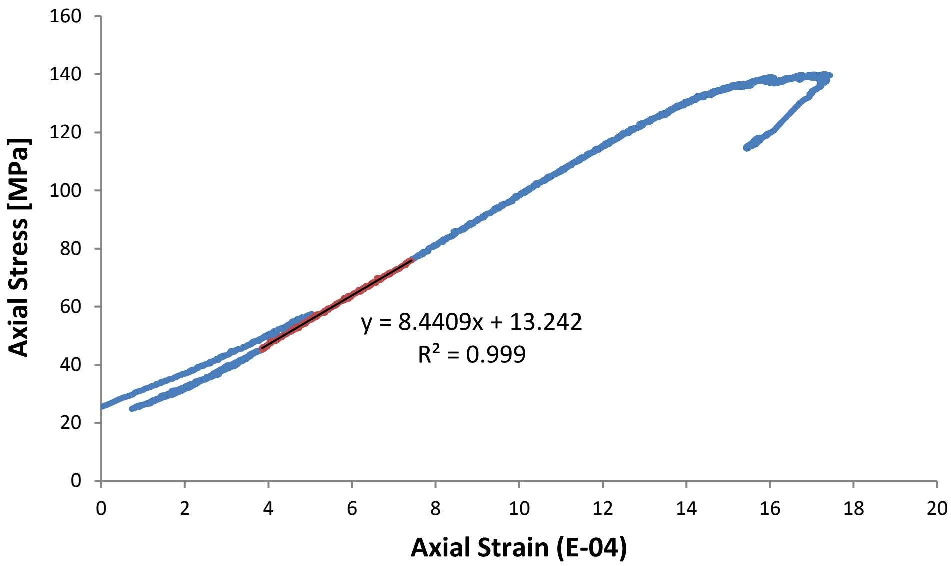

Figure A.6 Specimen 4: Young's modulus calculation

Figure A.7 Specimen 4: Before USC test and After UCS test

Specimen 5

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
5	SD-14	174.0	174.3	50.56	107.75	720.39	3.33	2007.72	5671	**113.3**	**85.60**

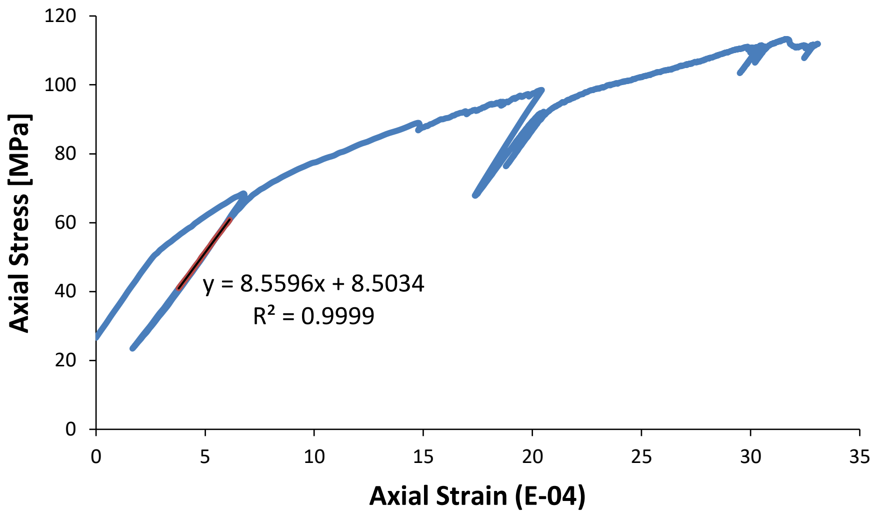

Figure A.8 Specimen 5: Young's modulus calculation

Figure A.9 Specimen 5: Before USC test and After UCS test

Specimen 6

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
6	SD-13	169.8	170.1	50.70	101.45	565.31	2.76	2018.86	4299	**110.3**	**55.43**

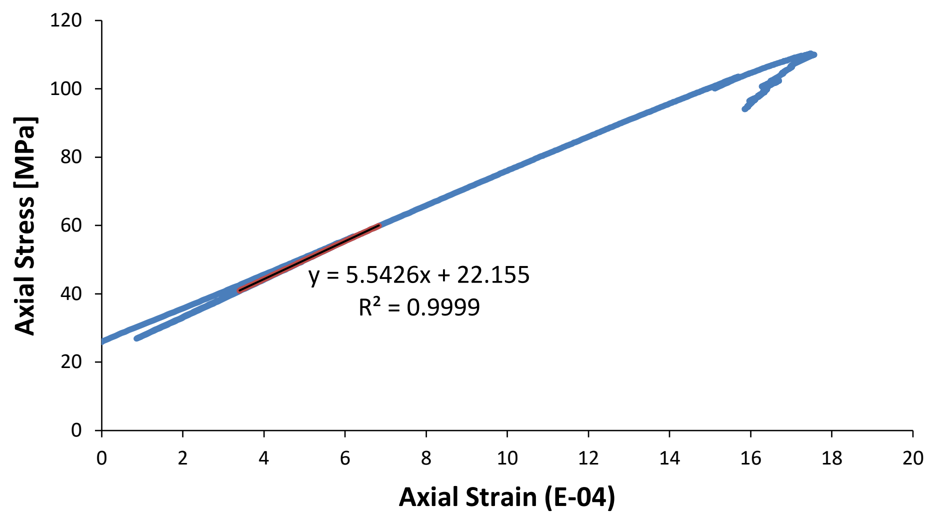

Figure A.10 Specimen 6: Young's modulus calculation


Figure A.11 Specimen 6: Before USC test and After UCS test

Specimen 7

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
7	SD-13	179.0	179.3	50.72	102.78	639.25	3.08	2020.45	4111	**111.4**	**55.61**

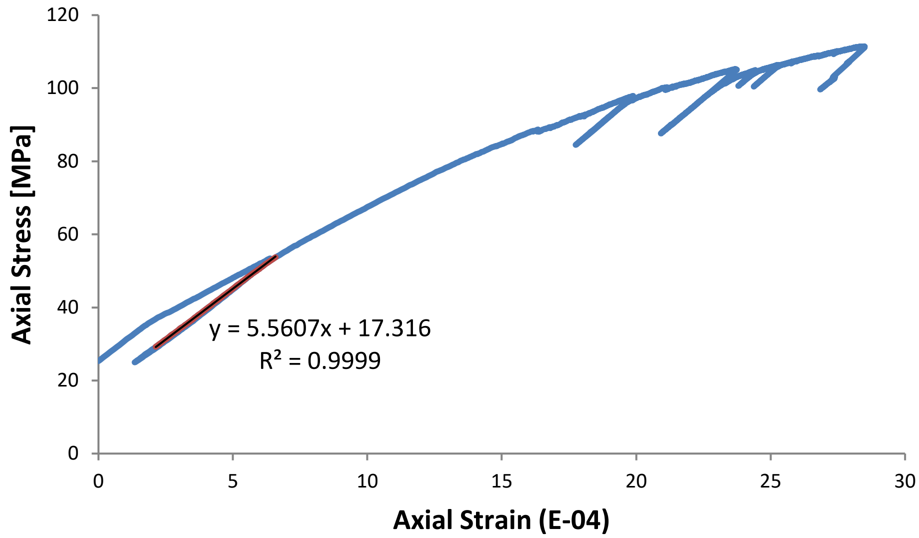

Figure A.12 Specimen 7: Young's modulus calculation

Figure A.13 Specimen 7: Before USC test and After UCS test

Specimen 8

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
8	SD-12	188.3	188.7	50.89	104.49	716.25	3.37	2034.02	4318	**88.6**	**27.75**

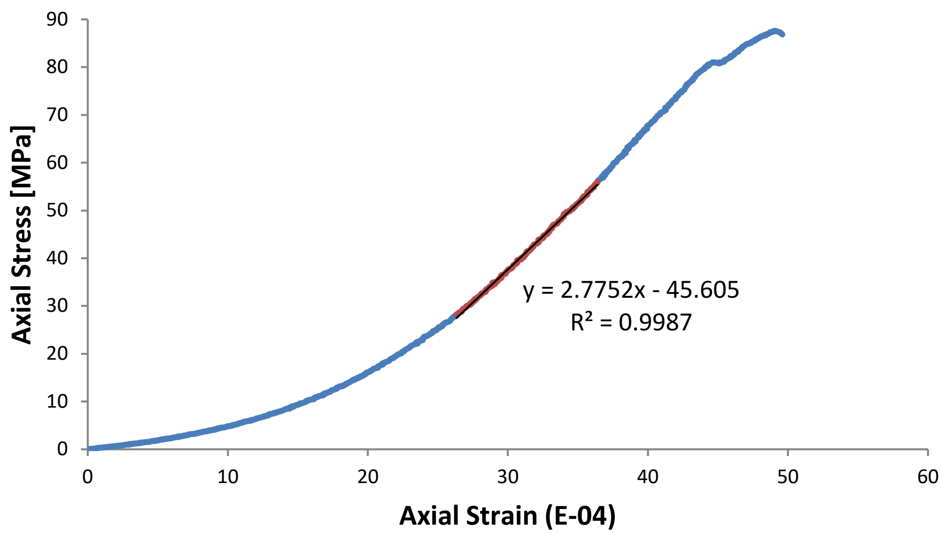

Figure A.14 Specimen 8: Young's modulus calculation

Figure A.15 Specimen 8: Before USC test and After UCS test

Specimen 9

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
9	SD-14	186.2	186.5	50.38	107.17	672.15	3.15	1993.45	4871	**133.3**	**46.22**

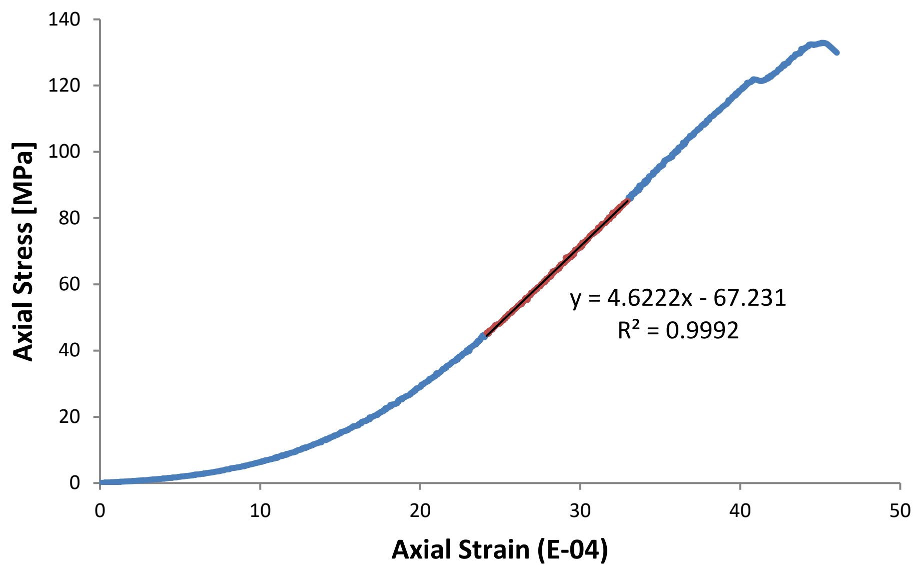

Figure A.16 Specimen 9: Young's modulus calculation

Figure A.17 Specimen 9: Before USC test and After UCS test

Specimen 10

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
10	SD-14	189.1	189.4	50.42	101.42	620.12	3.06	1996.62	5071	**99.6**	**45.87**

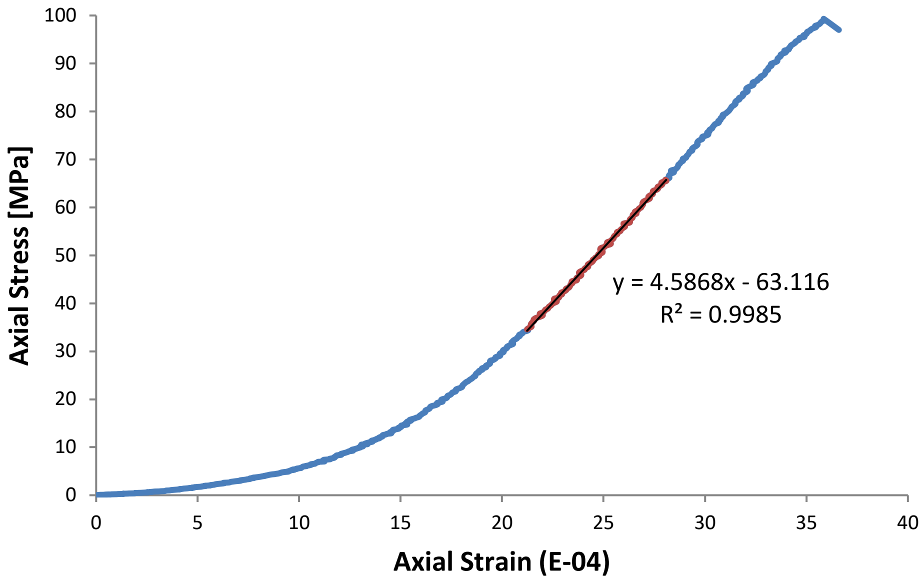

Figure A.18 Specimen 10: Young's modulus calculation

Figure A.19 Specimen 10: Before USC test and After UCS test

Specimen 11

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
11	SD-13	183.9	184.2	50.68	100.34	627.48	3.10	2017.27	4216	**56.8**	**20.33**

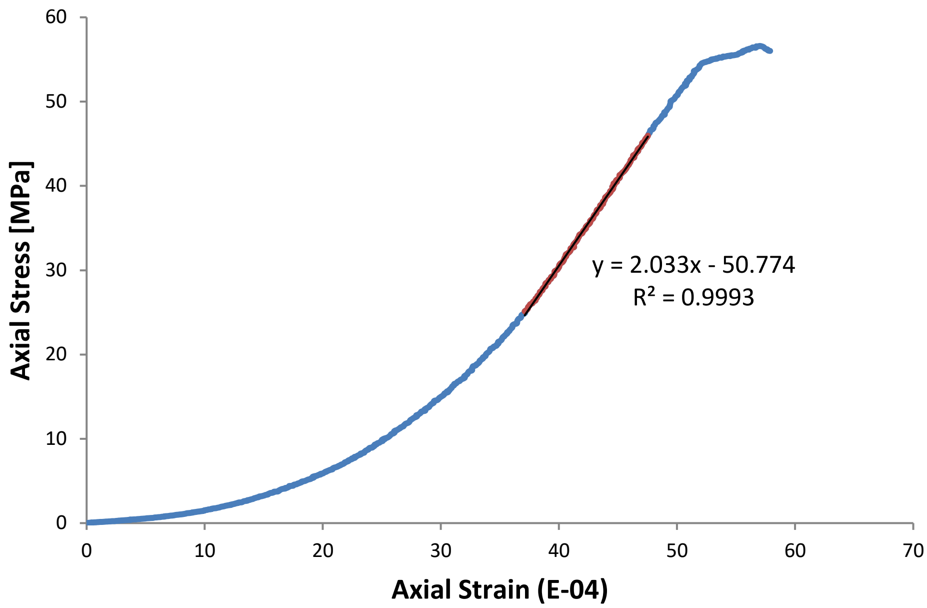

Figure A.20 Specimen 11: Young's modulus calculation

Figure A.21 Specimen 11: Before USC test and After UCS test

Specimen 12

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
12	SD-13	190.7	191.0	50.70	108.24	669.8	3.07	2018.86	3838	**45.7**	**15.36**

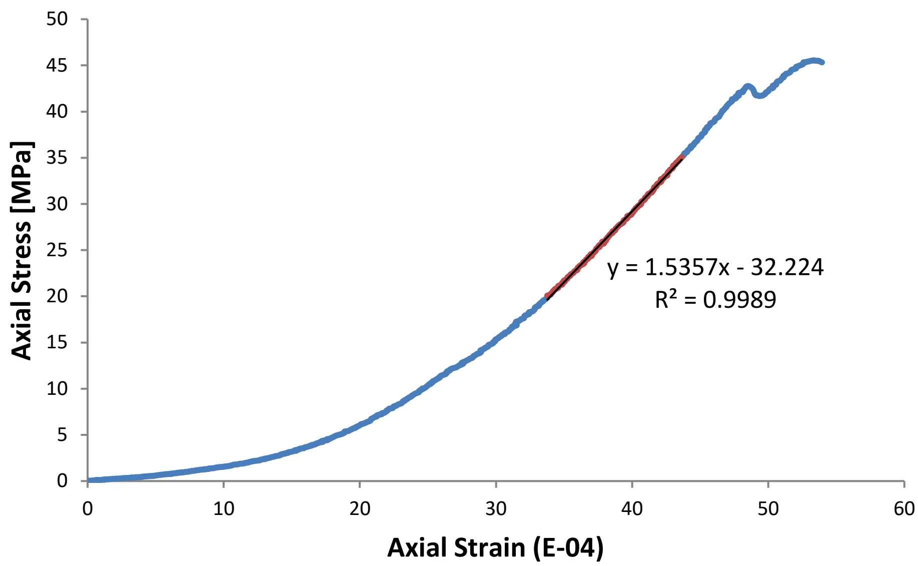

Figure A.22 Specimen 12: Young's modulus calculation

Figure A.23 Specimen 12: Before USC test and After UCS test

Specimen 13

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
13	DBA-01-01	36.5	37.2	50.80	103.43	682.24	3.25	2026.83	5472	**150.2**	**60.25**

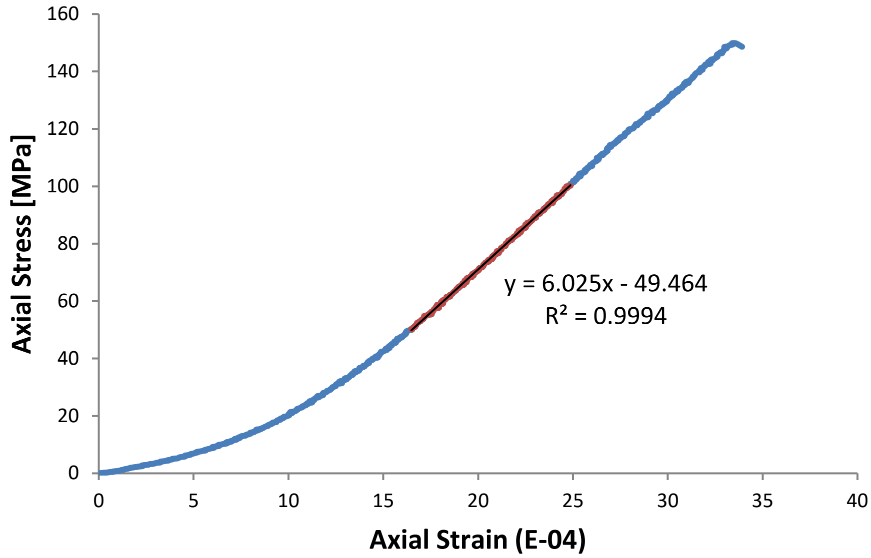

Figure A.24 Specimen 13: Young's modulus calculation

Figure A.25 Specimen 13: Before USC test and After UCS test

Specimen 14

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
14	DBA-02-01	19.6	20.2	50.49	105.68	654.19	3.09	2002.17	5562	**222.6**	**65.02**

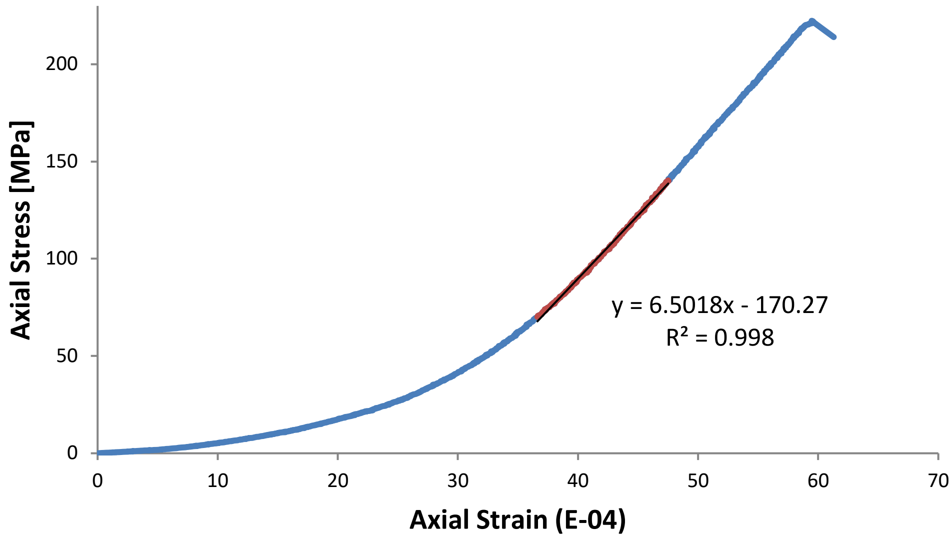

Figure A.26 Specimen 14: Young's modulus calculation

Figure A.27 Specimen 14: Before USC test and After UCS test

Specimen 15

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
15	DBA-02-02	70.8	71.4	50.17	103.72	711.31	3.47	1976.87	4736	**189.3**	**45.46**

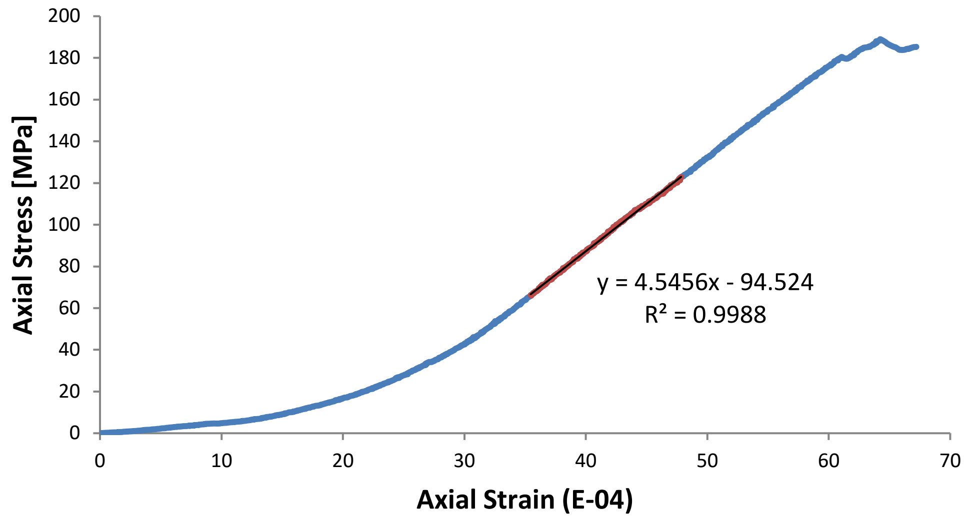

Figure A.28 Specimen 15: Young's modulus calculation

Figure A.29 Specimen 15: Before USC test and After UCS test

Specimen 16

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
16	DBA-02-03	53.1	53.9	50.42	104.38	678.39	3.26	1996.62	4209	**99.0**	**28.13**

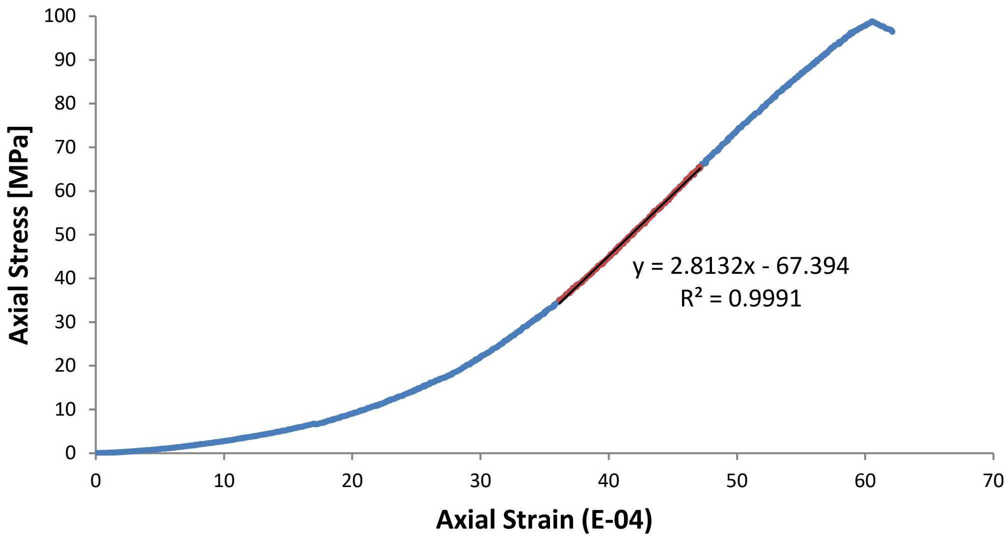

Figure A.30 Specimen 16: Young's modulus calculation

Figure A.31 Specimen 16: Before USC test and After UCS test

Specimen 17

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
17	DBA-03-01	33.1	33.7	50.76	103.95	652.26	3.10	2023.64	4747	**89.4**	**38.60**

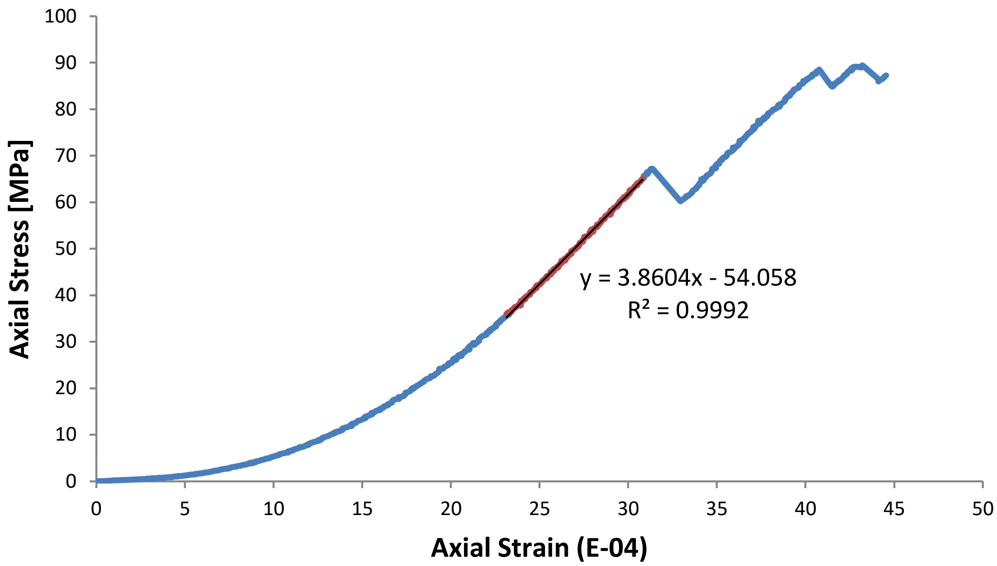

Figure A.32 Specimen 17: Young's modulus calculation

Figure A.33 Specimen 17: Before USC test and After UCS test

Specimen 18

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
18	DBA-03-02	63.5	64.0	50.51	104.17	712.57	3.41	2003.75	4150	**207.8**	**33.27**

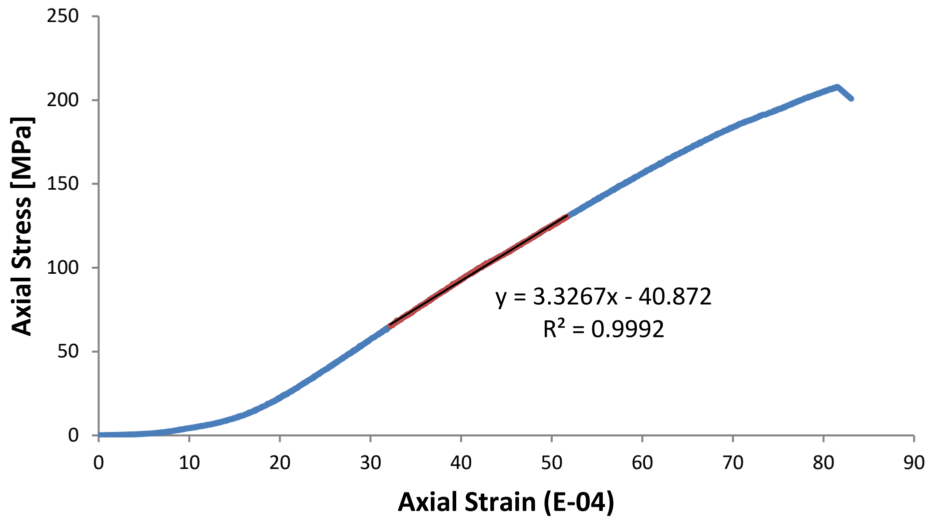

Figure A.34 Specimen 18: Young's modulus calculation

Figure A.35 Specimen 18: Before USC test and After UCS test

Specimen 19

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
19	DBA-03-03	68.1	68.8	50.54	104.08	713.18	3.42	2006.14	4355	**223.5**	**40.00**

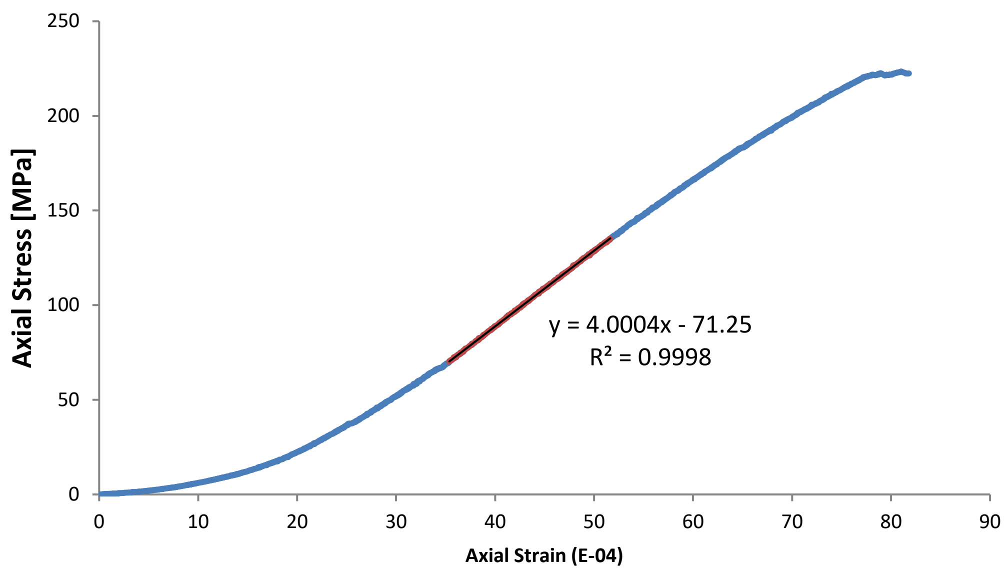

Figure A.36 Specimen 19: Young's modulus calculation

Figure A.37 Specimen 19: Before USC test and After UCS test

Specimen 20

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
20	DBA-03-04	77.5	78.2	50.34	104.25	709.4	3.42	1990.29	4533	**103.5**	**28.67**

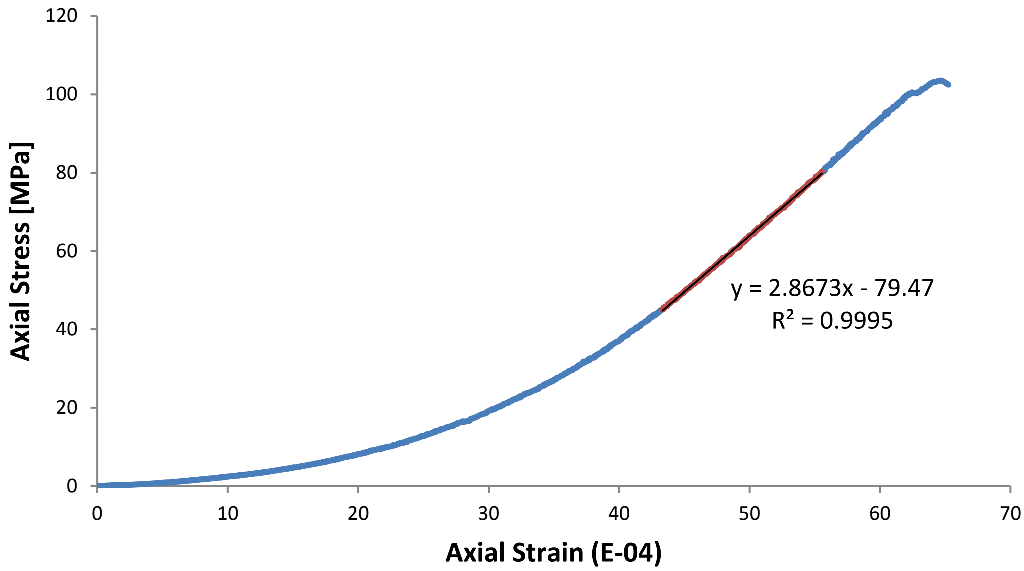

Figure A.38 Specimen 20: Young's modulus calculation

Figure A.39 Specimen 20: Before USC test and After UCS test

Specimen 21

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
21	DBA-03-05	83.5	84.2	50.37	104.26	660.96	3.18	1992.66	4418	**35.3**	**15.44**

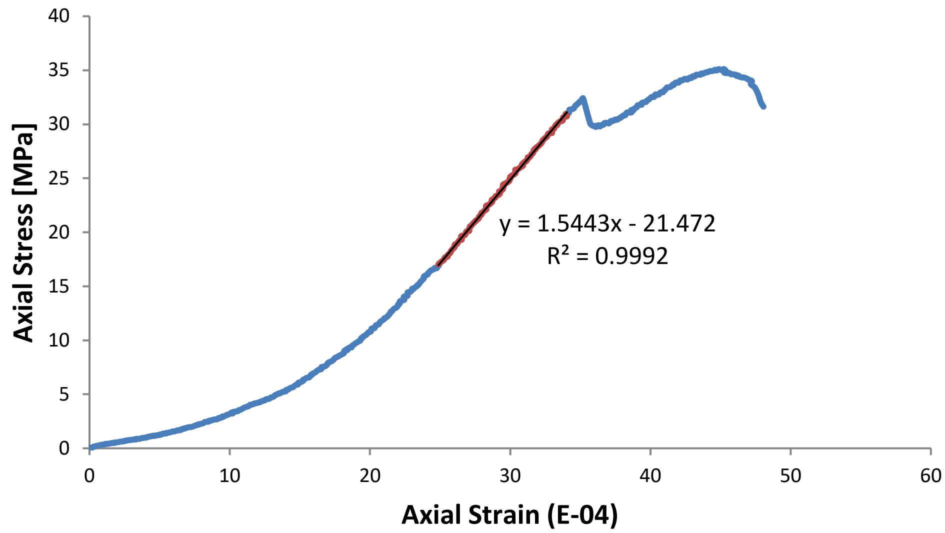

Figure A.40 Specimen 21: Young's modulus calculation

Figure A.41 Specimen 21: Before USC test and After UCS test

Specimen 22

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
22	DBA-03-06	95.4	96.0	50.21	104.08	654.92	3.18	1980.02	5393	**167.0**	**57.80**

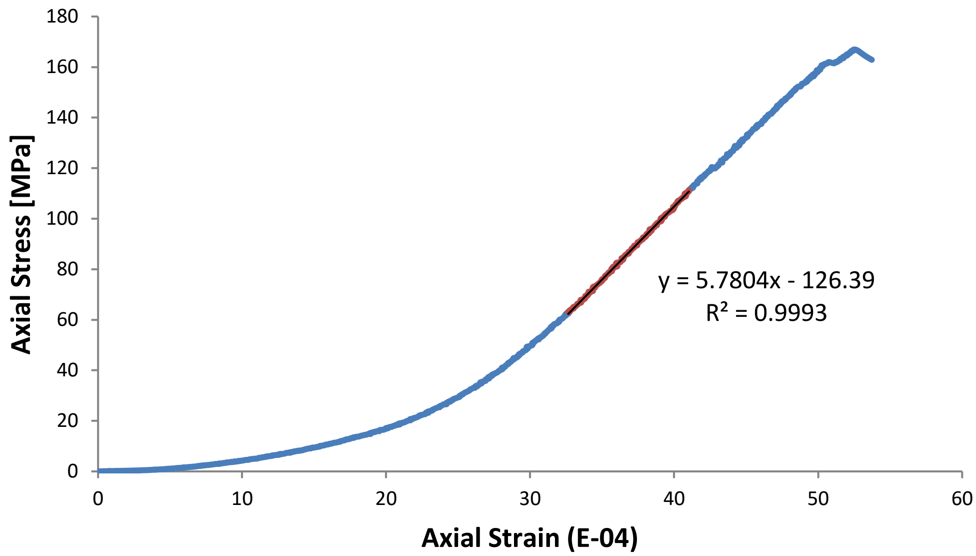

Figure A.42 Specimen 22: Young's modulus calculation

Figure A.43 Specimen 22: Before USC test and After UCS test

Specimen 23

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
23	DBA-03-07	102.1	102.8	50.37	103.89	623.91	3.01	1992.66	5556	**336.0**	**69.49**

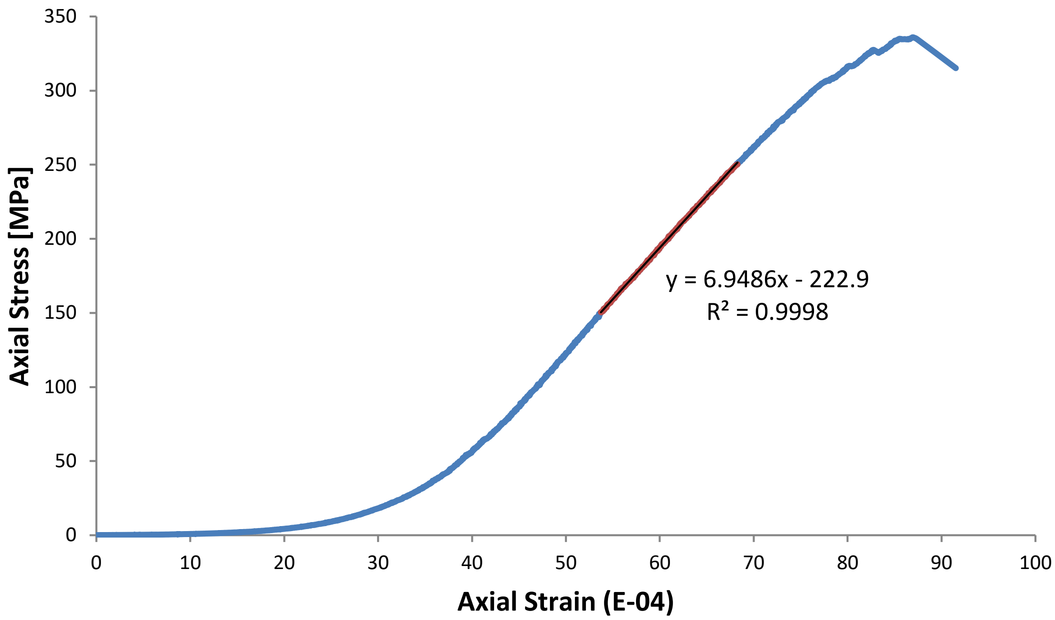

Figure A.44 Specimen 23: Young's modulus calculation

Figure A.45 Specimen 23: Before USC test and After UCS test

Specimen 24

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
24	DBA-03-08	126.7	127.2	50.37	104.35	631.92	3.04	1992.66	4876	**100.8**	**26.39**

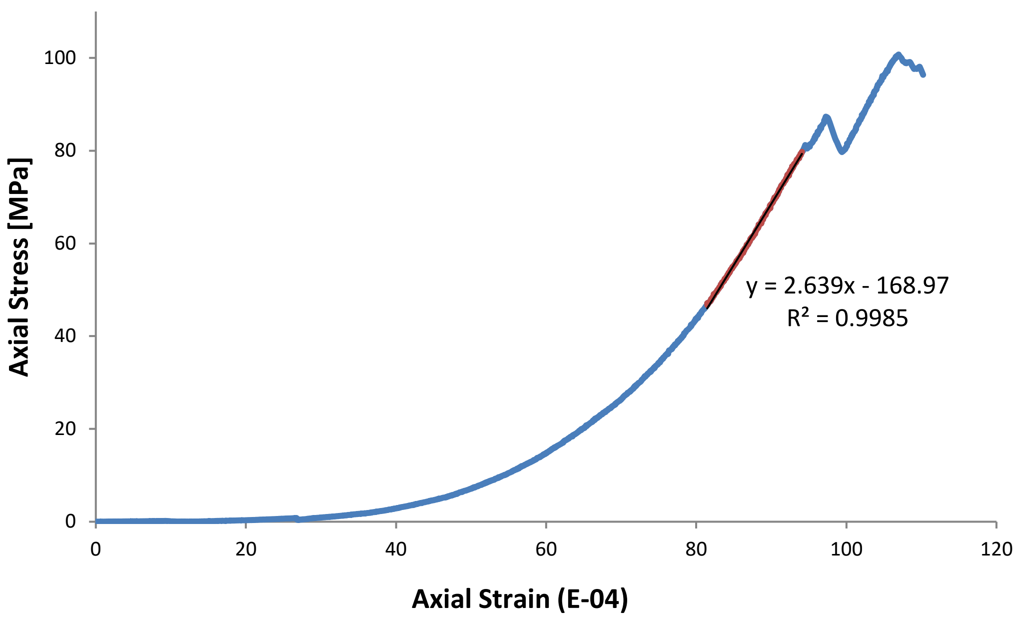

Figure A.46 Specimen 24: Young's modulus calculation

Figure A.47 Specimen 24: Before USC test and After UCS test

Specimen 25

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
25	DBA-03-09	158.2	158.9	50.17	103.42	650.56	3.18	1976.87	5530	**240.6**	**50.35**

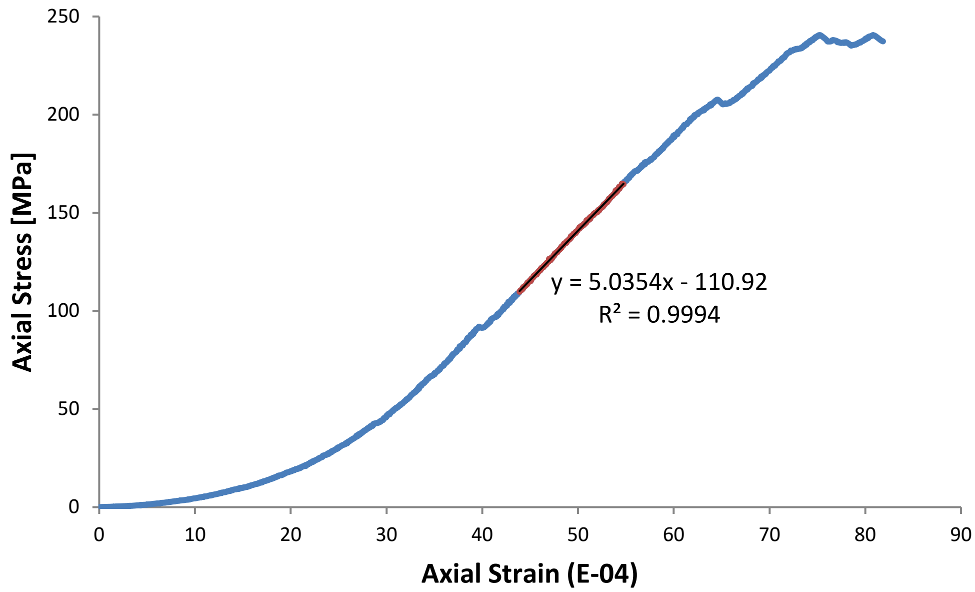

Figure A.48 Specimen 25: Young's modulus calculation

Figure A.49 Specimen 25: Before USC test and After UCS test

Specimen 26

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
26	DBA-04-01	65.3	65.8	50.37	103.10	719.96	3.50	1992.66	5181	**165.1**	**49.12**

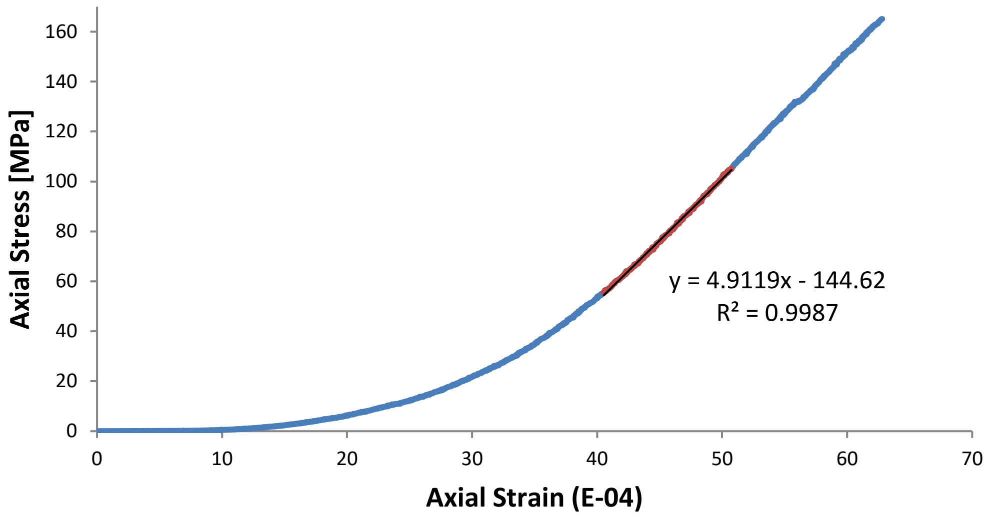

Figure A.50 Specimen 26: Young's modulus calculation

Figure A.51 Specimen 26: Before USC test and After UCS test

Specimen 27

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
27	DBA-04-02	74.5	75.4	50.44	104.64	683.84	3.27	1998.20	4219	**170.9**	**34.38**

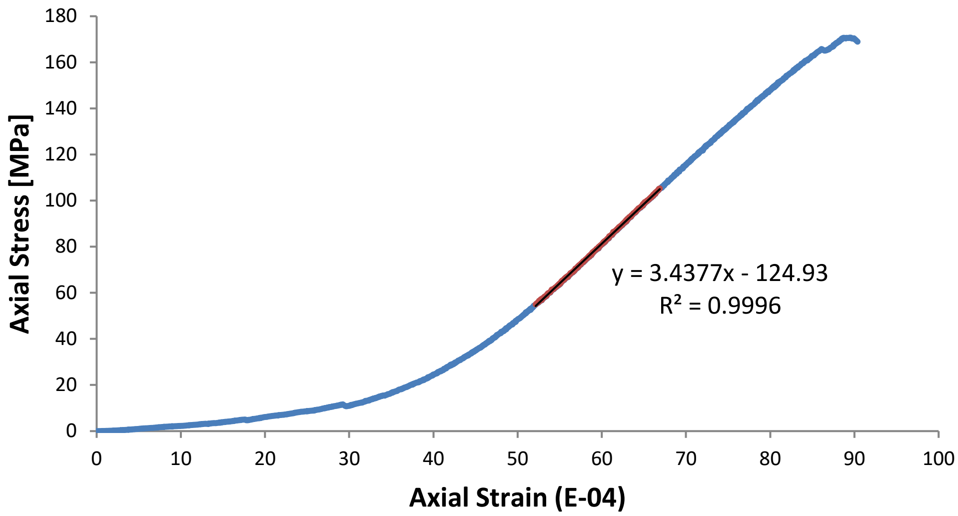

Figure A.52 Specimen 27: Young's modulus calculation

Figure A.53 Specimen 27: Before USC test and After UCS test

Specimen 28

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
28	DBA-04-03	84.5	85.1	50.41	103.22	663.91	3.22	1995.83	4064	**139.9**	**25.24**

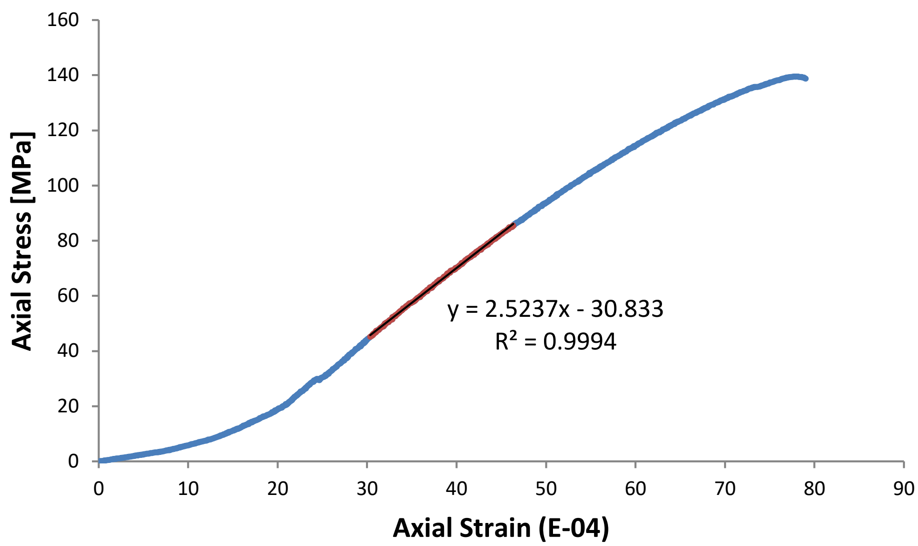

Figure A.54 Specimen 28: Young's modulus calculation

Figure A.55 Specimen 28: Before USC test and After UCS test

Specimen 29

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
29	DBA-04-04	94.9	95.7	50.55	105.95	692.77	3.26	2006.93	5986	**183.1**	**69.54**

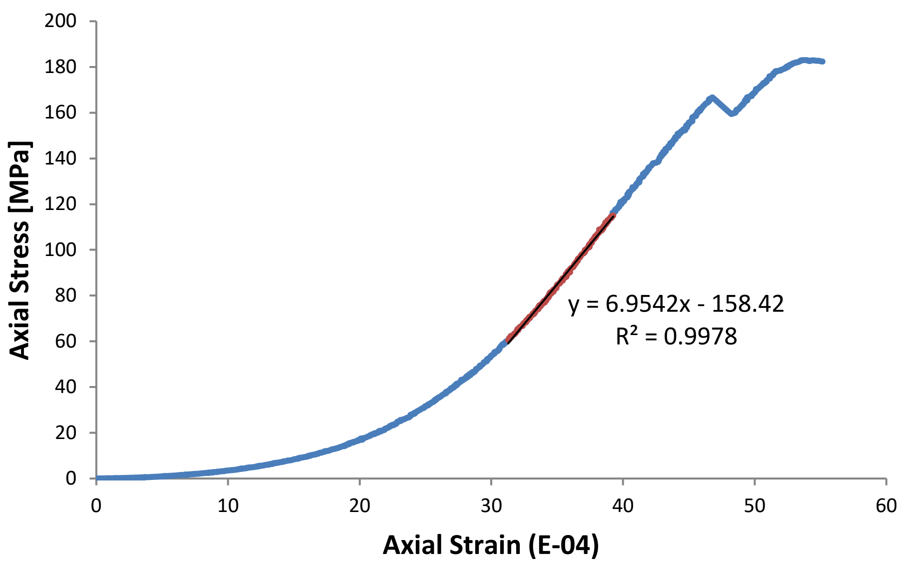

Figure A.56 Specimen 29: Young's modulus calculation

Figure A.57 Specimen 29: Before USC test and After UCS test

Specimen 30

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
30	DBA-04-05	104.4	104.9	50.56	95.11	575.55	3.01	2007.72	4662	**128.0**	**45.01**

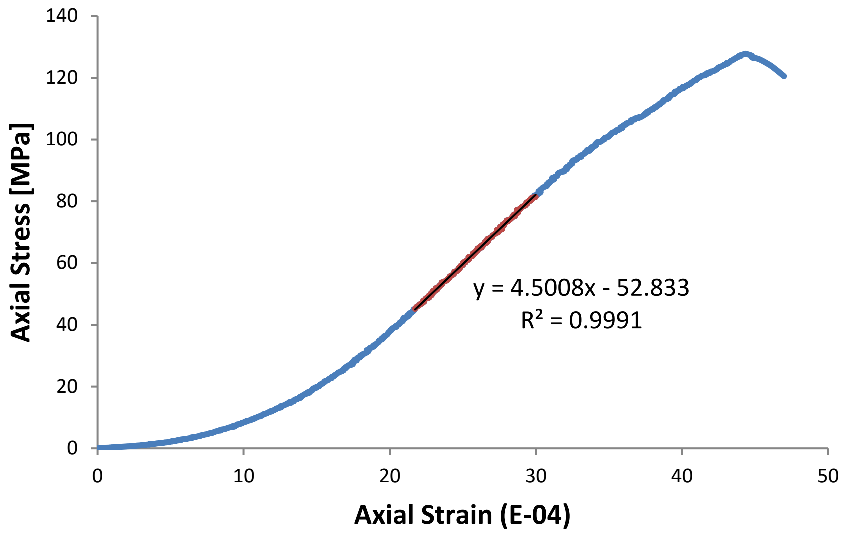

Figure A.58 Specimen 30: Young's modulus calculation

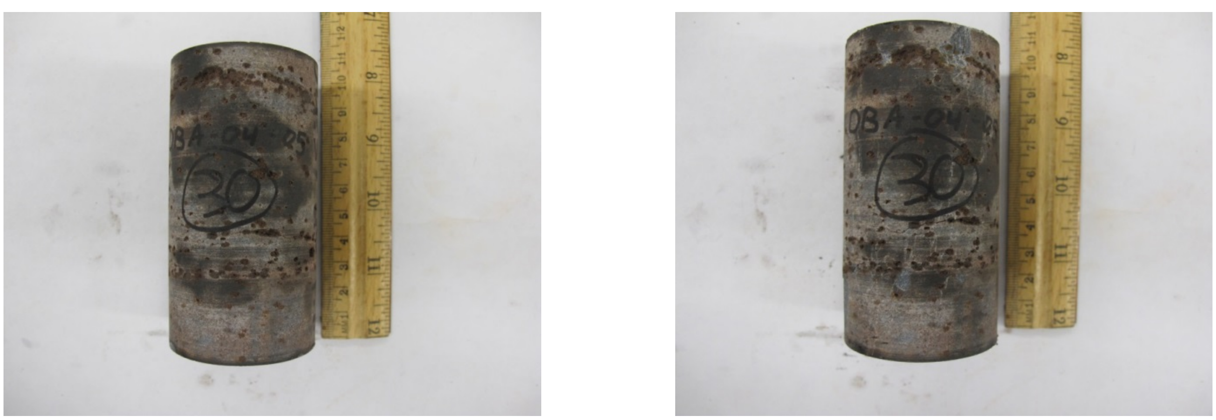

Figure A.59 Specimen 30: Before USC test and After UCS test

Specimen 31

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
31	DBA-05A-01	19.6	20.1	50.59	105.92	596.56	2.80	2010.11	4729	**87.2**	**35.87**

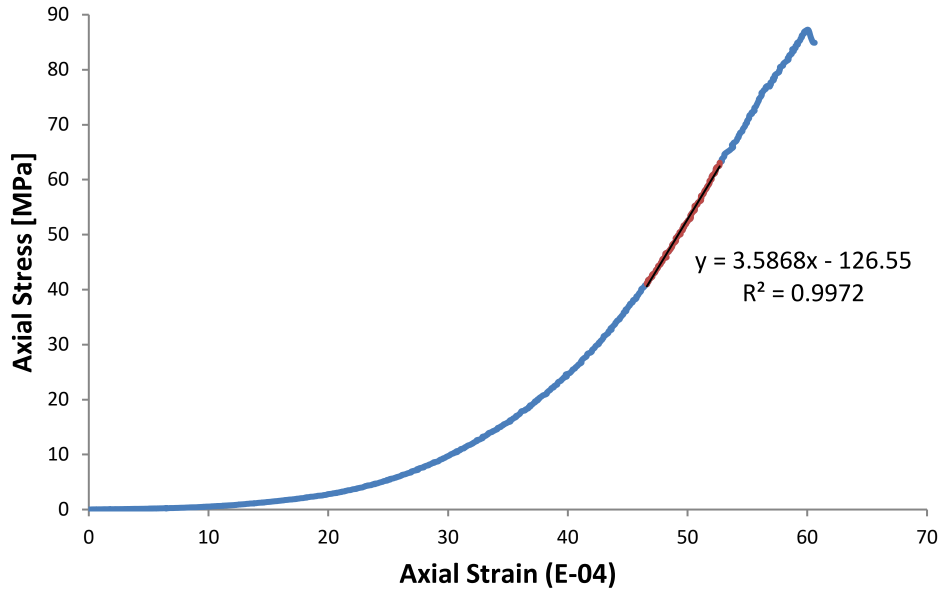

Figure A.60 Specimen 31: Young's modulus calculation


Figure A.61 Specimen 31: Before USC test and After UCS test

Specimen 32

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
32	DBA-05A-02	40.2	41.0	50.62	103.18	675.16	3.25	2012.49	5159	**97.0**	**36.03**

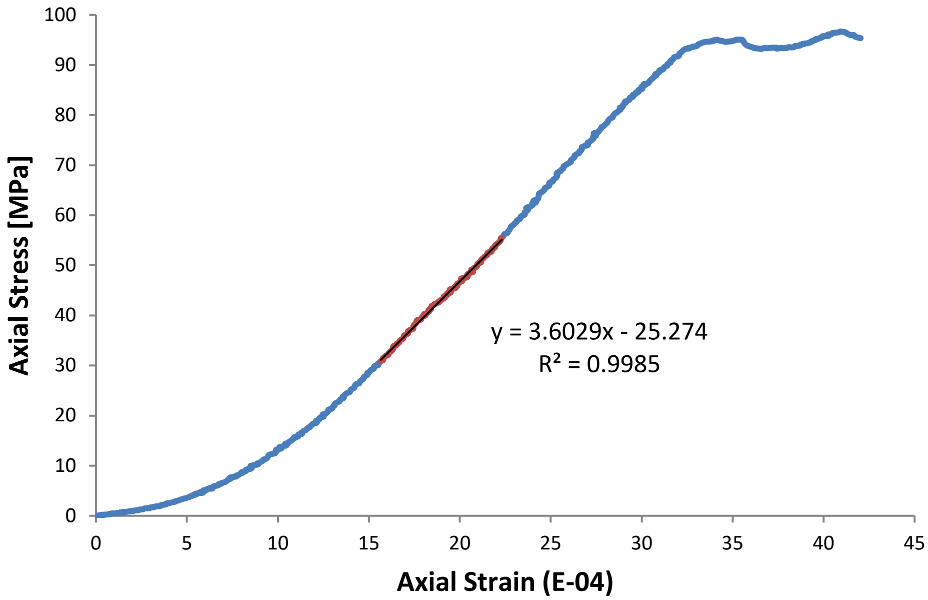

Figure A.62 Specimen 32: Young's modulus calculation

Figure A.63 Specimen 32: Before USC test and After UCS test

Specimen *33*

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
33	DBA-05A-03	49.2	49.9	50.46	105.10	726.64	3.46	1999.79	5474	**117.8**	**55.50**

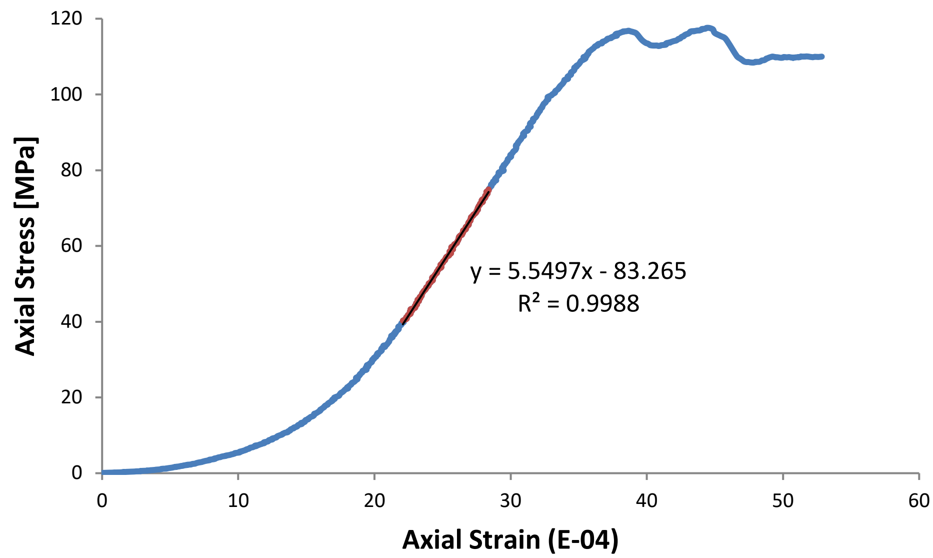

Figure A.64 Specimen 33: Young's modulus calculation

 

Figure A.65 Specimen 33: Before USC test and After UCS test

Specimen 34

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
34	DBA-05A-04	58.9	59.4	50.48	102.53	582.52	2.84	2001.38	5231	**95.4**	**38.83**

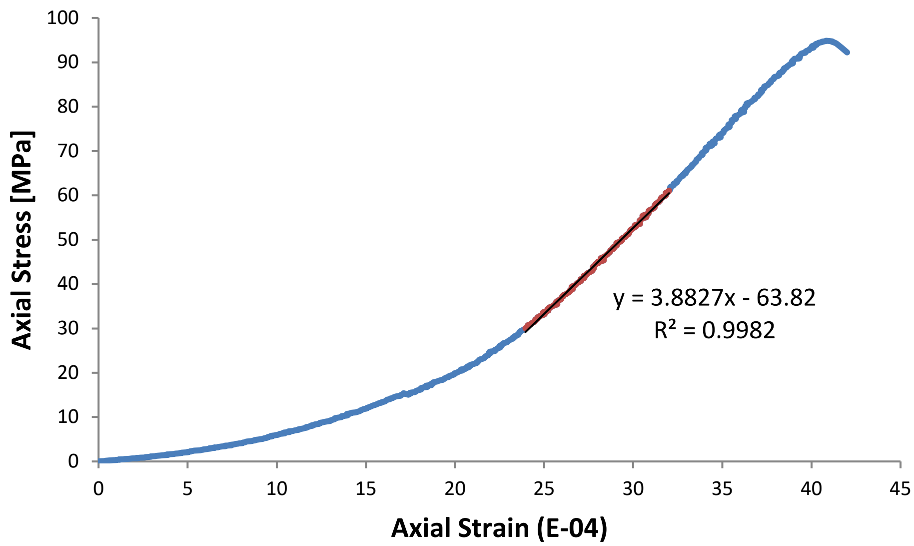

Figure A.66 Specimen 34: Young's modulus calculation

Figure A.67 Specimen 34: Before USC test and After UCS test

Specimen 35

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
35	DBA-05A-05	61.7	62.2	50.49	103.90	617.69	2.97	2002.17	5440	**158.3**	**49.08**

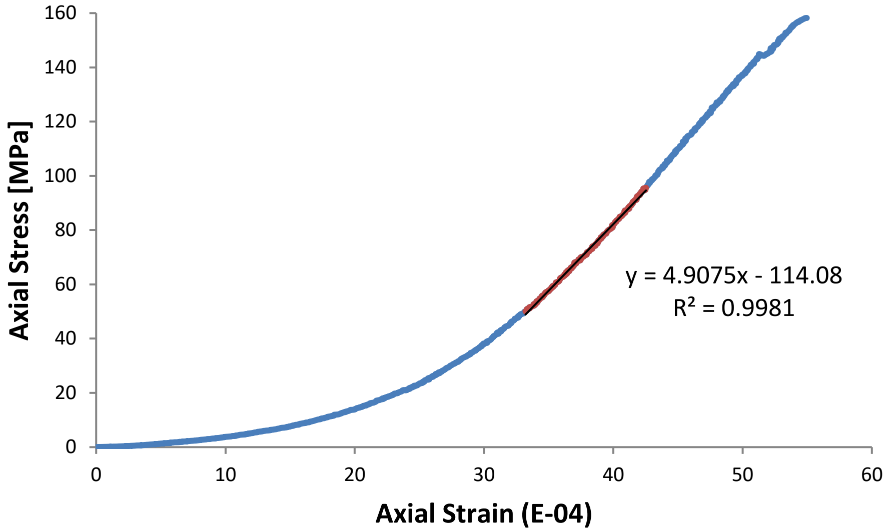

Figure A.68 Specimen 35: Young's modulus calculation

Figure A.69 Specimen 35: Before USC test and After UCS test

Specimen 36

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
36	DBA-05A-06	70.0	70.5	50.35	102.93	563.41	2.75	1991.08	4657	**102.8**	**33.67**

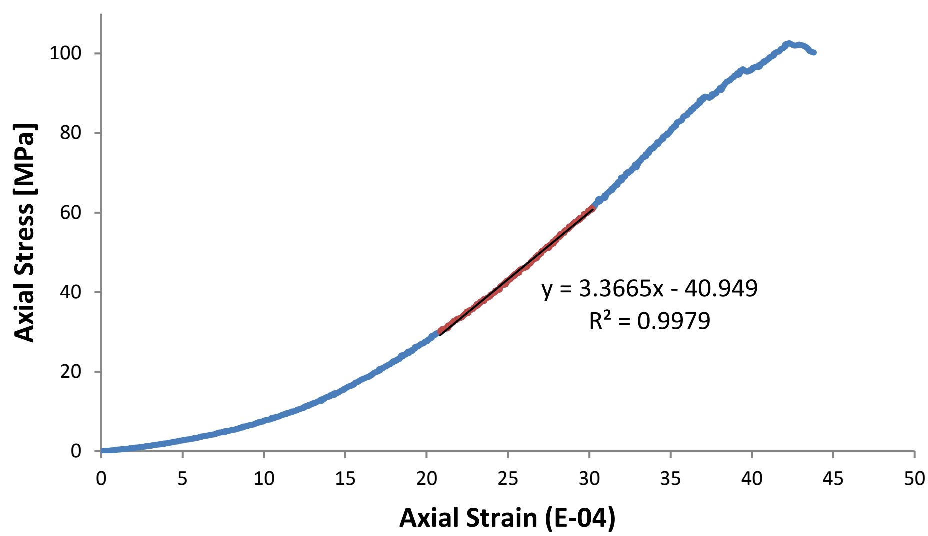

Figure A.70 Specimen 36: Young's modulus calculation

Figure A.71 Specimen 36: Before USC test and After UCS test

Specimen 37

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
37	DBA-05A-07	78.0	78.6	50.37	103.72	654.57	3.17	1992.66	5186	**186.7**	**49.74**

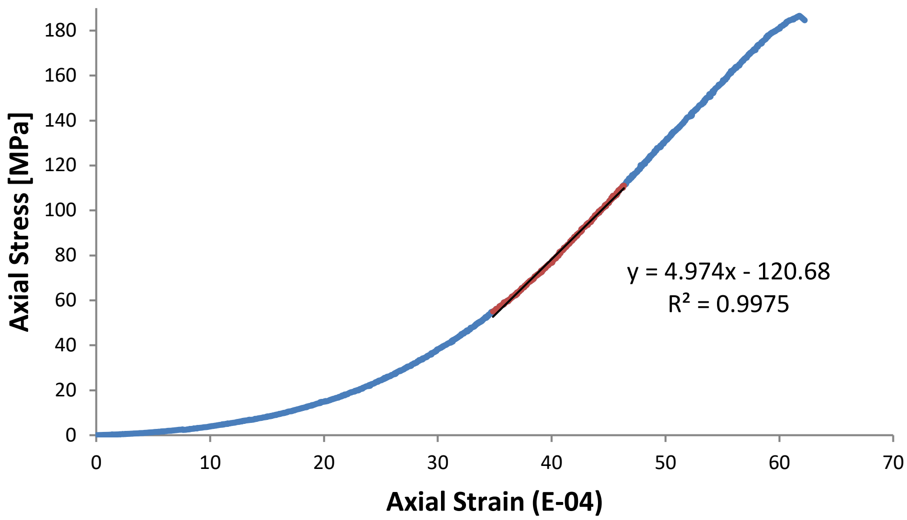

Figure A.72 Specimen 37: Young's modulus calculation

Figure A.73 Specimen 37: Before USC test and After UCS test

Specimen 38

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
38	DBA-05A-08	100.8	101.5	50.55	101.92	664.49	3.25	2006.93	5096	**173.8**	**50.06**

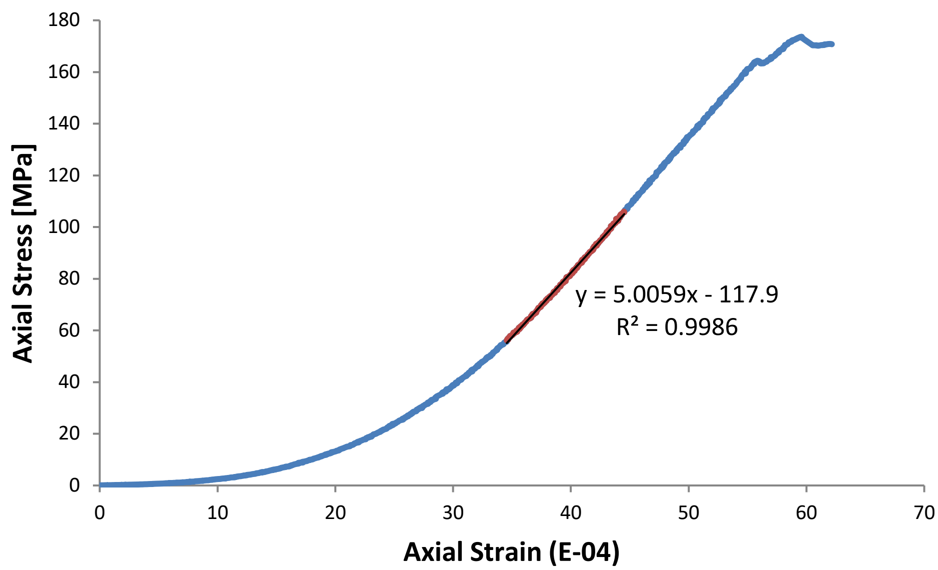

Figure A.74 Specimen 38: Young's modulus calculation

Figure A.75 Specimen 38: Before USC test and After UCS test

Specimen 39

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
39	DBA-06-01	29.3	29.9	50.53	105.68	659.03	3.11	2005.34	4782	**35.2**	**8.77**

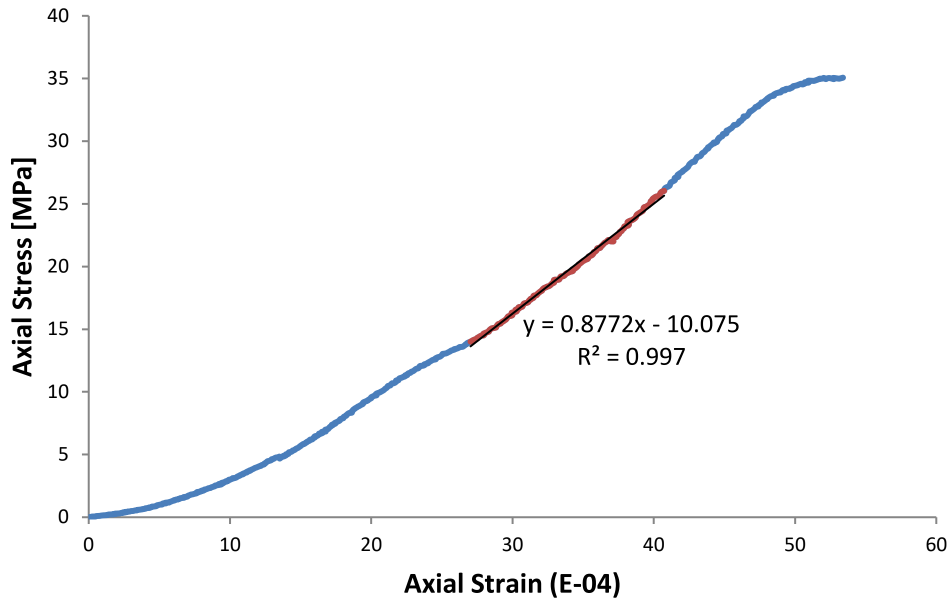

Figure A.76 Specimen 39: Young's modulus calculation

Figure A.77 Specimen 39: Before USC test and After UCS test

Specimen 40

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
40	DBA-06-02	50.2	50.8	50.59	103.76	702.33	3.37	2010.11	5461	**176.3**	**63.36**

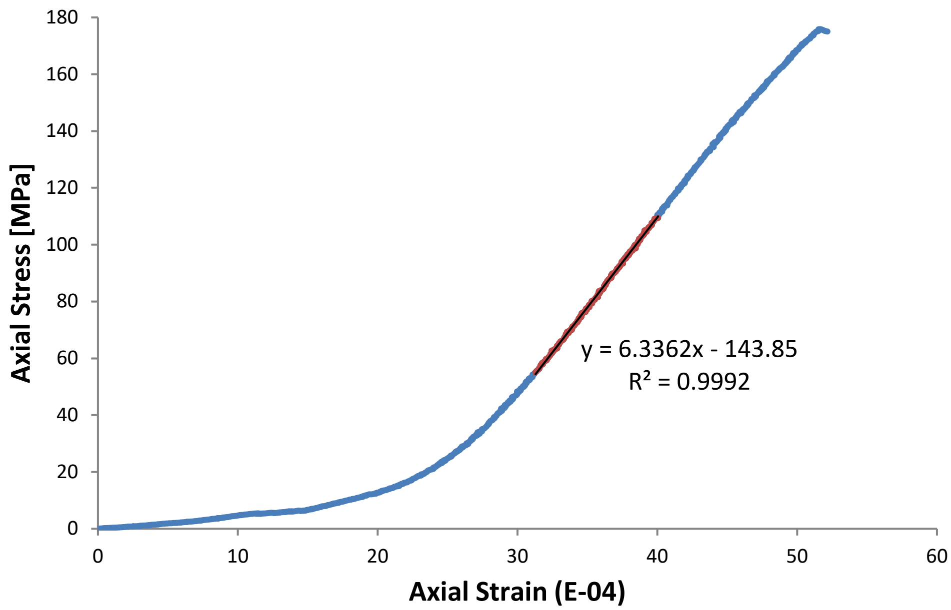

Figure A.78 Specimen 40: Young's modulus calculation

Figure A.79 Specimen 40: Before USC test and After UCS test

Specimen 41

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
41	DBA-06-03	58.1	58.8	50.50	105.06	769.64	3.66	2002.96	5559	**158.6**	**62.09**

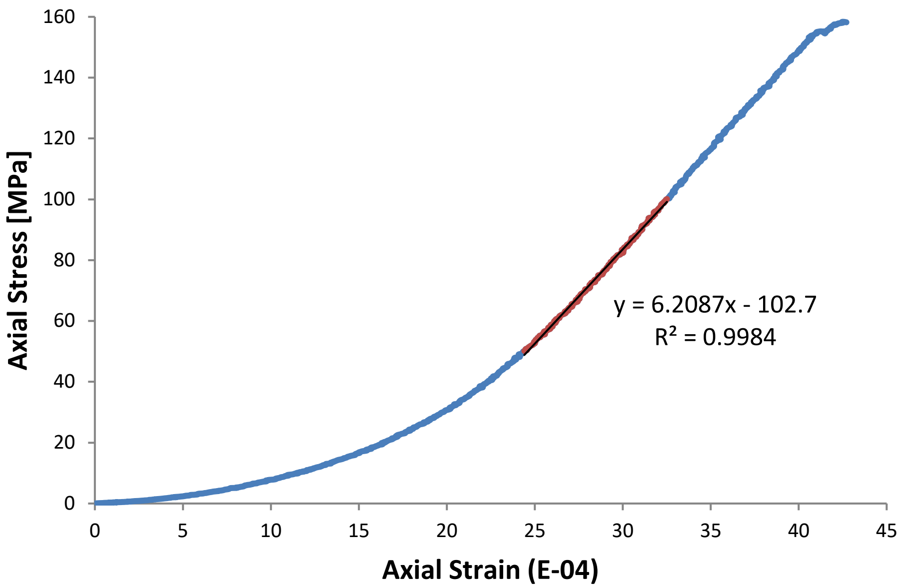

Figure A.80 Specimen 41: Young's modulus calculation

Figure A.81 Specimen 41: Before USC test and After UCS test

Specimen 42

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Mass	Density	Area	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[g]	[g/cm^3]	[mm^2]	[m/s]	[MPa]	[GPa]
42	DBA-06-04	77.8	78.5	50.49	104.72	611.8	2.92	2002.17	5454	**59.4**	**29.00**

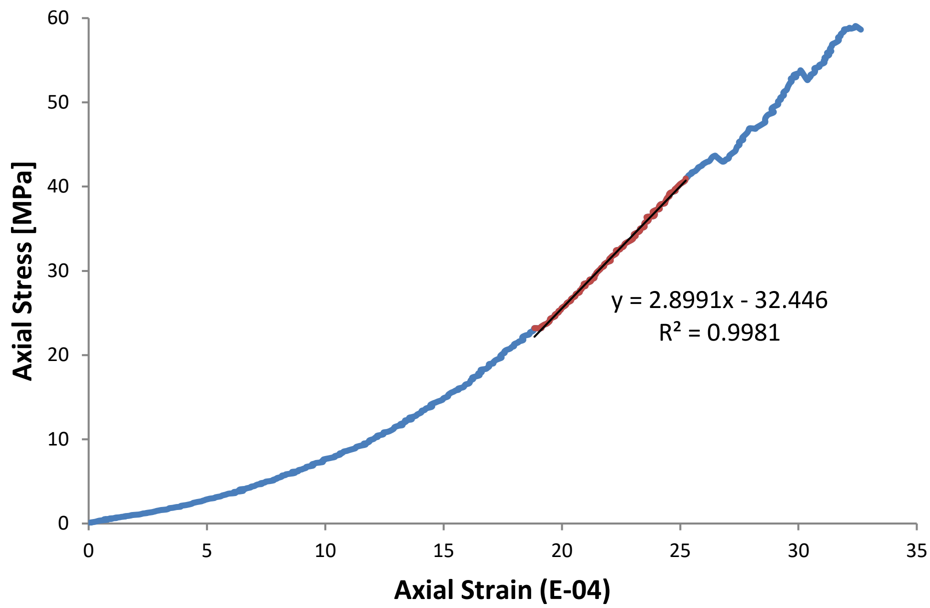

Figure A.82 Specimen 42: Young's modulus calculation

Figure A.83 Specimen 42: Before USC test and After UCS test

Specimen 43

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
43	DBA-01a-01	48.0	48.6	50.58	103.77	2009.31	613.85	2.94	5520	**128.8**	**39.61**

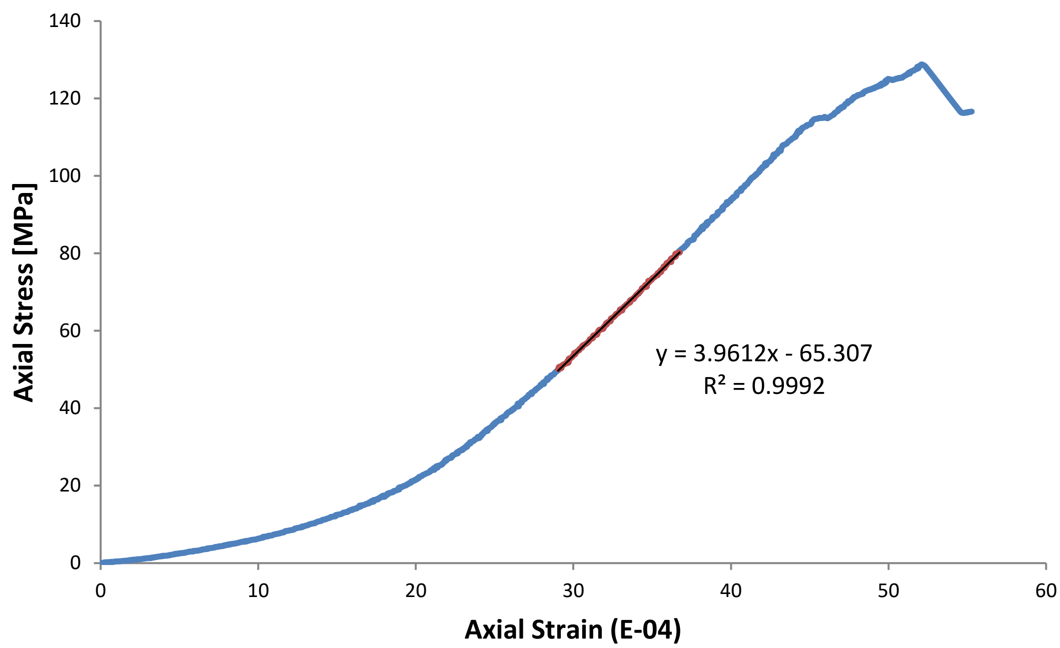

Figure A.84 Specimen 43: Young's modulus calculation

Figure A.85 Specimen 43: Before USC test and After UCS test

Specimen 44

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]	
44	DBA-01a-02	102.8	103.4	50.55	107.58	2006.93	N/A	N/A	N/A	**N/A**	**N/A**	**Specimen fractured during preparation**

Figure A.86 Fracture in specimen 44 occurred during cutting portion of preparation

Specimen 45

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
45	DBA-01a-03	156.3	156.8	50.34	101.11	1990.29	554.34	2.75	4956	**22.0**	**10.43**

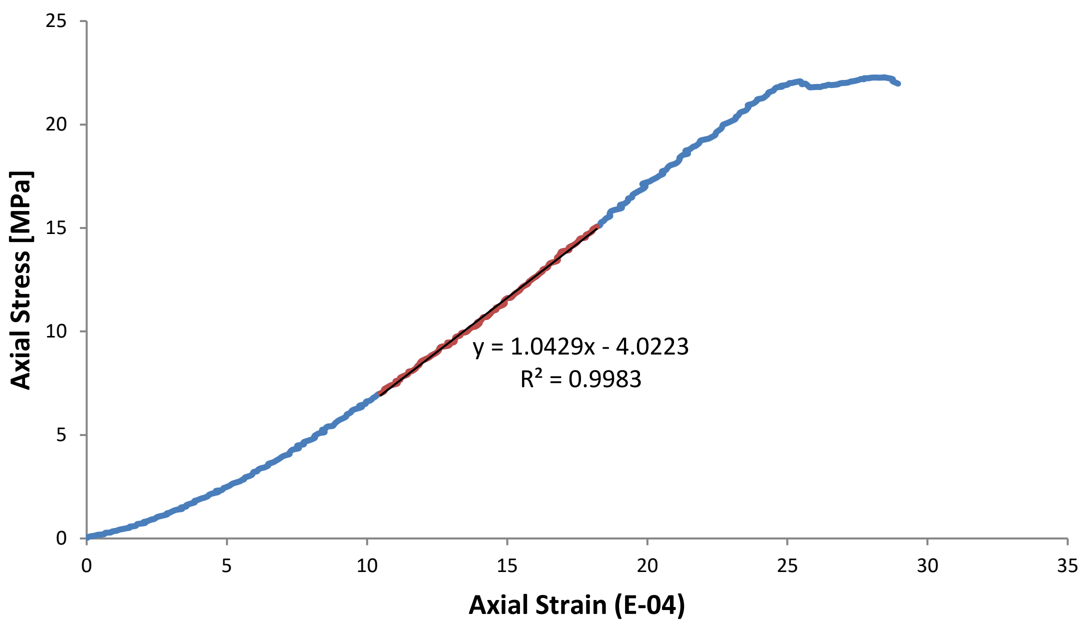

Figure A.87 Specimen 45: Young's modulus calculation

Figure A.88 Specimen 45: Before USC test and After UCS test

Specimen 46

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
46	DBA-01a-04	196.9	197.4	50.64	104.78	2014.08	619.05	2.93	5789	**102.0**	**39.85**

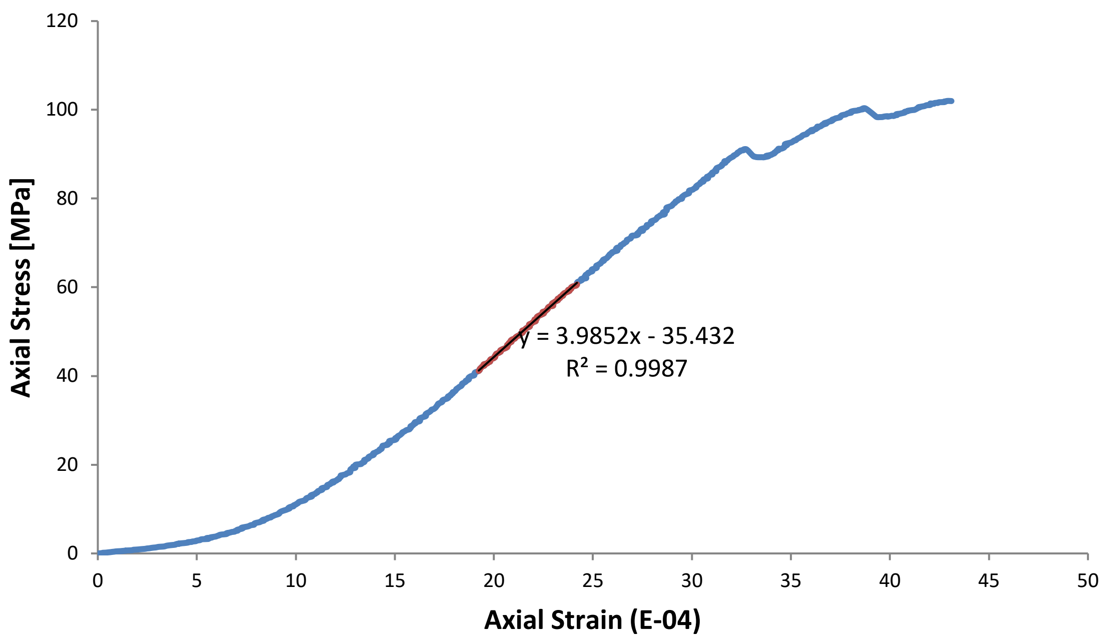

Figure A.89 Specimen 46: Young's modulus calculation

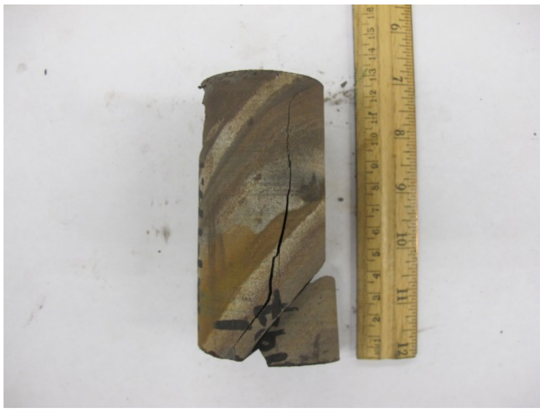

Figure A.90 Specimen 46: Before USC test and After UCS test

Specimen 47

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
47	DBA-01a-05	253.4	254.2	50.70	106.25	2018.86	749.06	3.49	5682	**262.6**	**56.87**

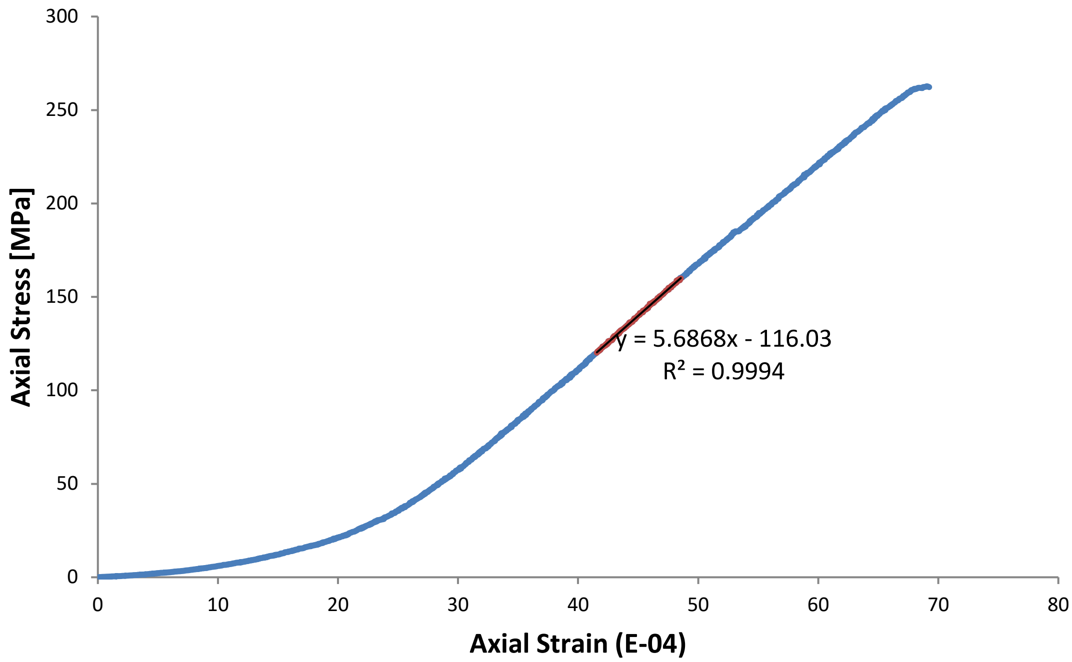

Figure A.91 Specimen 47: Young's modulus calculation

Figure A.92 Specimen 47: Before USC test and After UCS test

Specimen 48

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
48	DBA-01a-06	300.5	301.0	50.57	104.69	2008.52	649.32	3.09	6584	**231.0**	**56.40**

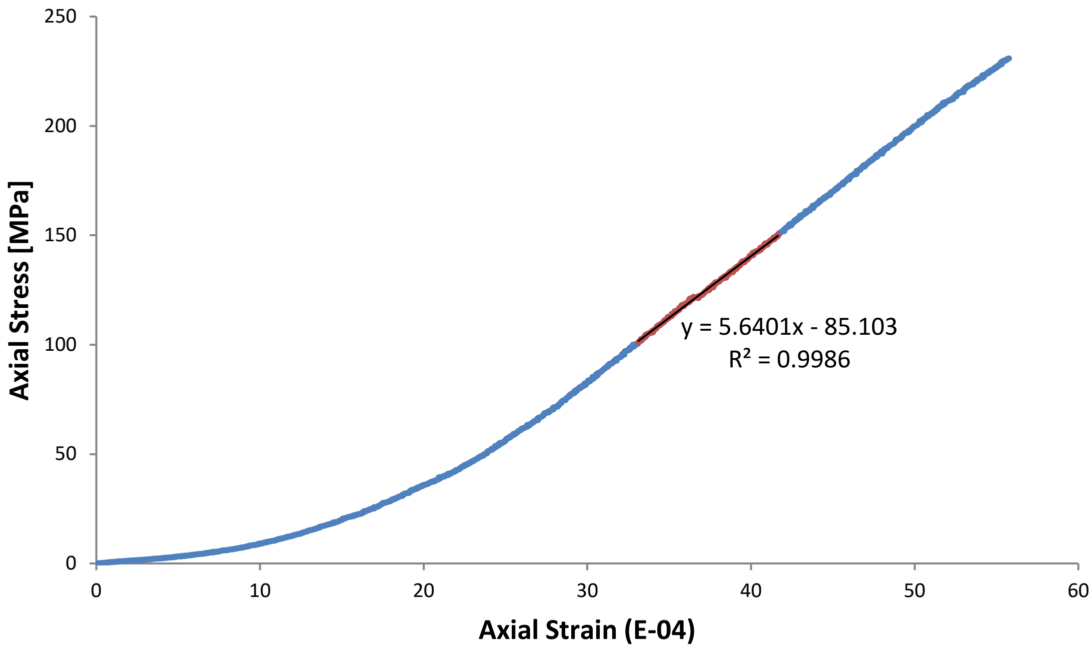

Figure A.93 Specimen 48: Young's modulus calculation

Figure A.94 Specimen 48: Before USC test and After UCS test

Specimen 49

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
49	DBA-01a-07	356.0	356.7	50.49	104.54	2002.17	557.68	2.66	4526	**152.0**	**29.54**

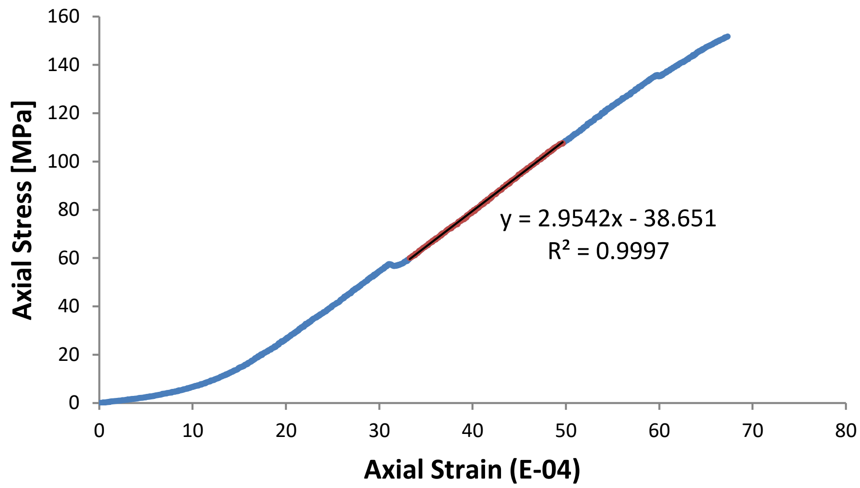

Figure A.95 Specimen 49: Young's modulus calculation

Figure A.96 Specimen 49: Before USC test and After UCS test

Specimen 50

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]	
50	DBA-01a-08	364.2	370.0	50.50	106.89	2002.96	561.00	2.62	5426	**40.3**	**20.34**	One end intially very fractured

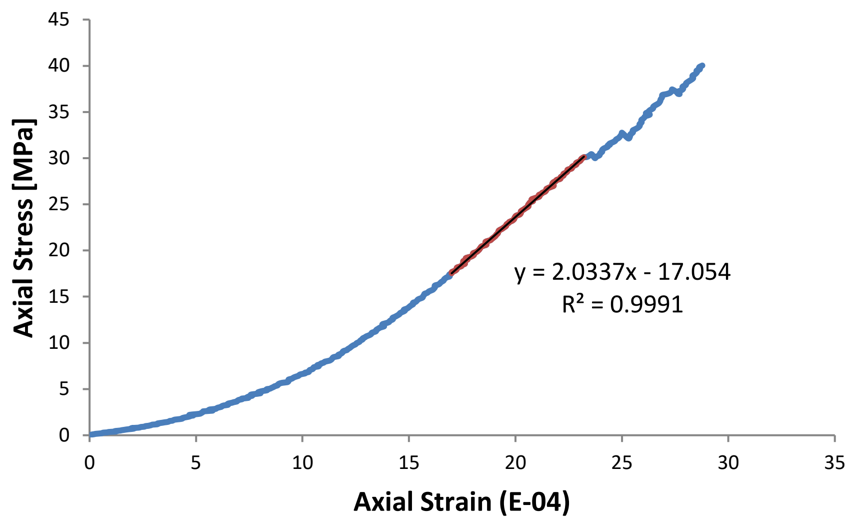

Figure A.97 Specimen 50: Young's modulus calculation

Figure A.98 Specimen 50: Before USC test and After UCS test

Specimen 51

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
51	DBA-01a-09	367.7	368.3	50.44	105.78	1998.20	570.13	2.70	3186	**14.0**	**4.56**

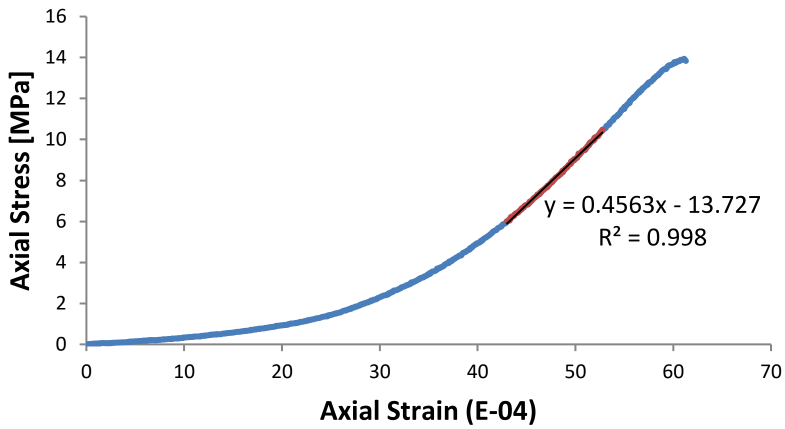

Figure A.99 Specimen 51: Young's modulus calculation

Figure A.100 Specimen 51: Before USC test and After UCS test

Specimen 52

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
52	DBA-01a-10	370.3	371.0	50.50	103.95	2002.96	622.21	2.99	3713	**56.9**	**15.87**

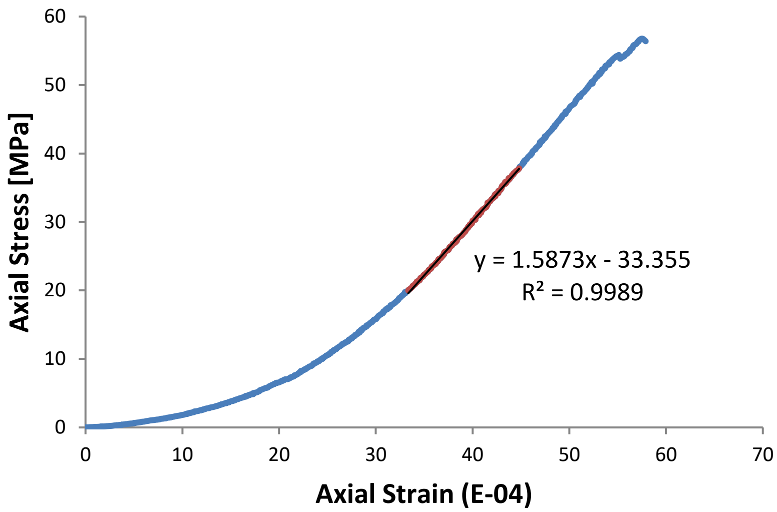

Figure A.101 Specimen 52: Young's modulus calculation

Figure A.102 Specimen 52: Before USC test and After UCS test

Specimen 53

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
53	DBA-01a-11	372.9	373.6	50.51	106.74	2003.75	578.60	2.71	4942	**127.1**	**25.21**

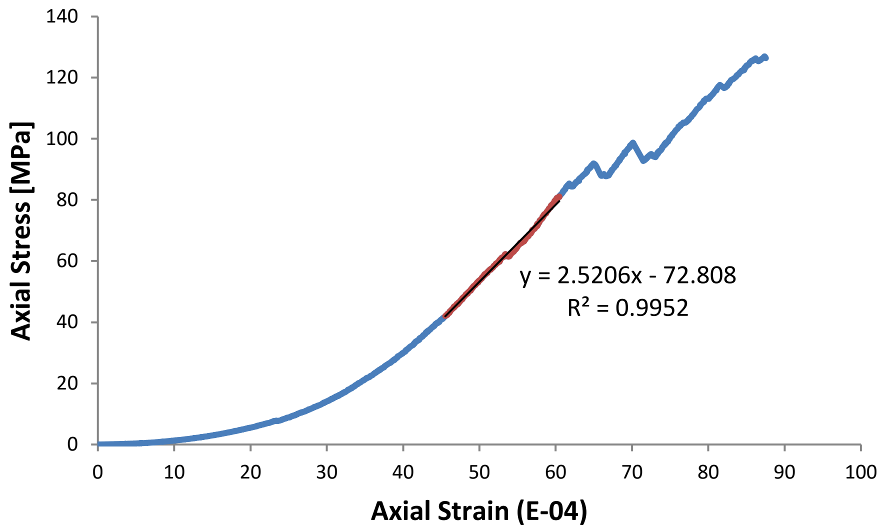

Figure A. 103 Specimen 53: Young's modulus calculation

Figure A.104 Specimen 53: Before USC test and After UCS test

Specimen 54

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
54	DBA-01a-12	389.0	389.9	50.57	104.55	2008.52	616.36	2.94	3556	**50.1**	**14.12**

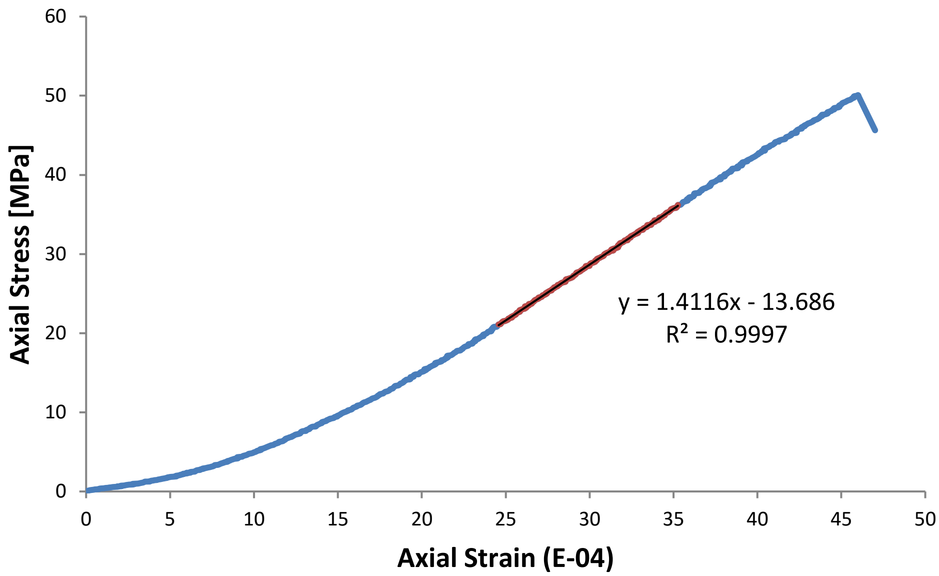

Figure A.105 Specimen 54: Young's modulus calculation

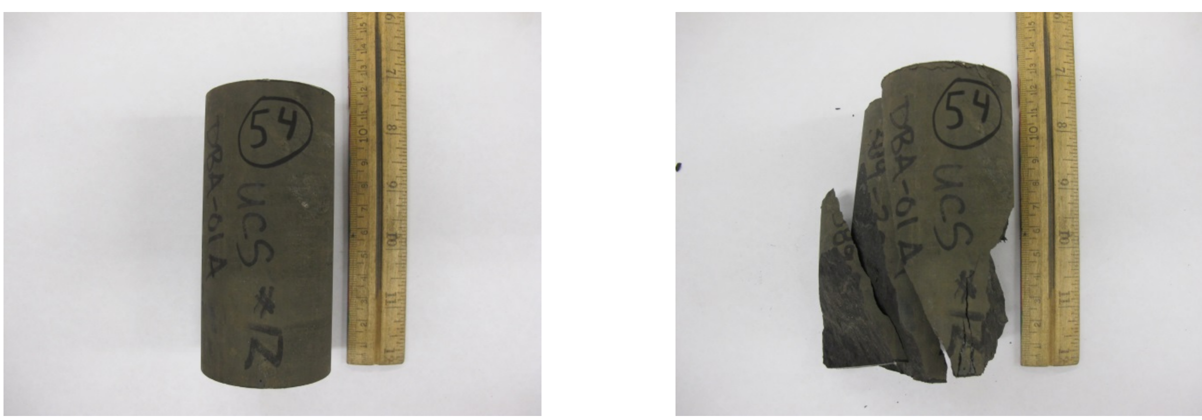

Figure A.106 Specimen 54: Before USC test and After UCS test

Specimen 55

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
55	DBA-01a-13	395.0	395.6	50.56	104.11	2007.72	551.93	2.64	4607	**55.1**	**21.87**

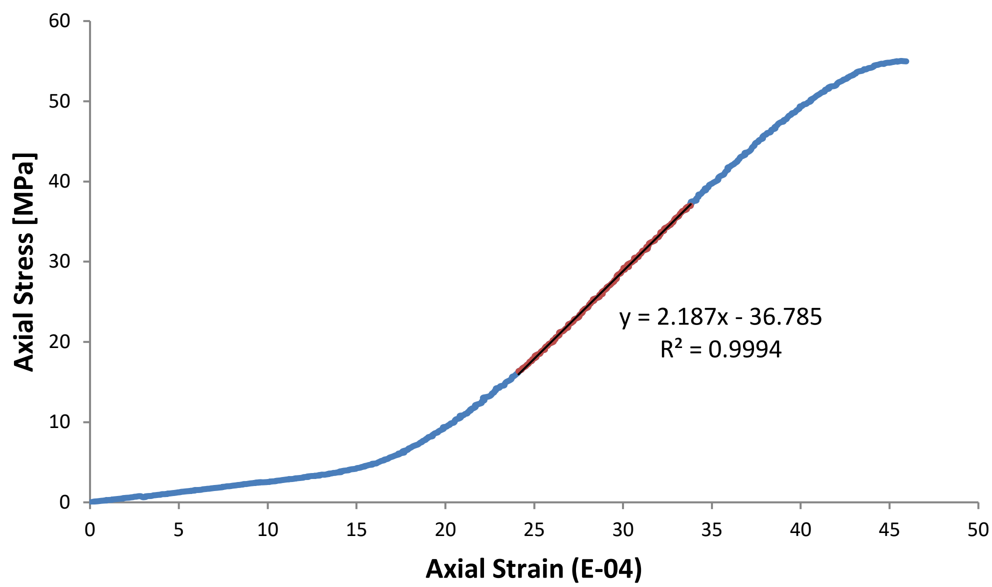

Figure A.107 Specimen 55: Young's modulus calculation

Figure A.108 Specimen 55: Before USC test and After UCS test

Specimen 56

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
56	DBA-01a-14	401.8	402.5	50.57	105.19	2008.52	582.86	2.76	5844	**320.1**	**58.21**

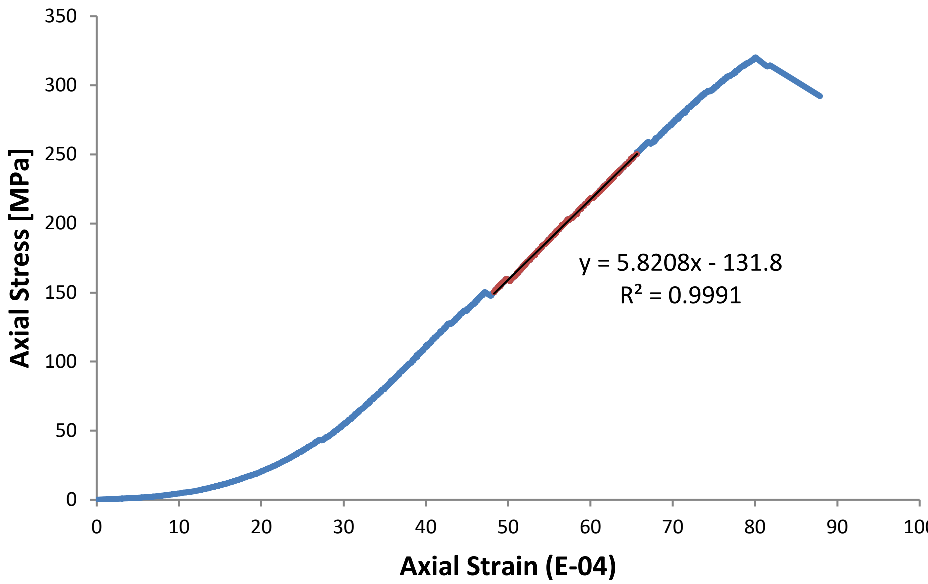

Figure A.109 Specimen 56: Young's modulus calculation

Figure A.110 Specimen 56: Before USC test and After UCS test

Specimen 57

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
57	DBA-01a-15	452.9	453.8	50.20	105.64	1979.23	751.17	3.59	5649	**53.8**	**14.88**

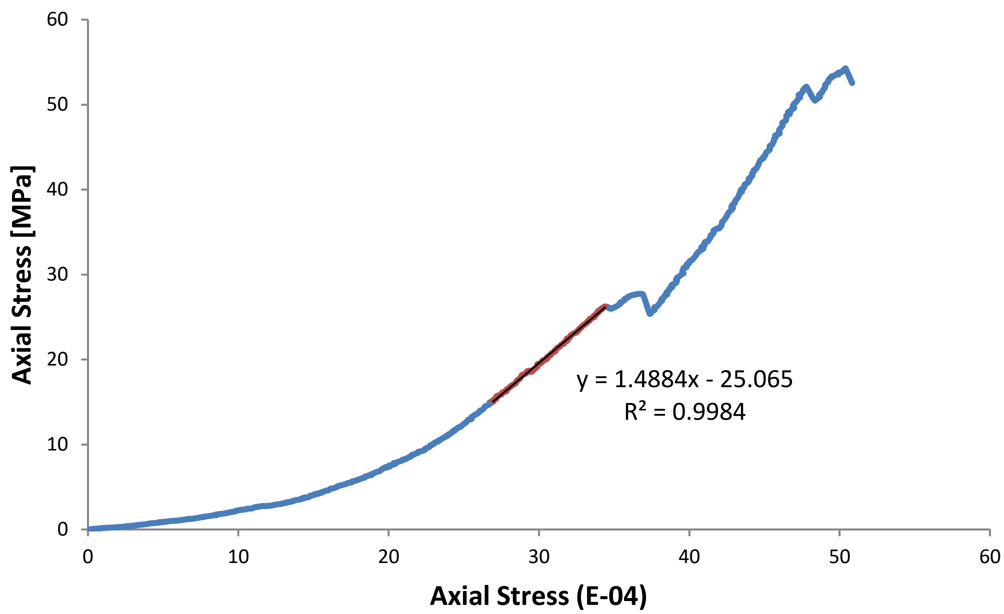

Figure A. 111 Specimen 57: Young's modulus calculation

Figure A.112 Specimen 57: Before USC test and After UCS test

Specimen 58

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
58	DBA-01a-16	490.4	491.3	49.46	105.84	1921.31	603.21	2.97	5266	**179.0**	**53.15**

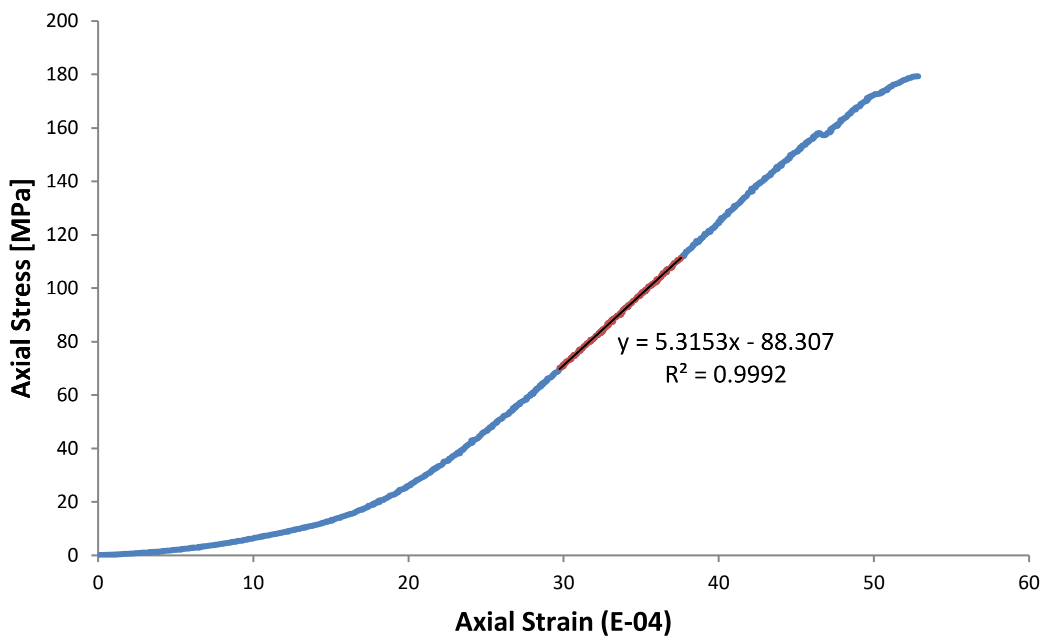

Figure A.113 Specimen 58: Young's modulus calculation

Figure A.114 Specimen 58: Before USC test and After UCS test

Specimen 59

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
59	DBA-01a-17	549.3	550.1	50.49	104.88	2002.17	699.02	3.33	5434	**123.0**	**45.10**

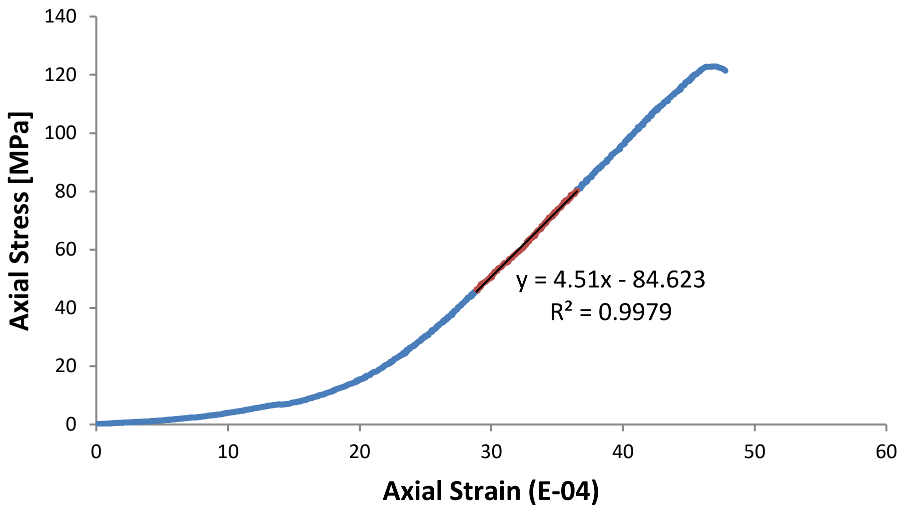

Figure A.115 Specimen 59: Young's modulus calculation

Figure A.116 Specimen 60: Before USC test and After UCS test

Specimen 60

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
60	DBA-01a-18	600.6	601.4	50.17	105.46	1976.87	709.95	3.41	5992	**221.2**	**63.06**

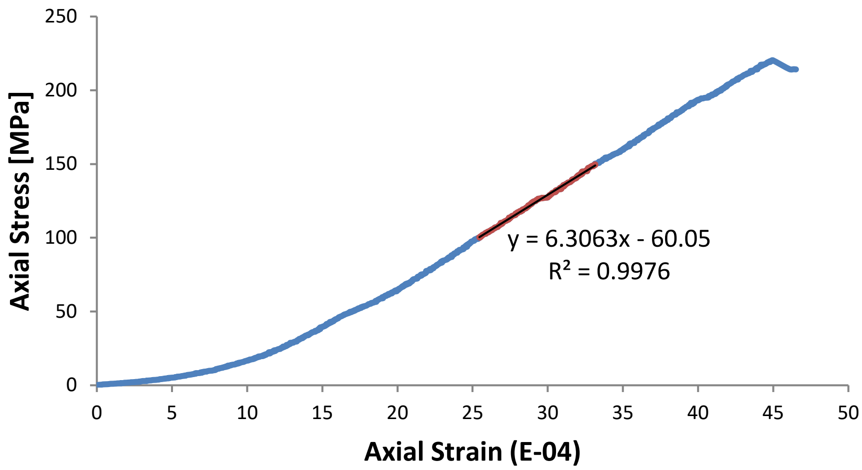

Figure A.117 Specimen 60: Young's modulus calculation

Figure A.118 Specimen 60: Before USC test and After UCS test

Specimen 61

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
61	DBA-01a-19	651.8	652.4	50.19	106.28	1978.45	662.10	3.15	5594	**178.0**	**56.85**

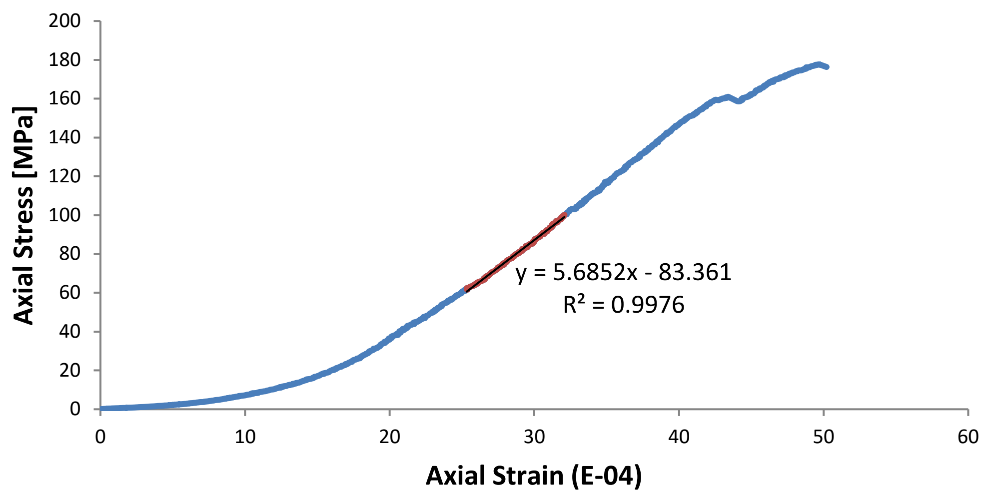

Figure A.119 Specimen 61: Young's modulus calculation

Figure A.120 Specimen 61: Before USC test and After UCS test

Specimen 62

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
62	DBA-01a-20	703.2	703.9	50.37	105.56	1992.66	597.42	2.84	5441	**150.1**	**50.74**

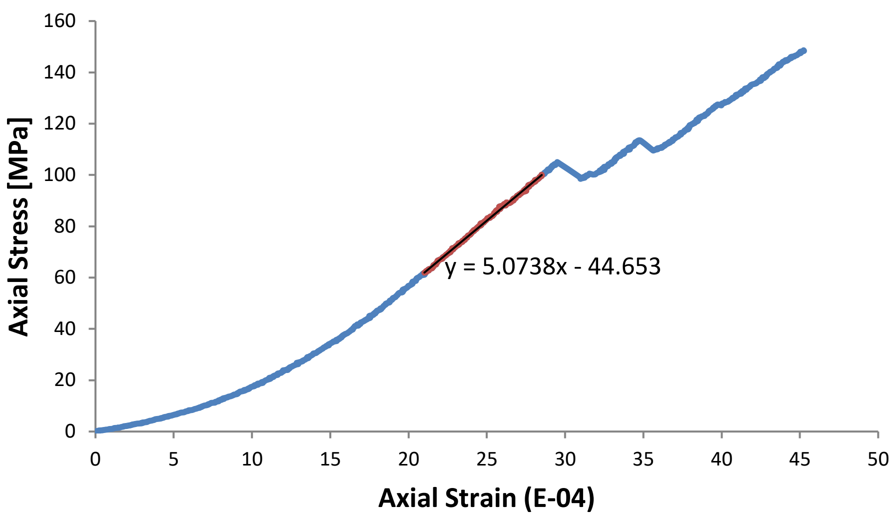

Figure A.121 Specimen 62: Young's modulus calculation

Figure A.122 Specimen 62: Before USC test and After UCS test

Specimen 63

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
63	DBA-01a-21	755.0	755.8	50.59	105.28	2010.11	594.37	2.81	5013	**167.5**	**54.18**

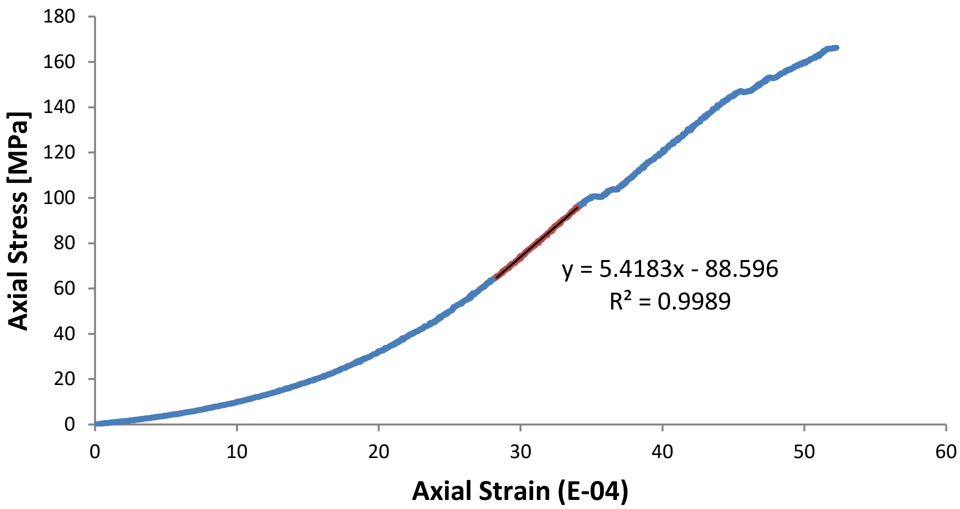

Figure A.123 Specimen 63: Young's modulus calculation

Figure A.124 Specimen 63: Before USC test and After UCS test

Specimen 64

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
64	DBA-06-05	108.0	108.6	50.49	105.73	2002.17	630.08	2.98	4387	**73.3**	**18.53**

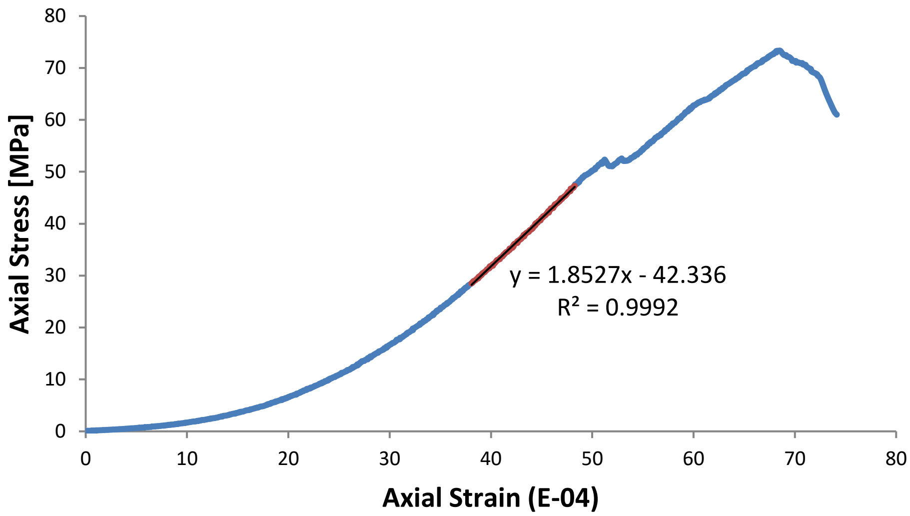

Figure A.125 Specimen 64: Young's modulus calculation

Figure A.126 Specimen 64: Before USC test and After UCS test

Specimen 65

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
65	DBA-06-06	151.6	152.4	50.17	105.60	1976.87	706.53	3.38	5708	**266.9**	**76.40**

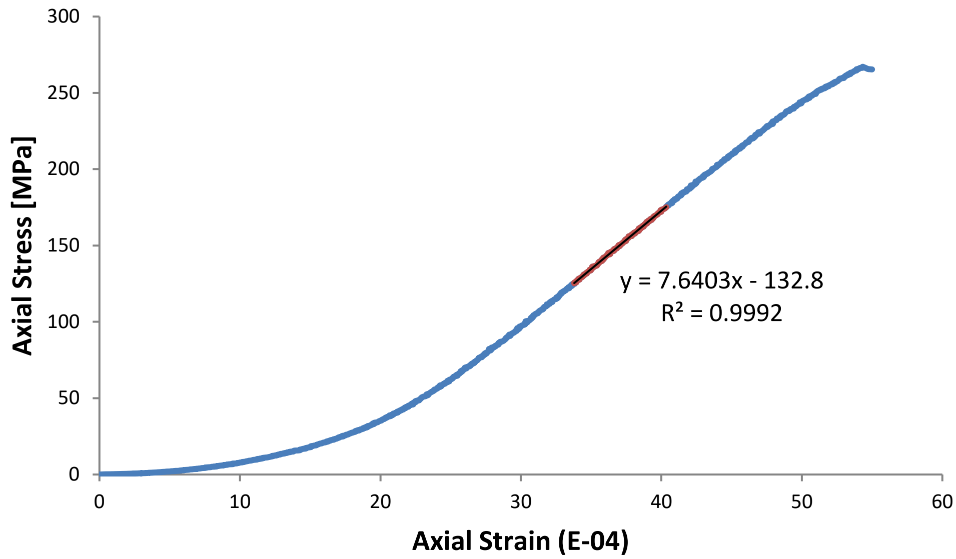

Figure A.127 Specimen 65: Young's modulus calculation

Figure A.128 Specimen 65: Before USC test and After UCS test

Specimen 66

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
66	DBA-06-07	187.6	188.2	50.48	103.74	2001.38	643.89	3.10	5460	**303.2**	**83.49**

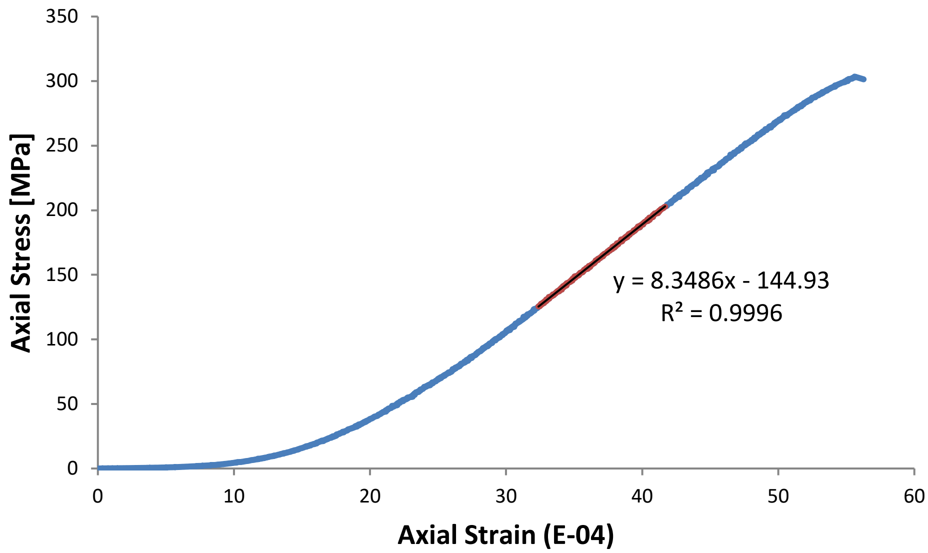

Figure A.129 Specimen 66: Young's modulus calculation

Figure A.130 Specimen 66: Before USC test and After UCS test

Specimen 67

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
67	DBA-06-08	248.0	248.7	50.50	104.90	2002.96	632.19	3.01	5828	**355.2**	**77.25**

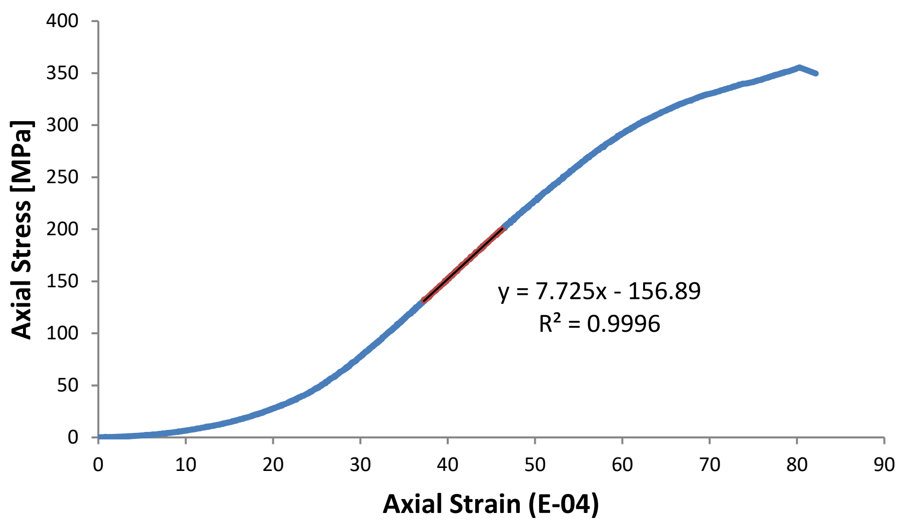

Figure A.131 Specimen 67: Young's modulus calculation

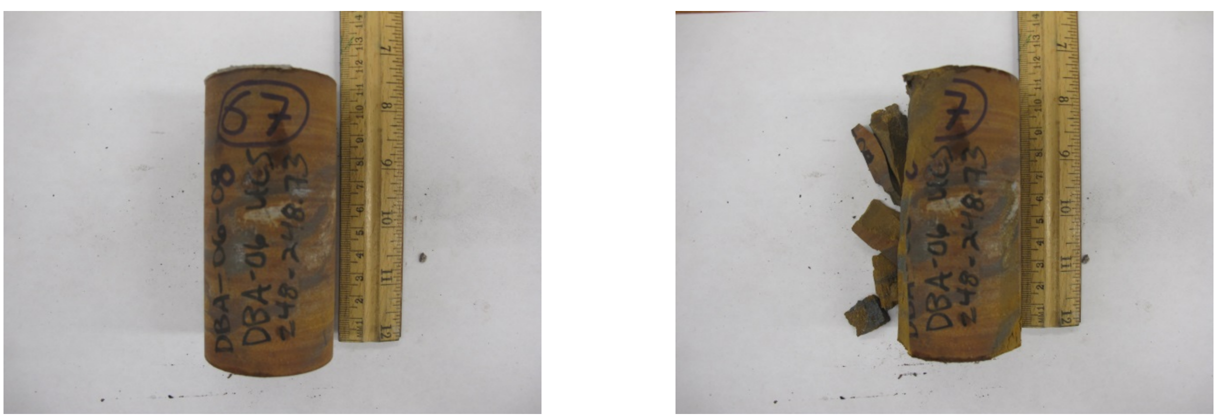

Figure A.132 Specimen 67: Before USC test and After UCS test

Specimen 68

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
68	IDH-02-01	248.2	249.0	50.55	104.69	2006.93	657.64	3.13	5598	**229.8**	**58.78**

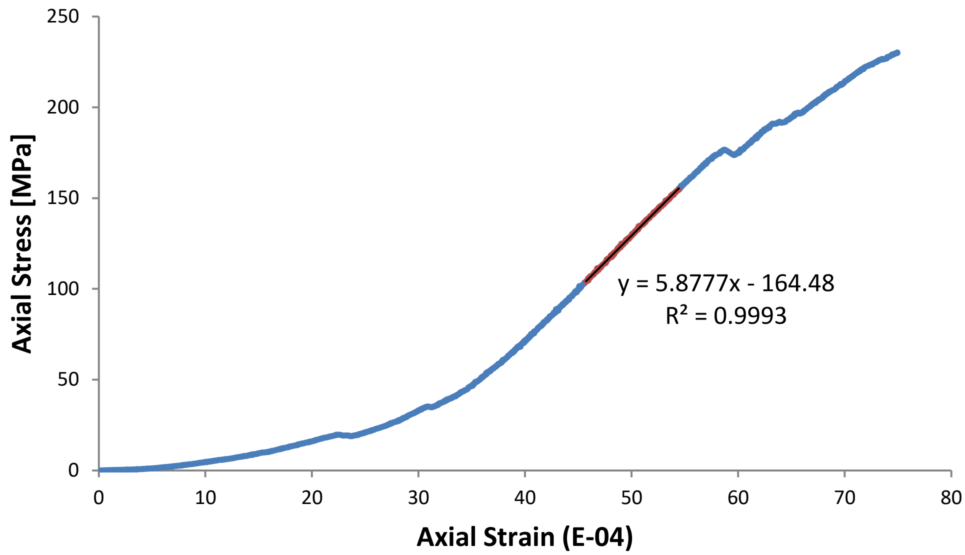

Figure A.133 Specimen 68: Young's modulus calculation

Figure A.134 Specimen 68: Before USC test and After UCS test

Specimen 69

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm²]	[g]	[g/cm³]	[m/s]	[MPa]	[GPa]
69	IDH-02-02	293.4	294.4	50.61	104.80	2011.70	631.06	2.99	5402	**102.3**	**38.36**

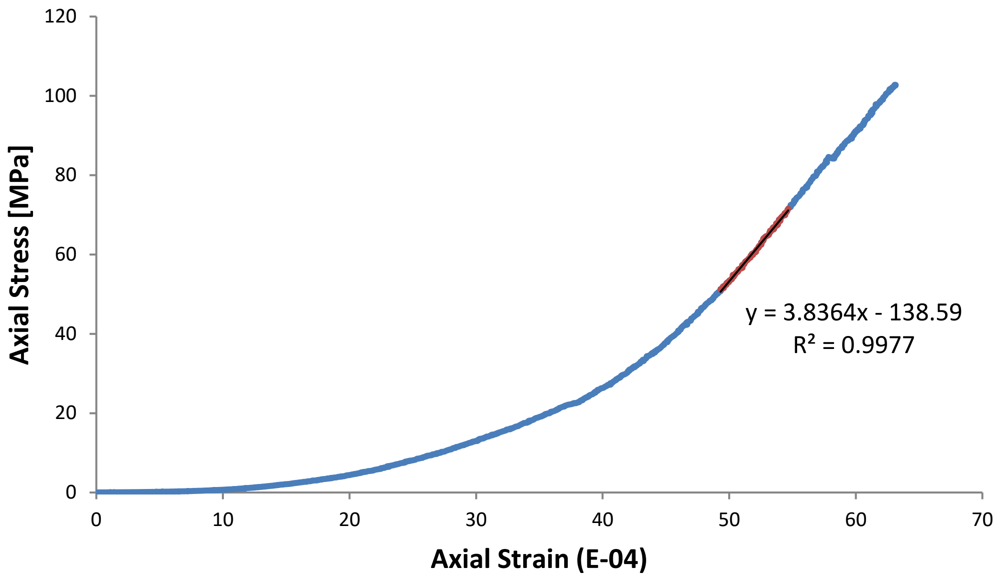

Figure A.135 Specimen 69: Young's modulus calculation

Figure A.136 Specimen 69: Before USC test and After UCS test

Specimen 70

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
70	IDH-02-03	346.8	347.6	50.59	105.97	2010.11	591.70	2.78	4839	**98.8**	**40.28**

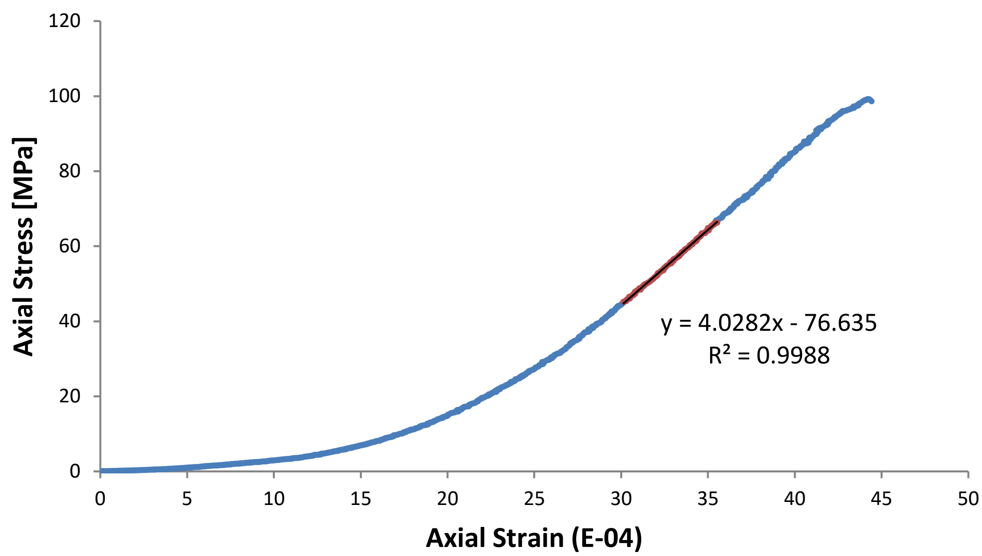

Figure A.137 Specimen 70: Young's modulus calculation

Figure A.138 Specimen 70: Before USC test and After UCS test

Specimen 71

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]	
71	IDH-02-04	361.9	362.5	50.56	105.23	2007.72	635.51	3.01	4176	**22.7**	**9.23**	**Chip missing from end of specimen**

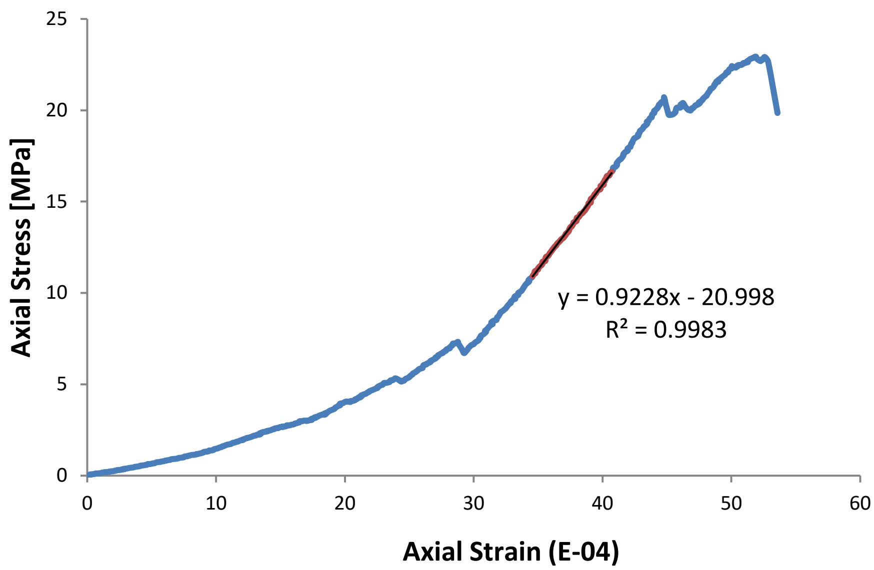

Figure A.139 Specimen 71: Young's modulus calculation

Figure A.140 Specimen 71: Before USC test and After UCS test

Specimen 72

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
72	IDH-02-05	373.5	374.2	50.55	104.03	2006.93	634.10	3.04	4112	**102.0**	**24.97**

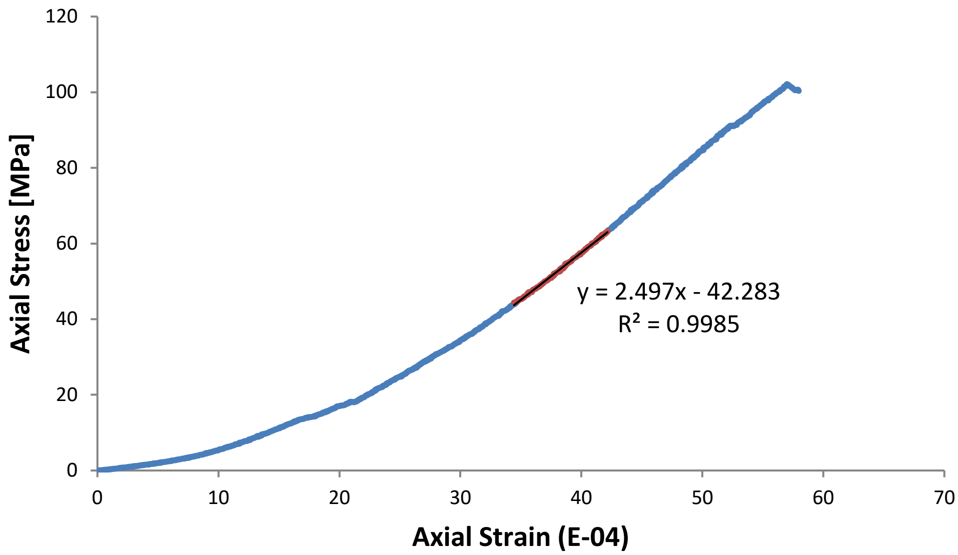

Figure A.141 Specimen 72: Young's modulus calculation

Figure A.142 Specimen 72: Before USC test and After UCS test

Specimen 73

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
73	IDH-02-06	408.0	408.8	50.12	105.66	1972.93	611.47	2.93	5363	**226.2**	**58.08**

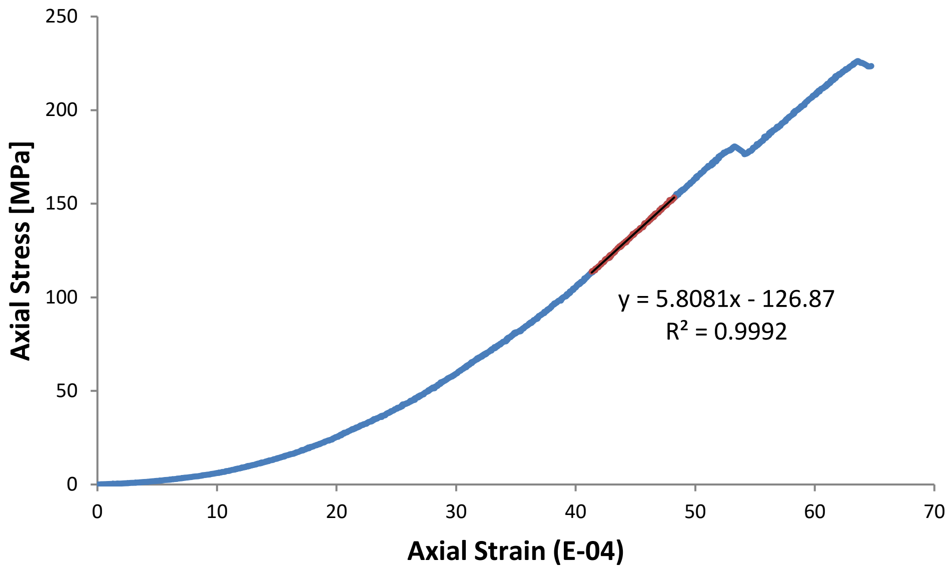

Figure A.143 Specimen 73: Young's modulus calculation

Figure A.144 Specimen 73: Before USC test and After UCS test

Specimen 74

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]	
74	IDH-08-01	96.0	97.0	50.53	104.10	2005.34	557.11	2.67	5816	**103.2**	**40.16**	Core sample in poor condition

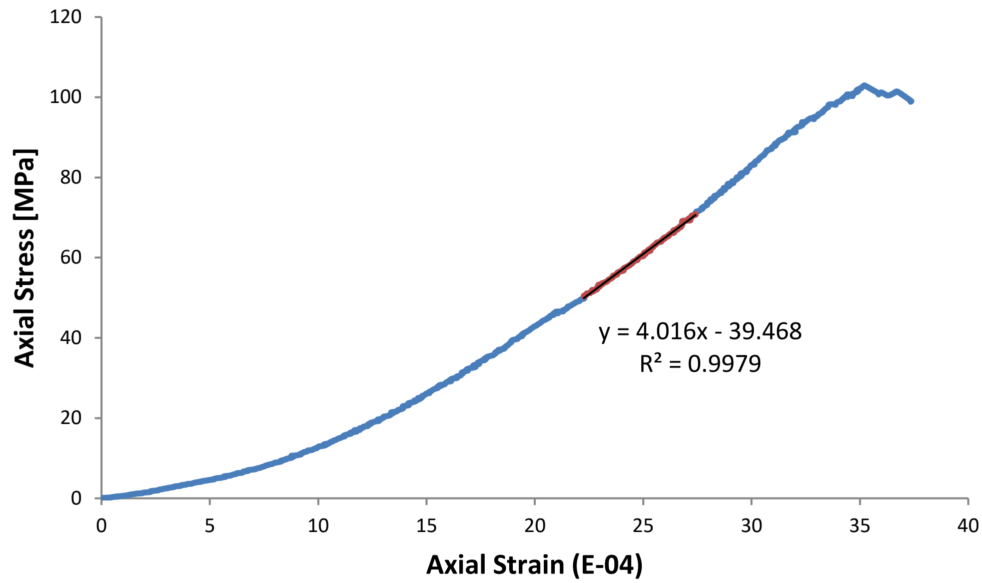

Figure A.145 Specimen 74: Young's modulus calculation

Figure A.146 Specimen 74: Before USC test and After UCS test

Specimen 75

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
75	IDH-08-02	222.6	223.2	50.58	105.19	2009.31	726.40	3.44	5340	**62.1**	**27.19**

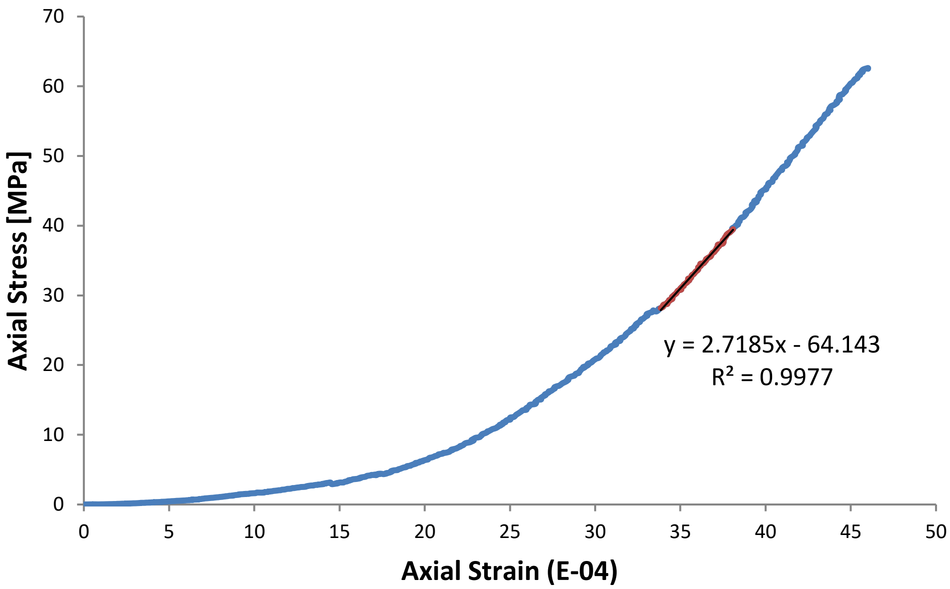

Figure A.147 Specimen 75: Young's modulus calculation

Figure A.148 Specimen 75: Before USC test and After UCS test

Specimen 76

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
76	IDH-08-04	167.0	167.6	50.60	104.95	2010.90	702.25	3.33	6102	**228.7**	**65.58**

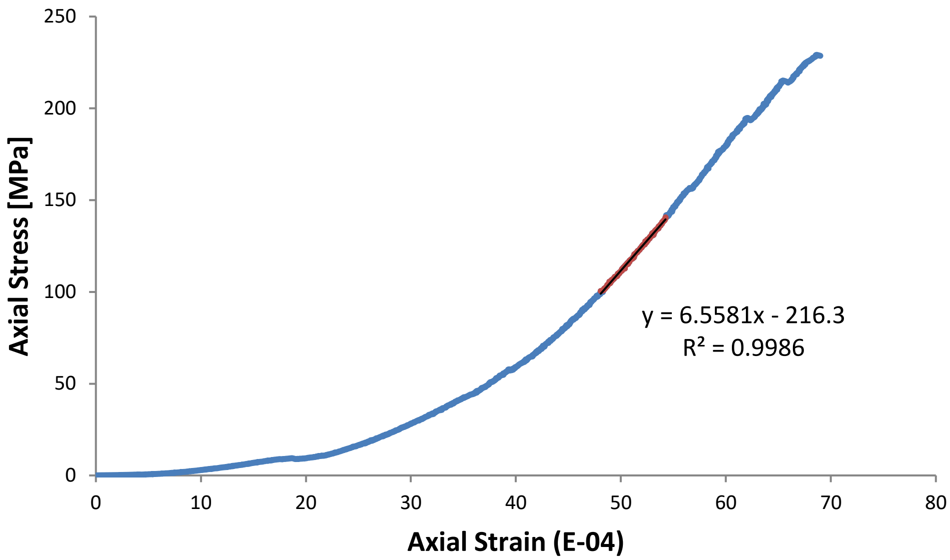

Figure A.149 Specimen 76: Young's modulus calculation

Figure A.150 Specimen 76: Before USC test and After UCS test

Specimen 77

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
77	IDH-08-05	321.7	322.2	49.98	103.76	1961.92	662.13	3.25	5670	**379.1**	**78.98**

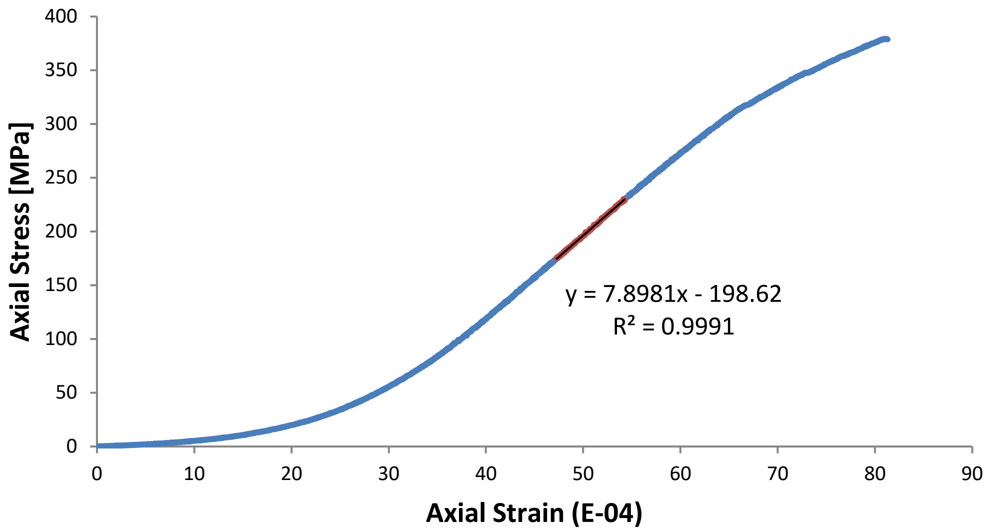

Figure A.151 Specimen 77: Young's modulus calculation

Figure A.152 Specimen 77: Before USC test and After UCS test

Specimen 78

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
78	IDH-08-06	378.1	378.7	50.51	104.47	2003.75	576.12	2.75	5470	**158.2**	**51.26**

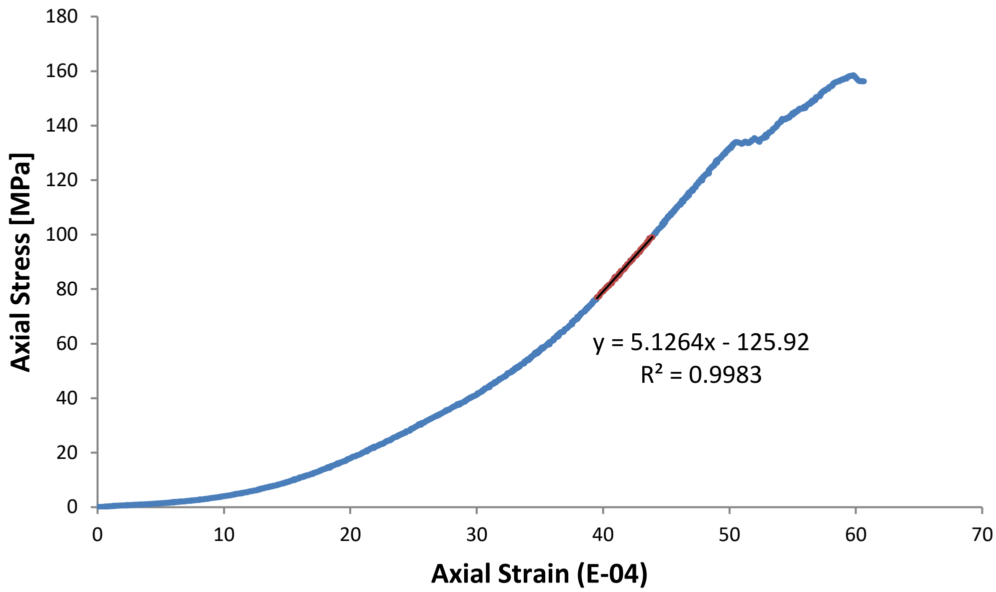

Figure A.153 Specimen 78: Young's modulus calculation

Figure A. 154 Specimen 78: Before USC test and After UCS test

Specimen 79

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
79	IDH-08-07	418.5	419.0	50.55	104.47	2006.93	618.62	2.95	5557	**126.6**	**47.66**

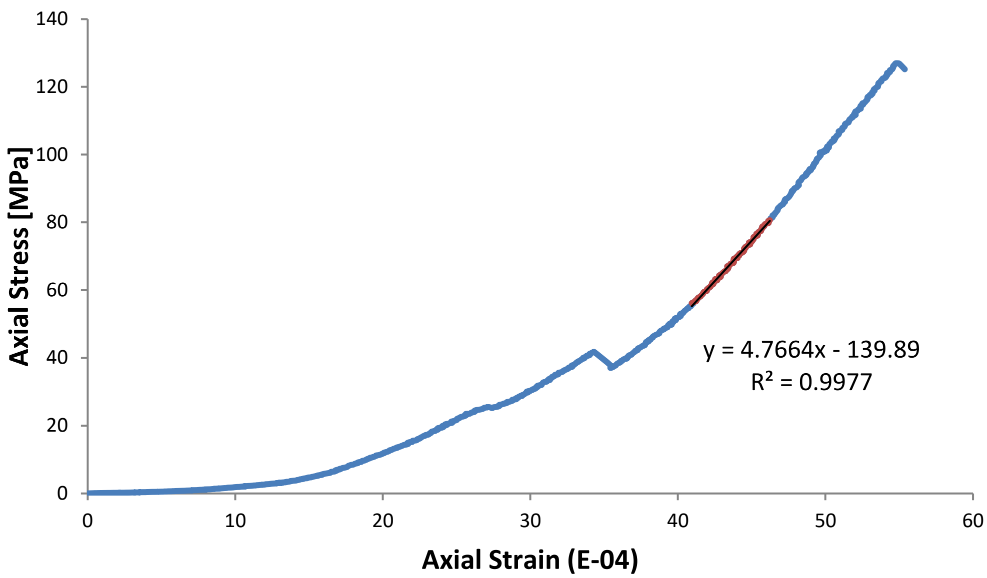

Figure A.155 Specimen 79: Young's modulus calculation

Figure A.156 Specimen 79: Before USC test and After UCS test

Specimen 80

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
80	IDH-09-01	161.2	161.8	50.29	104.24	1986.34	654.10	3.16	4964	**92.2**	**34.42**

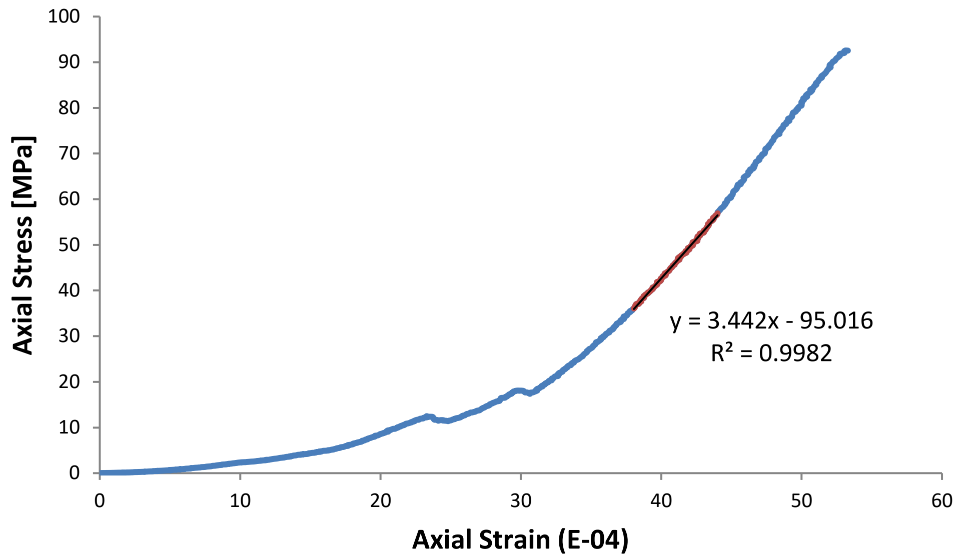

Figure A.157 Specimen 80: Young's modulus calculation

Figure A.158 Specimen 80: Before USC test and After UCS test

Specimen 81

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
81	IDH-09-02	286.1	286.6	50.55	104.90	2006.93	656.25	3.12	5550	**170.1**	**51.16**

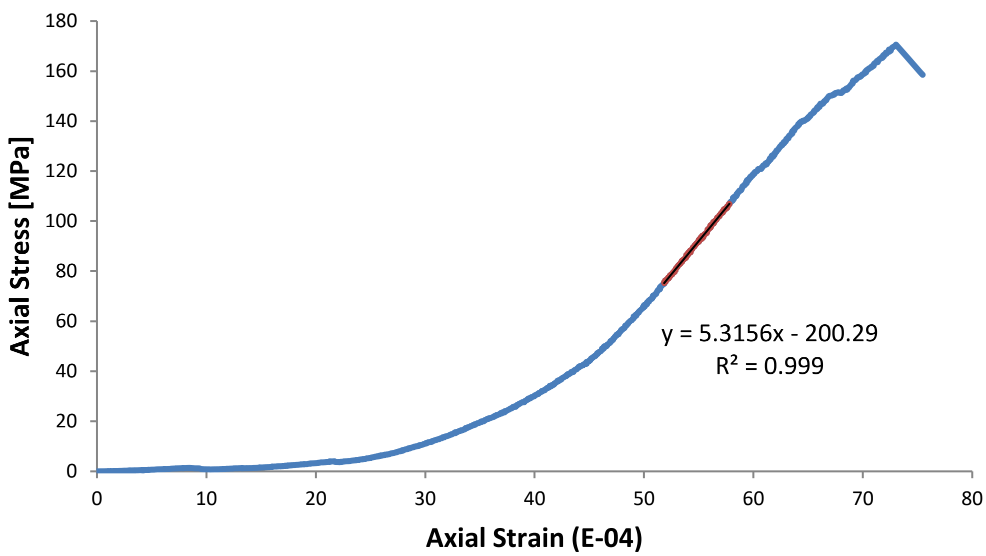

Figure A.159 Specimen 81: Young's modulus calculation


Figure A.160 Specimen 81: Before USC test and After UCS test

Specimen 82

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
82	IDH-09-03	247.0	247.8	50.70	104.97	2018.86	624.99	2.95	5768	**107.5**	**43.02**

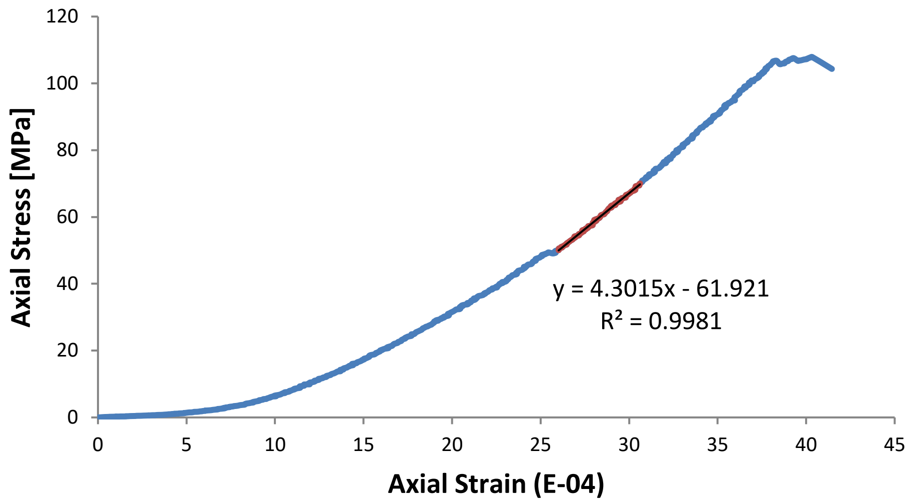

Figure A.161 Specimen 82: Young's modulus calculation

Figure A.162 Specimen 82: Before USC test and After UCS test

Specimen 83

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[mm²]	[g]	[g/cm³]	[m/s]	[MPa]	[GPa]	
83	IDH-09-04	137.8	138.2	50.10	89.40	1971.36	476.39	2.70	4448	**49.3**	**18.88**	Core in poor condition resulting in spec. length

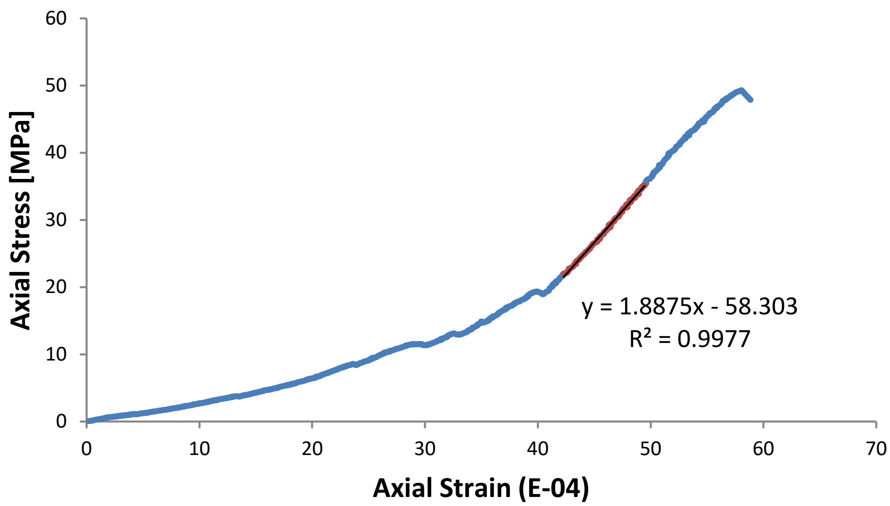

Figure A.163 Specimen 83: Young's modulus calculation

Figure A.164 Specimen 83: Before USC test and After UCS test

Specimen 84

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
84	IDH-09-05	191.7	192.2	50.28	105.61	1985.55	692.74	3.30	5102	**125.2**	**46.72**

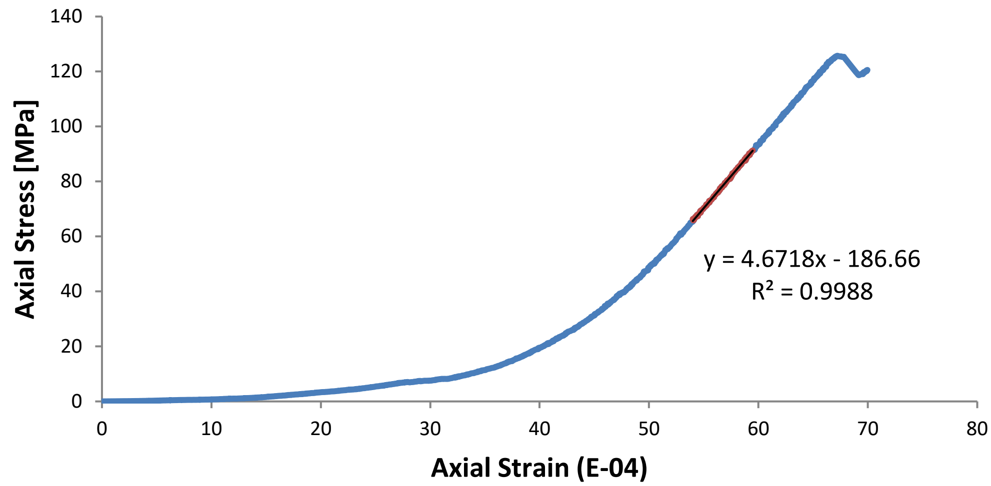

Figure A.165 Specimen 84: Young's modulus calculation

Figure A.166 Specimen 84: Before USC test and After UCS test

Specimen 85

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
85	IDH-09-06	96.1	96.7	50.48	104.34	2001.38	607.59	2.91	4992	**137.3**	**51.08**

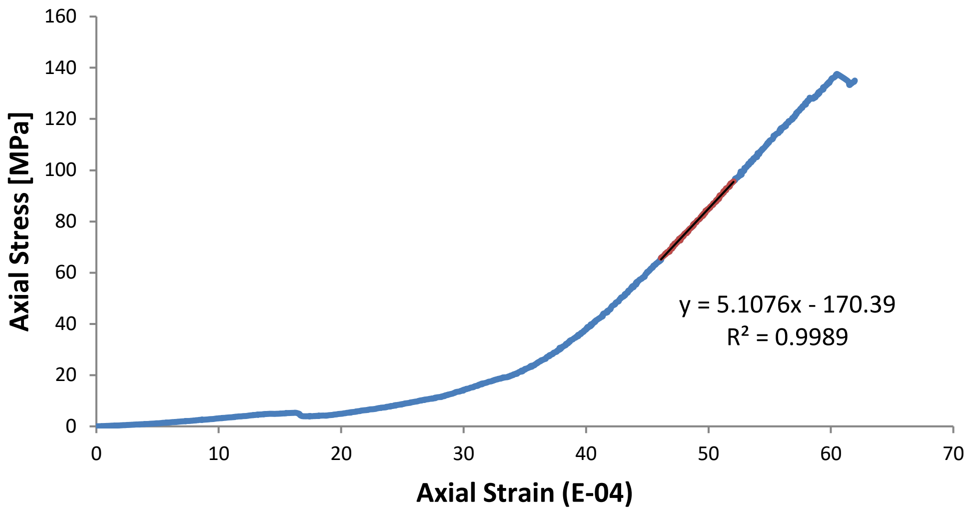

Figure A.167 Specimen 85: Young's modulus calculation

Figure A.168 Specimen 85: Before USC test and After UCS test

Specimen 86

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
86	IDH-09-07	41.9	42.4	50.70	104.81	2018.86	699.23	3.30	5347	**369.0**	**67.21**

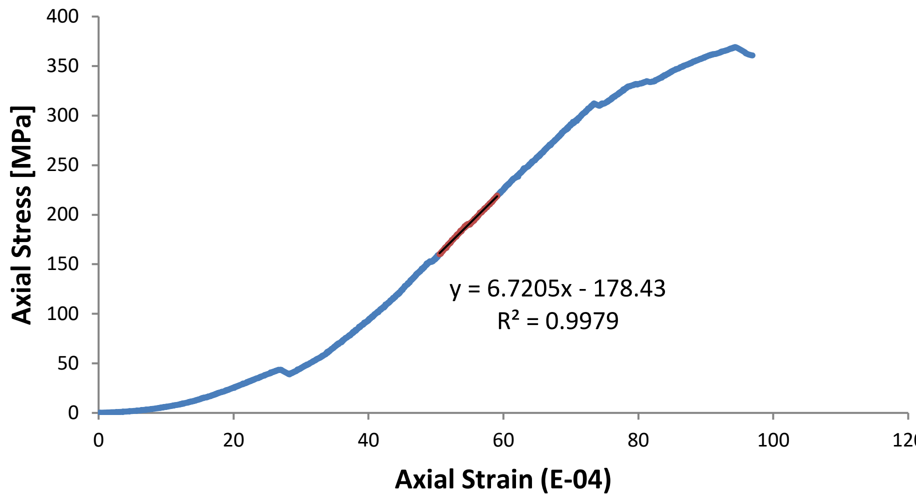

Figure A.169 Specimen 86: Young's modulus calculation

Figure A.170 Specimen 86: Before USC test and After UCS test

Specimen 87

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
87	IDH-02-07	436.0	437.1	50.53	104.87	2005.34	732.08	3.48	6062	**185.6**	**27.27**

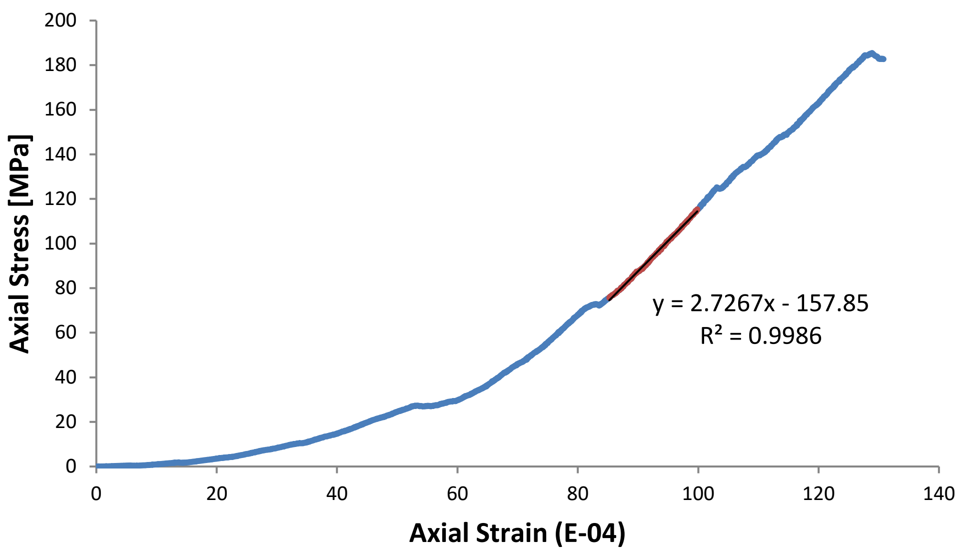

Figure A.171 Specimen 87: Young's modulus calculation

Figure A.172 Specimen 87: Before USC test and After UCS test

Specimen 88

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
88	IDH-02-08	464.0	464.7	50.55	104.59	2006.93	639.55	3.05	5534	**170.0**	**24.34**

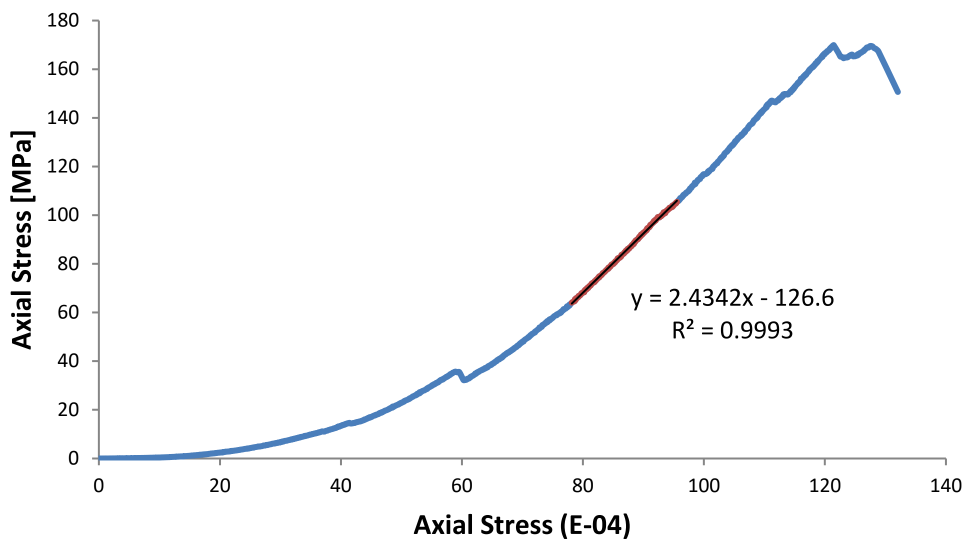

Figure A.173 Specimen 88: Young's modulus calculation

Figure A.174 Specimen 88: Before USC test and After UCS test

Specimen 89

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
89	IDH-02-09	489.3	490.2	50.54	104.11	2006.14	597.19	2.86	5628	**161.8**	**24.95**

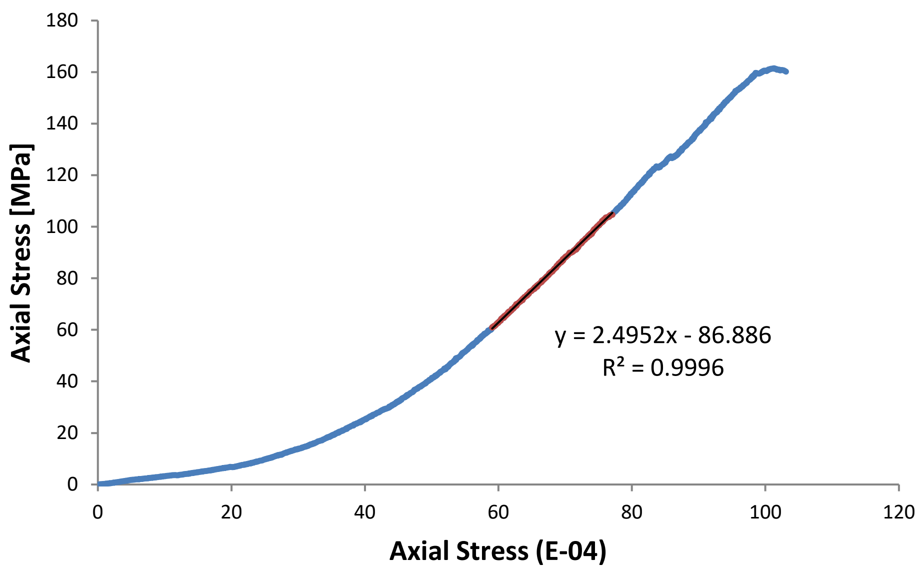

Figure A. 175 Specimen 89: Young's modulus calculation

Figure A.176 Specimen 89: Before USC test and After UCS test

Specimen 90

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
90	IDH-02-10	568.4	569.2	50.74	104.67	2022.04	786.74	3.72	4961	**109.3**	**21.92**

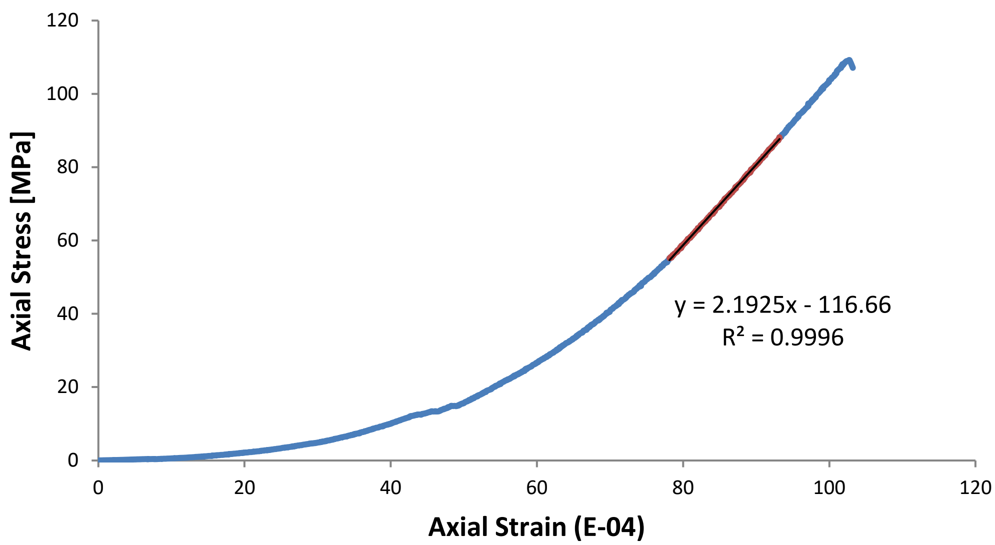

Figure A.177 Specimen 90: Young's modulus calculation

Figure A.178 Specimen 90: Before USC test and After UCS test

Specimen 91

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
91	IDH-02-11	634.5	635.1	50.58	104.05	2009.31	593.29	2.84	5100	**65.4**	**14.54**

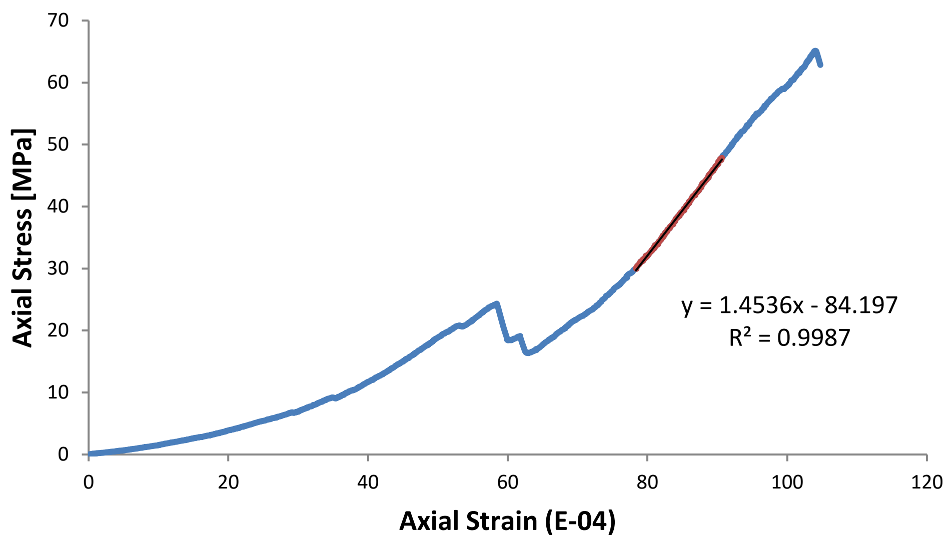

Figure A.179 Specimen 91: Young's modulus calculation

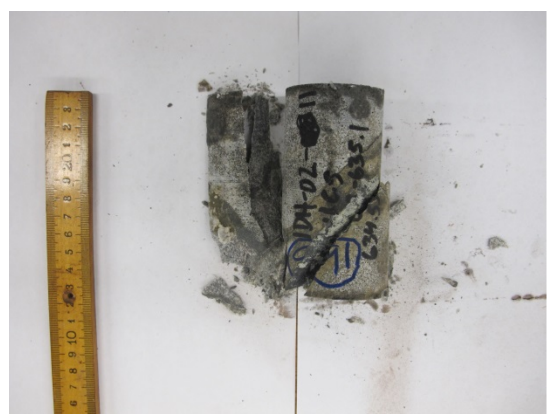

Figure A.180 Specimen 91: Before USC test and After UCS test

Specimen 92

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]	
92	IDH-02-12	708.5	709.1	50.37	105.46	1992.66	652.87	3.11	5353	**41.6**	**10.3**	**Ends visibly fractured prior to testing**

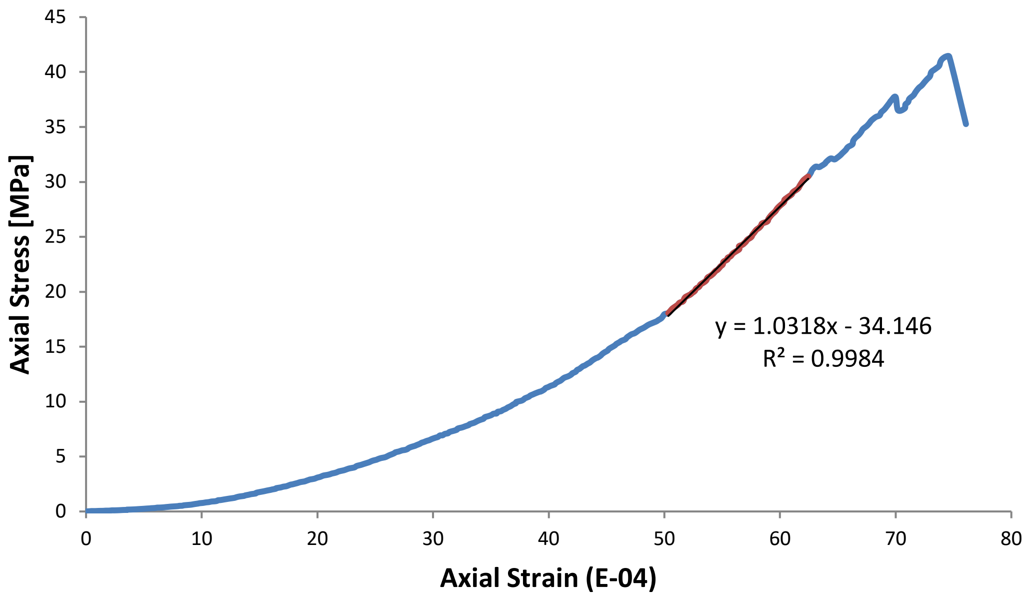

Figure A.181 Specimen 92: Young's modulus calculation

Figure A.182 Specimen 92: Before USC test and After UCS test

Specimen 93

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
93	IDH-02-13	764.0	764.8	50.50	104.09	2002.96	561.23	2.69	5566	**97.6**	**17.7**

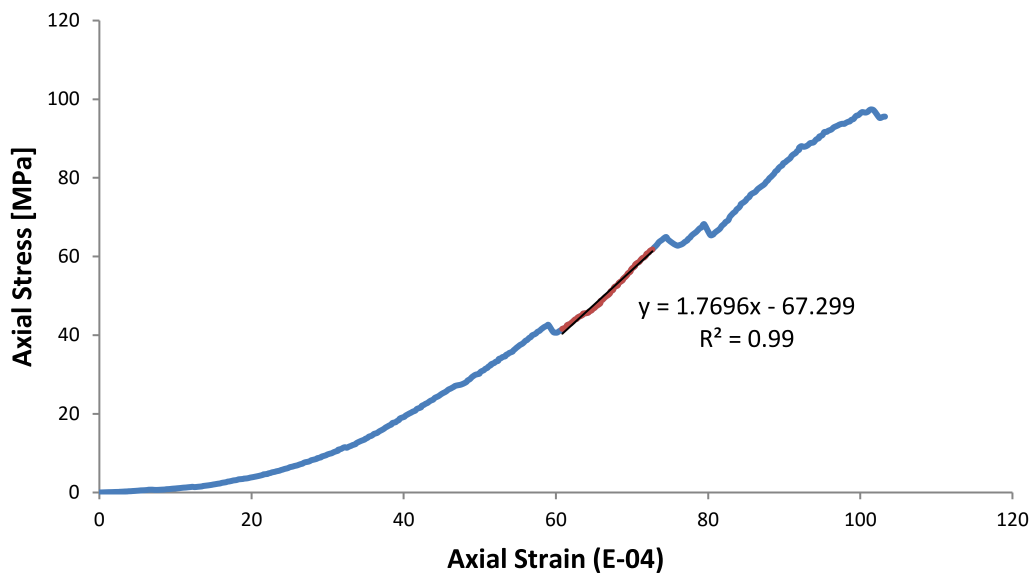

Figure A.183 Specimen 93: Young's modulus calculation


Figure A.184 Specimen 93: Before USC test and After UCS test

Specimen 94

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
94	IDH-10-01	244.2	245.0	50.56	104.68	2007.72	615.6	2.93	5424	**204.0**	**26.3**

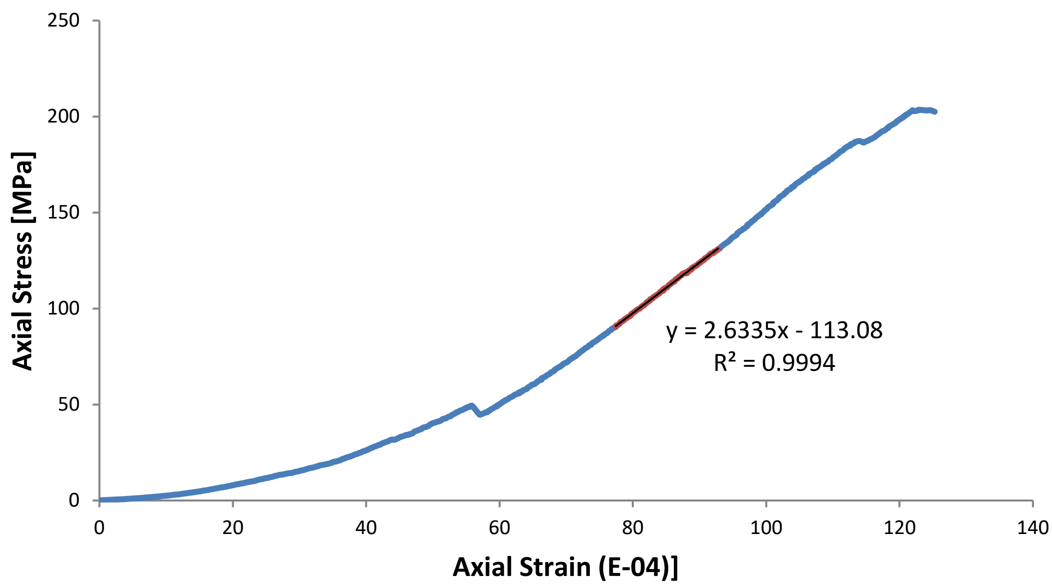

Figure A.185 Specimen 94: Young's modulus calculation

Figure A.186 Specimen 94: Before USC test and After UCS test

Specimen 95

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
95	IDH-10-02	253.6	254.7	50.32	105.01	1988.71	633.38	3.03	5304	**87.6**	**12.6**

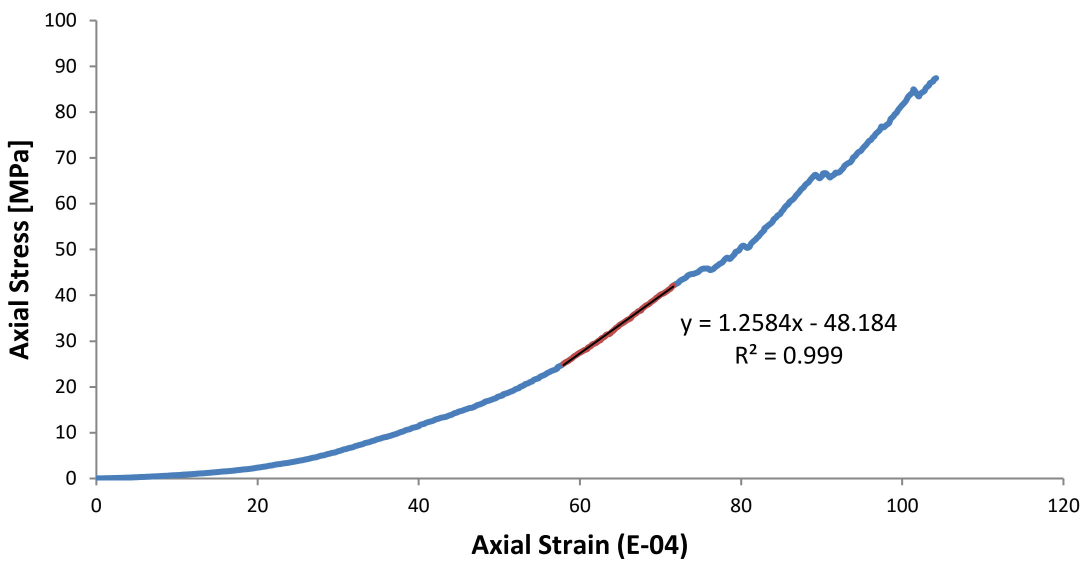

Figure A.187 Specimen 95: Young's modulus calculation

Figure A.188 Specimen 95: Before USC test and After UCS test

Specimen 96

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
96	IDH-11-01	56.2	56.9	50.32	105.44	1988.71	605.94	2.89	5699	**190.5**	**23.2**

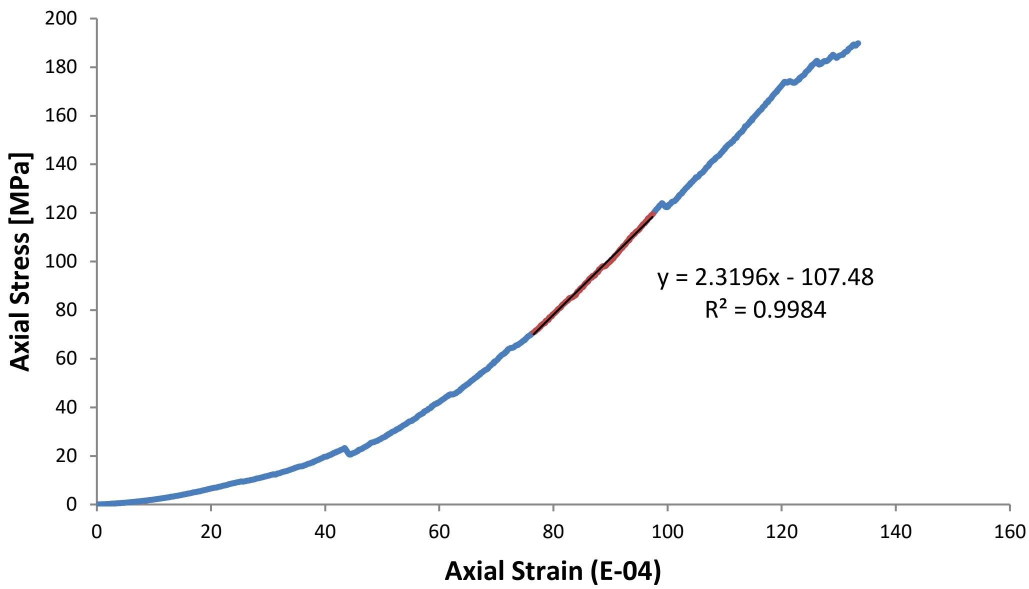

Figure A.189 Specimen 96: Young's modulus calculation

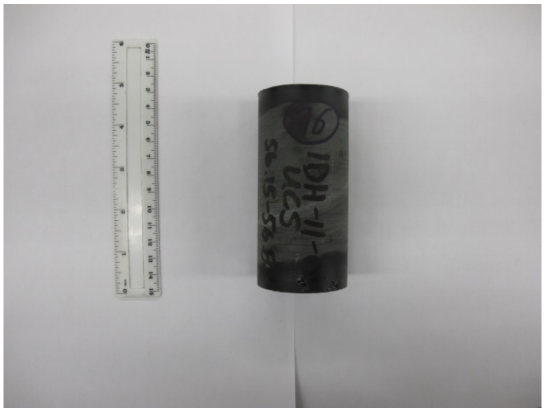

Figure A.190 Specimen 96: Before USC test and After UCS test

Specimen 97

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus	Additional Notes
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]	
97	IDH-11-02	135.1	135.7	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**	**N/A**	**Specimen fractured during preparation**

Figure A.191 Specimen 97: Fracture occurred during cutting portion of preparation

Specimen 98

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm²]	[g]	[g/cm³]	[m/s]	[MPa]	[GPa]
98	IDH-11-03	196.7	197.5	50.34	104.9	1990.29	640.23	3.07	5960	**215.4**	**28.1**

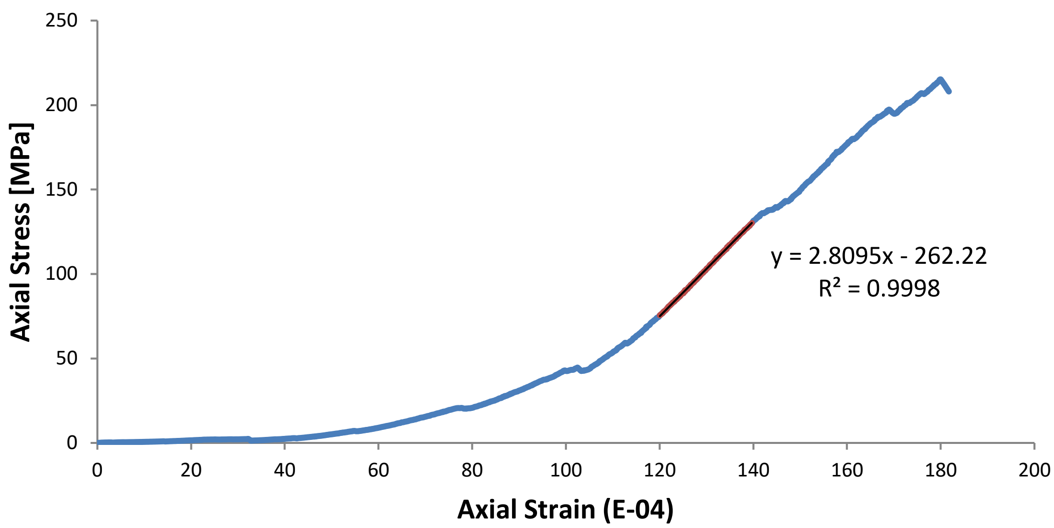

Figure A.192 Specimen 98: Young's modulus calculation

Figure A. 193 Specimen 98: Before USC test and After UCS test

Specimen 99

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
99	IDH-11-04	212.1	212.9	50.36	103.98	1991.87	655.19	3.16	5908	**223.8**	**28.4**

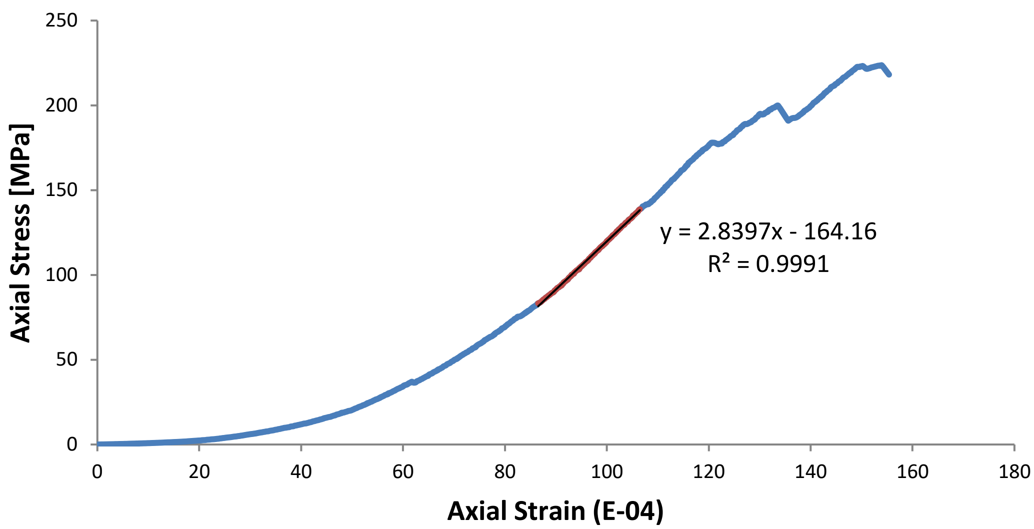

Figure A.194 Specimen 99: Young's modulus calculation

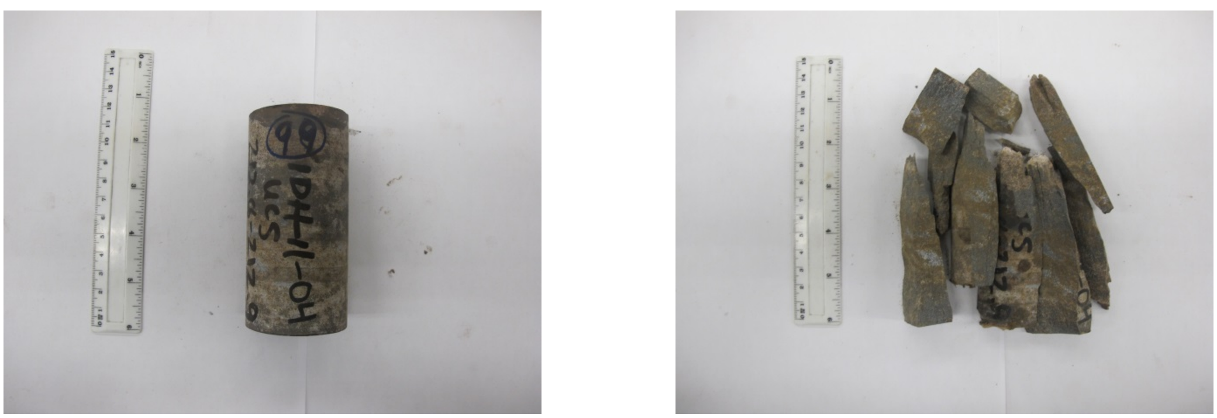

Figure A.195 Specimen 99: Before USC test and After UCS test

Specimen 100

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
100	IDH-11-05	232.9	233.8	50.44	103.99	1998.20	659.07	3.17	5445	**135.5**	**21.2**

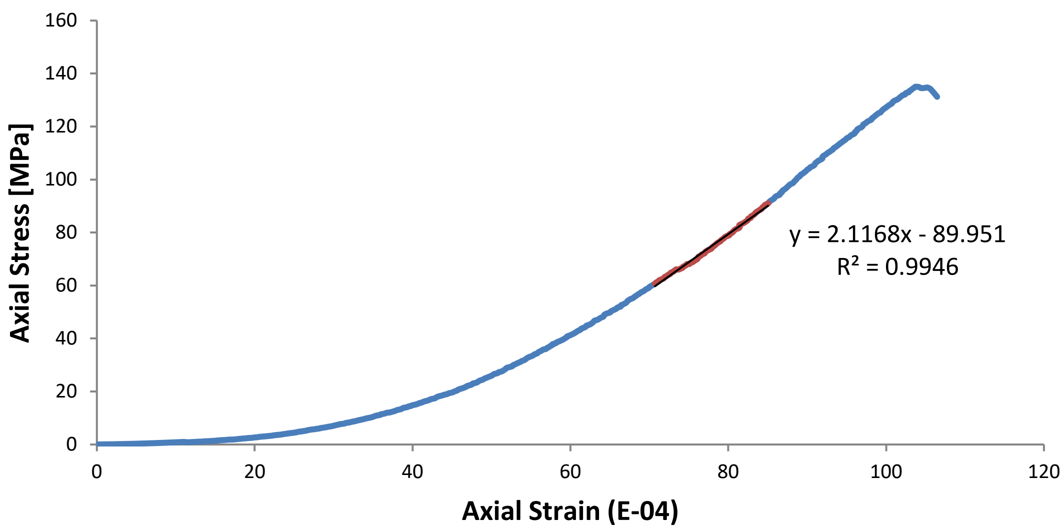

Figure A.196 Specimen 100: Young's modulus calculation

Figure A.197 Specimen 100: Before USC test and After UCS test

Specimen 101

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
101	IDH-11-06	240.6	241.5	50.60	105.51	2010.90	671.20	3.16	5024	**41.9**	**8.5**

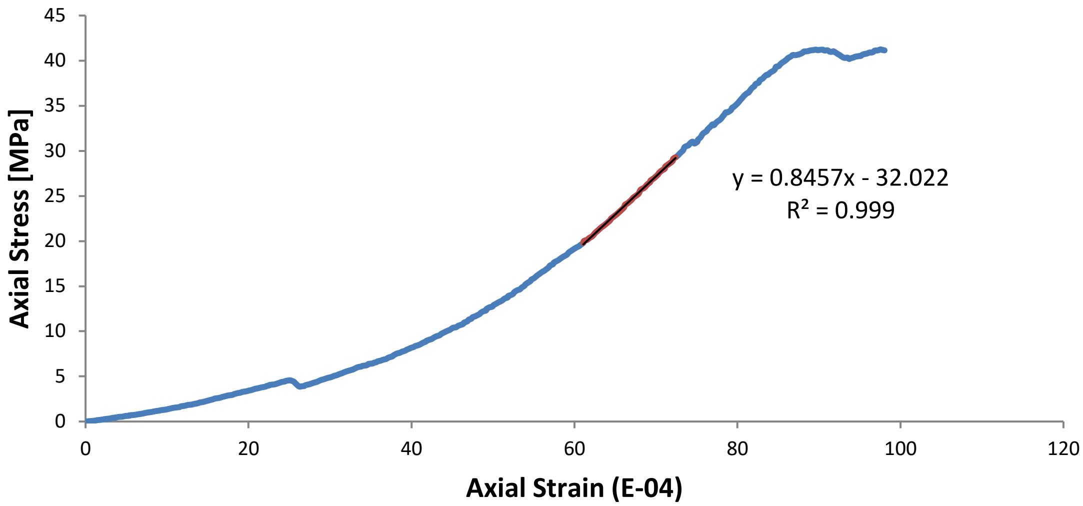

Figure A.198 Specimen 101: Young's modulus calculation

Figure A.199 Specimen 101: Before USC test and After UCS test

Specimen 102

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
102	IDH-11-07	248.0	248.7	50.36	104.41	1991.87	687.06	3.30	4350	**78.8**	**13.7**

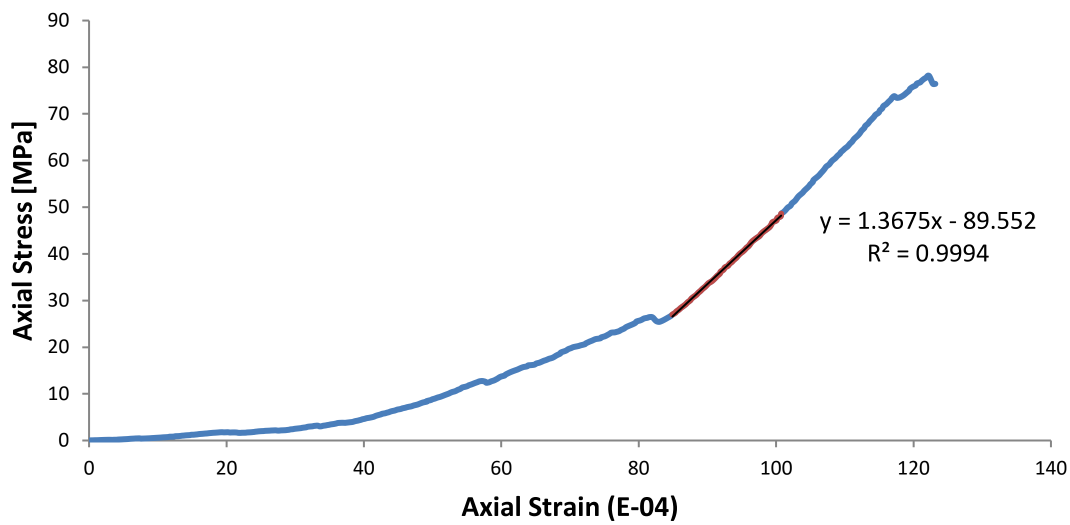

Figure A.200 Specimen 102: Young's modulus calculation

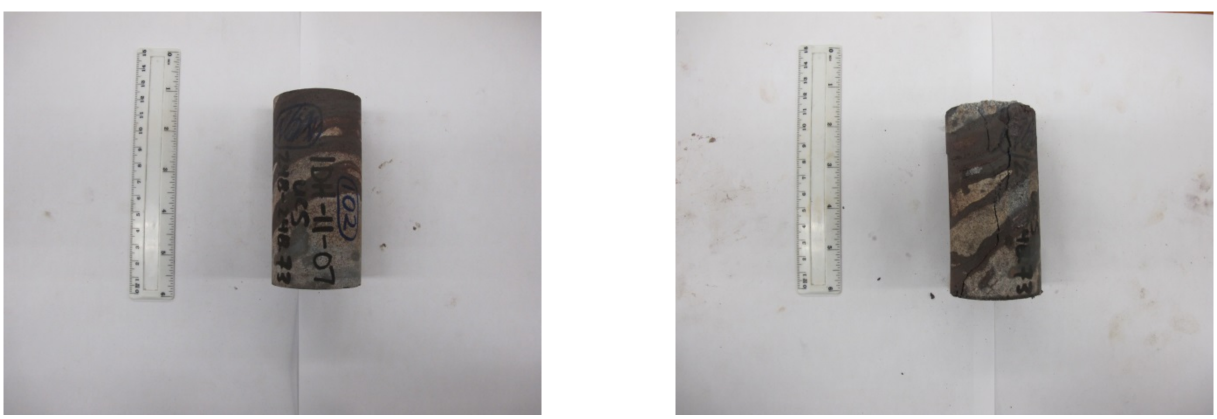

Figure A.201 Specimen 102: Before USC test and After UCS test

Specimen 103

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
103	IDH-11-08	275.3	276.3	50.53	105.40	2005.34	711.85	3.37	4925	**81.8**	**15.5**

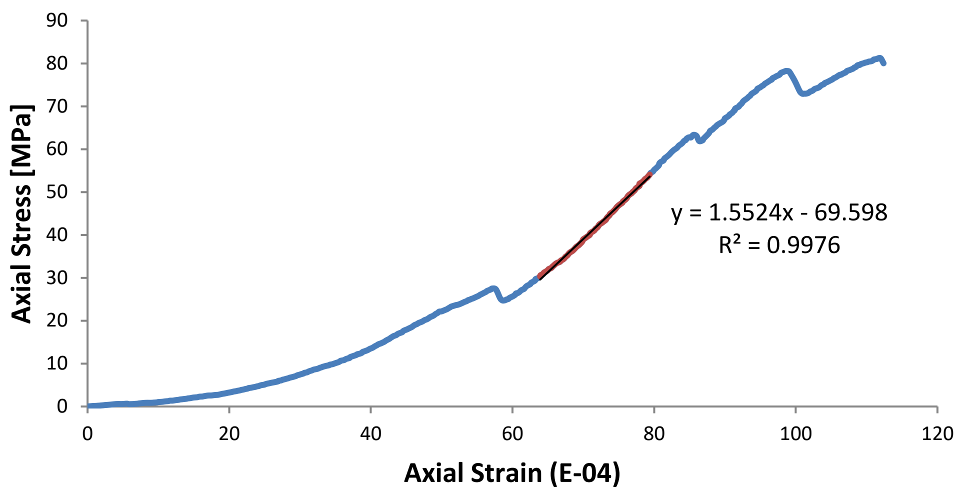

Figure A.202 Specimen 103: Young's modulus calculation

Figure A.203 Specimen 103: Before USC test and After UCS test

Specimen 104

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
104	IDH-11-09	292.1	292.1	50.21	104.73	1980.02	611.00	2.95	4173	**95.3**	**14.1**

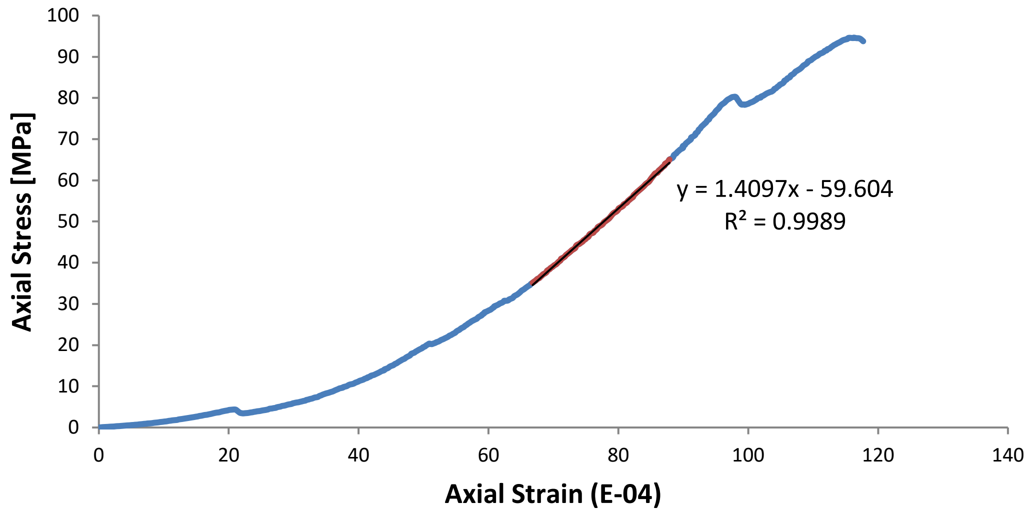

Figure A.204 Specimen 104: Young's modulus calculation

Figure A.205 Specimen 104: Before USC test and After UCS test

Specimen 105

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
105	IDH-11-10	358.8	359.5	50.44	105.18	1998.20	623.78	2.97	5507	**132.9**	**21.6**

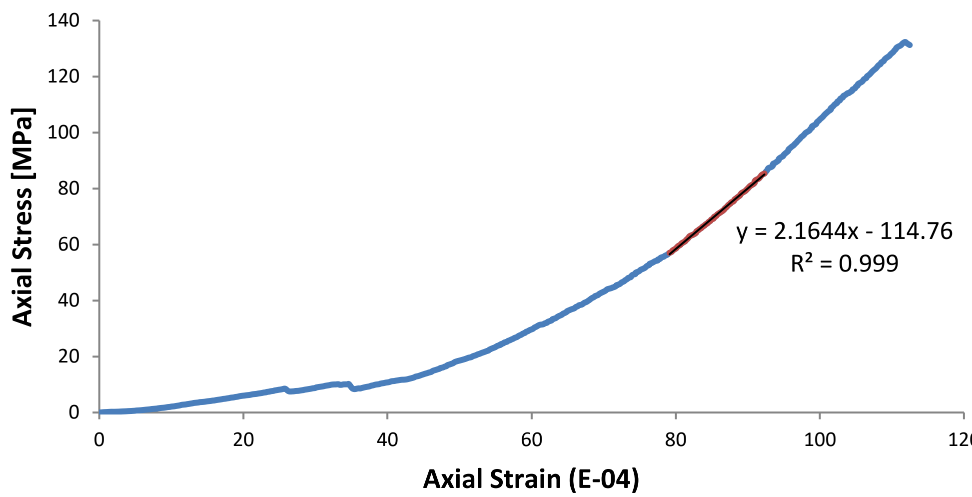

Figure A.206 Specimen 105: Young's modulus calculation

Figure A.207 Specimen 105: Before USC test and After UCS test

Specimen 106

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
106	IDH-11-11	412.6	413.2	50.45	105.17	1999.00	574.14	2.73	4759	**139.9**	**21.4**

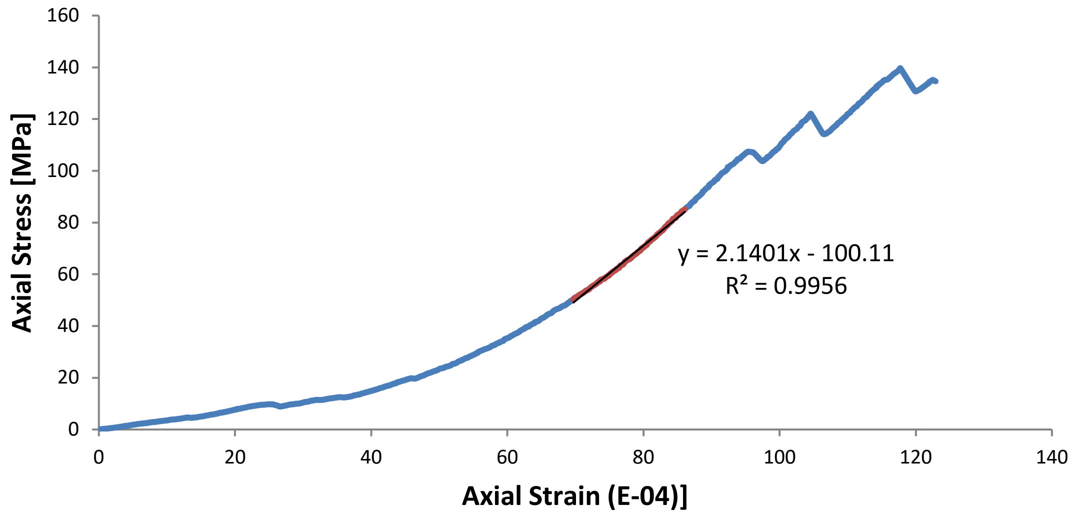

Figure A.208 Specimen 106: Young's modulus calculation

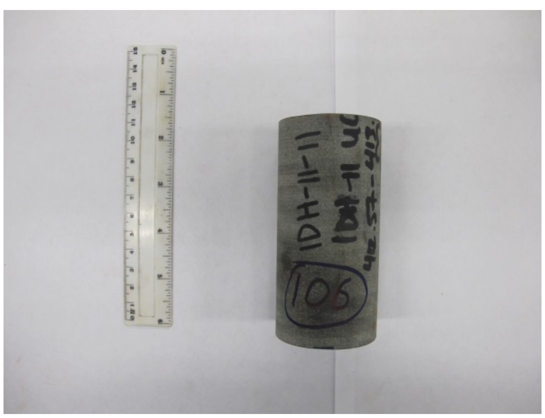

Figure A.209 Specimen 106: Before USC test and After UCS test

Specimen 107

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
107	IDH-11-12	224.0	224.9	50.5	106.27	2002.96	683.77	3.21	5623	**168.4**	**20.5**

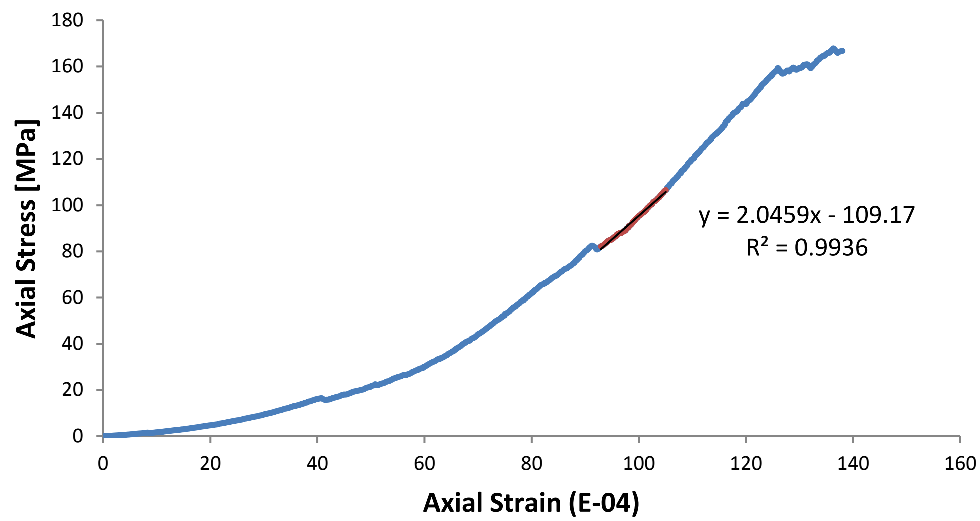

Figure A.210 Specimen 107: Young's modulus calculation

Figure A.211 Specimen 107: Before USC test and After UCS test

Specimen 108

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm²]	[g]	[g/cm³]	[m/s]	[MPa]	[GPa]
108	DBA-07-01	22.2	23.0	50.27	102.07	1984.76	602.92	2.98	4619	**109.1**	**14.5**

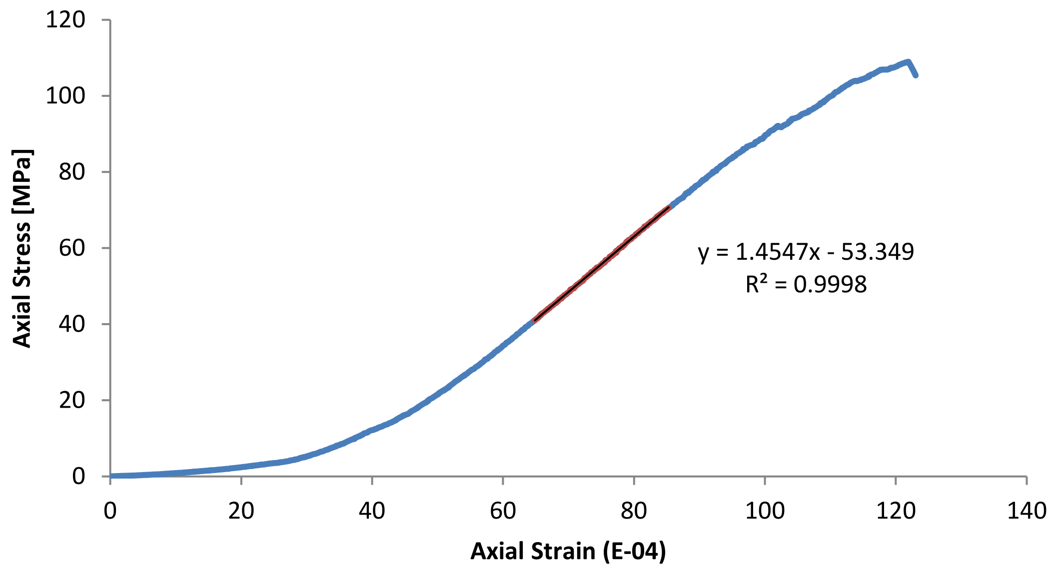

Figure A.212 Specimen 108: Young's modulus calculation

Figure A.213 Specimen 108: Before USC test and After UCS test

Specimen 109

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm²]	[g]	[g/cm³]	[m/s]	[MPa]	[GPa]
109	DBA-07-02	27.6	28.3	50.34	101.07	1990.29	605.17	3.01	5183	**102.0**	**18.2**

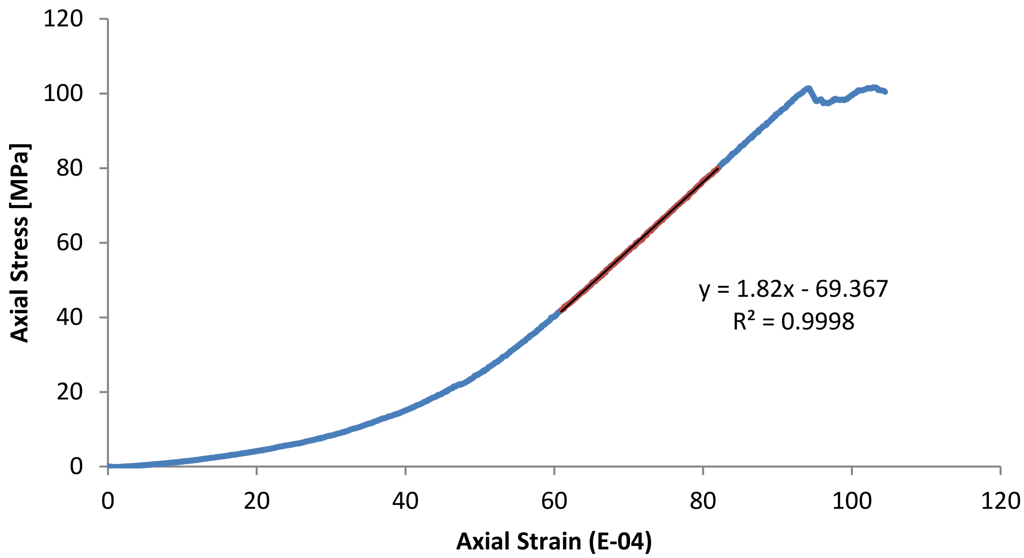

Figure A.214 Specimen 109: Young's modulus calculation

Figure A.215 Specimen 109: Before USC test and After UCS test

Specimen 110

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
110	DBA-07-03	46.9	47.4	50.47	100.62	2000.58	569.39	2.83	6845	**144.9**	**26.3**

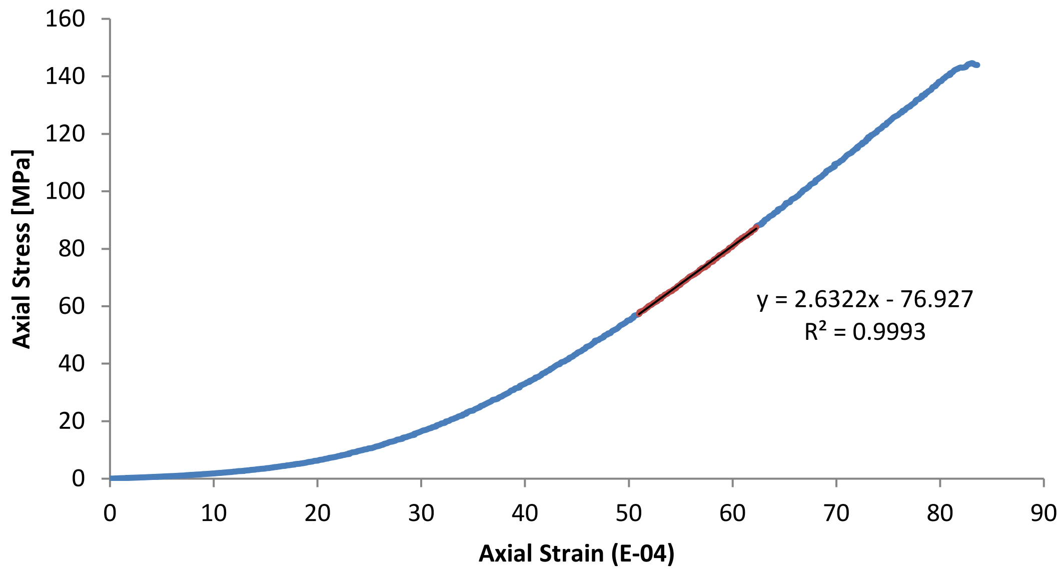

Figure A.216 Specimen 110: Young's modulus calculation

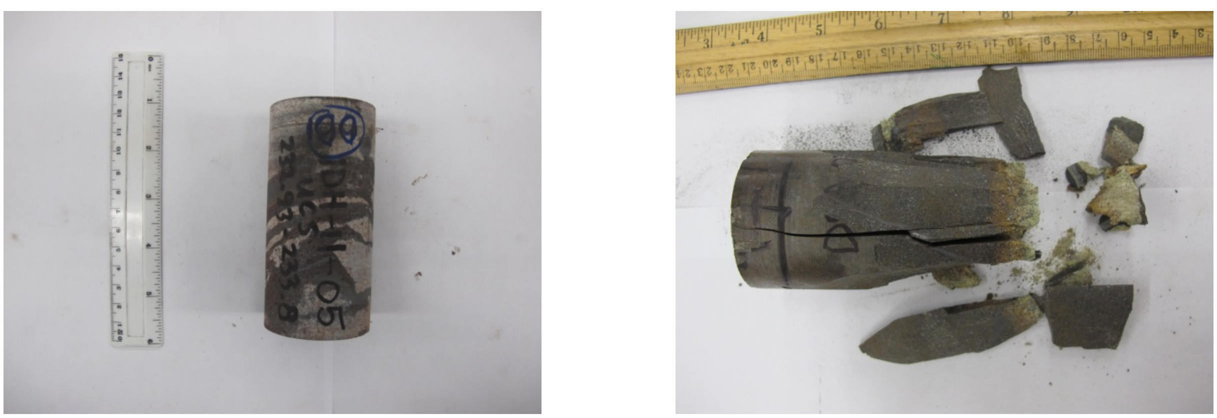

Figure A.217 Specimen 110: Before USC test and After UCS test

Specimen 111

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
111	DBA-07-04	59.8	60.4	50.5	101.08	2002.96	587.31	2.90	6357	**255.7**	**29.3**

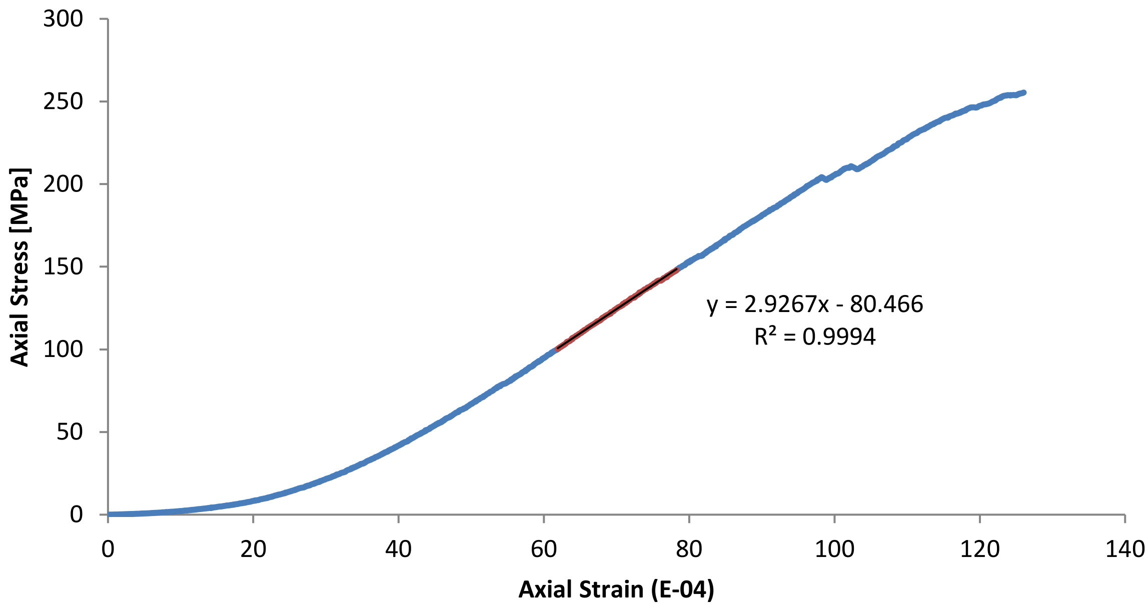

Figure A.218 Specimen 111: Young's modulus calculation

Figure A.219 Specimen 111: Before USC test and After UCS test

Specimen 112

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
112	DBA-08-01	32.3	32.8	50.45	102.56	1999.00	569.53	2.78	1906	**57.8**	**3.6**

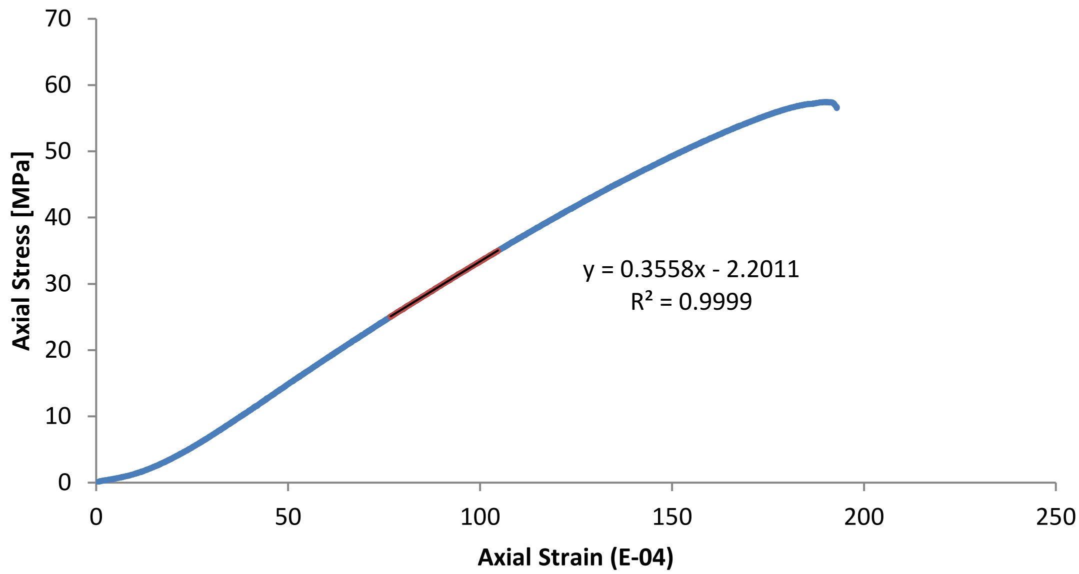

Figure A.220 Specimen 112: Young's modulus calculation

Figure A.221 Specimen 112: Before USC test and After UCS test

Specimen 113

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
113	DBA-08-02	40.9	41.5	50.55	101.45	2006.93	565.44	2.78	7246	**425.1**	**61.4**

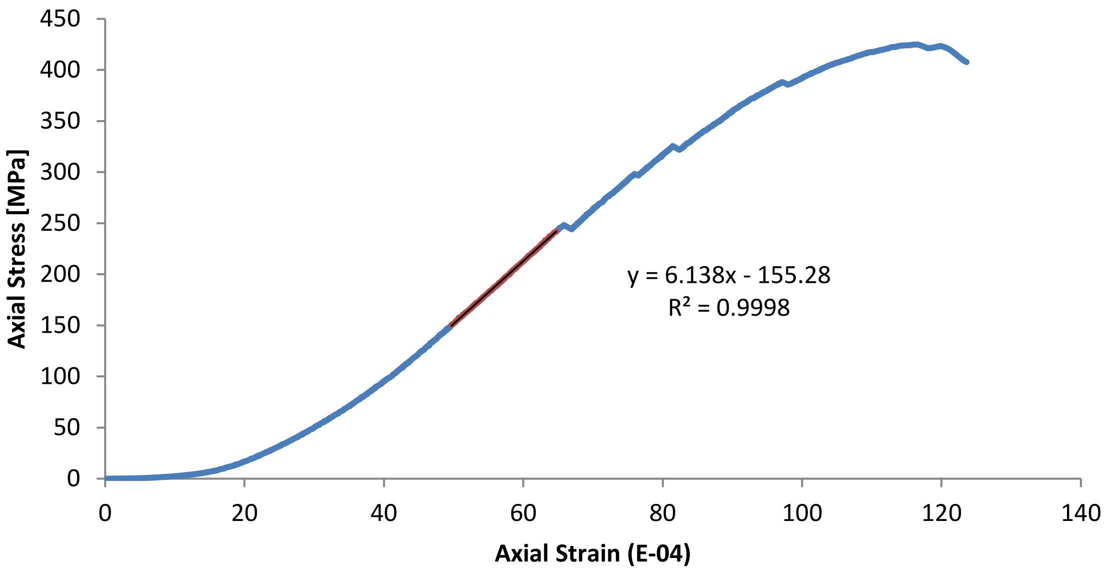

Figure A.222 Specimen 113: Young's modulus calculation

Figure A.223 Specimen 113: Before USC test and After UCS test

Specimen 114

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
114	DBA-08-03	44.6	45.4	50.49	100.23	2002.17	558.66	2.78	7480	**293.2**	**54.8**

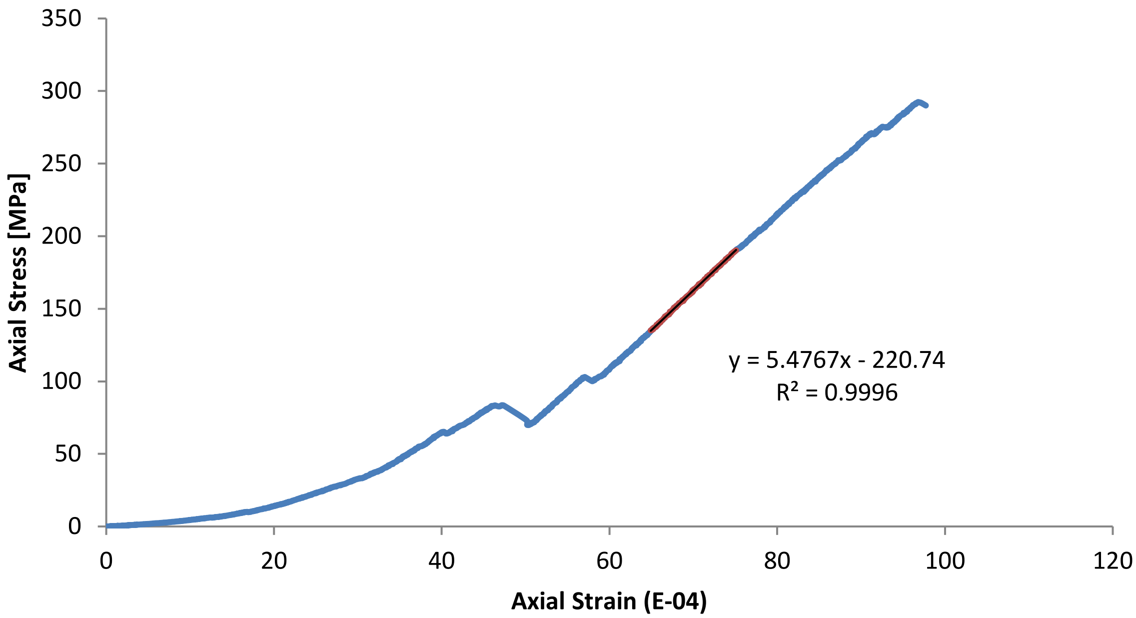

Figure A.224 Specimen 114: Young's modulus calculation

Figure A.225 Specimen 114: Before USC test and After UCS test

Specimen 115

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
115	DBA-08-04	56.1	56.7	50.32	101.30	1988.71	630.75	3.13	6845	**378.1**	**60.5**

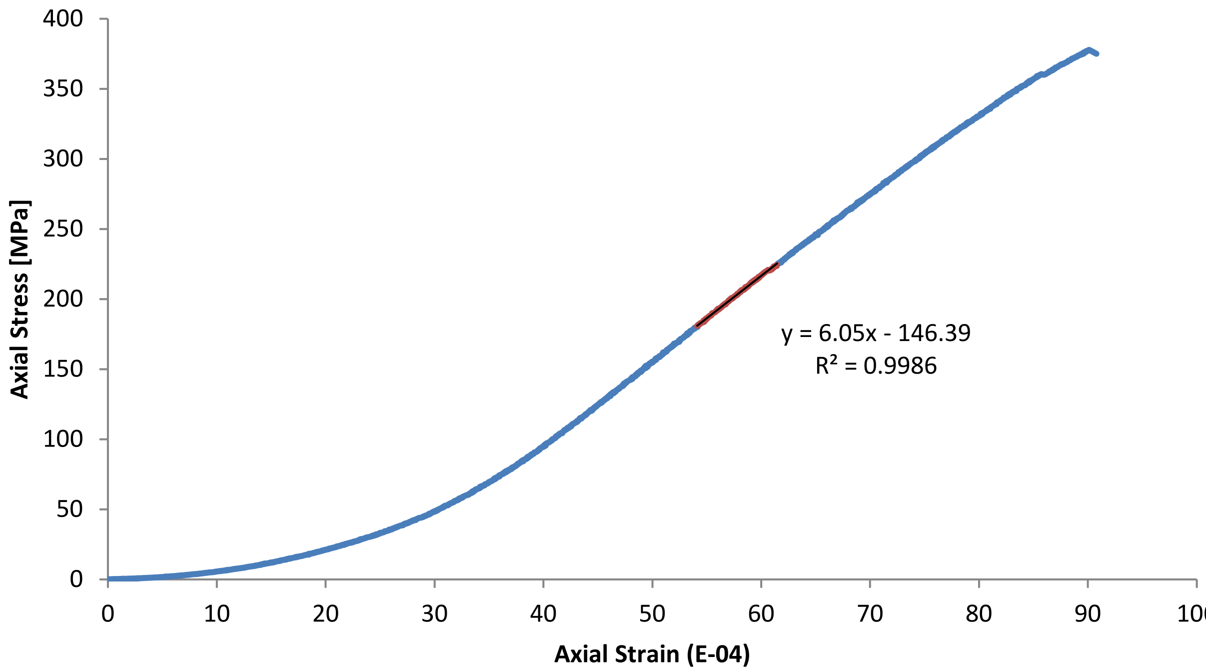

Figure A.226 Specimen 115: Young's modulus calculation

Figure A.227 Specimen 115: Before USC test and After UCS test

Specimen 116

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
116	DBA-09-01	15.1	15.8	50.40	100.30	1995.04	600.19	3.00	4438	**91.8**	**16.7**

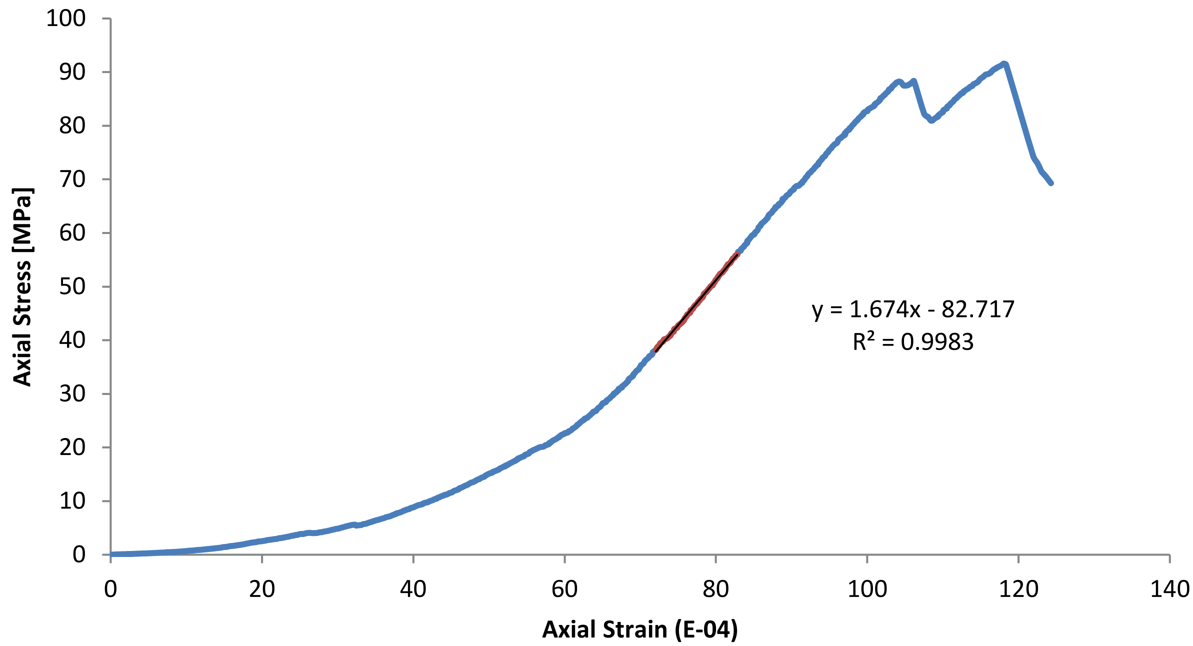

Figure A.228 Specimen 116: Young's modulus calculation

Figure A.229 Specimen 116: Before USC test and After UCS test

Specimen 117

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm²]	[g]	[g/cm³]	[m/s]	[MPa]	[GPa]
117	DBA-09-02	31.1	31.6	50.49	100.71	2002.17	531.22	2.63	6031	**75.5**	**19.6**

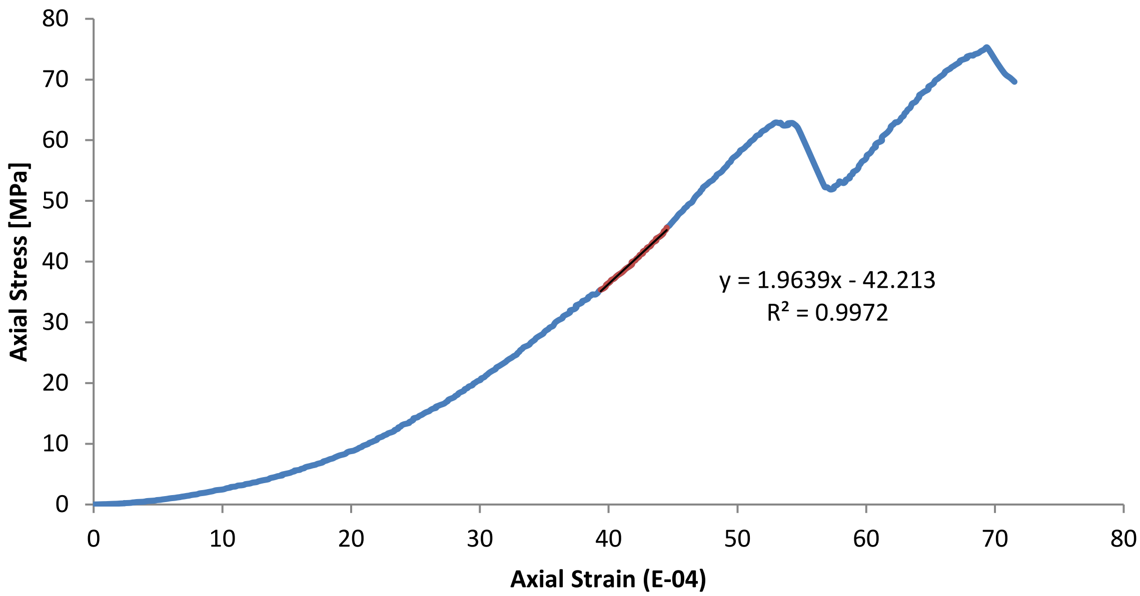

Figure A.230 Specimen 117: Young's modulus calculation

Figure A.231 Specimen 117: Before USC test and After UCS test

Specimen 118

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
118	DBA-09-03	44.0	44.6	50.52	100.13	2004.55	566.75	2.82	7309	**266.0**	**57.8**

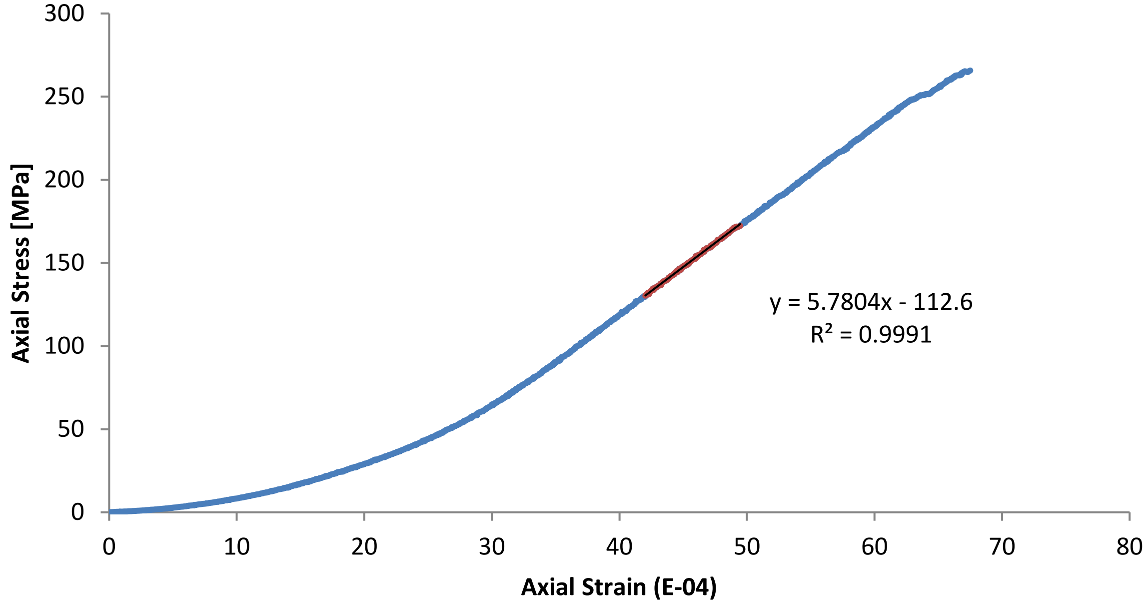

Figure A.232 Specimen 118: Young's modulus calculation

Figure A.233 Specimen 118: Before USC test and After UCS test

Specimen 119

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
119	DBA-09-04	49.9	50.6	50.57	99.53	2008.52	535.92	2.68	5753	**108.3**	**30.0**

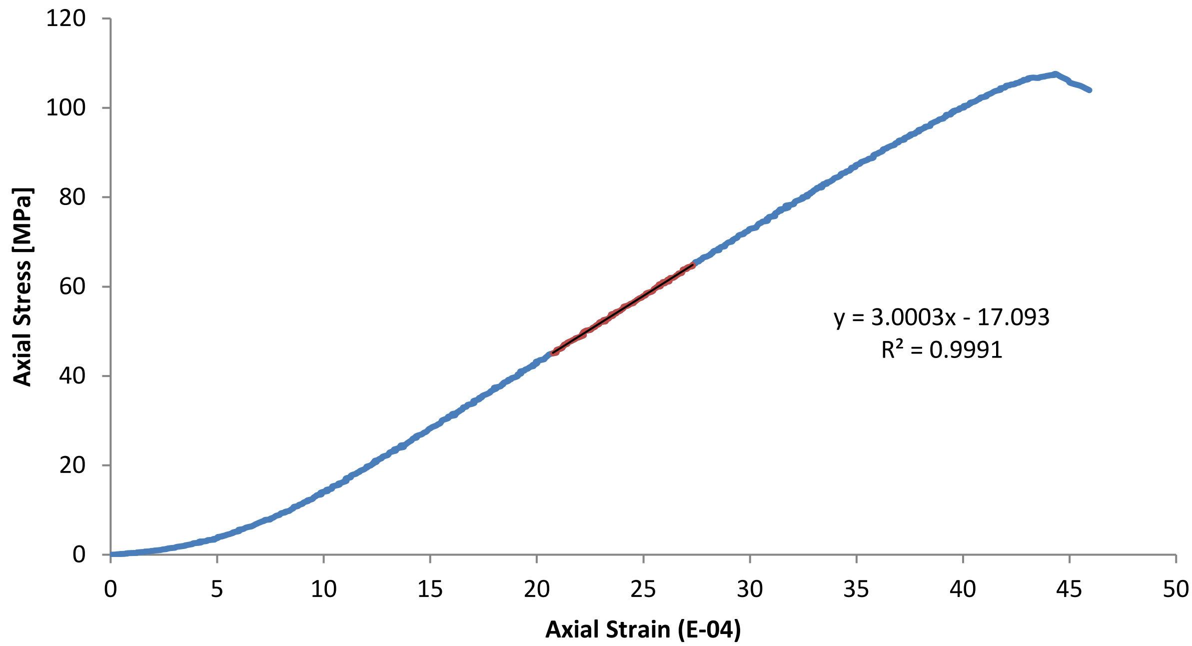

Figure A.234 Specimen 119: Young's modulus calculation

Figure A.235 Specimen 119: Before USC test and After UCS test

Specimen 120

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
120	DBA-01	168.5	169.3	50.43	99.65	1997.41	625.12	3.14	5137	**107.4**	**53.8**

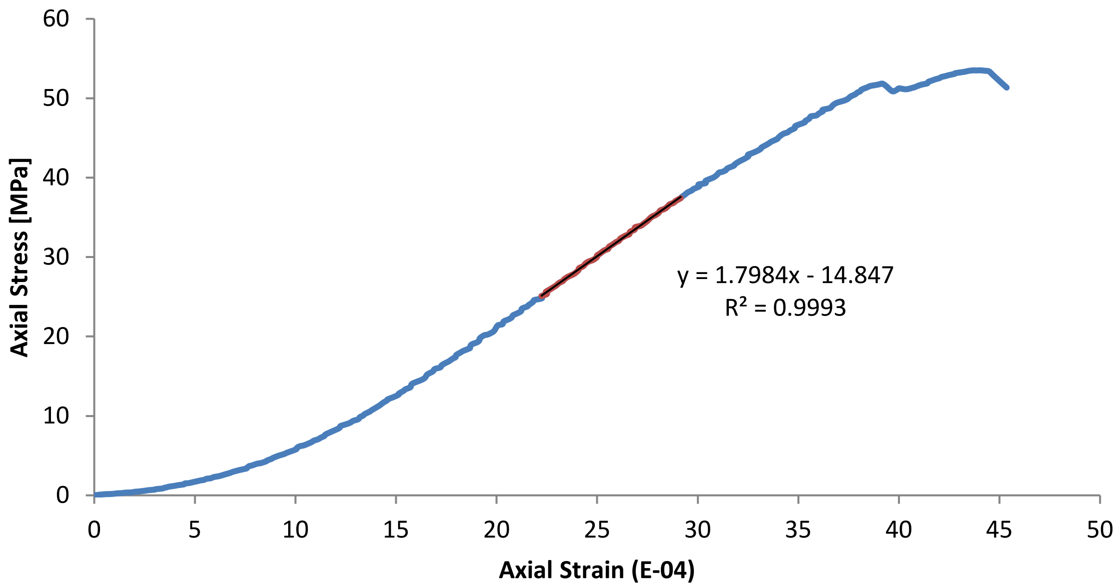

Figure A.236 Specimen 120: Young's modulus calculation

Figure A.237 Specimen 120: Before USC test and After UCS test

Specimen 121

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
121	DBA-01A	405.3	406.0	50.5	100.94	2002.96	595.89	2.95	3838	**15.6**	**4.5**

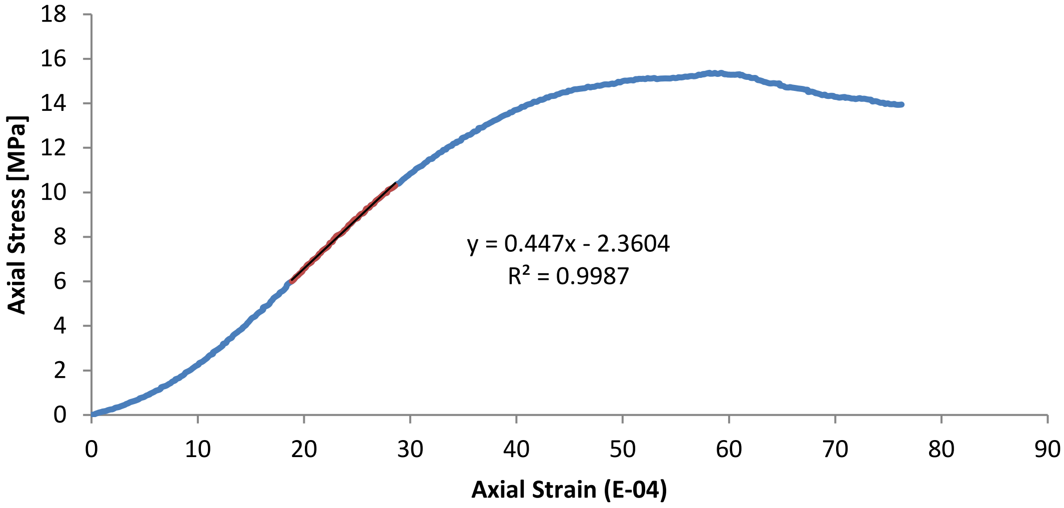

Figure A.238 Specimen 121: Young's modulus calculation

Figure A.239 Specimen 121: Before USC test and After UCS test

Specimen 122

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
122	DBA-01A	383.9	384.5	50.63	100.73	2013.29	587.76	2.90	3178	**31.3**	**6.9**

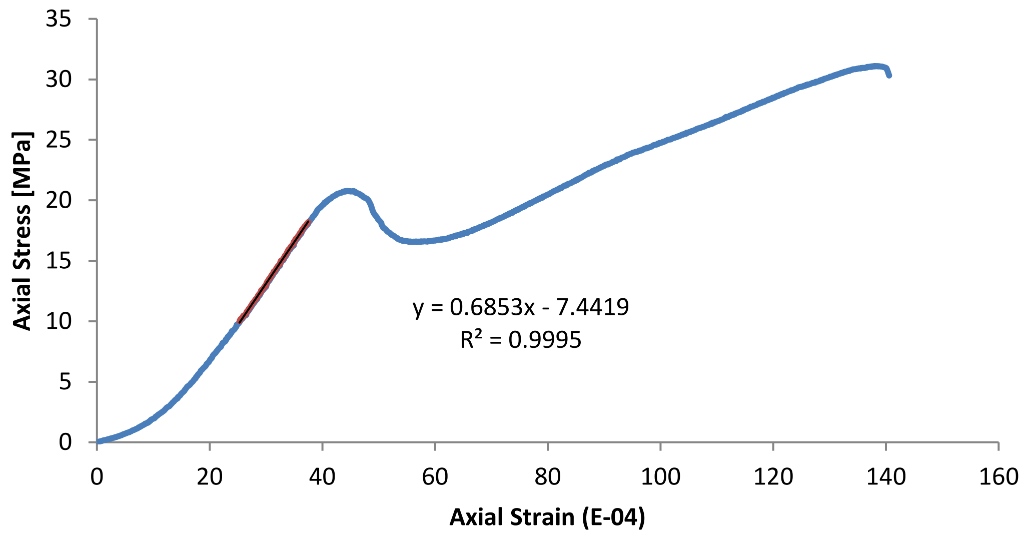

Figure A.240 Specimen 122: Young's modulus calculation

Figure A.241 Specimen 122: Before USC test and After UCS test

Specimen 123

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
123	IDH-01	371.0	371.7	50.32	80.54	1988.71	446.88	2.79	3183	**9.3**	**1.2**

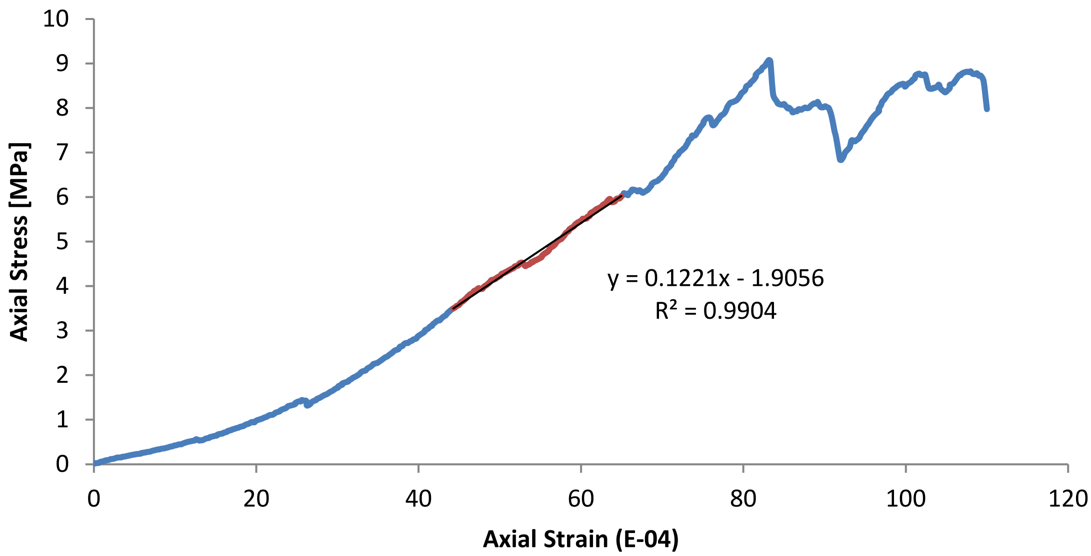

Figure A.242 Specimen 123: Young's modulus calculation

Figure A.243 Specimen 123: Before USC test and After UCS test

Specimen 124

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
124	IDH-02	364.5	365.0	50.61	101.14	2011.70	609.43	3.00	4359	**140.6**	**27.8**

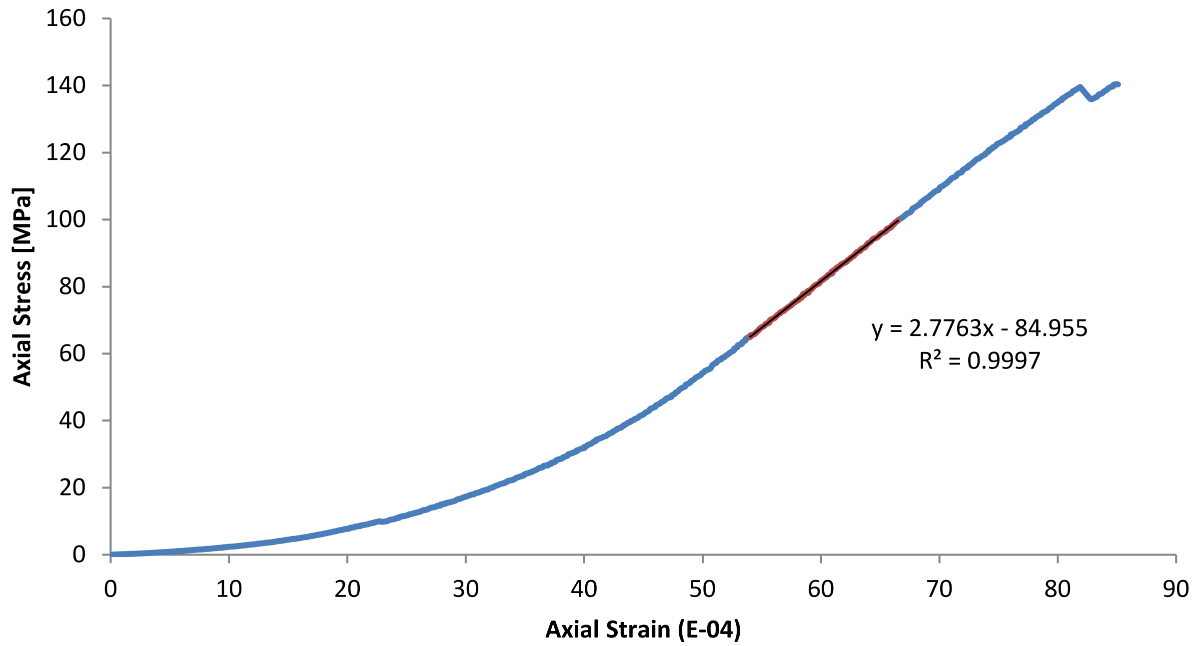

Figure A.244 Specimen 124: Young's modulus calculation

Figure A.245 Specimen 124: Before USC test and After UCS test

Specimen 125

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
125	IDH-06	189.0	189.6	50.04	103.49	1966.64	582.87	2.86	3644	**16.2**	**8.4**

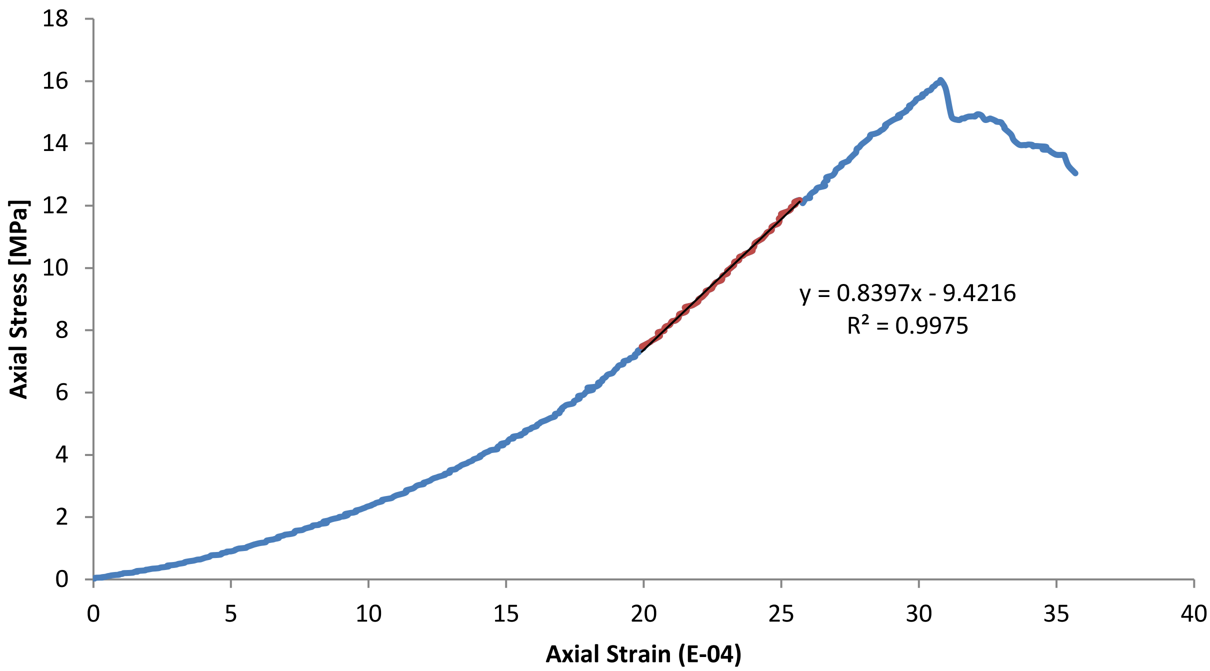

Figure A.246 Specimen 125: Young's modulus calculation

Figure A.247 Specimen 125: Before USC test and After UCS test

Specimen 126

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
126	IDH-07	76.0	76.6	50.39	100.83	1994.25	597.62	2.97	5016	**155.6**	**35.0**

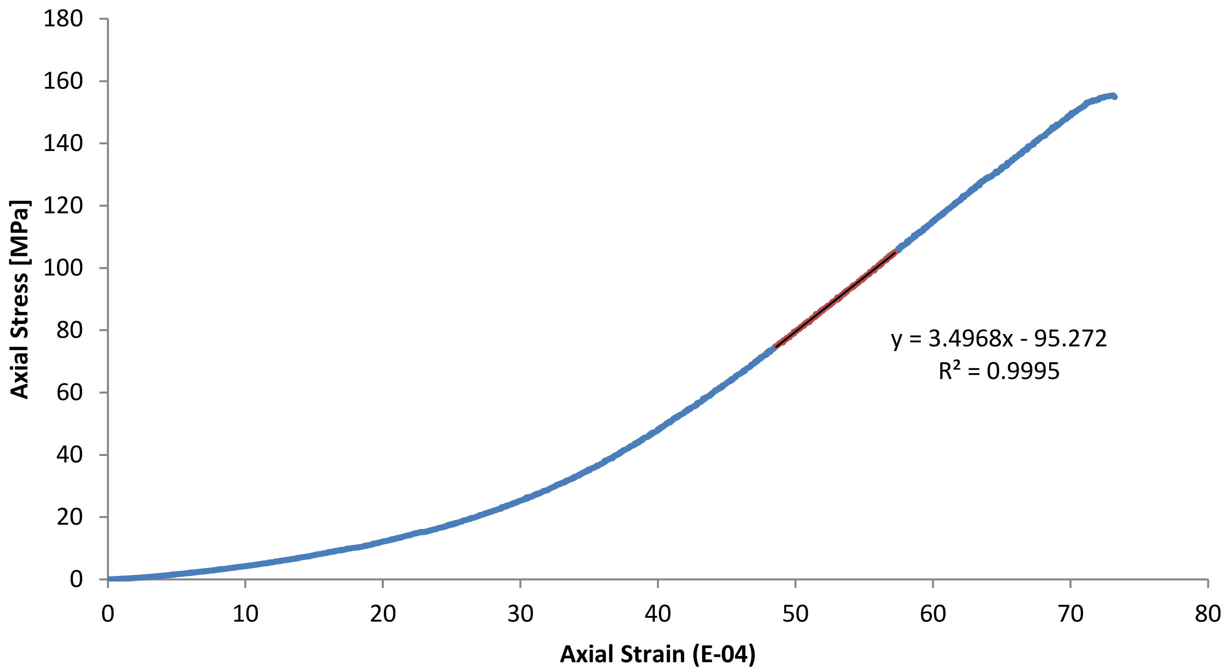

Figure A.248 Specimen 126: Young's modulus calculation

Figure A.249 Specimen 126: Before USC test and After UCS test

Specimen 127

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
127	IDH-07	362.0	362.6	50.13	102.38	1973.72	512.55	2.54	4612	**27.2**	**8.5**

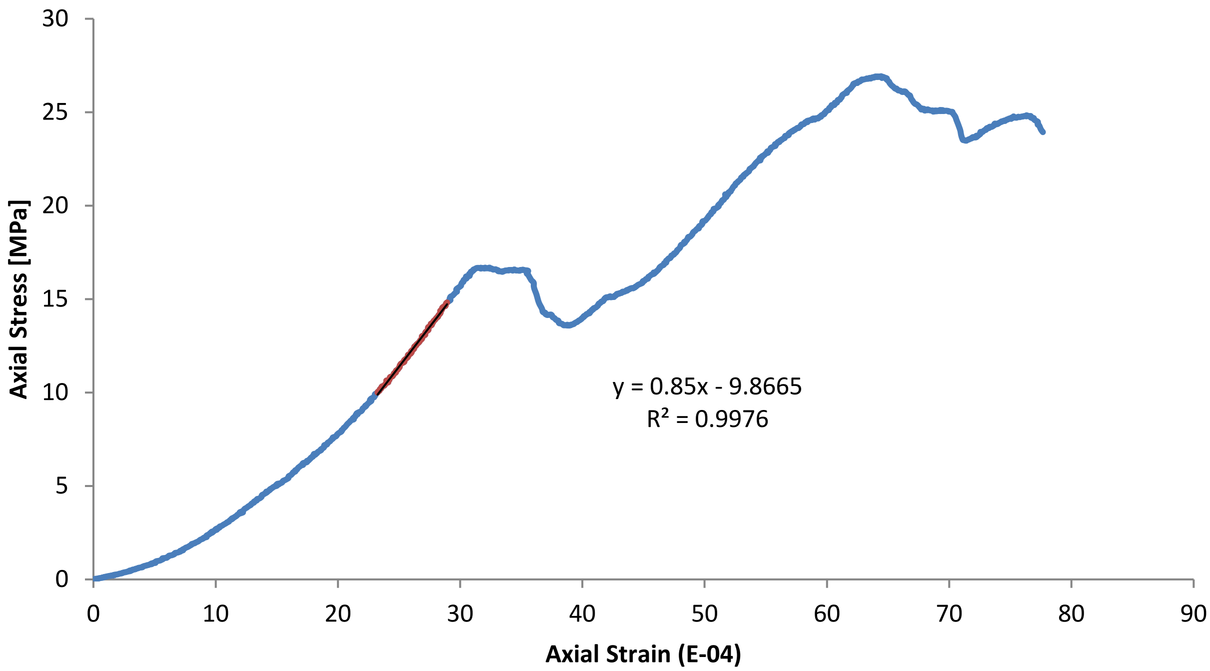

Figure A.250 Specimen 127: Young's modulus calculation

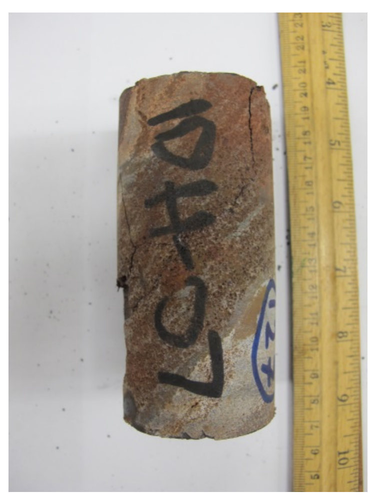

Figure A.251 Specimen 127: Before USC test and After UCS test

Specimen 128

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
128	IDH-09	78.9	79.5	50.52	103.75	2004.55	610.2	2.93	5608	**241.6**	**46.7**

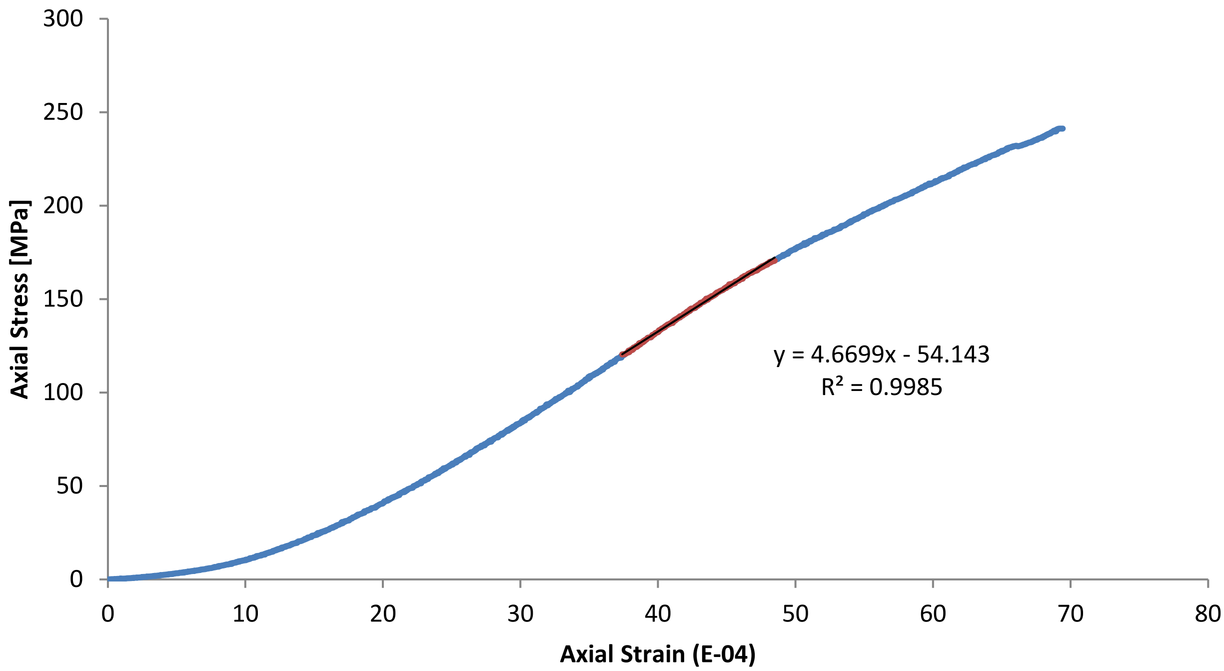

Figure A.252 Specimen 128: Young's modulus calculation

Figure A.253 Specimen 128: Before USC test and After UCS test

Specimen 129

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
129	IDH-09	237.0	237.6	50.68	101.33	2017.27	556.27	2.72	5333	**97.1**	**22.0**

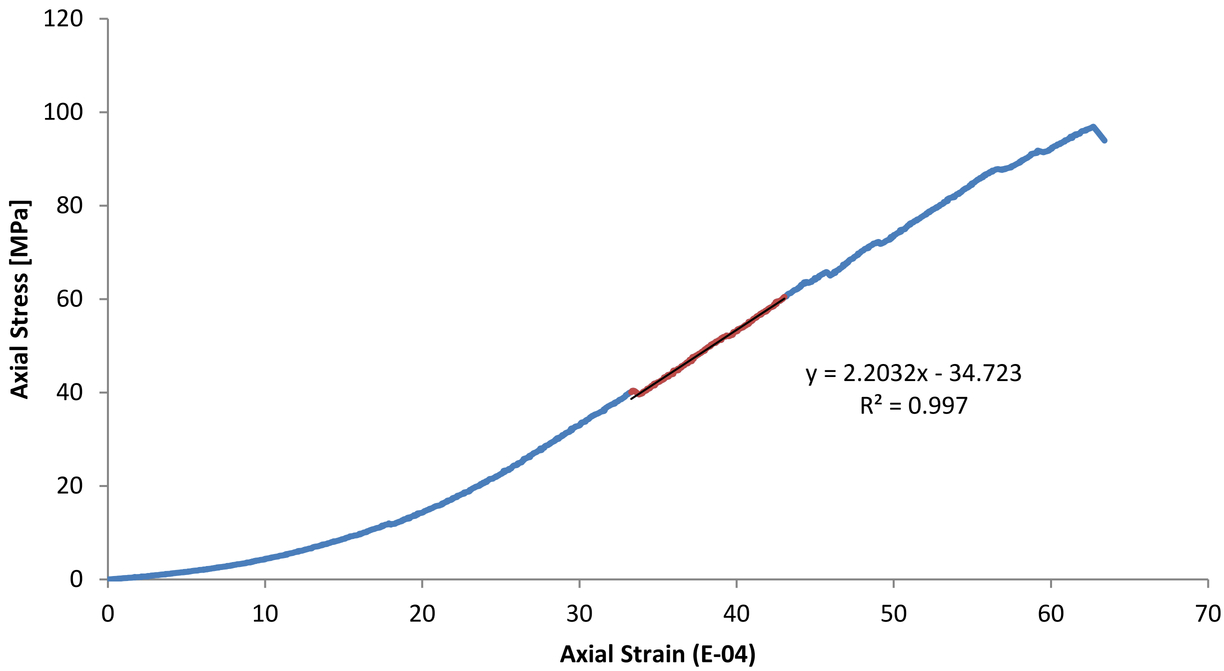

Figure A.254 Specimen 129: Young's modulus calculation

Figure A.255 Specimen 129: Before USC test and After UCS test

Specimen 130

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm²]	[g]	[g/cm³]	[m/s]	[MPa]	[GPa]
130	IDH-10	124.0	124.6	50.46	101.95	1999.79	574.16	2.82	5511	**162.8**	**28.9**

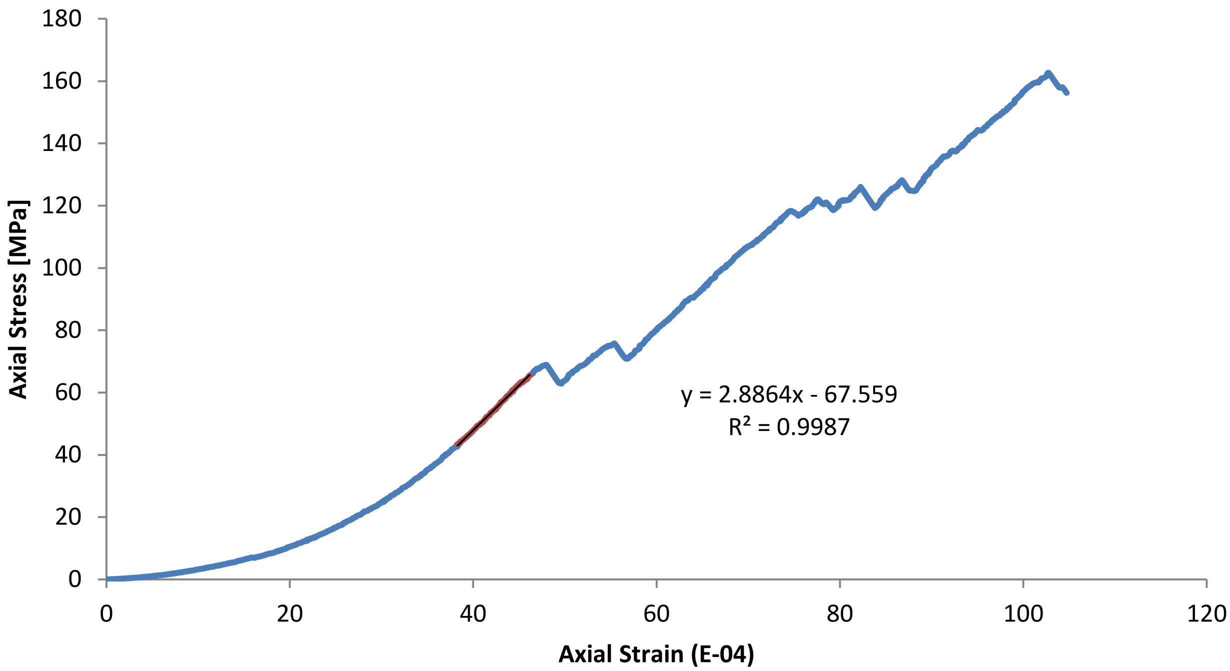

Figure A.256 Specimen 130: Young's modulus calculation

Figure A.257 Specimen 130: Before USC test and After UCS test

Specimen 131

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm²]	[g]	[g/cm³]	[m/s]	[MPa]	[GPa]
131	IDH-10	200.8	200.1	50.58	103.37	2009.31	587.26	2.83	5743	**267.4**	**47.1**

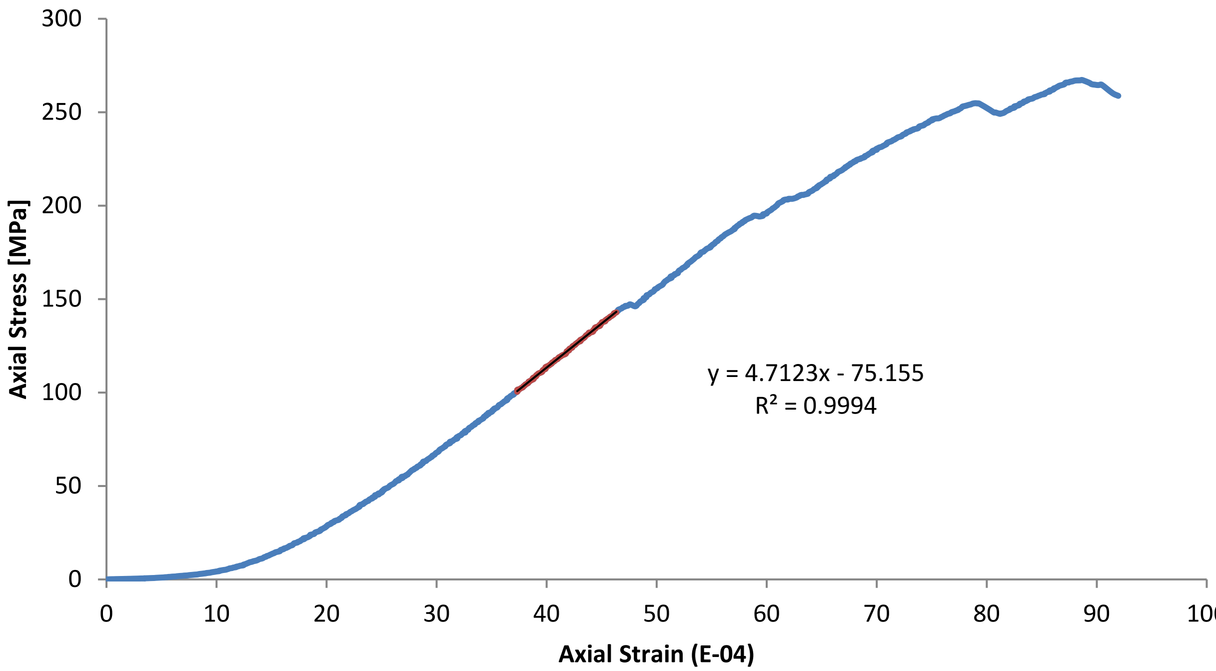

Figure A.258 Specimen 131: Young's modulus calculation

Figure A.259 Specimen 131: Before USC test and After UCS test

Specimen 132

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm²]	[g]	[g/cm³]	[m/s]	[MPa]	[GPa]
132	IDH-11	118.1	118.9	50.36	101.88	1991.87	623.66	3.07	5145	**125.4**	**35.8**

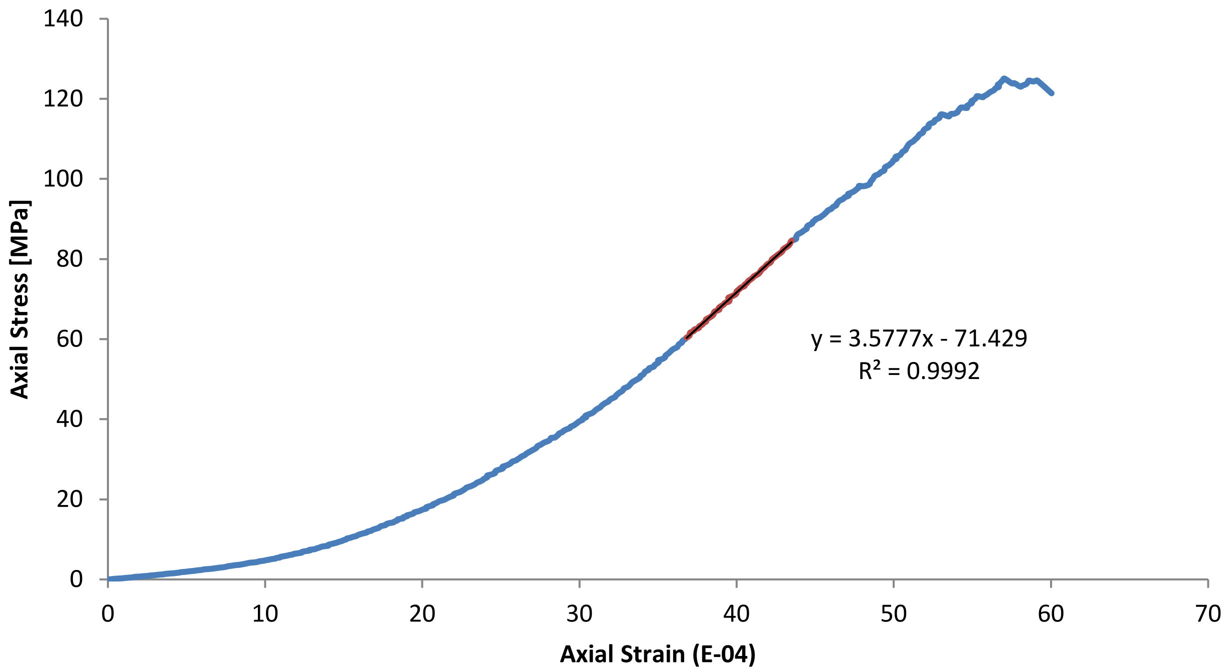

Figure A.260 Specimen 132: Young's modulus calculation

Figure A.261 Specimen 132: Before USC test and After UCS test

Specimen 133

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm^2]	[g]	[g/cm^3]	[m/s]	[MPa]	[GPa]
133	IDH-11	358.7	386.3	50.52	101.90	2004.55	538.06	2.63	3287	**22.8**	**5.6**

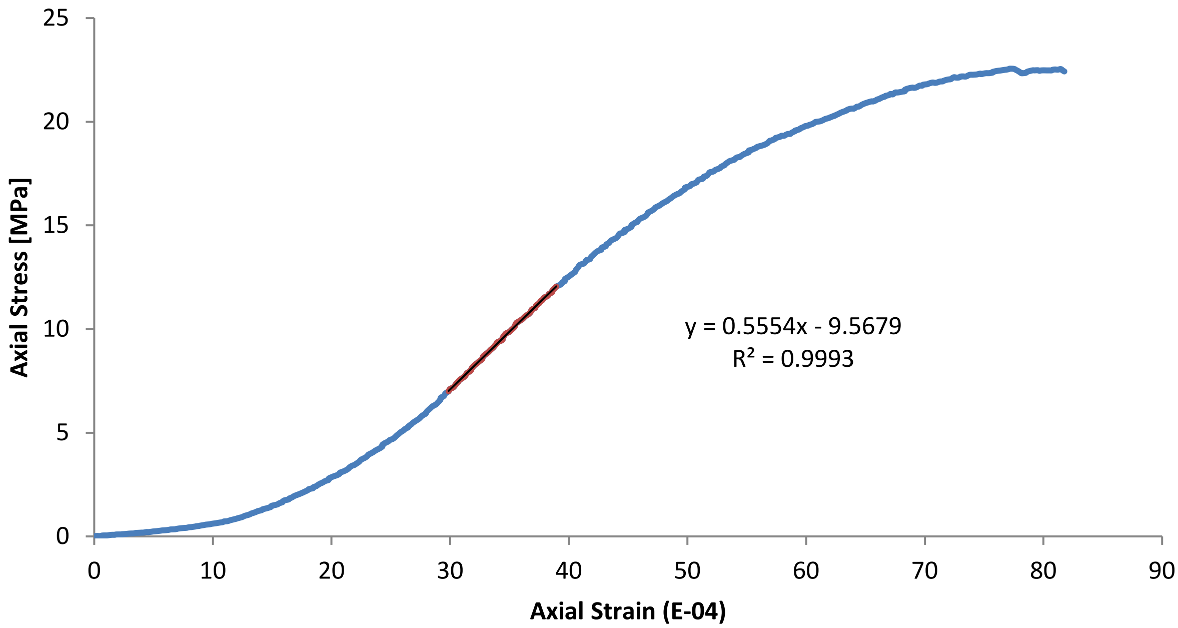

Figure A.262 Specimen 133: Young's modulus calculation

Figure A.263 Specimen 133: Before USC test and After UCS test

Specimen 134

Assigned ID	Bore Hole #	Depth From	Depth To	Diameter	Length	Area	Mass	Density	V_p	UCS	Young's Modulus
		[ft]	[ft]	[mm]	[mm]	[mm²]	[g]	[g/cm³]	[m/s]	[MPa]	[GPa]
134	IDH-11	386.5	387.2	50.54	102.01	2006.14	550.07	2.69	3435	**19.3**	**4.6**

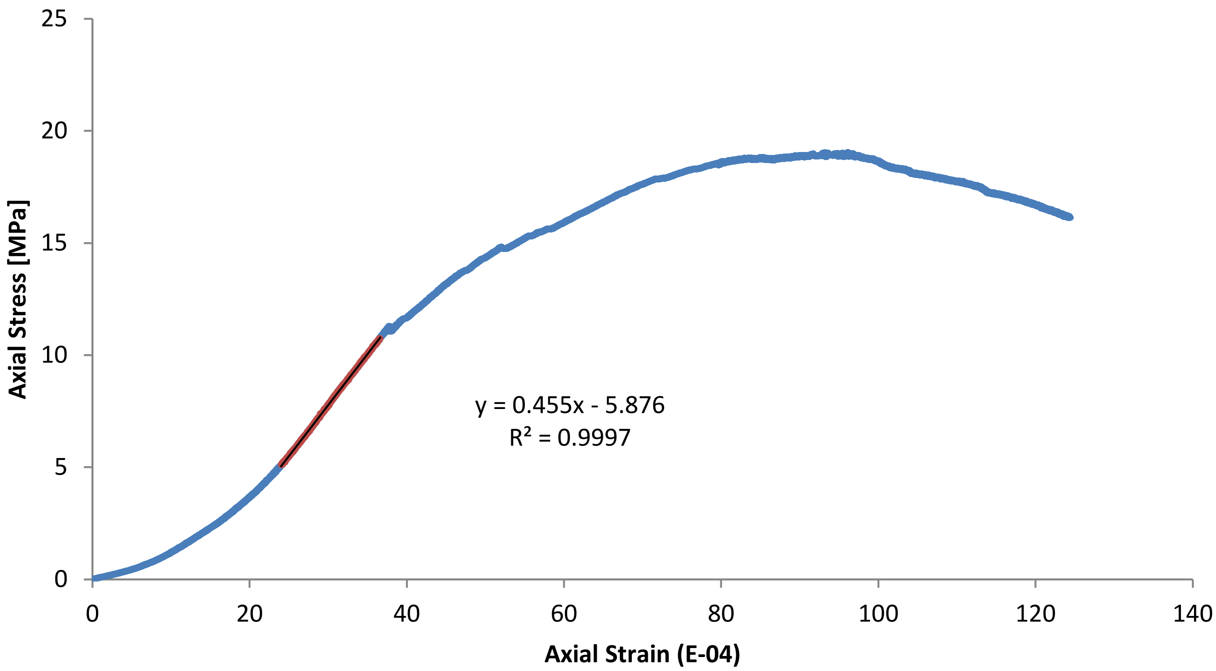

Figure A.264 Specimen 134: Young's modulus calculation

Figure A.265 Specimen 134: Before USC test and After UCS test

APPENDIX B: STRESS - STRAIN PLOTS SP2782-334

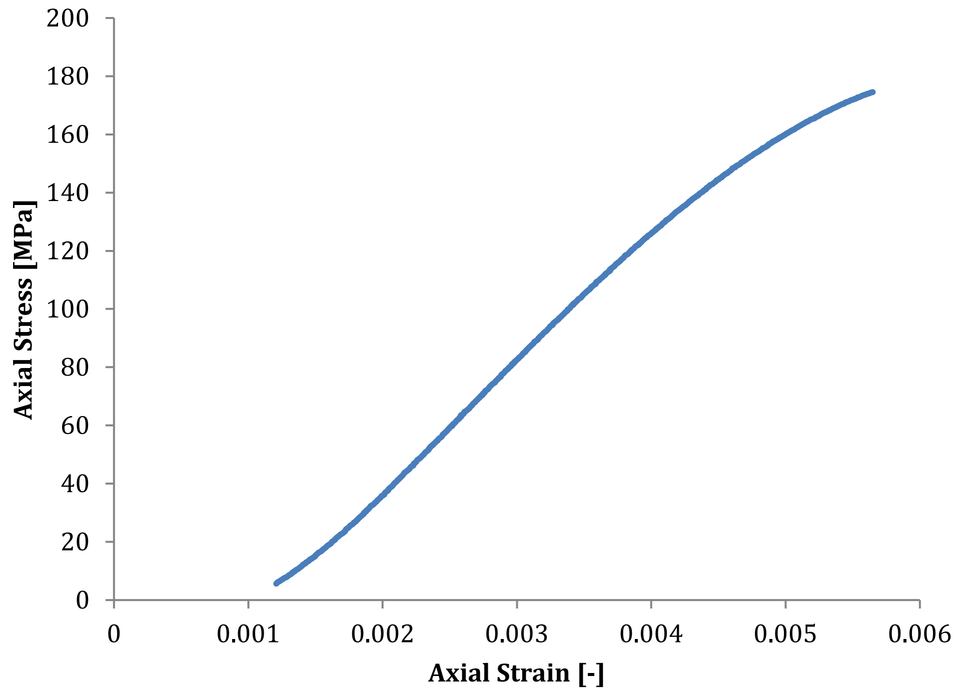

Figure B.1 Sample x1: Axial stress vs axial strain curve

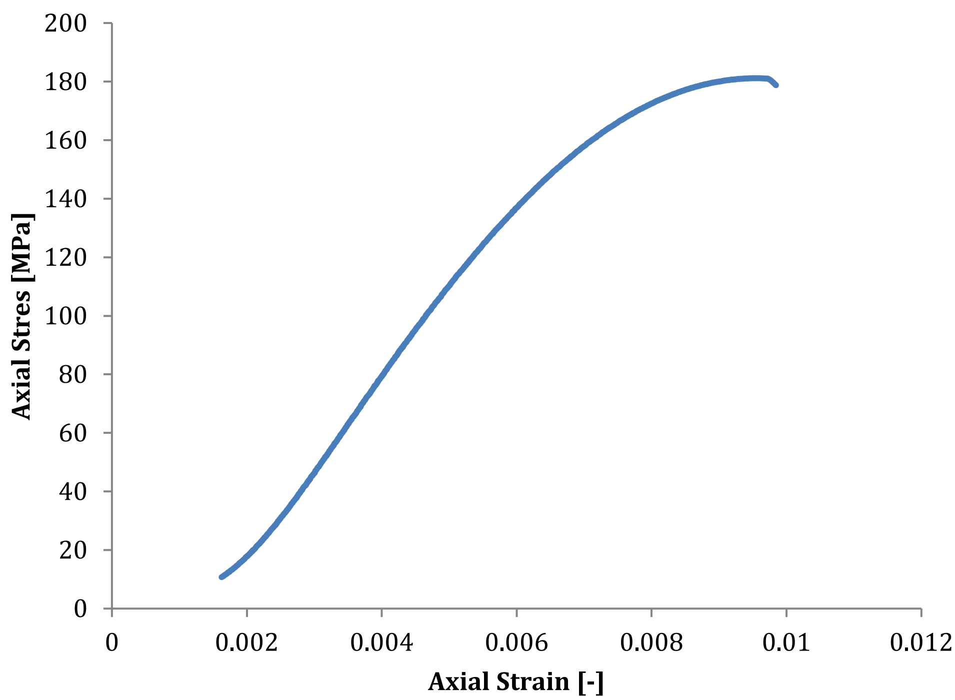

Figure B.2 Sample x2: Axial stress vs axial strain curve

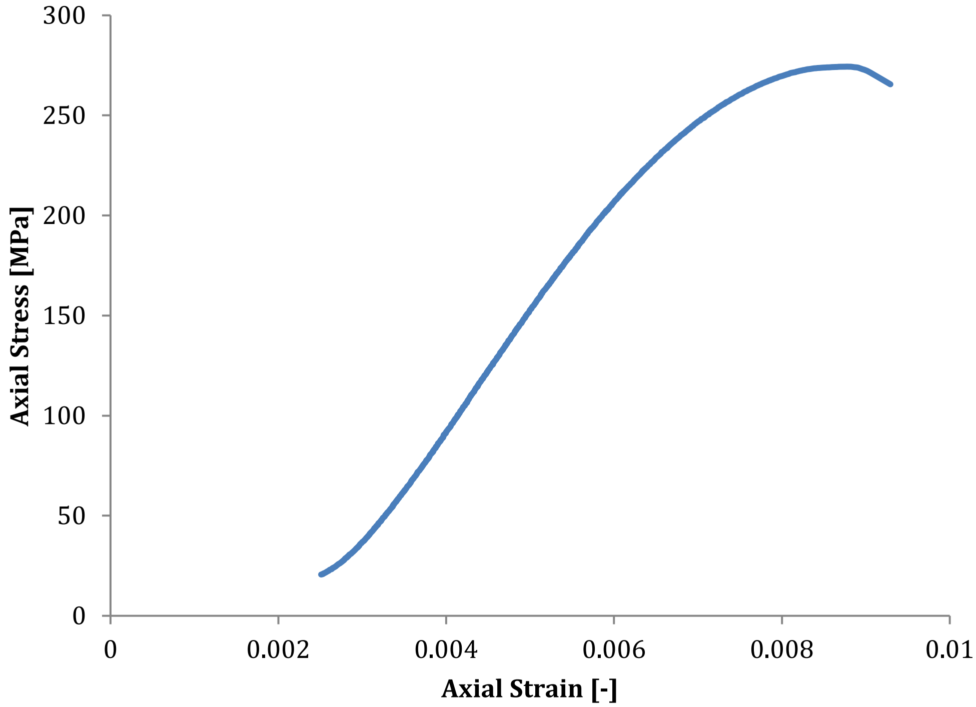

Figure B.3 Sample x3: Axial stress vs axial strain curve

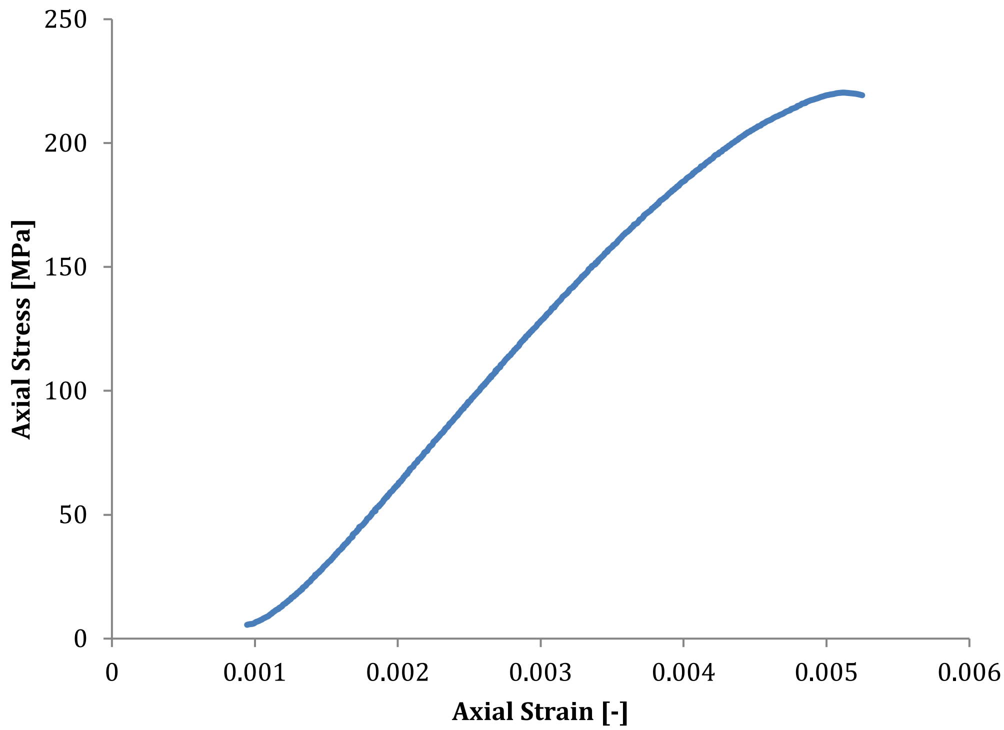

Figure B.4 Sample x4: Axial stress vs axial strain curve

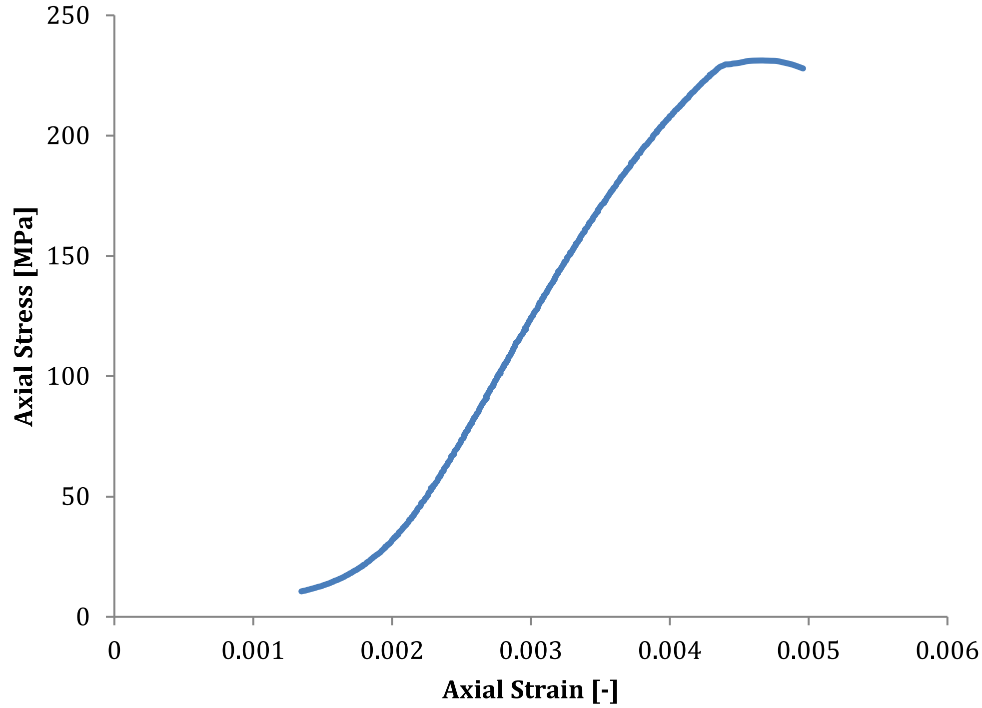

Figure B.5 Sample x5: Axial stress vs axial strain curve

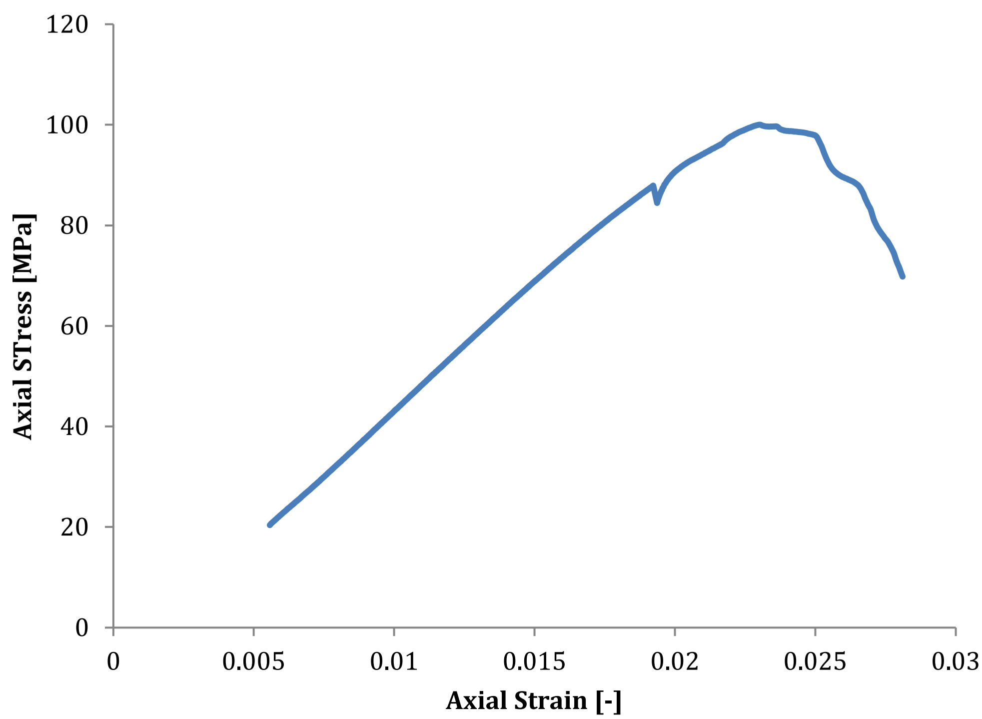

Figure B.6 Sample x6: Axial stress vs axial strain curve

APPENDIX C: STRESS - STRAIN PLOTS SP804-81

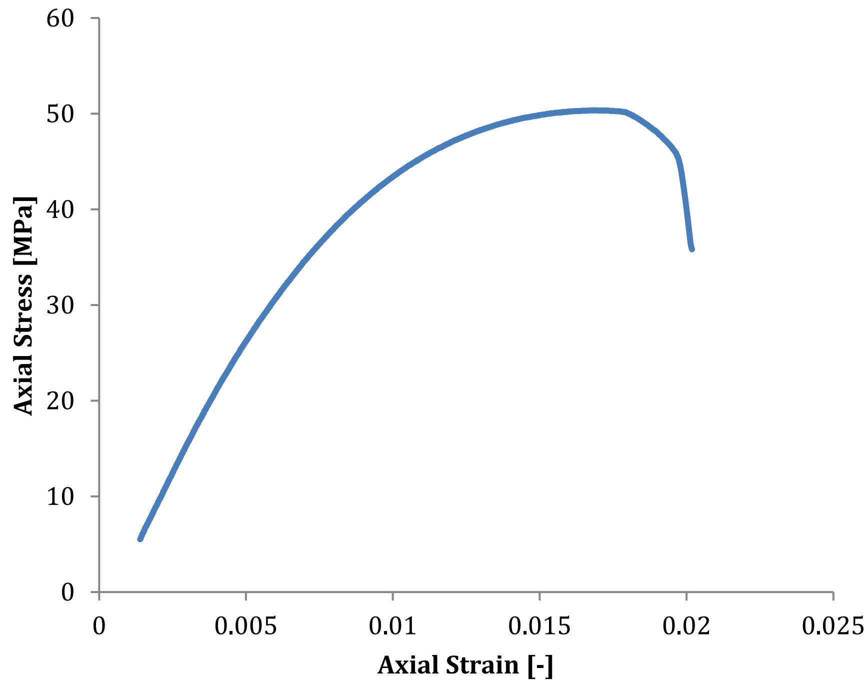

Figure C.1 Specimen 9: axial stress vs. axial strain plot (triaxial group 1, σ_3=5 MPa)

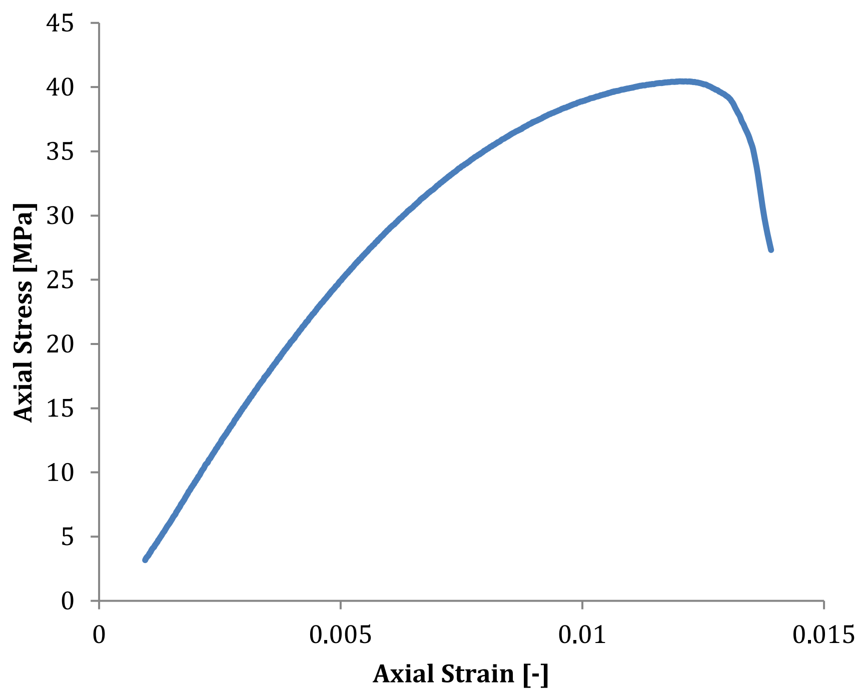

Figure C.2 Specimen 19: axial stress vs. axial strain plot (triaxial group 1, σ_3=2.5 MPa)

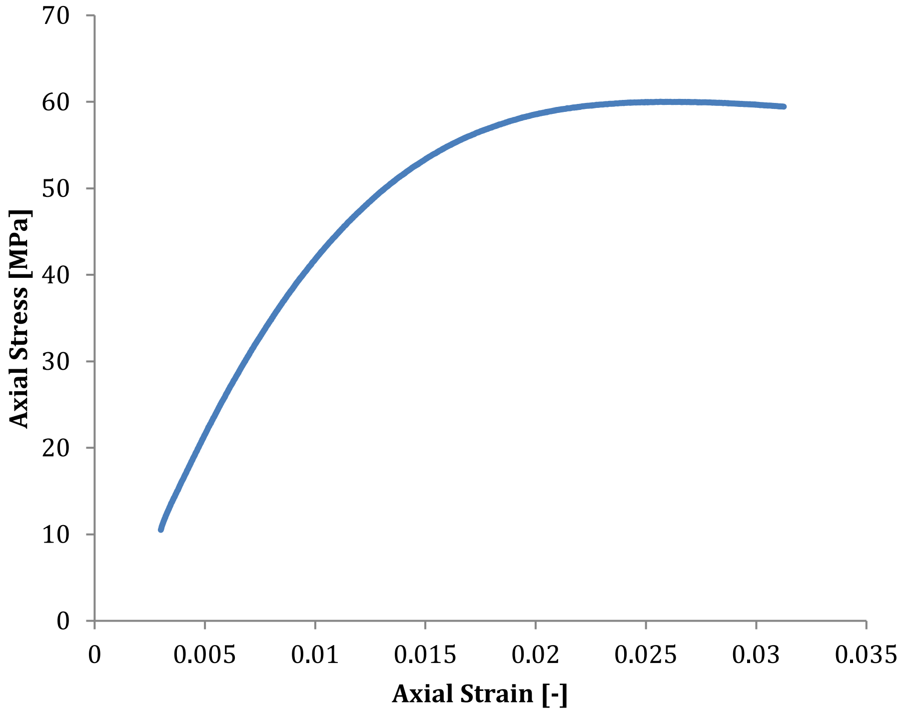

Figure C.3 Specimen 22: axial stress vs. axial strain plot (triaxial group 1, σ_3=10 MPa)

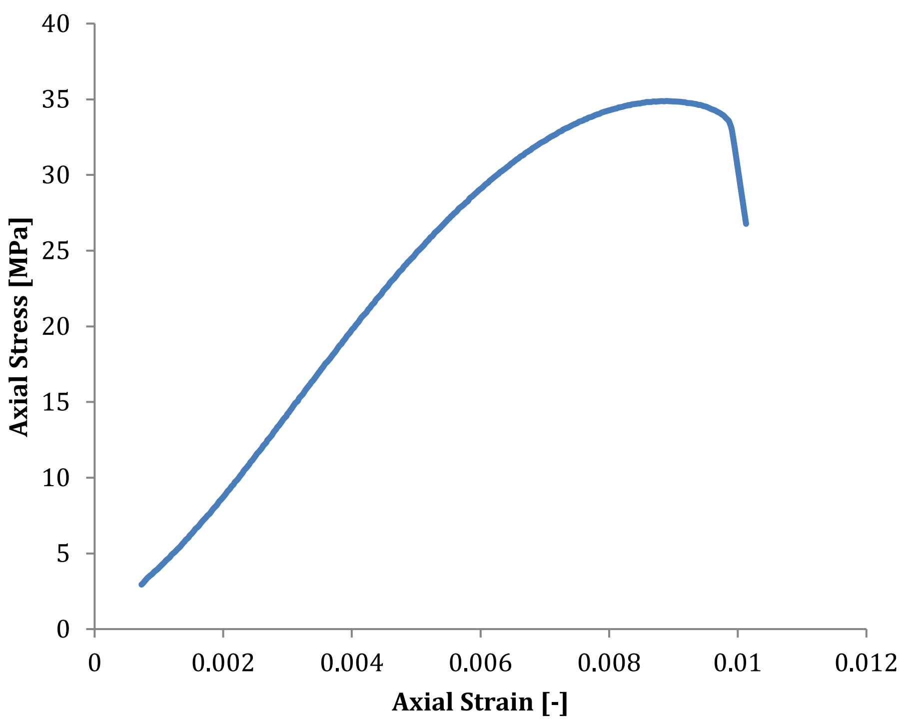

Figure C.4 Specimen 12: axial stress vs. axial strain plot (triaxial group 2, σ_3=2.5 MPa)

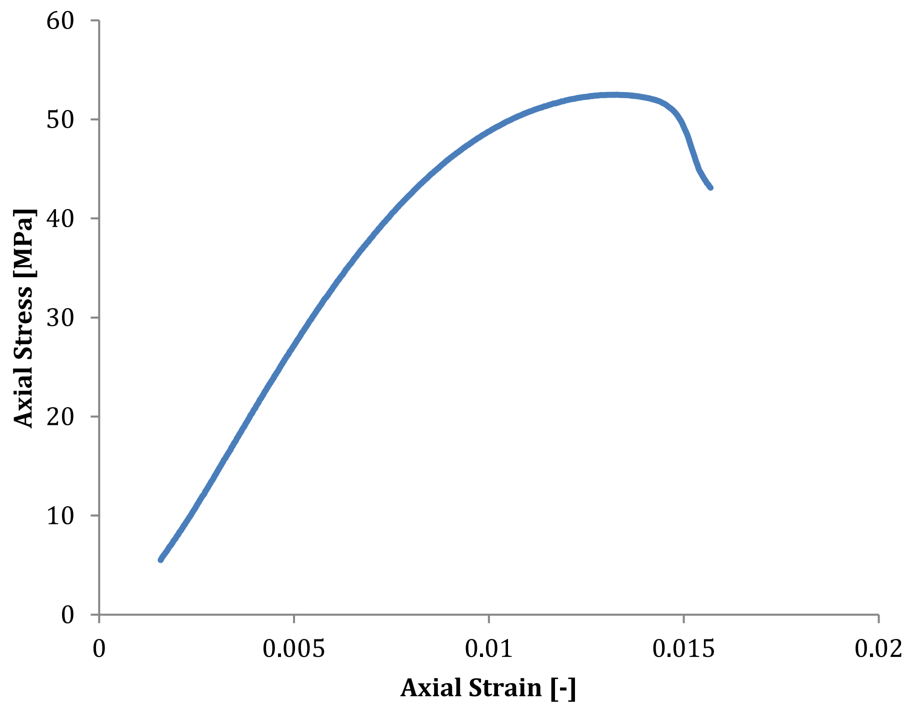

Figure C.5 Specimen 13: axial stress vs. axial strain plot (triaxial group 2, σ_3=5 MPa)

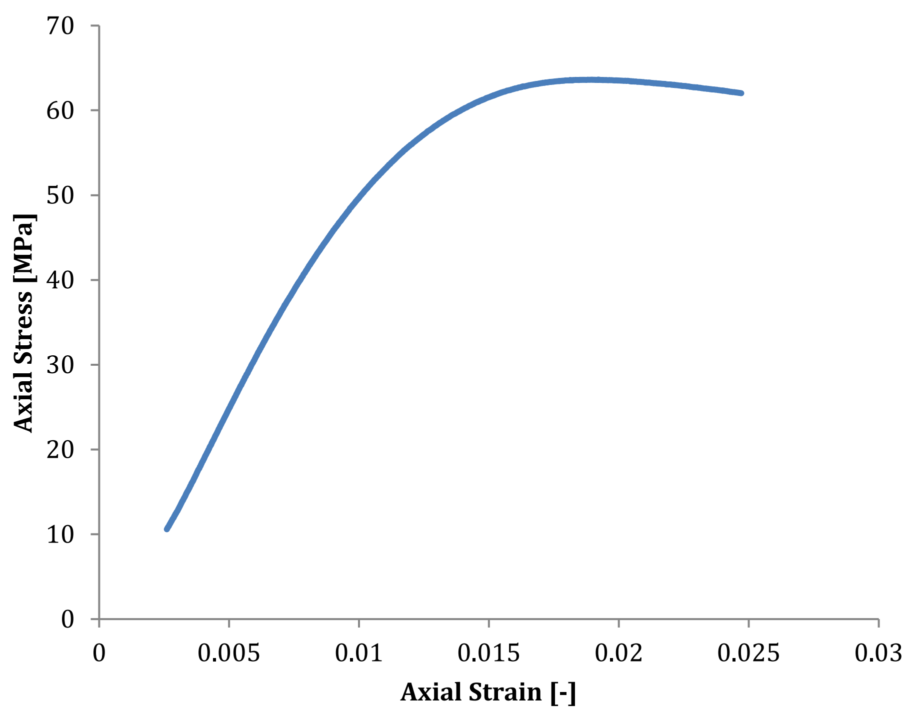

Figure C.6 Specimen 14: axial stress vs. axial strain plot (triaxial group 2, σ_3=10 MPa)

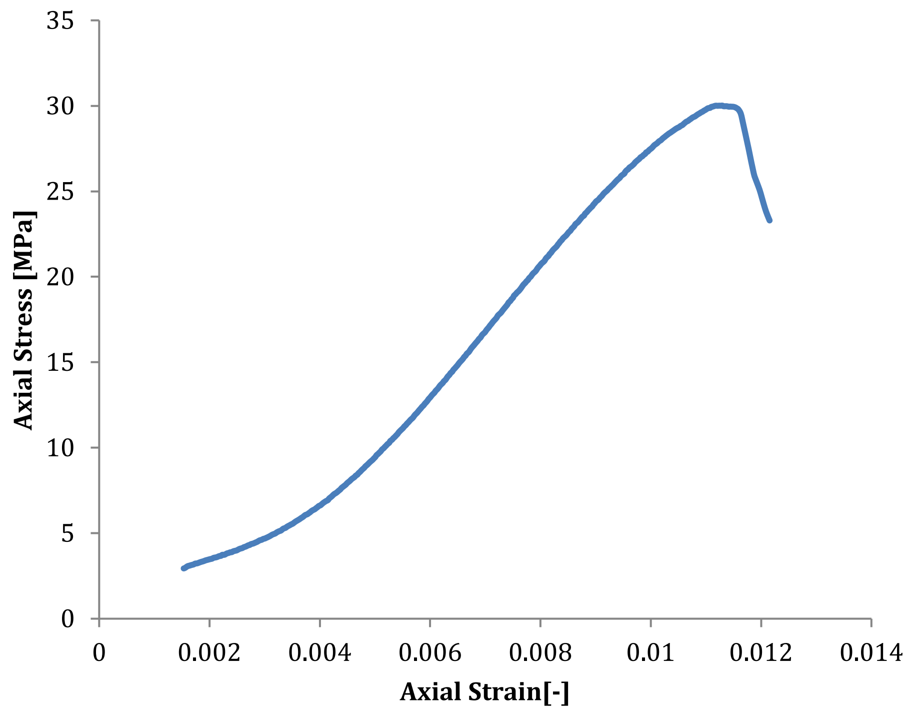

Figure C.7 Specimen 7: axial stress vs. axial strain plot (triaxial group 3, σ_3=2.5 MPa)

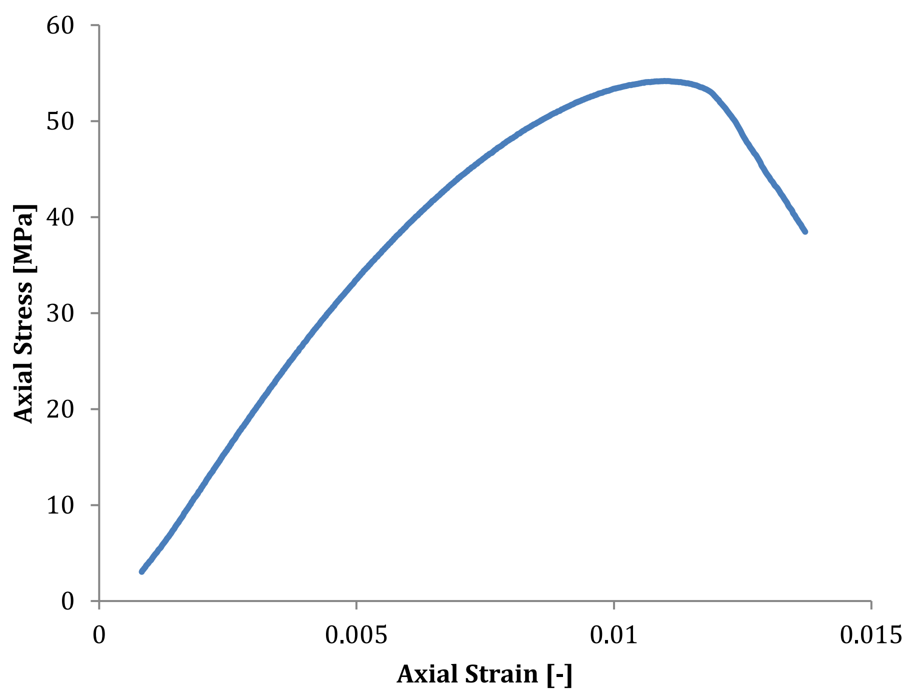

Figure C.8 Specimen 10: axial stress vs. axial strain plot (triaxial group 3, σ_3=2.5 MPa)

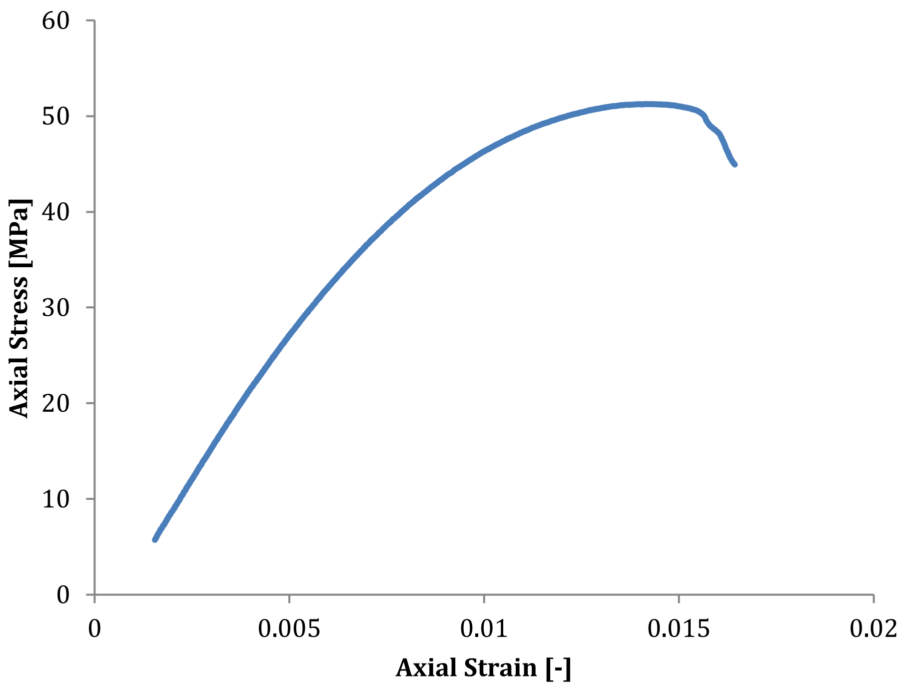

Figure C.9 Specimen 18: axial stress vs. axial strain plot (triaxial group 3, σ_3=5 MPa)

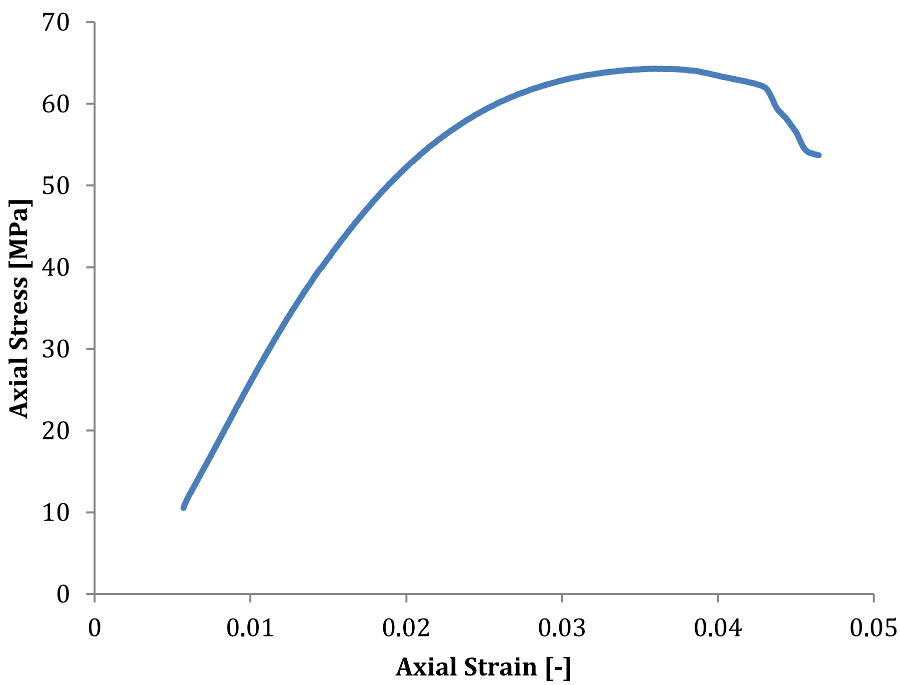

Figure C.10 Specimen 8: axial stress vs. axial strain plot (triaxial group 4, σ_3=10 MPa)

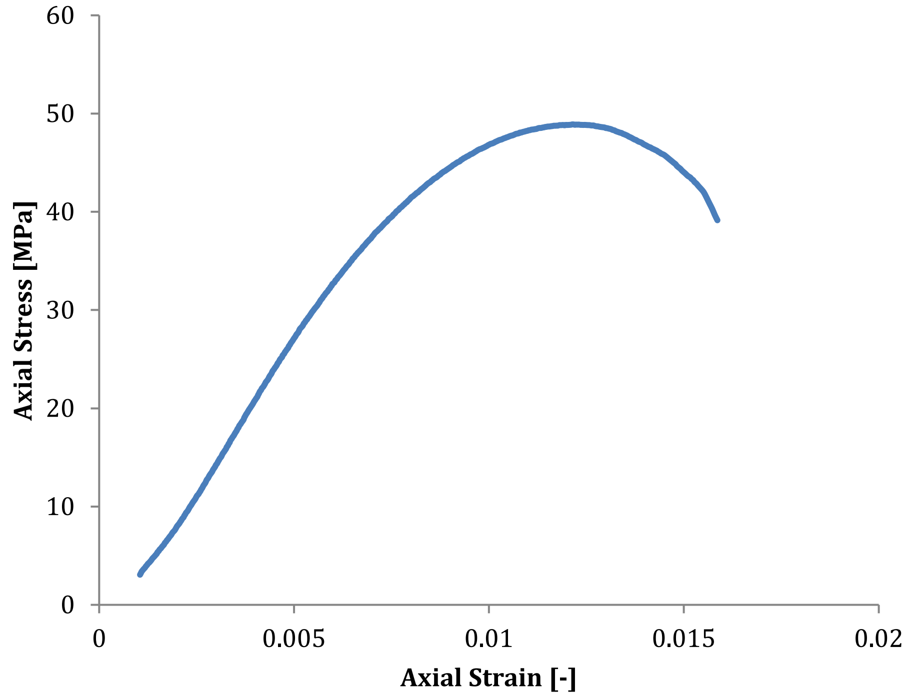

Figure C.11 Specimen 11: axial stress vs. axial strain plot (triaxial group 4, σ_3=2.5 MPa)

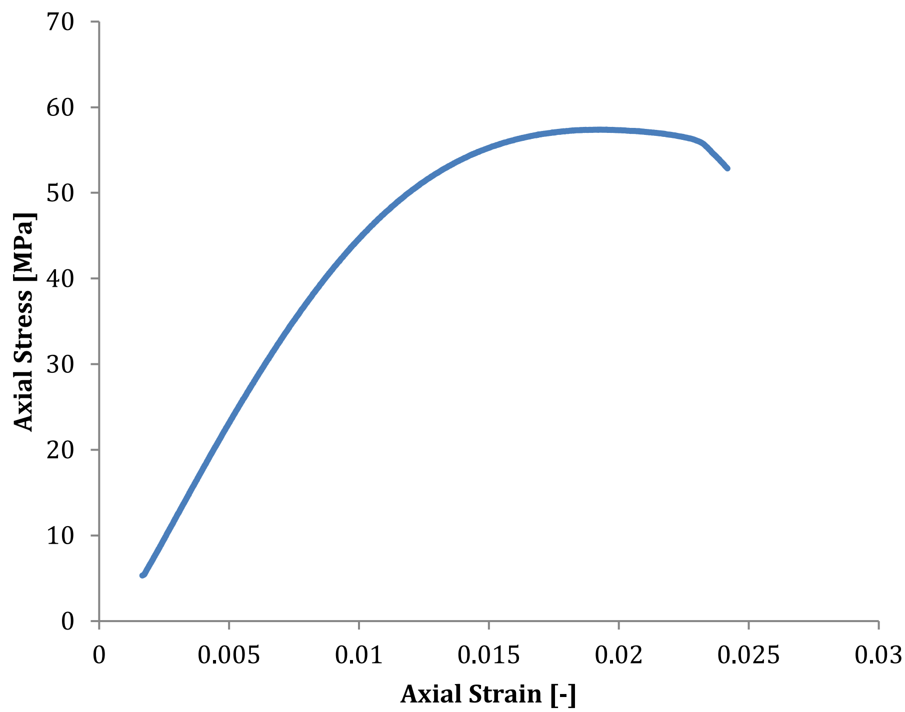

Figure C.12 Specimen 15: axial stress vs. axial strain plot (triaxial group 4, σ_3=5 MPa)

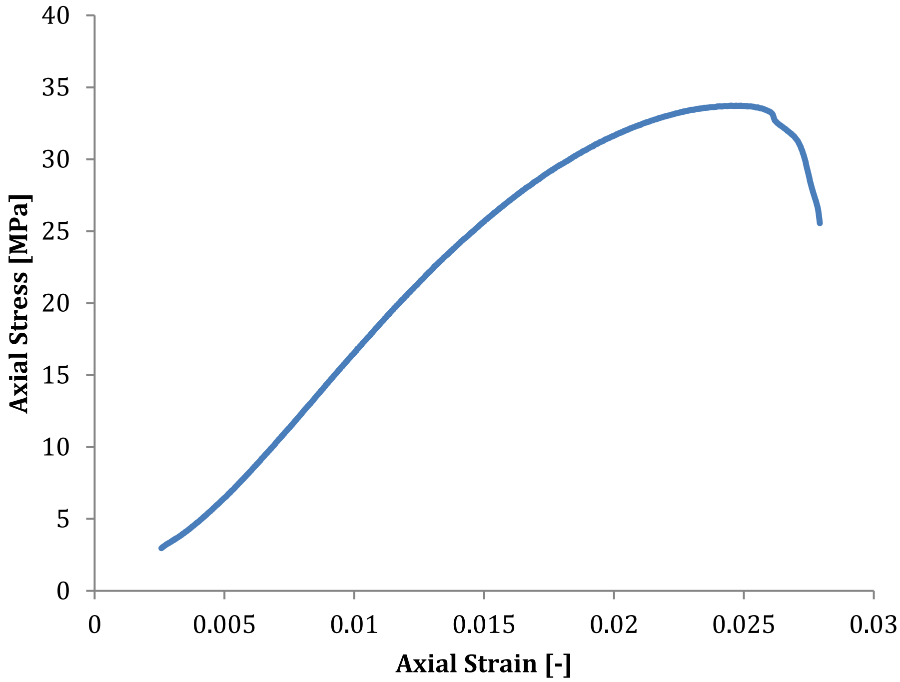

Figure C.13 Specimen 20: axial stress vs. axial strain plot (triaxial group 5, σ_3=2.5 MPa)

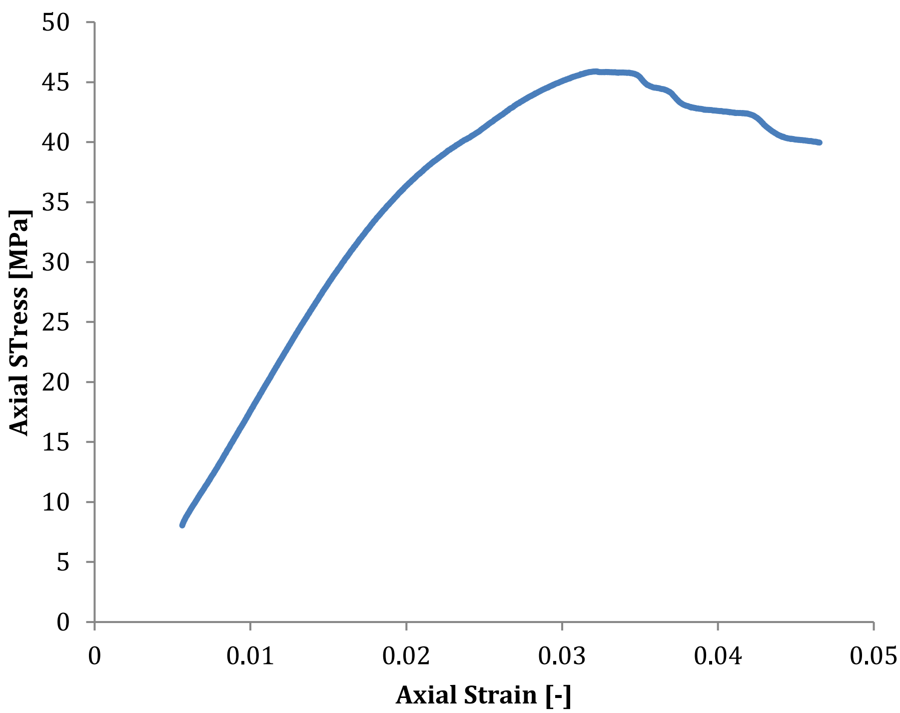

Figure C.14 Specimen 23: axial stress vs. axial strain plot (triaxial group 5, σ_3=7.5 MPa)

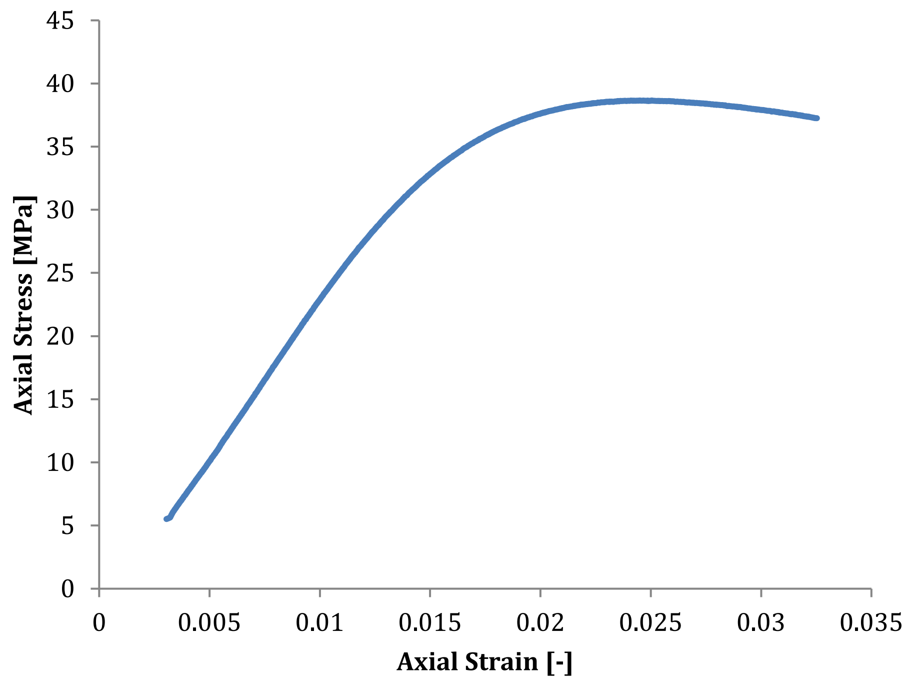

Figure C.15 Specimen 24: axial stress vs. axial strain plot (triaxial group 5, σ_3=5 MPa)

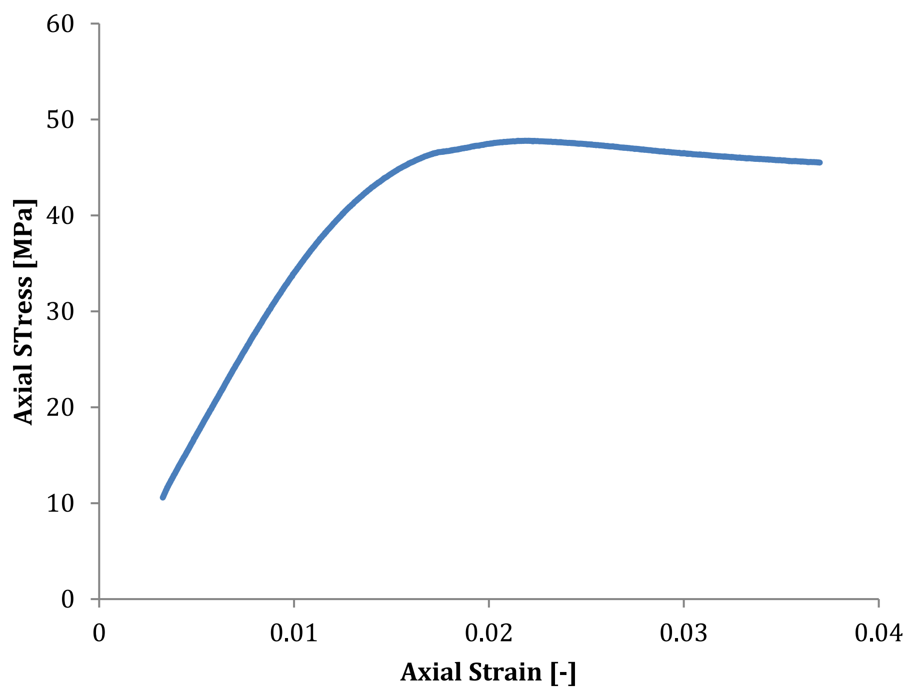

Figure C.16 Specimen 25: axial stress vs. axial strain plot (triaxial group 5, σ_3=10 MPa)

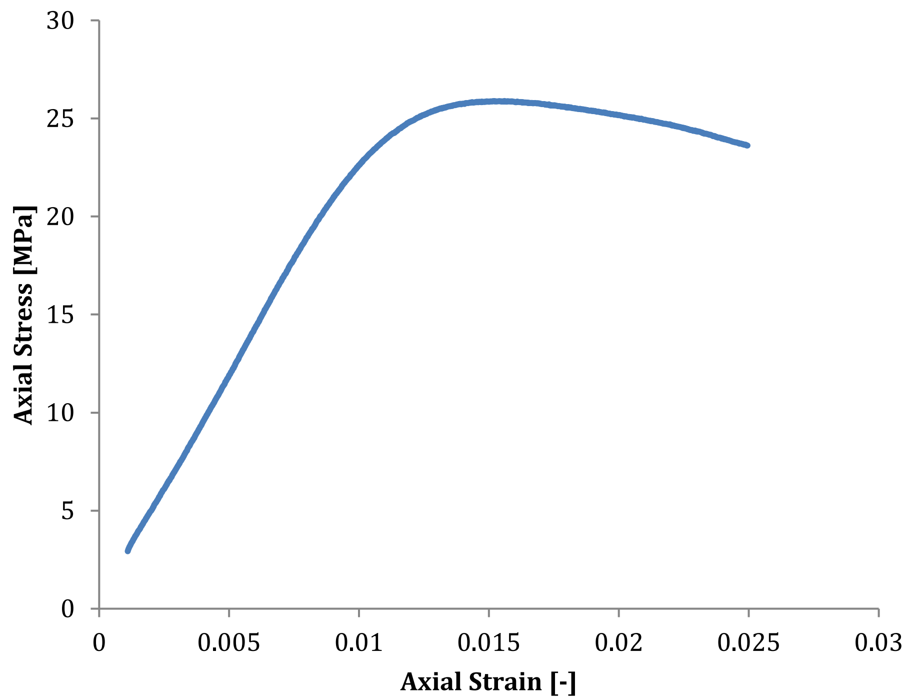

Figure C.17 Specimen 26: axial stress vs. axial strain plot (triaxial group 6, σ_3=2.5 MPa)

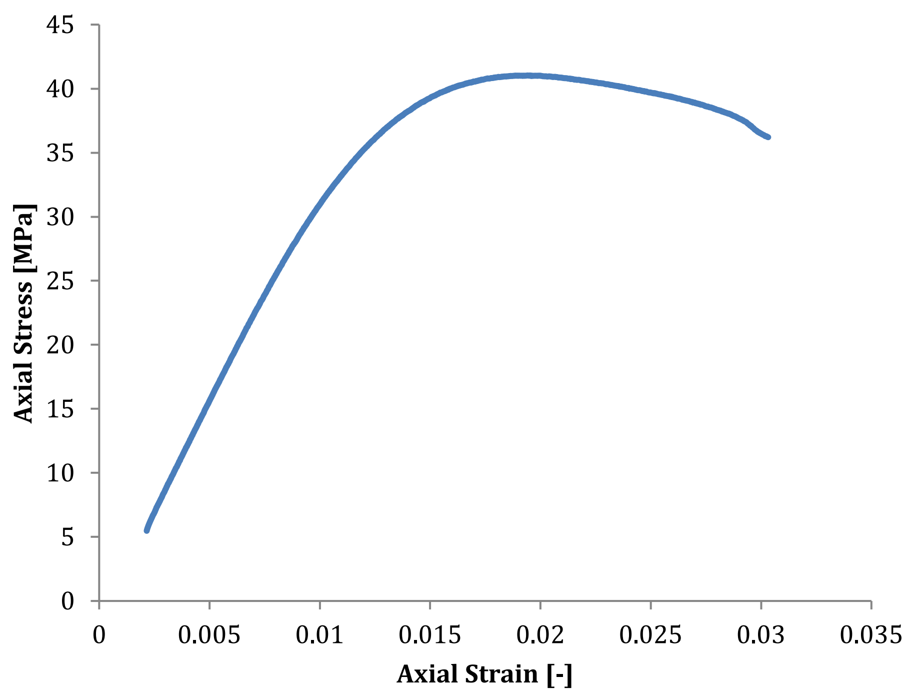

Figure C.18 Specimen 27: axial stress vs. axial strain plot (triaxial group 6, σ_3=5 MPa)

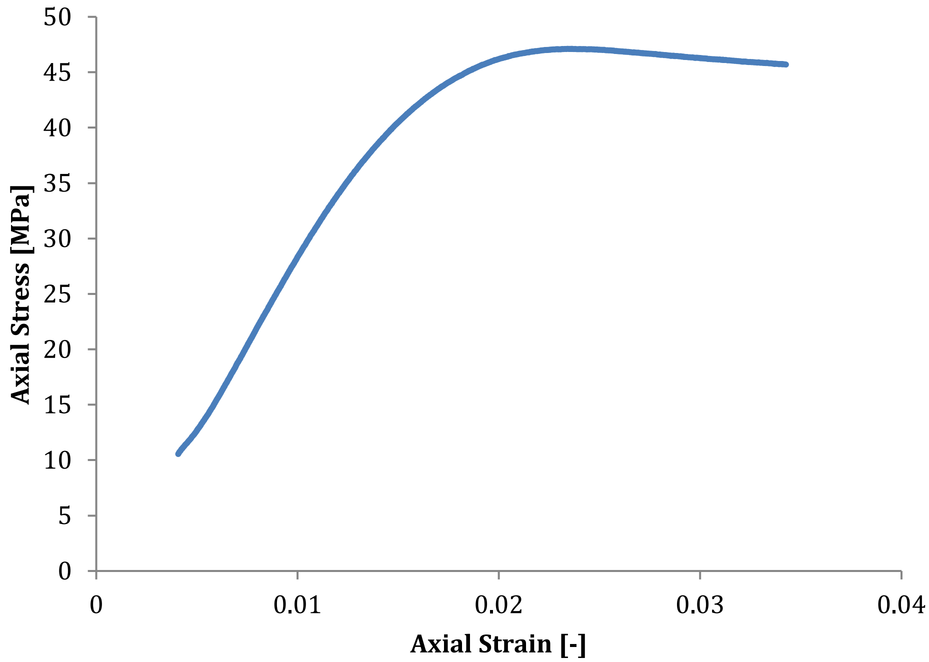

Figure C.19 Specimen 28: axial stress vs. axial strain plot (triaxial group 6, σ_3=10 MPa)

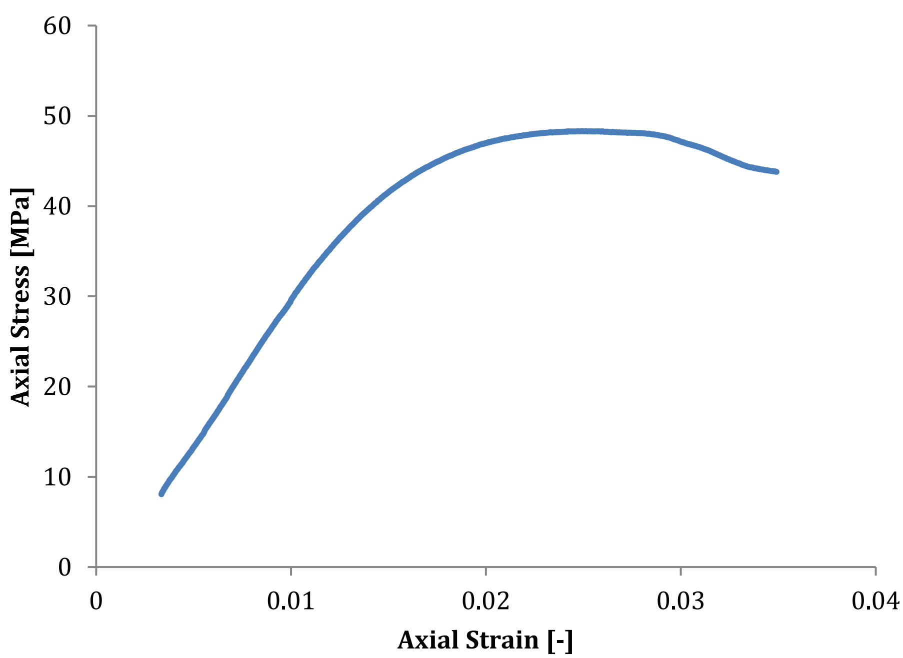

Figure C.20 Specimen 29: axial stress vs. axial strain plot (triaxial group 6, σ_3=7.5 MPa)

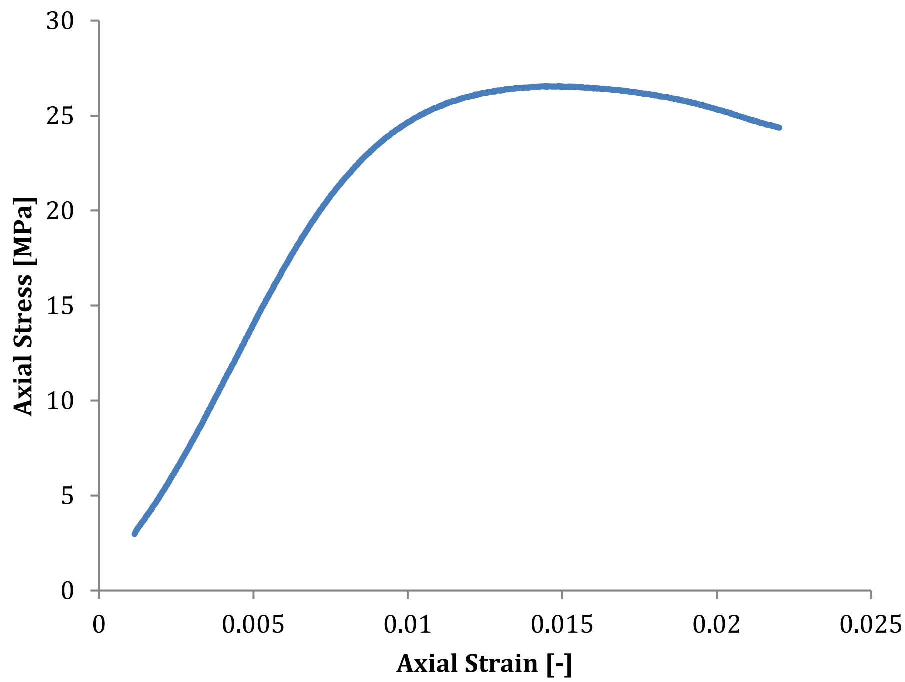

Figure C.21 Specimen 16: axial stress vs. axial strain plot (triaxial group 7, σ_3=2.5 MPa)

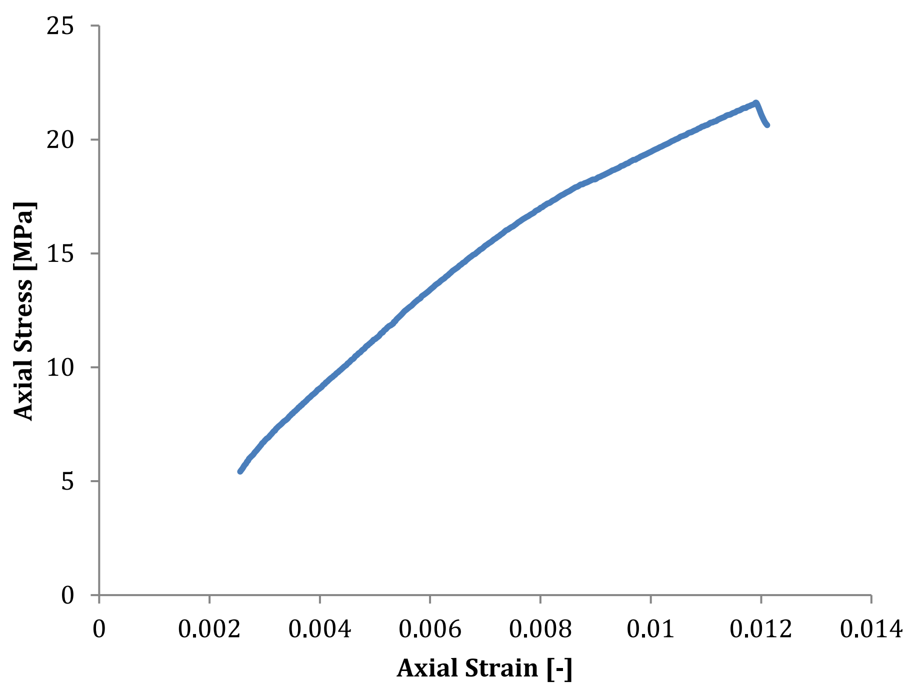

Figure C.22 Specimen 17: axial stress vs. axial strain plot (triaxial group 7, σ_3=0 MPa, leaked)

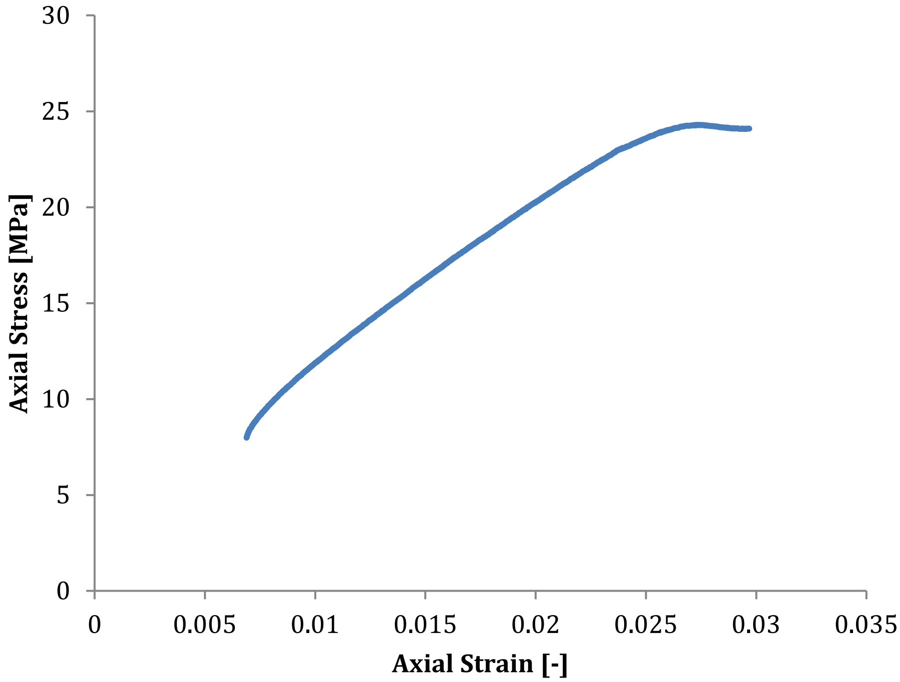

Figure C.23 Specimen 21: axial stress vs. axial strain plot (triaxial group 7, σ_3=0 MPa, leaked)

APPENDIX D: STRESS - STRAIN PLOTS ST. PETER SANDSTONE

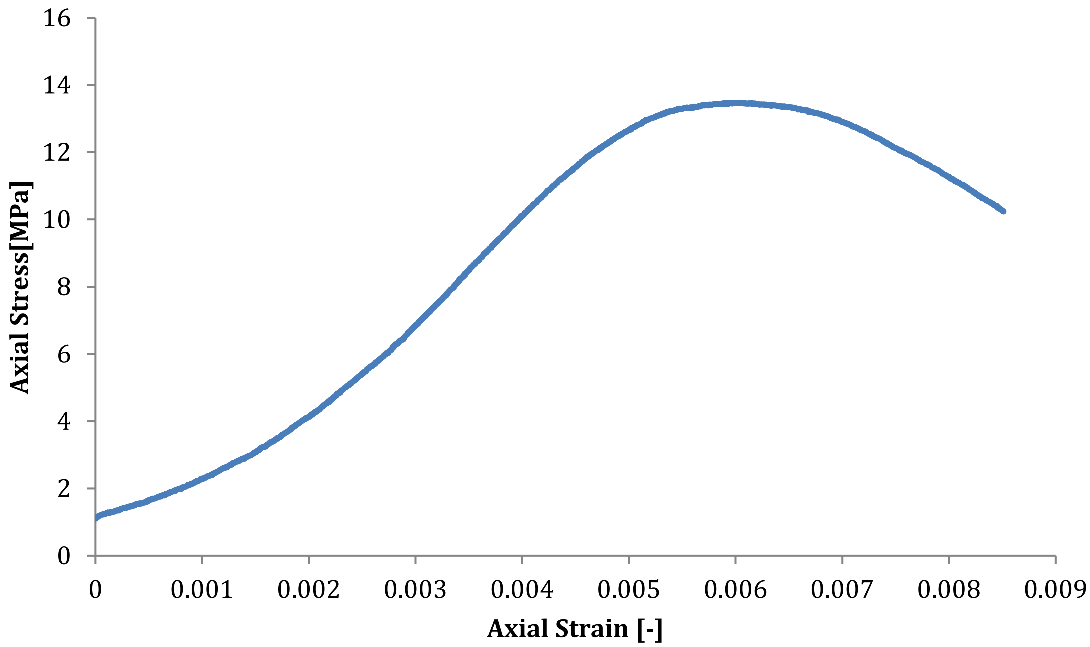

Figure D.1 Specimen SPSS 1: axial stress vs. axial strain plot (σ_3=1 MPa)

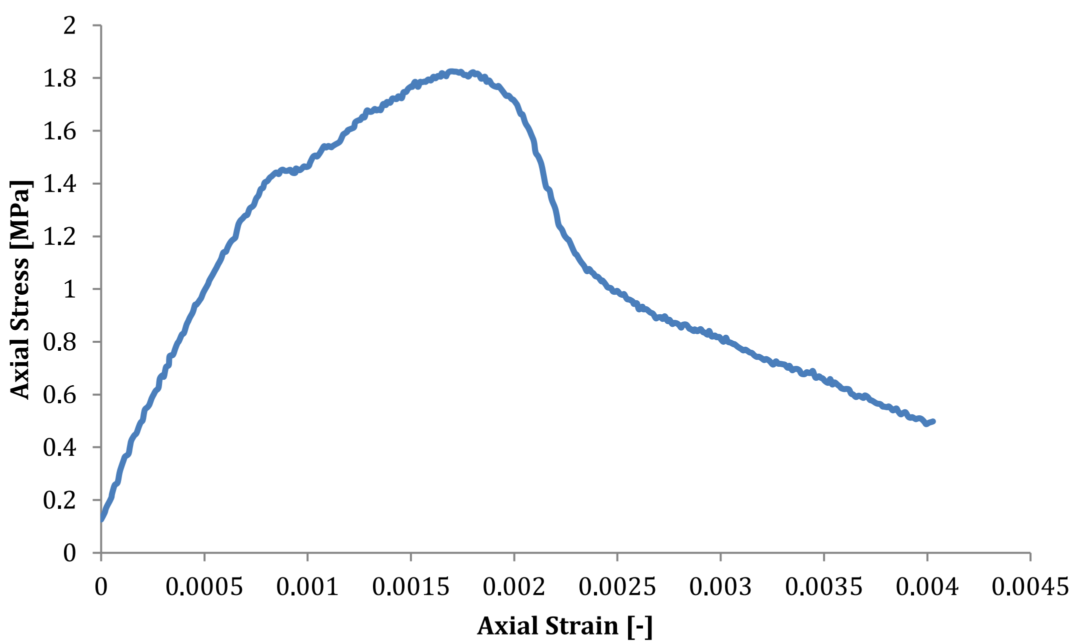

Figure D.2 Specimen SPSS 2: axial stress vs. axial strain plot (σ_3=0 MPa)

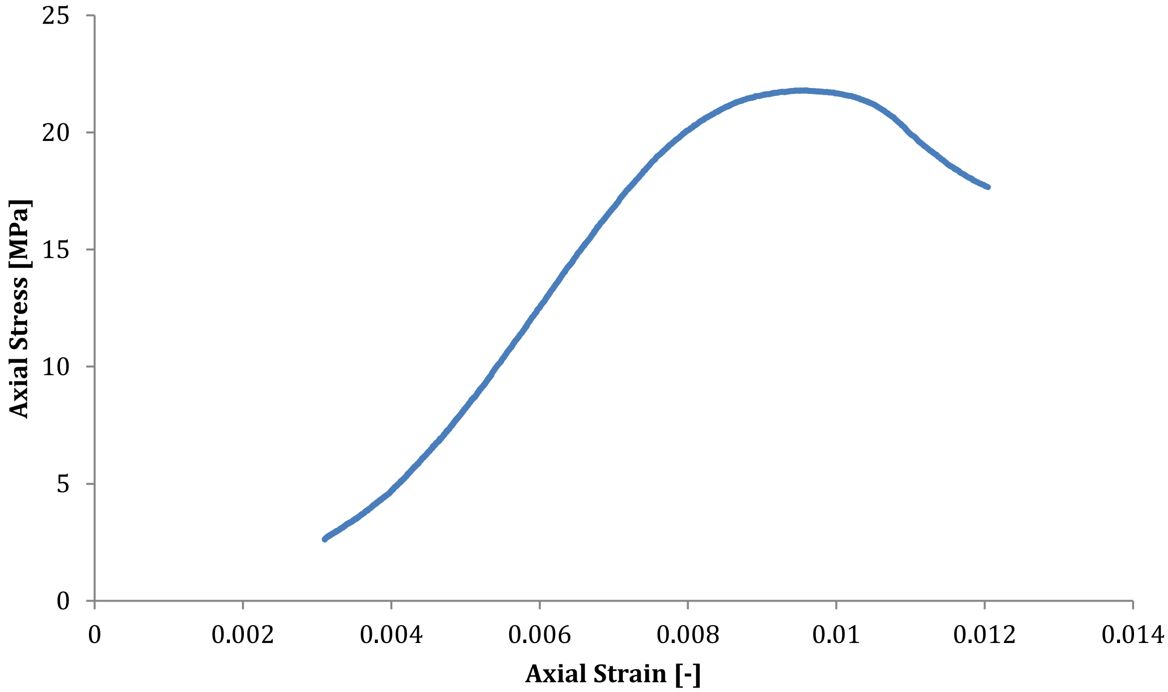

Figure D.3 Specimen SPSS 3: axial stress vs. axial strain plot (σ_3=2.5 MPa)

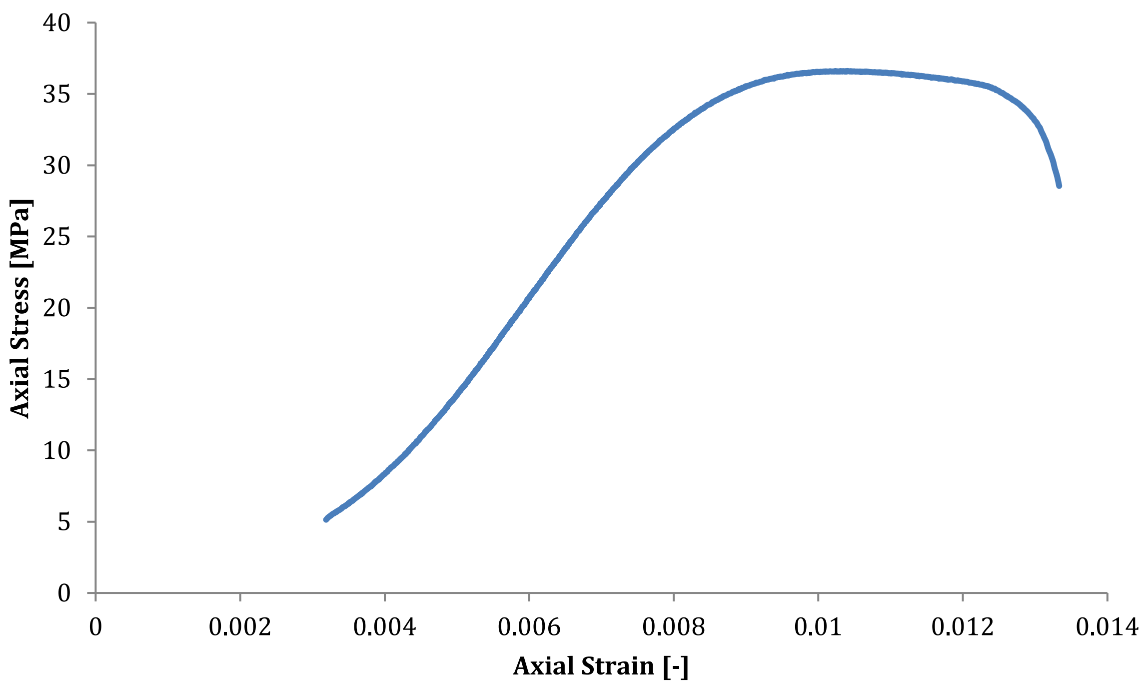

Figure D.4 Specimen SPSS 4: axial stress vs. axial strain plot (σ_3=5 MPa)

APPENDIX E: PHOTOS OF TRIAXIAL SPECIMENS FOR SP2782-334

Figure E.1 Specimen x1 before triaxial compression test

Figure E.2 Specimen x1 after triaxial compression test (σ_3=5 MPa)

Figure E.3 Specimen x2 before triaxial compression test

Figure E.4 Specimen x2 after triaxial compression test (σ_3=10 MPa)

Figure E.5 Specimen x3 before triaxial compression test

Figure E.6 Specimen x3 after triaxial compression test (σ_3=20 MPa)

Figure E.7 Specimen x4 before triaxial compression test

Figure E.8 Specimen x4 after triaxial compression test (σ_3=5 MPa)

Figure E.9 Specimen x5 before triaxial compression test

Figure E.10 Specimen x5 after triaxial compression test (σ_3=10 MPa)

Figure E.11 Specimen x6 before triaxial compression test

Figure E.12 Specimen x6 after triaxial compression test (σ_3=20 MPa)

APPENDIX F: PHOTOS OF TRIAXIAL SPECIMENS FOR SP2782-334

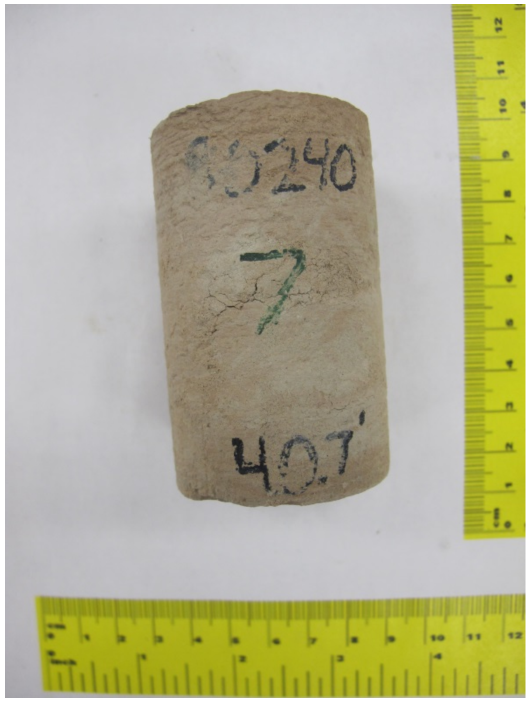

Figure F.1 Specimen 7 before triaxial compression

Figure F.2 Specimen 7 after triaxial compression (σ_3=2.5 MPa)

Figure F.3 Specimen 8 before triaxial compression

Figure F.4 Specimen 8 after triaxial compression (σ_3=10 MPa)

Figure F.5 Specimen 9 before triaxial compression

Figure F.6 Specimen 9 after triaxial compression (σ_3=5 MPa)

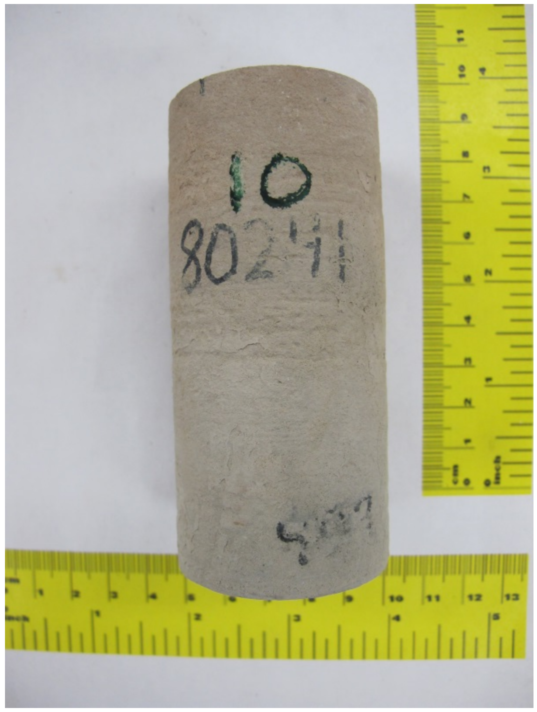

Figure F.7 Specimen 10 before triaxial compression

Figure F.8 Specimen 10 after triaxial compression (σ_3=2.5 MPa)

Figure F.9 Specimen 11 before triaxial compression

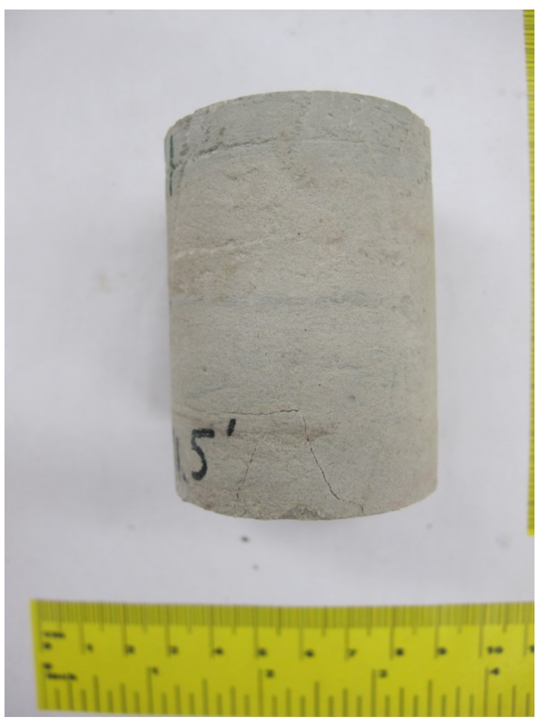

Figure F.10 Specimen 11 after triaxial compression (σ_3=2.5 MPa)

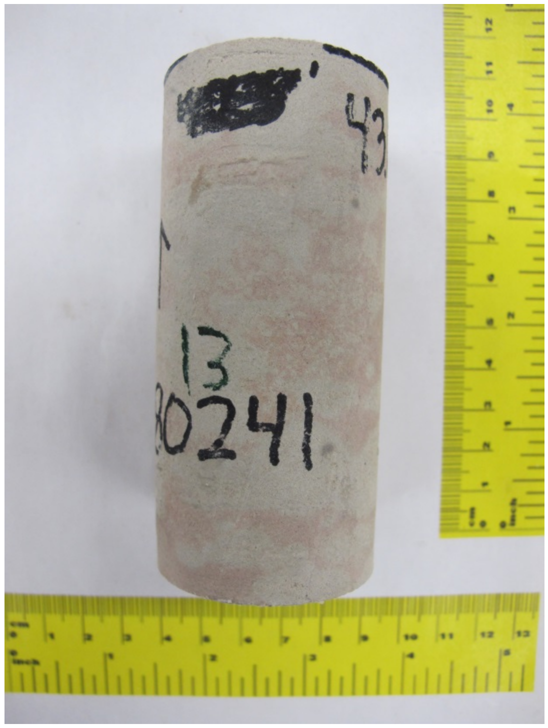

Figure F.11 Specimen 13 before triaxial compression

Figure F.12 Specimen 13 after triaxial compression (σ_3=5 MPa)

Figure F.13 Specimen 14 before triaxial compression

Figure F.14 Specimen 14 after triaxial compression (σ_3=10 MPa)

Figure F.15 Specimen 15 before triaxial compression

Figure F.16 Specimen 15 after triaxial compression (σ_3=5 MPa)

Figure F.17 Specimen 16 before triaxial compression

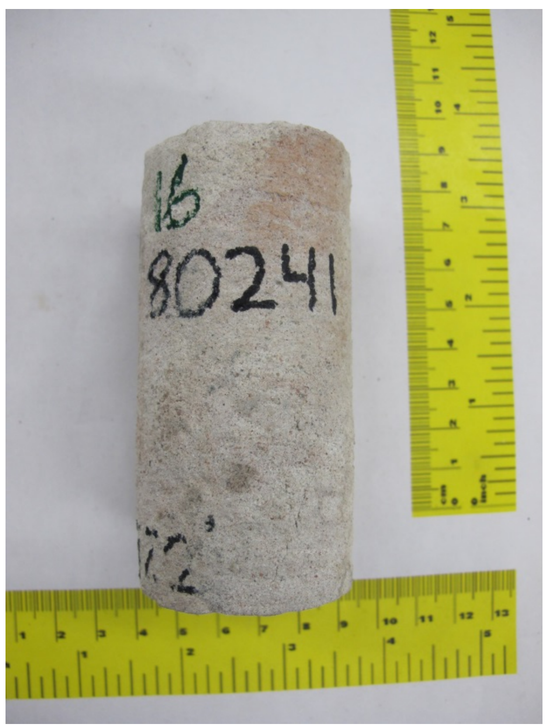

Figure F.18 Specimen 16 after triaxial compression (σ_3=2.5 MPa)

Figure F.19 Specimen 17 before triaxial compression

Figure F.20 Specimen 17 after triaxial compression (σ_3=0 MPa, leaked)

Figure F.21 Specimen 18 before triaxial compression

Figure F.22 Specimen 18 after triaxial compression (σ_3=5 MPa)

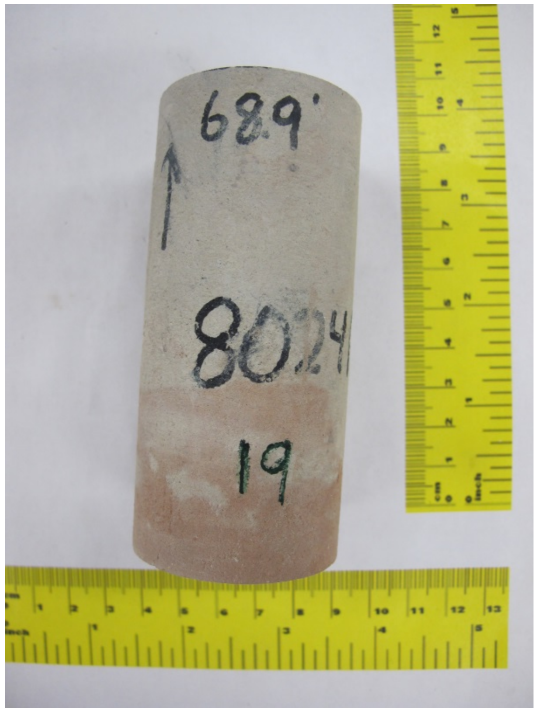

Figure F.23 Specimen 19 before triaxial compression

Figure F.24 Specimen 19 after triaxial compression (σ_3=2.5 MPa)

Figure F.25 Specimen 20 before triaxial compression

Figure F.26 Specimen 20 after triaxial compression (σ_3=2.5 MPa)

Figure F.27 Specimen 21 before triaxial compression

Figure F.28 Specimen 21 after triaxial compression (σ_3=0 MPa, leaked)

Figure F.29 Specimen 22 before triaxial compression

Figure F.30 Specimen 22 after triaxial compression (σ_3=10 MPa)

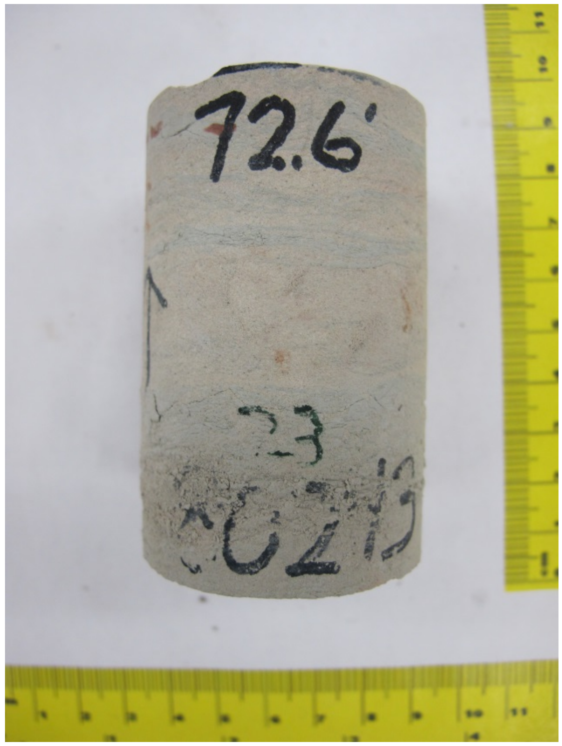

Figure F.31 Specimen 23 before triaxial compression

Figure F.32 Specimen 23 after triaxial compression (σ_3=7.5 MPa)

Figure F.33 Specimen 24 before triaxial compression

Figure F.34 Specimen 24 after triaxial compression (σ_3=5 MPa)

Figure F.35 Specimen 25 before triaxial compression

Figure F.36 Specimen 25 after triaxial compression (σ_3=10 MPa)

Figure F.37 Specimen 26 before triaxial compression

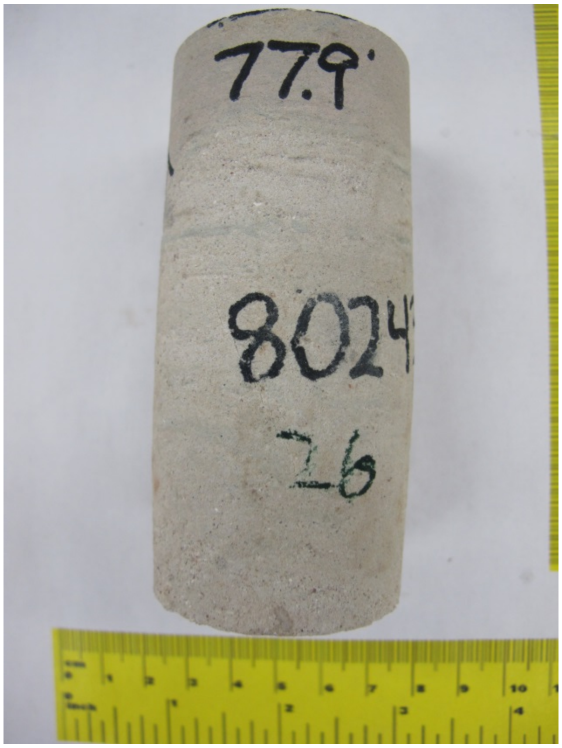

Figure F.38 Specimen 26 after triaxial compression (σ_3=2.5 MPa)

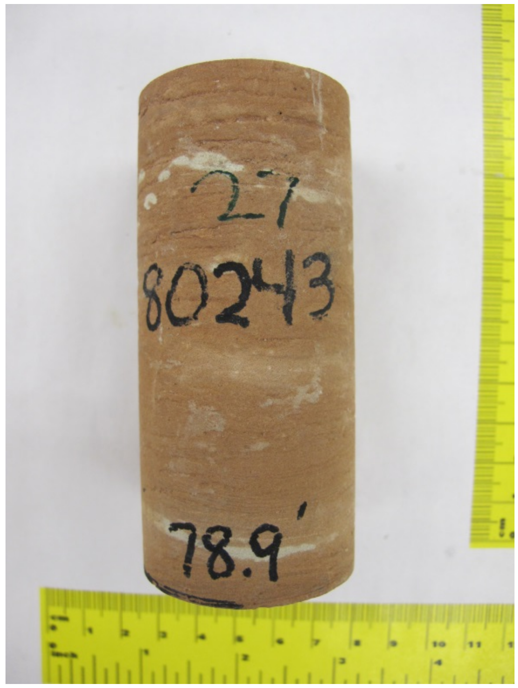

Figure F.39 Specimen 27 before triaxial compression

Figure F.40 Specimen 27 after triaxial compression (σ_3=5 MPa)

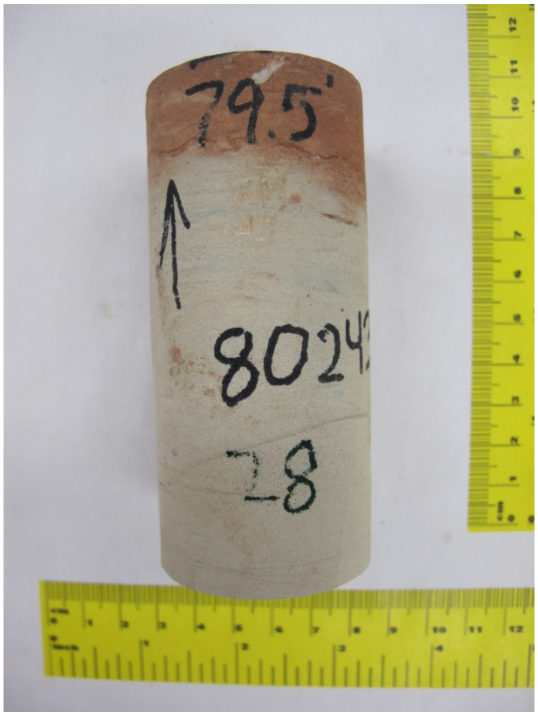

Figure F.41 Specimen 28 before triaxial compression

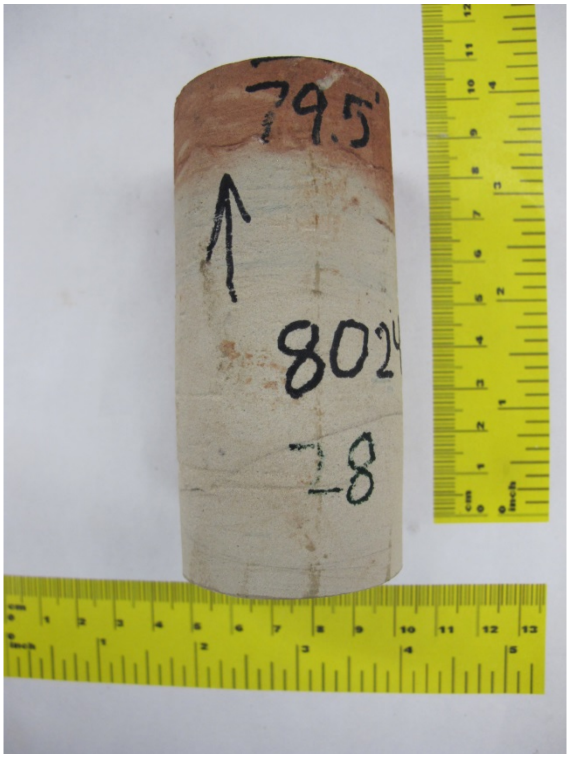

Figure F.42 Specimen 28 after triaxial compression (σ_3=10 MPa)

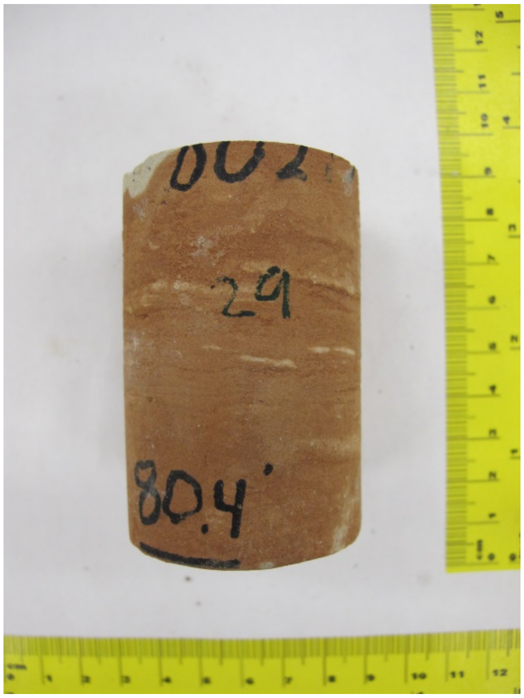

Figure F.43 Specimen 29 before triaxial compression

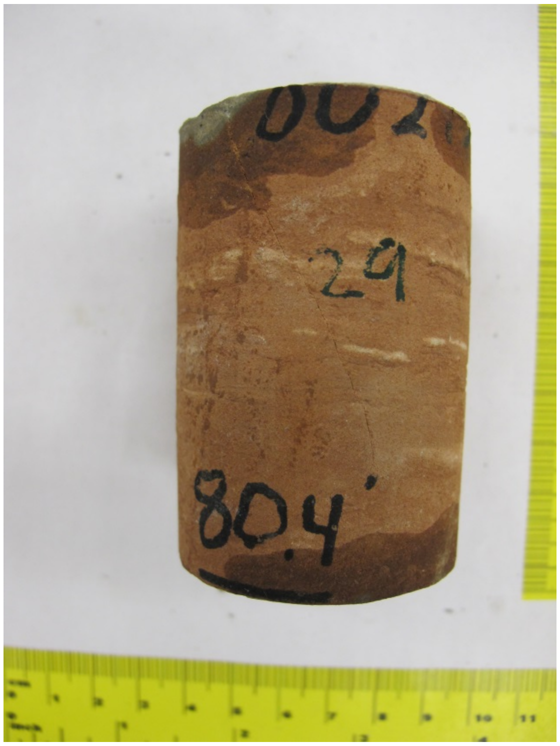

Figure F.44 Specimen 29 after triaxial compression (σ_3=7.5 MPa)

APPENDIX G: PHOTOS OF TRIAXIAL SPECIMENS FOR SP2782-334

Figure G.1 Specimen SPSS 1 before triaxial compression

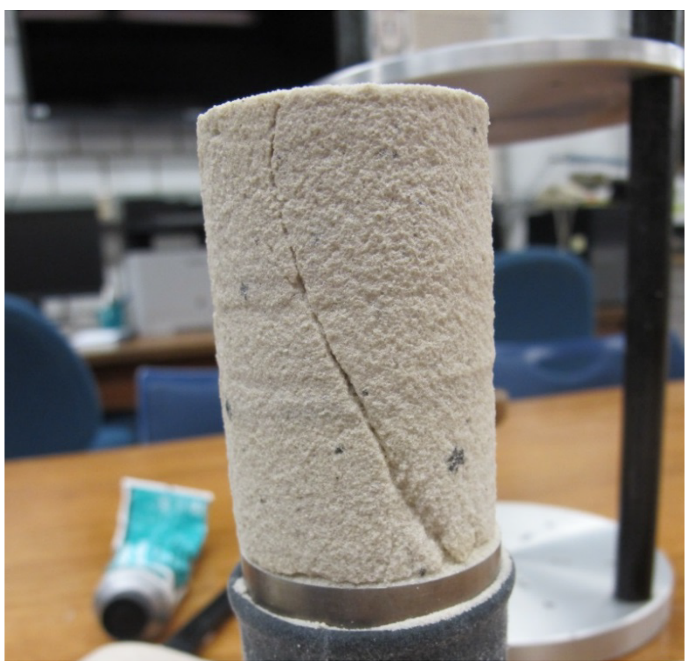

Figure G.2 Specimen 28 after triaxial compression (σ_3=1 MPa)

Figure G.3 Specimen SPSS 2 before triaxial compression

Figure G.4 Specimen SPSS 2 after compression (σ_3=0 MPa)

Figure G.5 Specimen SPSS 3 before triaxial compression

Figure G.6 Specimen SPSS 3 after triaxial compression (σ_3=2.5 MPa)

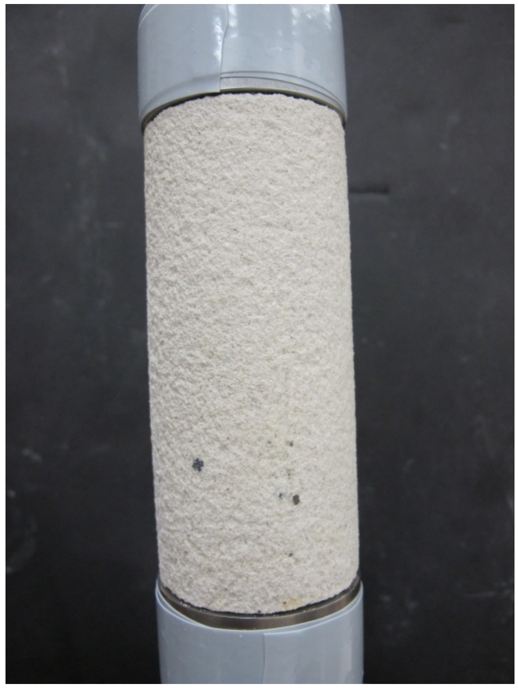

Figure G.7 Specimen SPSS 4 before triaxial compression

Figure G.8 Specimen SPSS 4 after triaxial compression (σ_3=5 MPa)

Figure G.9 St. Peter Sandstone coring setup. Sandstone block (bottom-middle) placed in wood contained (middle) and confined with compacted sand (bottom left and bottom right). Wood container then clamped down while dry coring with toothed core barrel (top-middle).

Figure G.10 Coarse saw-tooth core barrel