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MEMORANDUM

To: Program Manager, Reclamation Dam Safety Office
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From: Janet White, Group Manager
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Subject: Concrete Tensile Strength Specimen Size Effects, Dam Safety Technology Development Program, Report DSO-2016-02.

Attached for your use is an electronic copy of Report DSO-2016-02, *Concrete Tensile Strength Specimen Size Effects* prepared for the Dam Safety Technology Development Program.If you have any questions, or if you would like hard copies of this report, please contact Janet White at 303-445-2373.

cc: Archives
DSDAMS
86-68530 (Bartojay, Madera)

RECLAMATION
Managing Water in the West

Report DSO-2016-02

Concrete Tensile Strength Specimen Size Effects

Dam Safety Technology Development Program

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

April 2017

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14. ABSTRACT
Three concrete mixtures with different nominal maximum size aggregates (NMSA) were developed and 3-foot cubical blocks were cast from which cores of various diameter were extracted for testing. Specimens were cut from the cores and tested in compression, splitting tension, static direct tension, and cyclic dynamic direct tension. Due to the complexity and cost associated with obtaining and testing the specimens, only a very limited number of tests were conducted. The study was not intended to present a statistically representative sample size, but to see if any trends could be observed for each combination of NMSA and core diameter. The Principle Investigator for the project left Reclamation prior to completing a draft report. Subsequently, staff from the Concrete, Geotechnical and Structural Laboratory assembled the figures and data to present in this report. By documenting this program and the test results, future studies can be performed that will add to the available data and perhaps lead to more robust findings.

KEYWORDS:
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Report DSO-2016-02

Concrete Tensile Strength Specimen Size Effects

Dam Safety Technology Development Program

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

April 2017

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BUREAU OF RECLAMATION
Dam Safety Technology Development Program
Concrete, Geotechnical and Structural Laboratory, 86-68530

DSO-2016-02

Concrete Tensile Strength Specimen Size Effects

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ACRONYMS AND ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
NMSA	Nominal maximum size aggregate
USBR	U.S. Bureau of Reclamation

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF FIGURES

APPENDICES

ABSTRACT

Three concrete mixtures with different nominal maximum size aggregates (NMSA) were developed and 3-foot cubical blocks were cast from which cores of various diameter were extracted for testing. Specimens were cut from the cores and tested in compression, splitting tension, static direct tension, and cyclic dynamic direct tension. Due to the complexity and cost associated with obtaining and testing the specimens, only a very limited number of tests were conducted. The study was not intended to present a statistically representative sample size, but to see if any trends could be observed for each combination of NMSA and core diameter. The Principle Investigator for the project left Reclamation prior to completing a draft report. Subsequently, staff from the Concrete, Geotechnical and Structural Laboratory assembled the figures and data to present in this report. By documenting this program and the test results, future studies can be performed that will add to the available data and perhaps lead to more robust findings.

KEYWORDS

Tensile strength, cyclic direct tension, dynamic direct tension

BACKGROUND

This report documents the results of research conducted by a former Reclamation employee, Mr. Bret Robertson.

INTRODUCTION

Three concrete mixtures were designed with a NMSA of either 3/8-inch, 1½-inch, or 8-inches. Mixes were proportioned in accordance with USBR 4211, *Selecting Proportions for Concrete Mixtures* [1]. Fine aggregate as well as the 3/8-inch, ¾- inch and 1½-inch coarse aggregates were obtained from Bestway's Firestone Pit located in Firestone CO (material reference numbers M-8825, M-8841, M-8826, and M-8827 respectively). The larger coarse aggregates were obtained from the Pioneer Sand & Gravel Company's Santa Fe location in Littleton CO and were provided in two size fractions, 2- to 4-inch and 4- to 8-inch (material reference numbers M-8828 and M-8829 respectively). Appendix A contains additional aggregate physical properties and alkali aggregate reactivity test data for the Firestone Pit source as well as petrographic analysis of the 2- to 4-inch coarse aggregate.

Table 1 shows gradations for the No.4 and No.57/67 coarse aggregates and the fine aggregate used for these mixes alongside American Society for Testing and Materials (ASTM C33) [2] specification limits for these sizes.

Table 1 – Aggregate Gradation

Sieve Size	Size No.4, % Passing	ASTM C33 Limits	Size No.57/67 % Passing	ASTM Limits No.57	ASTM Limits No.67	Fine Aggregate % Passing	ASTM C33 Limits
2”		100					
1½”	100	90-100	100	100			
1”	37	20-55	100	95-100	100		
¾”	6	0-15	91	-	90-100		
½”	2	-	53	25-60	-		
3/8”	1	0-5	36	-	20-55	100	100
#4	1	-	7	0-10	0-10	100	95-100
#8	1	-	3	0-5	0-5	90	80-100
#16	1	-	2	-	-	64	50-85
#30	1	-	2	-	-	36	25-60
#50	1	-	1	-	-	16	5-30
#100	1	-	1	-	-	5	0-10
#200	0.3	0-1.5	0.7	0-1.5	0-1.5	1.7	0-3

Table 2 shows the targeted proportions for each concrete mix. Fresh properties are unknown so yield quantities cannot be reported. The cement certification report can be found in Appendix B. Appendix C contains the water reducing admixture data sheet.

Table 2 – Target Concrete Mixture Proportions

Material pounds	3/8-inch NMSA	1½-inch NMSA	8-inch NMSA
Cement	470	376	376
Water	265	216	200
WRA (oz/cwt)	5.75	2.0	2.0
4- to 8-inch	0	0	663
2- to 4-inch	0	0	875
¾- to 1½-inch	0	1100	530
3/8- to ¾-inch	1305	1100	283
Fine aggregate	2004	1303	900

Mixtures were not air entrained to minimize variability and to eliminate the need to wet-sieve the large aggregate solely to test for air content. Additionally, the required sample size for determining the unit weight of a mixture with 8-inch NMSA is very large so determining unit weight for this concrete mix was not feasible. Each block required one cubic yard of concrete, which is the capacity of the mixer, so there was no additional material available from which to make any other test specimens from the same concrete made when the blocks were cast.

Hardened properties data available for cylinders cast from the 1½-inch and 8-inch NMSA trial batches – which were made on June 23, 2014 and tested in compression at 7 and 28 days age – are presented in Table 3. The 8-inch NMSA concrete was wet sieved over a 1½-inch sieve to remove the large aggregate in order to cast 6- by 12-inch cylinders. There is no data available for any of the 3/8-inch trial mixes.

Table 3 – Compressive Strength of 6-by 12-inch Cylinders from 1½- and 8-inch NMSA Trial Mixtures

NMSA inches	Age days	Ultimate Load pounds	Compressive Strength lb/in²	Average Strength lb/in²
1½	7	106,961	3,780	-
	28	132,794	4,700	-
8	7	112,493	3,980	3,780
		106,338	3,760	
	28	131,026	4,630	4,910
		137,625	4,870	
		139,922	4,950	
		146,848	5,190	

Two 3-foot concrete cubes were cast from each of the three different NMSA mixes. Forms for these blocks are depicted in Figure 1. A total of six concrete cubes were cast over the course of three days. Two blocks with a NMSA of 8-inches were made on August 5, 2014. Photographs taken while casting the 8-inch NMSA blocks are contained in Appendix D. Two 1 ½-inch NMSA blocks were cast on August 6, 2014. Two blocks with a NMSA of 3/8-inch were then made on August 7, 2014. This research provided an opportunity for the Concrete, Geotechnical and Structural Laboratory staff to experience firsthand the challenges associated with making concrete with large aggregates and a new appreciation for the effort involved with developing all the mass concrete mixes for various dams constructed over the course of Reclamation's history.

All six blocks were stored in Building 56 of the Denver Federal Center. The blocks were cured by pooling water on top for approximately one month. Figure 2 shows that there was sufficient space in the forms above the completed blocks for which to continually add water for curing. The blocks were not tested for nearly two years, after which time the strength gain curve should have been relatively flat, which serves to reduce variations in strength that could occur if comparable samples are not tested at the same time. The blocks were moved outside for drilling operations, at which time the forms were removed.

Figure 1 – Forms for 3-foot by 3-foot by 3-foot concrete blocks

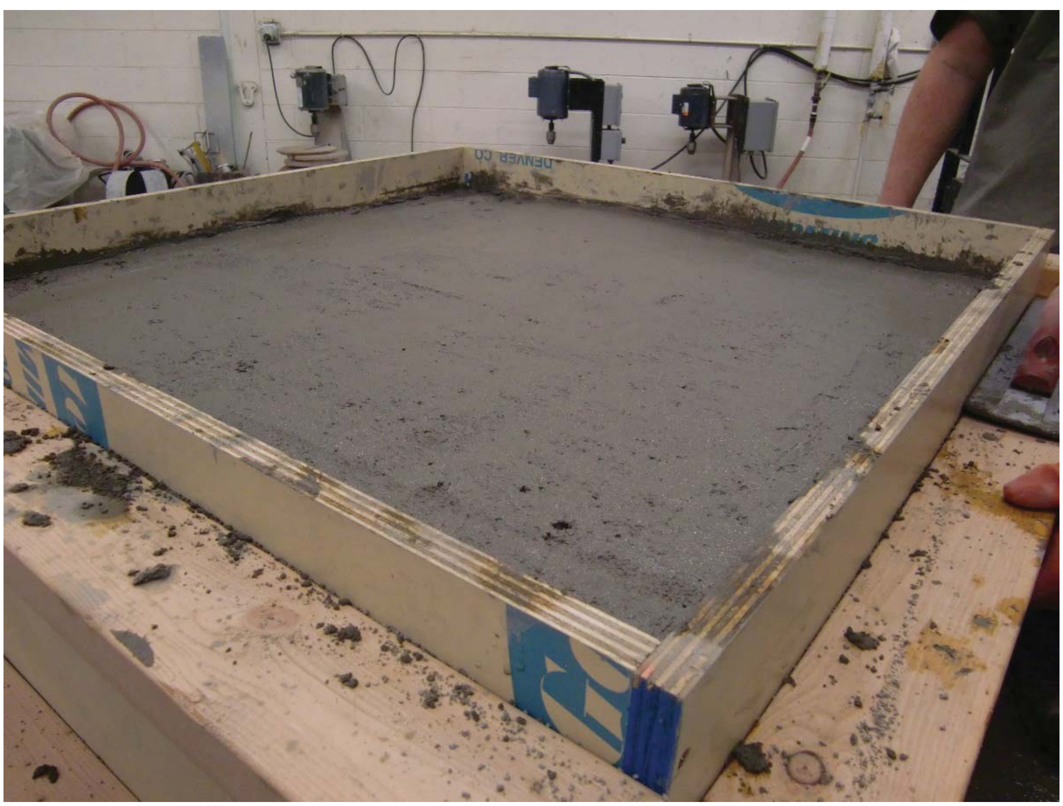

Figure 2 – Completed 8-inch NMSA concrete block

Cores of various diameters were extracted from the blocks during September 2015. Figure 3 shows core locations for each block and drilling operations are depicted in Figure 4. Cores were drilled through the full depth of the block and cut to a length suitable for testing, with length to diameter ratios approximately equal to 2:1. At least two test specimens could be obtained from each of the larger diameter cores and a larger number of test specimens could be cut from each of the smaller diameter cores.

The 16-inch diameter holes were never drilled because of difficulties encountered with drilling cores larger than 8-inch diameter. The mass of the 3-foot concrete cubes was not sufficient to resist movement of the block while drilling with larger diameter core barrels. Another block of similar mass was anchored to the block when extracting 10, 12, and 14-inch diameter cores, as shown in the picture on the right side of Figure 4, but this was still not enough to resist movement of the drilling equipment and it was deemed unsafe to attempt drilling any 16-inch diameter cores.

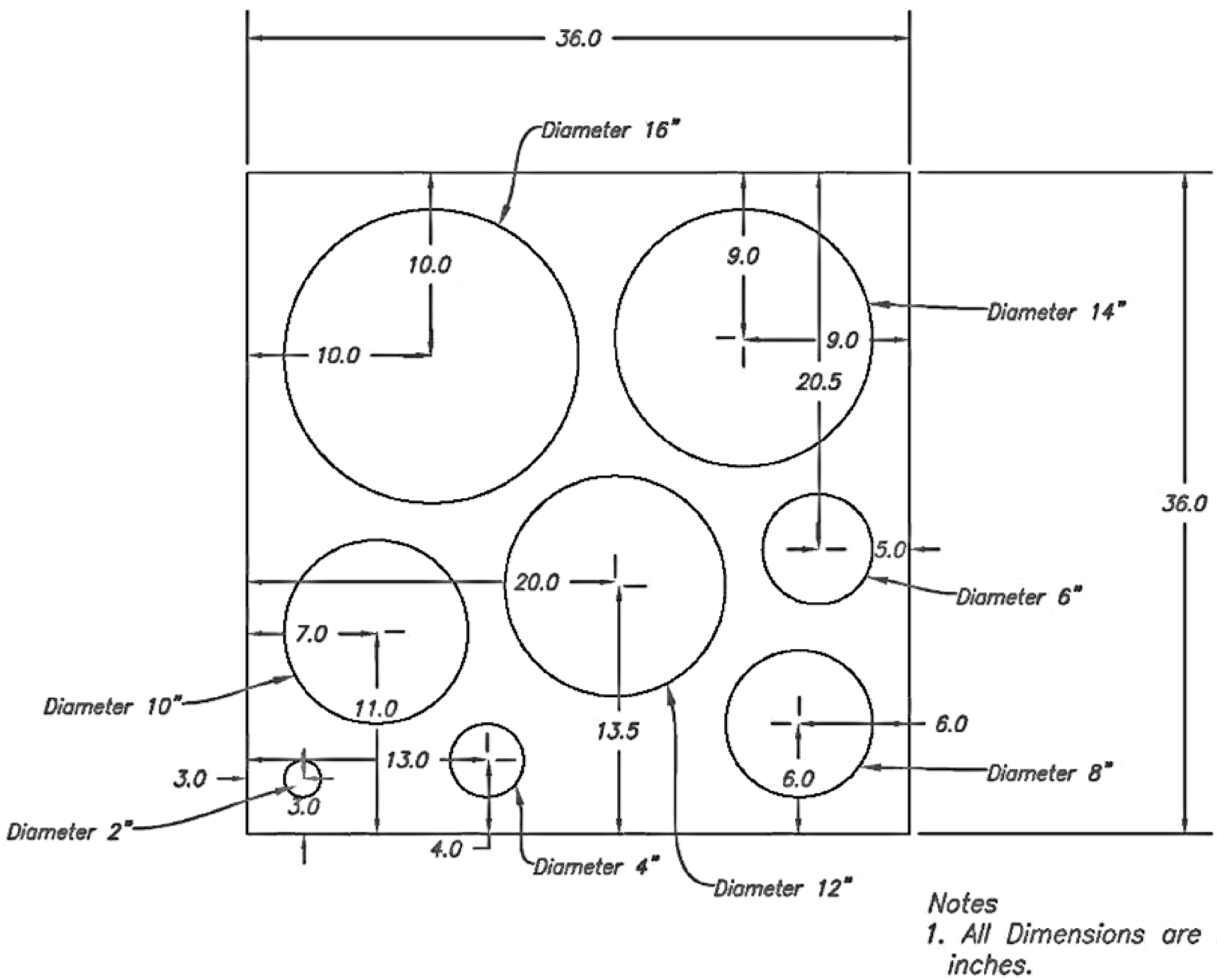

Figure 3 – Drill hole locations

Figure 4 – Drilling operations

After drilling, the extracted cores were stored in a moist room meeting the requirements of ASTM C511, *Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes*. Direct tension specimens were removed from the moist room a couple days prior to testing in order to affix the loading platens to both ends of the cut cores. Compression and splitting tension specimens were not removed from the moist room until the day they were tested.

TEST PROCEDURES

Specimens were tested in compression, splitting tension and (static) direct tension in general accordance with the following testing standards:

- ASTM C469 – *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*
- ASTM C496 – *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*
- USBR 4914 – *Procedure for Direct Tensile Strength, Static Modulus of Elasticity, and Poisson's Ratio of Cylindrical Concrete Specimens in Tension*
- USBR M-85 – *Procedure for Dynamic (Cyclic) Direct Tensile Strength of Cylindrical Concrete Specimens in Tension* [3]

A frame used to test 12-inch diameter cores from a Canadian dam [4] was modified to accommodate different size specimens for this research. Figure 5 shows both a schematic and photograph of the test setup.

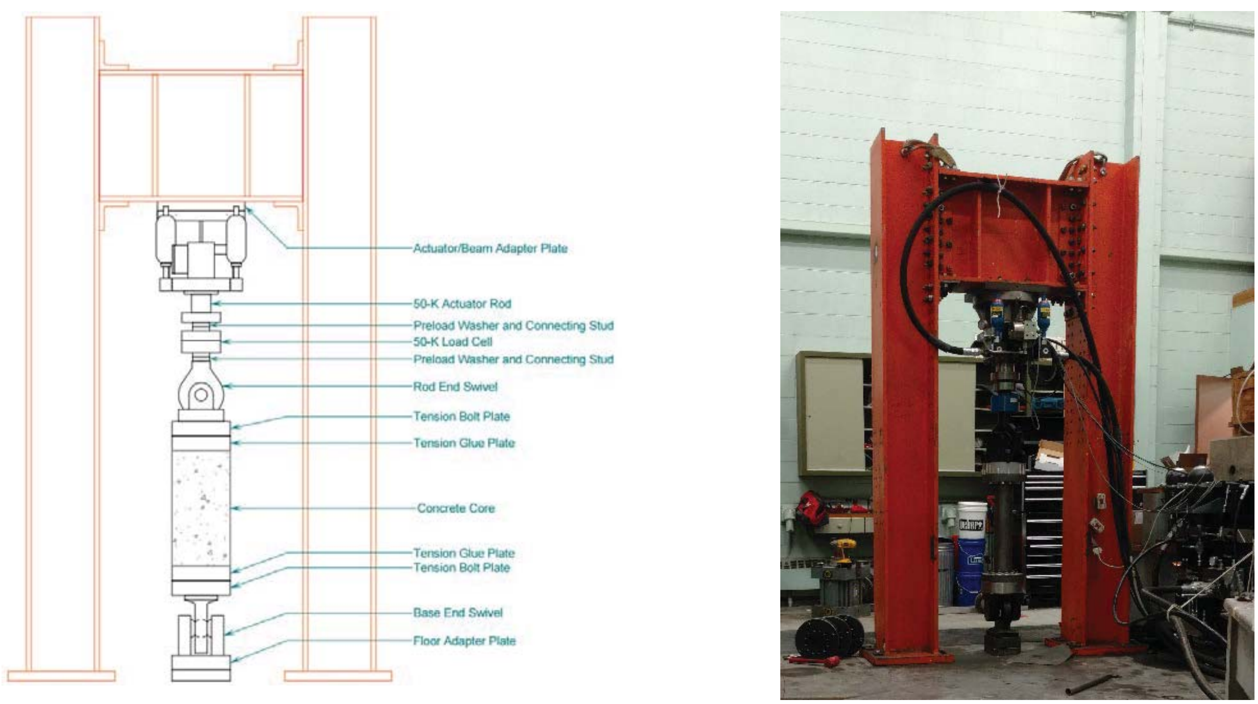

Figure 5 – Cyclic dynamic direct tension test setup

TESTING PROGRAM

It is important to note that the American Concrete Institute (ACI) defines a strength test as the average strength of at least two 6- by 12-inch specimens or at least three 4- by 8-inch specimens [5]. In most cases there was only a single specimen tested for each test type and core diameter combination from each of the three concrete mixtures so average strengths cannot be calculated. However, average values are shown in the tables for comparison purposes. Statistical relevancy was not incorporated in the research objectives for this preliminary evaluation of various NMSA concrete as the required amount of testing would greatly exceed the available budget to perform the additional tests.

There is no test data available for the 2-inch diameter cores because testing of 2-inch diameter specimens was discontinued. For the 8-inch and 1½-inch NMSA mixes, the cores consisted primarily of rock and were therefore not a representative sample of the concrete. Additionally, for direct tension specimens, the mass of the steel platens attached to the ends of the core failed the samples prior to testing.

Static Testing

One 6-inch diameter core specimen from each of the three concrete mixes was tested in static direct tension on March 4, 2016 in order to estimate the direct tensile strength of each mix prior to performing cyclic dynamic direct tension testing. These results are presented in Table 4. Note that only one specimen was tested so the data is merely an indication of the strength. Figure 6 shows the direct tension test setup; this photograph is for a 12-inch diameter core from the 1½-inch NMSA concrete mix. Photographs of failed test specimens can be located in Appendix H.

Figure 6 – Static direct tension test setup
(12-inch diameter core from 1½-inch NMSA concrete mix shown)

Table 4 – Static Direct Tensile Strength of 6-inch Diameter Cores

Concrete NMSA inches	Test Age days	Ultimate Load pounds	Static Direct Tensile Strength lb/in²
8	577	1,237	50
1½	576	5,558	215
3/8	575	5,164	200

The remainder of the static direct tension specimens were tested over the course of a week, from May 19 to May 26, 2016 at ages ranging from 653 to 660 days. Photographs of failed static direct tension test specimens are located in Appendix H. Splitting tensile strength testing was performed on May 24, 2016 at 658 days age. Photographs of failed splitting tension test specimens are contained in Appendix G. Compressive strength testing was performed on May 26, 2016 at 658 to 660 days age.

Table 5 through Table 7 present results of the compression, direct tension and splitting tension tests respectively. Figure 7 displays the compressive strength versus core diameter. Splitting tensile strength versus core diameter is illustrated in Figure 8. Stress versus strain plots for the static direct tension tests are contained in Appendix E.

The direct tensile strength of the 8-inch NMSA concrete is 3% of the compressive strength. The direct tensile strength of the 1½-inch NMSA concrete is 5% of the compressive strength. The direct tensile strength of the 3/8-inch NMSA concrete is 5% of the compressive strength. These values are all close to the average for mass concrete cores from numerous Reclamation dams of 4.4% [6].

The splitting tensile strength of the 8-inch NMSA concrete is 10% of the compressive strength. The splitting tensile strength of the 1½-inch NMSA concrete is 8% of the compressive strength. The splitting tensile strength of the 3/8-inch NMSA concrete is 7% of the compressive strength. The typical range is 8 to 14% [7].

Table 5 – Compressive Strength of Cores

Concrete NMSA inches	Nominal Core Diameter inches	Actual Core Diameter Inches	Test Age days	Ultimate Load pounds	Compressive Strength lb/in²	Average Compressive Strength lb/in²
8	8	7.75	660	184,213	3,910	4,980
	6	5.75		161,507	6,220	
	4	3.75		48,101	4,360	
	4	3.75		60,020	5,430	
1½	8	7.75	659	256,674	5,440	4,690
	6	5.75		105,163	4,050	
	4	3.75		51,652	4,680	
	4	3.75		50,429	4,570	
3/8	8	7.75	658	229,056	4,860	4,260
	6	5.75		105,020	4,040	
	4	3.75		52,307	4,740	
	4	3.75		37,696	3,410	

Table 6 – Static Direct Tensile Strength of Cores

Concrete NMSA inches	Nominal Core Diameter inches	Actual Core Diameter inches	Test Age days	Ultimate Load pounds	Direct Tensile Strength lb/in²	Average Tensile Strength lb/in²	Standard Deviation lb/in²	Coefficient of Variation
8	14	13.68	657	24,295	165	140	18	13%
	12	11.7	654	14,020	130			
	10	9.7	657	1,953	25*			
	8	7.75	659	6,122	130			
	6	5.75	577	1,237	50*			
	4	3.75	658	1,432	130			
1½	14	13.68	652	36,275	245	240	15	6%
	12	11.7	652	24,916	230			
	10	9.7	656	18,790	255			
	8	7.75	658	11,067	235			
	6	5.75	576	5,558	215			
	4	3.75	657	2,751	250			
3/8	14	13.68	652	12,982	90*	210	33	15%
	12	11.7	652	23,742	220			
	10	9.7	655	13,851	185			
	8	7.75	658	8,906	190			
	6	5.75	575	5,164	200			
	4	3.75	656	2,915	265			

* These values are not a true representation of strength and are not included in calculations for the average strength, standard deviation, or coefficient of variation

Table 7 – Splitting Tensile Strength of Cores

Concrete NMSA inches	Nominal Core Diameter inches	Actual Core Diameter inches	Specimen Length inches	Test Age days	Ultimate Load pounds	Splitting Tensile Strength lb/in²	Average Strength lb/in²	Standard Deviation lb/in²	Coefficient of Variation
8	10	9.7	11.5	658	55,941	320	490	153	31%
	6	5.75	11.5		55,562	535			
	4	3.75	7.5		27,154	615			
1½	10	9.7	12.25	657	64,309	345	390	48	12%
	6	5.75	11.5		40,511	390			
	4	3.75	7.5		19,353	440			
3/8	10	9.7	17.5	656	70,623	265	290	36	12%
	6	5.75	11.5		27,828	270			
	4	3.75	7.5		14,611	330			

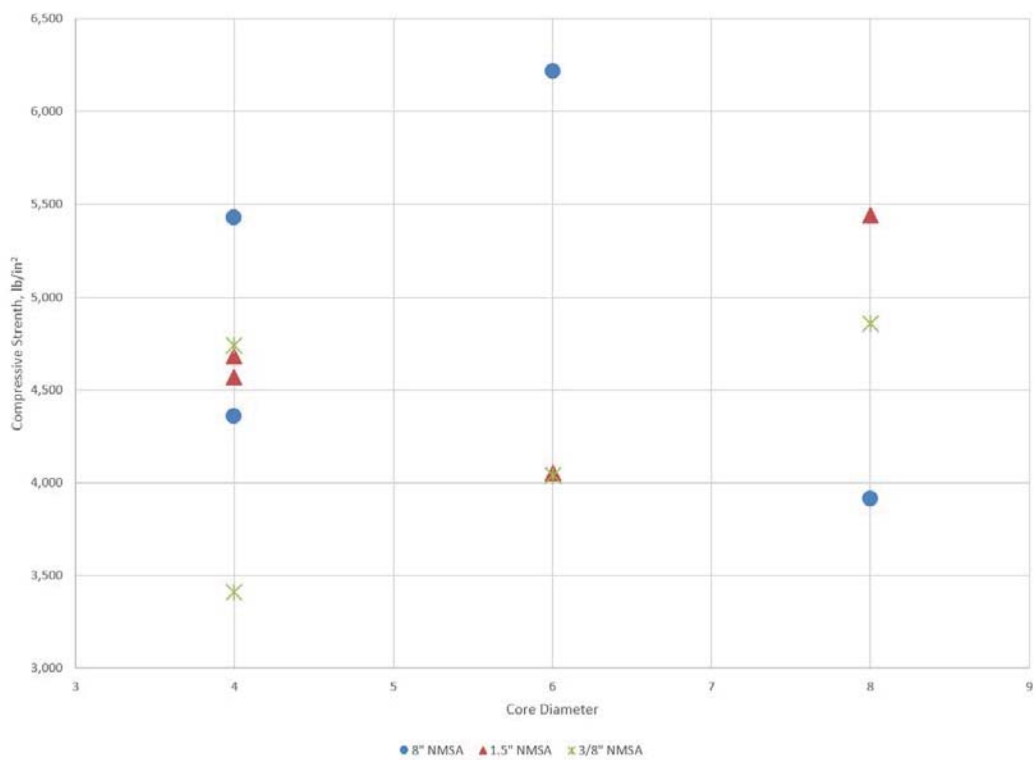

Figure 7 – Compressive Strength versus Core Diameter

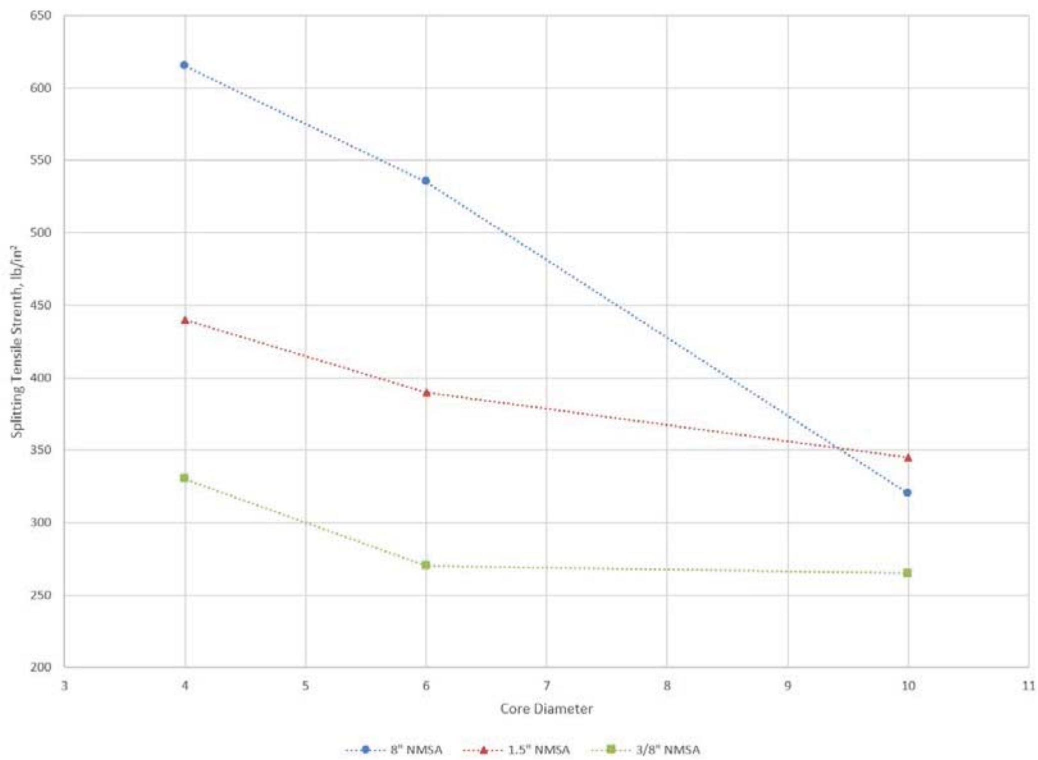

Figure 8 – Splitting Tensile Strength versus Core Diameter

Dynamic Testing

Cyclic dynamic direct tension testing was performed over the course of two weeks, from March 7 to March 18, 2016. The data acquisition system recorded four channels: displacement measured by the hydraulic actuator which has a stroke of ± 1-inch; load measured by the load cell which has a 50,000 lb capacity; and two strain readings measured by two sets of axially mounted strain gauges. Data was acquired at a rate of 1,000 readings per second per channel. Each channel was sampled simultaneously with an anti-aliasing filter at 420 Hz.

A total of 18 specimens were tested but data for the 6-inch diameter core from the 1½-inch NMSA mix is not available. The frequency of the cyclic load for dynamic testing was 8 Hz. Test results are presented in Table 8. Plots of load, strain, and stress versus time as well as stress versus strain for each test can be found in Appendix F. Photographs of failed cyclic dynamic direct tension test specimens are located in Appendix I.

Table 8 – Cyclic Dynamic Direct Tension Test Results*

Concrete NMSA inches	Nominal Core Diameter inches	Actual Core Diameter inches	Test Age days	Seconds To Failure	Number of Cycles to Failure	Max Load lbs	Max Comp. Strain 10^{-6} in/in	Max Tensile Strain 10^{-6} in/in	Max Tensile Stress lb/in²	Average Max Stress lb/in²
8	14	13.68	581	348	2,781	-	-	-	90	145
	12	11.7	582	134	1,069	21,112	-	-	195	
	10	9.7	582	92	734	6,869	101	74	95	
	8	7.75	588	471	3,764	5,480	51	32	115	
	6	5.75	588	328	2,627	4,485	49	43	175	
	4	3.75	588	348	2,783	2,108	104	89	190	
1½	14	13.68	581	512	4,097	25,777	-	-	175	210
	12	11.7	581	436	3,486	27,844	-	-	260	
	10	9.7	581	17	137	5,214	43	35	70	
	8	7.75	587	1,052	8,413	11,736	64	60	250	
	4	3.75	587	545	4,359	3,352	106	86	305	
3/8	14	13.68	581	925	7,398	30,666	-	-	210	210
	12	11.7	580	459	3,670	26,309	-	-	245	
	10	9.7	580	74	593	6,950	-	-	95	
	8	7.75	587	1,154	9,229	13,192	59	61	280	
	6	5.75	586	788	6,304	2,655	64	45	200	
	4	3.75	586	449	3,558	2,655	78	64	240	

* Shaded rows indicate specimens which were loaded at a constant amplitude until failure

DISCUSSION

The Concrete, Geotechnical and Structural Laboratory encountered numerous challenges during the cyclic dynamic direct tension testing. Adjustments to the load amplitude were inconsistent due to variability of the hydraulics and sensitivity of the equipment. Although every effort was made to obtain accurate data not all tests yielded the anticipated information. The total volume of each block is one cubic yard, which is the capacity of the mixer which was used to make the concrete, so no additional cylinders were cast when the blocks were made. With the limited number of test samples this was an overall disadvantage because of the inability to calculate averages and determine whether there were any trends in the behavior of concrete subjected to cyclic dynamic loading.

For the 8-inch NMSA mix, every direct tension specimen failed where a large aggregate particle was located, for both static and cyclic dynamic tests. This is expected behavior because bleed water gets trapped underneath the large aggregate particles which results in a weakened paste-aggregate bond. The failure plane went underneath the largest aggregates and generally both around and through most of the smaller coarse aggregate particles. For cores from both the 1½- and 3/8-inch mixes, failure planes were generally both around and through coarse aggregate particles.

The cyclic dynamic testing protocol was adjusted as needed due to complications with the testing equipment. Plots of load, stress, and strain versus time (which are located in Appendix F) show that most of the specimens were loaded at a set amplitude for some duration then the load was incrementally increased, up to 19 times in one case, before the specimen failed. The length of time at each load amplitude was generally about one minute for most specimens but up to two minutes in some cases. Only two specimens were loaded at a constant amplitude until failure (10-inch diameters core from the 1½-inch NMSA and 3/8-inch NMSA blocks).

Most cyclic dynamic direct tension test specimens underwent at least a couple thousand loading cycles prior to failure. The average number of cycles to failure for all core diameters from the 8-inch, 1½-inch and 3/8-inch NMSA mixes was 2293, 4098 and 5130 respectively. It appears that as the aggregate size decreases the concrete can sustain more loading cycles. This behavior is not surprising when considering the weakened paste-aggregate bond underneath large coarse aggregate particles due to trapped bleed water. As the aggregate size decreases the potential for bleed water pooling underneath coarse aggregate particles also decreases which increases the paste-aggregate bond. However, it is important to note that the load amplitude was increased several times for most test specimens so the total number of cycles to failure is not indicative of the number of cycles it would take to fail the concrete if it were held at a constant amplitude.

SUMMARY OF FINDINGS

Sampling and testing was limited due to the complexity of casting and testing large concrete samples. Many test results are based on one or only a few tests.

The direct tensile strength of the 8-inch NMSA concrete is 3% of the compressive strength. The direct tensile strength of the 1½-inch NMSA concrete is 5% of the compressive strength. The direct tensile strength of the 3/8-inch NMSA concrete is 5% of the compressive strength. These values are all close to the average for mass concrete cores from numerous Reclamation dams of 4.4% [8].

The splitting tensile strength of the 8-inch NMSA concrete is 10% of the compressive strength. The splitting tensile strength of the 1½-inch NMSA concrete is 8% of the compressive strength. The splitting tensile strength of the 3/8-inch NMSA concrete is 7% of the compressive strength. The typical range is 8 to 14% [9]

There are no obvious trends in the limited compressive strength test data available as shown in Figure 7. Overall average strengths for all core diameters from the 8-inch, 1½-inch and 3/8-inch NMSA mixes were 4980 lb/in^2, 4690 lb/in^2, and 4260 lb/in^2 respectively.

There is an apparent trend toward higher strength for a smaller diameter core in the splitting tensile strength data, which was observed for all three mixes, as shown in Figure 8. This apparent trend is based on an extremely limited data set. The failure plane was both around and through the largest aggregate particles for all NMSA mixes as shown in the photographs in Appendix G.

For the 8-inch NMSA mix, every direct tension specimen failed where a large aggregate particle was located, for both static and cyclic dynamic tests.

The average static direct tensile strength and the average maximum dynamic tensile stress for all core diameters was very similar for each mix. The average static direct tensile strength for all core diameters from the 8-inch NMSA mix was 140 lb/in^2 which is nearly identical to the overall average maximum tensile stress for dynamic tests, 145 lb/in^2. The average maximum direct tensile stress for dynamic tests on cores from the 1½-inch NMSA mix was 210 lb/in^2 while the overall average strength for static tests was 240 lb/in^2. The average static direct tensile strength and the average maximum direct tensile stress for dynamic tests performed on cores from the 3/8-inch NMSA mix were both 210 lb/in^2.

There does not appear to be a substantial difference in direct tensile strength for various core diameters from the same NMSA mix. This is true for both static and cyclic dynamic tests. This behavior is understandable as direct tension testing of vertically drilled cores results in the concrete failing along the weakest plane. This zone of weakened paste-aggregate bond underneath coarse aggregate particles is referred to as the interface or transition zone (ITZ). The ITZ contains fewer cement particles and therefore a higher water to cementitious materials (w/cm) ratio which increases porosity and reduces strength [10]. The influence of this phenomenon appears to be greater under larger aggregate particles [11].

RECOMMENDATIONS

This research report does not represent a comprehensive look at determining the capacity of concrete to sustain a cyclic dynamic load but does outline a thorough test program and helps identify where additional research is needed.

Additional laboratory research is recommended to determine effect of load amplitude on the number of cycles of tensile loading that concrete can sustain in order to establish the relationship between these two variables, if any. Differences in aggregate size and specimen diameter should also be investigated.

It may be more cost effective to conduct similar research in the field during a large mass concrete construction project where a larger test block could be cast and additional specimens could more easily be obtained at a reasonable cost.

Testing of horizontally drilled cores from large NMSA concrete is also recommended in order to determine whether the effect of weak bond at the underside of large aggregate particles on the direct tensile strength of concrete can be reduced.

REFERENCES

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[3] M-85, *Procedure for Dynamic (Cyclic) Direct Tensile Strength of Cylindrical Concrete Specimens in Tension*. U.S. Bureau of Reclamation. Denver, CO. July 2014.

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[5] Specifications for Structural Concrete (ACI 301-10). American Concrete Institute. Farmington Hills, MI. December 2010.

[6] DSO-05-05. *Materials Properties Model of Aging Concrete*. U.S Bureau of Reclamation. Denver, CO. December 2005.

[7] Significance of Tests and Properties of Concrete and Concrete-Making Materials. STP 169C. ASTM, Philadelphia PA. August 1994.

[8] DSO-05-05. *Materials Properties Model of Aging Concrete*. U.S Bureau of Reclamation. Denver, CO. December 2005.

[9] Significance of Tests and Properties of Concrete and Concrete-Making Materials. STP 169C. ASTM, Philadelphia PA. August 1994.

[10] A.M. Neville. *Properties of Concrete*, Fourth Edition. 1995.

[11] T.P.Dolen and P.A. Mitchell. *2001-2002 Concrete Coring – Laboratory Testing Program, Folsom Dam Modifications*. U.S. Department of the Interior. Bureau of Reclamation. April 3, 2002.

Appendix A

Aggregate Properties

LABORATORY TEST REPORT

WesTest
Specialists to the Paving Industry
845 Navajo Street
Denver, CO 80204
303.975.9959, Fax 303.975.9969

CLIENT: Bestway Concrete
SOURCE: Firestone Pit
SAMPLED BY: Client
PROJECT: Firestone Pit C33 Testing

WesTest PROJECT NO.: 373513
REPORT DATE: April 4, 2013

MATERIAL DESCRIPTION	ASTM C 33 Size No. 4 Coarse Aggregate
DATE SAMPLED	February 21, 2013
SAMPLE LOCATION	Stockpile

Aggregate Physical Property and Quality Tests (ASTM C 33 Specifications)

ASTM C 117 & C 136, AASHTO T 11 & T 27

SIEVE SIZE	% Passing	ASTM No. 4 Specification
2"		100
1-1/2"	100	90 - 100
1"	37	20 - 55
3/4"	6	0 - 15
1/2"	2	
3/8"	1	0 - 5
# 4	1	
# 8	1	
# 16	1	
# 30	1	
# 50	1	
# 100	1	
# 200	0.3	0 - 1.5

ASTM C 127, AASHTO T 85, Bulk Specific Gravity = 2.57, Bulk Specific Gravity (SSD) = 2.60, Apparent Specific Gravity = 2.64, Absorption = 0.9%

ASTM C 535, L.A. Abrasion

Grading 3, Loss = 42%

Specification: 45% Max.

ASTM C 142, AASHTO T 112, Clay Lumps & Friable Particles

COARSE AGG. = 0.0%, Specification: 3.0% Max.

ASTM C 123, AASHTO T 113, Lightweight Particles in Aggregate

SAMPLE WT. (g)	LIQUID TYPE / SPECIFIC GRAVITY	LIGHTWEIGHT PARTICLES	SPEC.
3025.1	$ZnCl_2$/2.0	0.0%	0.5% Max.
3025.1	$ZnBr_2$/2.4	0.0%	3.0% Max.

ASTM C 88, AASHTO T 104, Sodium Sulfate Soundness, 5 Cycles

SIEVE SIZE	GRADING OF ORIGINAL SAMPLE	WEIGHT BEFORE TEST, g	PERCENT PASSING AFTER TEST	WEIGHTED PERCENT LOSS
1-1/2" to 1"	100	1012.6	0.5	0.5
1" to 3/4"		503.7		
3/4" to 1/2"				
1/2" to 3/8"				
3/8" to No.4				
TOTAL	100	COARSE AGG. TOTAL 99%		1
SPECIFICATION:				12 Max.

ASTM C 29, AASHTO T 19,
Bulk Density and Voids in Aggregate

Rodding Method; Bulk Density = 97 pcf

Voids in Aggregate = 39%

COMMENTS

TABLE 4

LABORATORY TEST REPORT

WesTest
SPECIALISTS TO THE PAVING INDUSTRY
845 Navajo Street
Denver, CO 80204
303.975.9959, Fax 303.975.9969

CLIENT: Bestway Concrete
SOURCE: Firestone Pit
SAMPLED BY: Client
PROJECT: Firestone Pit C33 Testing

WesTest PROJECT NO.: 373513
REPORT DATE: April 4, 2013

MATERIAL DESCRIPTION	ASTM C 33 Size No. 57/67 Coarse Aggregate
DATE SAMPLED	February 21, 2013
SAMPLE LOCATION	Stockpile

Aggregate Physical Property and Quality Tests (ASTM C 33 Specifications)

ASTM C 117 & C 136, AASHTO T 11 & T 27

SIEVE SIZE	% Passing	ASTM No. 57 Specification	ASTM No. 67 Specification
1-1/2"	100	100	
1"	100	95 - 100	100
3/4"	91		90 - 100
1/2"	53	25 - 60	
3/8"	36		20 - 55
# 4	7	0 - 10	0 - 10
# 8	3	0 - 5	0 - 5
# 16	2		
# 30	2		
# 50	1		
# 100	1		
# 200	0.7	0 - 1.5	0 - 1.5

ASTM C 127, AASHTO T 85,
Bulk Specific Gravity = 2.59, Bulk Specific Gravity (SSD) = 2.61, Apparent Specific Gravity = 2.66, Absorption = 1.2%

ASTM C 131, AASHTO T 96, L.A. Abrasion

Grading B, Loss = 43%

Specification: 45% Max.

ASTM C 142, AASHTO T 112, Clay Lumps & Friable Particles

COARSE AGG. = 0.0%, Specification: 3.0% Max.

ASTM C 123, AASHTO T 113, Lightweight Particles in Aggregate

SAMPLE WT. (g)	LIQUID TYPE / SPECIFIC GRAVITY	LIGHTWEIGHT PARTICLES	SPEC.
3025.1	$ZnCl_2$/2.0	0.0%	0.5% Max.
3025.1	$ZnBr_2$/2.4	0.0%	3.0% Max.

ASTM C 88, AASHTO T 104, Sodium Sulfate Soundness, 5 Cycles

SIEVE SIZE	GRADING OF ORIGINAL SAMPLE	WEIGHT BEFORE TEST, g	PERCENT PASSING AFTER TEST	WEIGHTED PERCENT LOSS
1-1/2" to 1"	10		0.5	0.1
1" to 3/4"		503.7		
3/4" to 1/2"	59	668.7	0.1	0.1
1/2" to 3/8"		330.4		
3/8" to No.4	31	302.1	0.3	0.1
TOTAL	100	COARSE AGG. TOTAL 93%		0
SPECIFICATION:				12 Max.

ASTM C 29, AASHTO T 19,
Bulk Density and Voids in Aggregate

Rodding Method; Bulk Density = 101 pcf

Voids in Aggregate = 37%

COMMENTS

TABLE 3

LABORATORY TEST REPORT

WESTEST
SPECIALISTS TO THE PAVING INDUSTRY
845 Navajo Street
Denver, CO 80204
303.975.9959, Fax 303.975.9969

CLIENT: Bestway Concrete
SOURCE: Firestone Pit
SAMPLED BY: Client
PROJECT: Firestone Pit C33 Testing

WesTest PROJECT NO.: 373513
REPORT DATE: April 4, 2013

MATERIAL DESCRIPTION	ASTM C 33 Fine Aggregate
DATE SAMPLED	February 21, 2013
SAMPLE LOCATION	Stockpile

Aggregate Physical Property and Quality Tests (ASTM C 33, AASHTO M 6 Specifications)

ASTM C 117 & C 136, AASHTO T 11 & T 27

SIEVE SIZE	% Passing	ASTM C 33 Spec.	AASHTO M 6 Spec.
1"			
3/4"			
1/2"			
3/8"	100	100	100
# 4	100	95 - 100	95 - 100
# 8	90	80 - 100	80 - 100
# 16	64	50 - 85	50 - 85
# 30	36	25 - 60	25 - 60
# 50	16	5 - 30	10 - 30
# 100	5	0 - 10	2 - 10
# 200	1.7	0 - 3	0 - 2
Fineness Modulus	2.89	2.3 - 3.1	2.3 - 3.1

ASTM C 128, AASHTO T 84,
Bulk Specific Gravity = 2.62, Bulk Specific Gravity (SSD) = 2.64, Apparent Specific Gravity = 2.69, Absorption = 1.0%

ASTM D 2419, AASHTO T 176,
Sand Equivalent Value = 87
Specification: 80 Min. (CDOT)

ASTM C 142, AASHTO T 112, Clay Lumps & Friable Particles
FINE AGG. = 0.0%, Specification: 3.0% Max.

ASTM C 123, AASHTO T 113, Lightweight Particles in Aggregate

SAMPLE WT.	LIQUID TYPE / SPECIFIC GRAVITY	LIGHTWEIGHT PARTICLES	SPEC.
215.3	$ZnCl_2$/2.0	0.0%	0.5% Max.
215.3	$ZnBr_2$/2.4	0.0%	3.0% Max.

ASTM C 88, AASHTO T 104, Sodium Sulfate Soundness, 5 Cycles

SIEVE SIZE	GRADING OF ORIGINAL SAMPLE	WEIGHT BEFORE TEST, g	PERCENT PASSING AFTER TEST	WEIGHTED PERCENT LOSS
Minus #100	5			
# 50 to # 100	11			
# 30 to # 50	20	100.0	0.7	0.1
# 16 to # 30	28	100.1	1.4	0.4
# 8 to # 16	26	100.1	0.6	0.2
# 4 to # 8	10	100.1	1.4	0.1
3/8" to # 4	0			
TOTAL	100	FINE AGG. TOTAL 100%		1
SPECIFICATION:				10 Max.

ASTM C 40, AASHTO T 21, Organic Impurities:
Less than Organic Plate No. 1
Specification: Organic Plate No. 3 or Less

COMMENTS:

TABLE 1

WESTEST

845 Navajo Street • Denver, CO 80204

SPECIALISTS TO THE PAVING INDUSTRY

Phone: 303.975.9959 • Fax: 303.975.9969 • Email:office@westest.net

April 4, 2013

Bestway Concrete
455 W. 115th Avenue, Unit 1
Northglenn, CO 80234

Attention: Mr. Dan Bentz

Subject: Laboratory Test Results
Firestone Pit
ASTM C 1260 Potential Alkali Reactivity of Aggregates
ASTM C 33 Fine Aggregate
ASTM C 33 Size No. 57/67 Coarse Aggregate
WesTest Project No. 373513

Gentlemen:

Enclosed as Figures 1 and 2 are the results of potential alkali reactivity testing (mortar bar method), performed on aggregate sampled from the above-referenced source on February 21, 2013. The aggregate was prepared and tested in general accordance with ASTM Procedures. ASTM C 1260 defines the potential of an aggregate for deleterious expansion as follows:

Test Expansion	Classification	Potential for Deleterious ASR
< 0.10%	Innocuous	Low
0.10% to 0.20%	Inconclusive	Not Predictable
> 0.20%	Deleterious	High

Based on the test results of 0.06% expansion at 14 days in solution, 16 days after casting, the potential for deleterious alkali-silica behavior of this aggregate in concrete is considered low.

If you have any questions on the data presented, please contact us at your convenience.

Sincerely,
WesTest

Amy J. Hearon, P.E.

COLORADO LICENSED AMY J. HEARON 43801 4-4-13 PROFESSIONAL ENGINEER

Reviewed by:
WesTest

Zach Wheeler, EIT

AASHTO R18

WESTEST
SPECIALISTS TO THE PAVING INDUSTRY
845 Navajo Street
Denver, CO 80204
303.975.9959

LABORATORY TEST REPORT

POTENTIAL ALKALI REACTIVITY OF AGGREGATES
(MORTAR-BAR METHOD)
ASTM C 1260

CLIENT: Bestway Concrete
PROJECT NO.: 336712

REPORT DATE: April 24, 2012
SAMPLE ID: 33671

AGGREGATE:
SOURCE: Firestone Pit
SIZE: ASTM C 33 Fine Aggregate

COMMENTS: Aggregate graded as per Section 8.2, Table 1

CEMENT:
SOURCE: Holcim
TYPE: I/II GU
AUTOCLAVE EXPANSION: 0.02%
ALKALIS CONTENT (as Na equivalent): 0.75%
COMMENTS: Cement data provided by Holcim

MIX WATER:
0.47 w/c ratio

EFFECTIVE GAUGE LENGTH = 250 mm

Specimen	4/5/12	4/6/12	4/10/12		4/13/12		4/17/12		4/20/12	
	Initial	Zero	4 Days		7 Days		11 Days		14 Days	
	Comparator Reading	Comparator Reading	Comparator Reading	Length Change	Comparator Reading	Length Change	Comparator Reading	Length Change	Comparator Reading	Length Change
A	-0.090	0.076	0.078	0.00%	0.098	0.01%	0.152	0.03%	0.212	0.05%
B	-0.194	-0.030	-0.022	0.00%	-0.010	0.01%	0.042	0.03%	0.106	0.05%
C	-0.416	-0.252	-0.248	0.00%	-0.230	0.01%	-0.172	0.03%	-0.116	0.05%
AVERAGE		-0.069	-0.064	0.00%	-0.047	0.01%	0.007	0.03%	0.067	0.05%

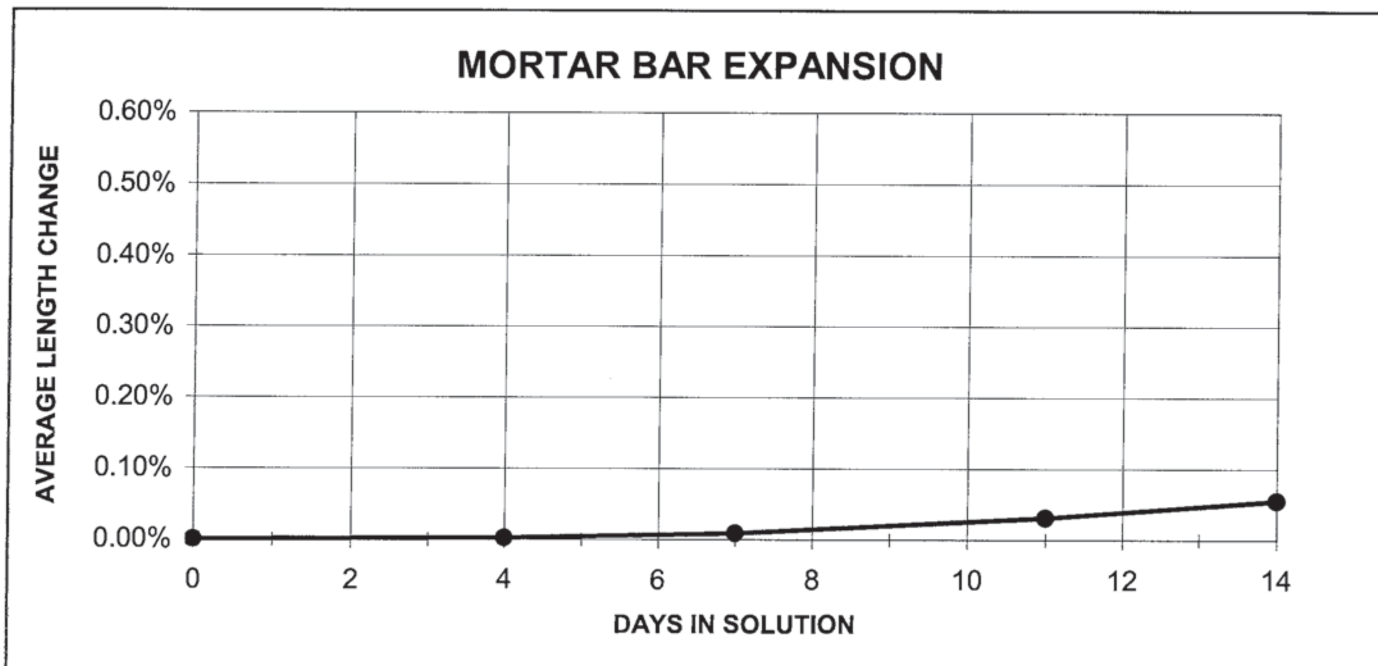


FIGURE 1

WESTEST
SPECIALISTS TO THE PAVING INDUSTRY
845 Navajo Street
Denver, CO 80204
303.975.9959

LABORATORY TEST REPORT

POTENTIAL ALKALI REACTIVITY OF AGGREGATES
(MORTAR-BAR METHOD)
ASTM C 1260

CLIENT: Bestway Concrete
PROJECT NO.: 373513

REPORT DATE: April 4, 2013
SAMPLE ID: 3735A

AGGREGATE:
SOURCE: Firestone Pit
SIZE: ASTM C 33 Size No. 57/67 Coarse Aggregate

COMMENTS: Aggregate graded as per Section 8.2, Table 1

CEMENT:
SOURCE: Holcim
TYPE: I/II
AUTOCLAVE EXPANSION: -0.03%
ALKALIS CONTENT (as Na equivalent): 0.68%
COMMENTS: Cement data provided by Holcim

MIX WATER:
0.47 w/c ratio

EFFECTIVE GAUGE LENGTH = 250 mm

	3/7/13	3/8/13	3/11/13		3/15/13		3/18/13		3/22/13	
	Initial	Zero	3 Days		7 Days		10 Days		14 Days	
Specimen	Comparator Reading	Comparator Reading	Comparator Reading	Length Change	Comparator Reading	Length Change	Comparator Reading	Length Change	Comparator Reading	Length Change
A	-0.980	-0.832	-0.828	0.00%	-0.786	0.02%	-0.740	0.04%	-0.694	0.06%
B	-0.250	-0.104	-0.090	0.01%	-0.062	0.02%	-0.010	0.04%	0.040	0.06%
C	-0.072	0.076	0.086	0.00%	0.118	0.02%	0.170	0.04%	0.208	0.05%
AVERAGE		-0.287	-0.277	0.00%	-0.243	0.02%	-0.193	0.04%	-0.149	0.06%

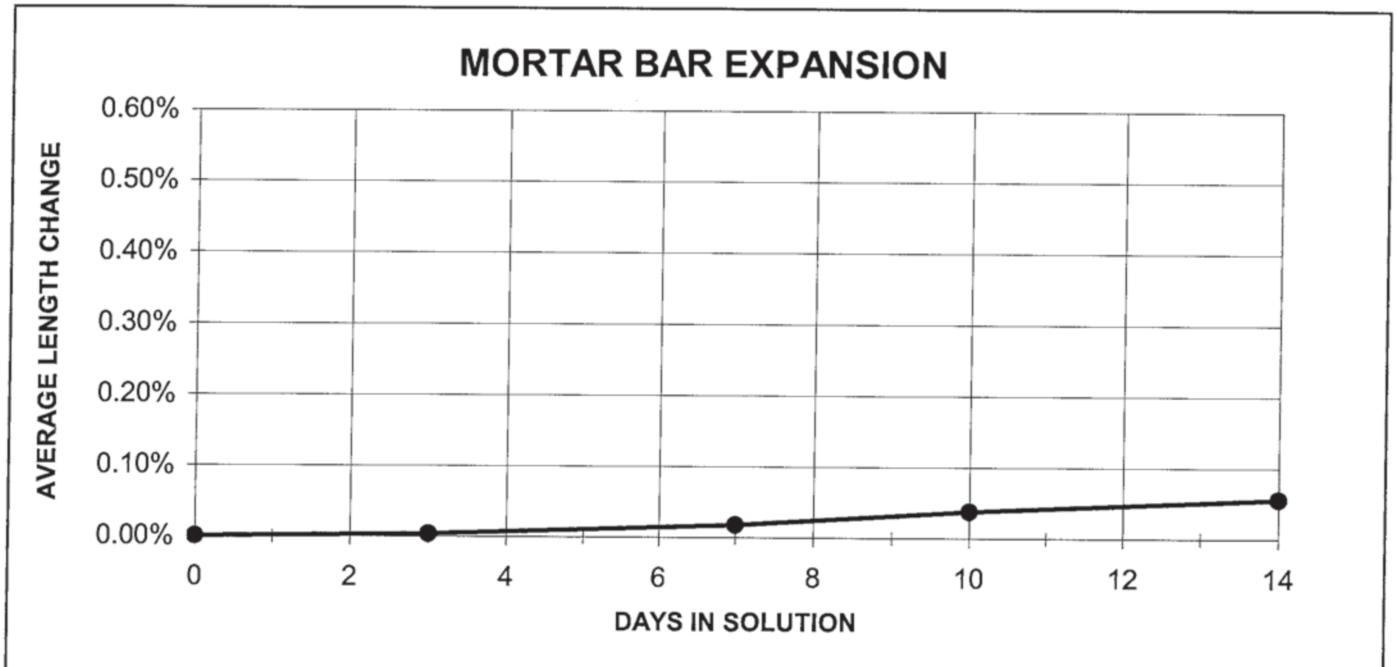


FIGURE 2

Petrographic Analysis of 2- to 4-inch Coarse Aggregate

M-8828
Pioneer S & G Santa Fe Location A. Rager
2 - 4" aggregate 12/18/2015 n = 50

Rock Type	Potentially Alkali Reactive?	Condition	Particle Count	% rock type by condition	% rock type
Granite	No	Satisfactory	36	72%	72%
		Fair		0%	
		Poor		0%	
Gneiss	No	Satisfactory	6	12%	12%
		Fair		0%	
		Poor		0%	
Quartzite	No	Satisfactory	3	6%	6%
		Fair		0%	
		Poor		0%	
Diorite	No	Satisfactory	3	6%	6%
		Fair		0%	
		Poor		0%	
Schist	No	Satisfactory	1	0%	2%
		Fair		2%	
		Poor		0%	
Quartz Diorite	No	Satisfactory	1	2%	2%
		Fair		0%	
		Poor		0%	

Appendix B

Cement Material Certification Report

Holcim

Material Certification Report

Material:	Portland Cement	Test Period:	01-Apr-2014
Type:	I-II	To:	30-Apr-2014

Certification

This Holcim cement meets the specifications of ASTM C150 for Type I-II cement, and complies with AASHTO M85 specifications for Type I-II cement.

General Information

Supplier:	Holcim (US) Inc.	Source Location:	Ste. Genevieve Plant
Address:	2942 US Highway 61 Bloomsdale, MO 63627		2942 US Highway 61 Bloomsdale, MO 63627
Telephone:	636-524-8155	Contact:	Erin Watson
Date Issued:	14-May-2014		

The following information is based on average test data during the test period.
The data is typical of cement shipped by Holcim; individual shipments may vary.

Tests Data on ASTM Standard Requirements

Chemical

Item	Limit[A]	Result
SiO_2 (%)	-	19.7
Al_2O_3 (%)	6.0 max	4.5
Fe_2O_3 (%)	6.0 max	3.2
CaO (%)	-	64.3
MgO (%)	6.0 max	2.6
SO_3 (%)	3.0 max[B]	3.6
Loss on Ignition (%)	3.0 max	2.6
Insoluble Residue (%)	0.75 max	0.45
CO_2 (%)	-	1.3
Limestone (%)	5.0 max	3.3
$CaCO_3$ in Limestone (%)	70 min	89
Inorganic Processing Addition (%)	5.0 max	0.0
Potential Phase Compositions[C]:		
C_3S (%)	-	62
C_2S (%)	-	7
C_3A (%)	8 max	6
C_4AF (%)	-	9
$C_3S + 4.75C_3A$ (%)	-	91.3

Physical

Item	Limit[A]	Result
Air Content (%)	12 max	7
Blaine Fineness (m^2/kg)	260 min	383
Autoclave Expansion (%) (C151)	0.80 max	0.10
Compressive Strength MPa (psi):		
3 days	12.0 (1740) min	30.0 (4350)
7 days	19.0 (2760) min	36.5 (5300)
Initial Vicat (minutes)	45-375	78
Mortar Bar Expansion (%) (C1038)	-	0.009

Tests Data on ASTM Optional Requirements

Chemical

Item	Limit[A]	Result
Equivalent Alkalies (%)	0.60 max	0.54

Physical

Item	Limit[A]	Result
False Set (%)	50 min	75

Notes

[A] Dashes in the limit / result columns mean Not Applicable.
[B] It is permissible to exceed the specification limit provided that ASTM C1038 Mortar Bar Expansion does not exceed 0.020 % at 14 days.
[C] Adjusted per Annex A1.6 of ASTM C150 and AASHTO M85.
[D] Test result represents most recent value and is provided for information only. Analysis of Heat of Hydration has been carried out by CTLGroup, Skokie, IL.
Equavalent Alkalies (%) Minimum = 0.5, Maximum = 0.58
This data may have been reported on previous mill certificates.

Additional Data

Inorganic Processing Addition Data

Item	Result[A]
Type	-
Amount (%)	-
SiO_2 (%)	-
Al_2O_3 (%)	-
Fe_2O3 (%)	-
CaO (%)	-
SO_3 (%)	-

Base Cement Phase Composition

Item	Result
C_3S (%)	64
C_2S (%)	7
C_3A (%)	6
C_4AF (%)	10

By , Quality Manager

Appendix C

Water Reducing Admixture Data Sheet

EUCON WR®

Water Reducing Admixture

EUCLID CHEMICAL

Description

EUCON WR is a solution of modified salt of ligno sulfonic acid which is completely free of any added chloride ions. It is a water-reducing, normal-set admixture for concrete. It provides a more plastic and cohesive mix in the fresh concrete and better durability, reduced shrinkage and less permeability in the hardened concrete.

- Ready mixed concrete
- Prestressed concrete
- Precast concrete
- General use concrete
- Lightweight concrete
- Expansive concrete

Features/Benefits

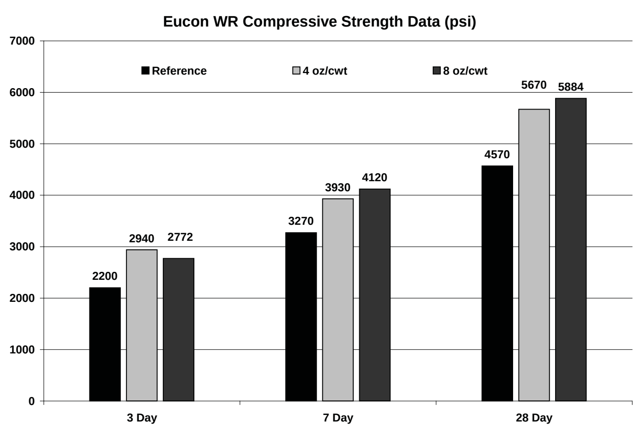
- Provides easier handling and finishing
- Increases strength
- Provides increased durability
- Reduces shrinkage and permeability

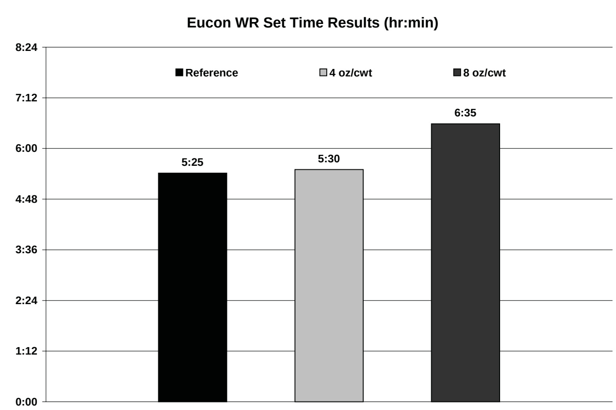
Technical Information

Perfomance Data

The following test results were achieved using typical ASTM C 494 mix design requirements, 517 lb/yd^3 (307 kg/m^3) cement content and similar (± 0.5)% air content.

These results were obtained under laboratory conditions with materials and mix designs meeting the specifications of ASTM C 494. Changes in materials and mix designs can affect the dosage response of EUCON WR.





EUCON WR is packaged in bulk, 275 gal (1041 L) totes, 55 gal (208 L) drums and 5 gal (18.9 L) pails.

1 year in original, unopened container.

EUCON WR meets or exceeds the requirements of:

- ASTM C 494, Type A and Type D
- AASHTO M 194
- ANSI/NSF STD 61 registered

Directions for Use

EUCON WR is typically used at dosages of 2 to 10 oz per 100 lbs (130 to 650 mL per 100 kg) of cementitious material. Higher dosages are acceptable with prior testing and confirmation of the desired performance with specific materials being used.

EUCON WR should be added to the initial batch water of the concrete mixture. Do not dispense onto dry cement.

Precautions/Limitations

- Care should be taken to maintain EUCON WR above freezing; however, freezing and subsequent thawing will not harm the material if thoroughly agitated.
- Add to mix independent of other admixtures.
- In all cases, consult the Safety Data Sheet before use.

Rev. 11.14

Appendix D

Photographs of 8-inch NMSA Block Casting

Figure D-1: Batched aggregates for 8-inch NMSA blocks

Figure D-2: Placing aggregates into concrete mixer loading hopper

Figure D-3: Hopper loading 1-cubic yard concrete mixer

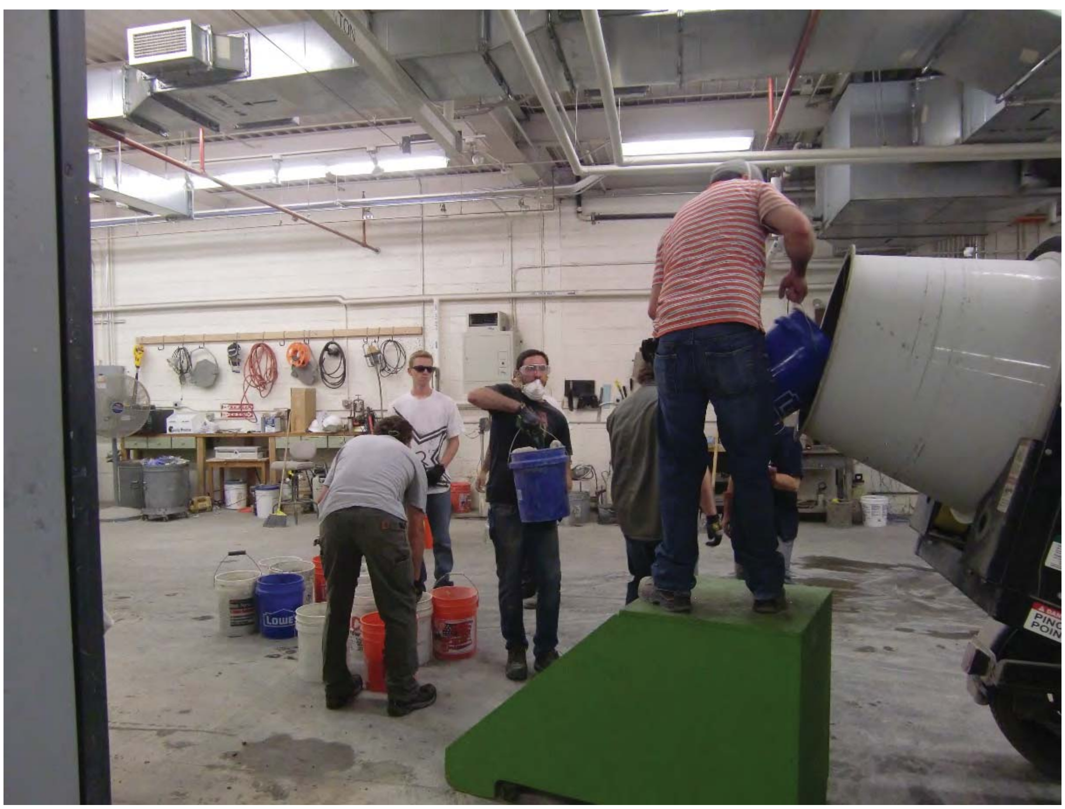


Figure D-4: Manual loading of 2- to 4-inch coarse aggregate

Figure D-5: 8-inch NMSA concrete mixing (note that 4- to 8-inch

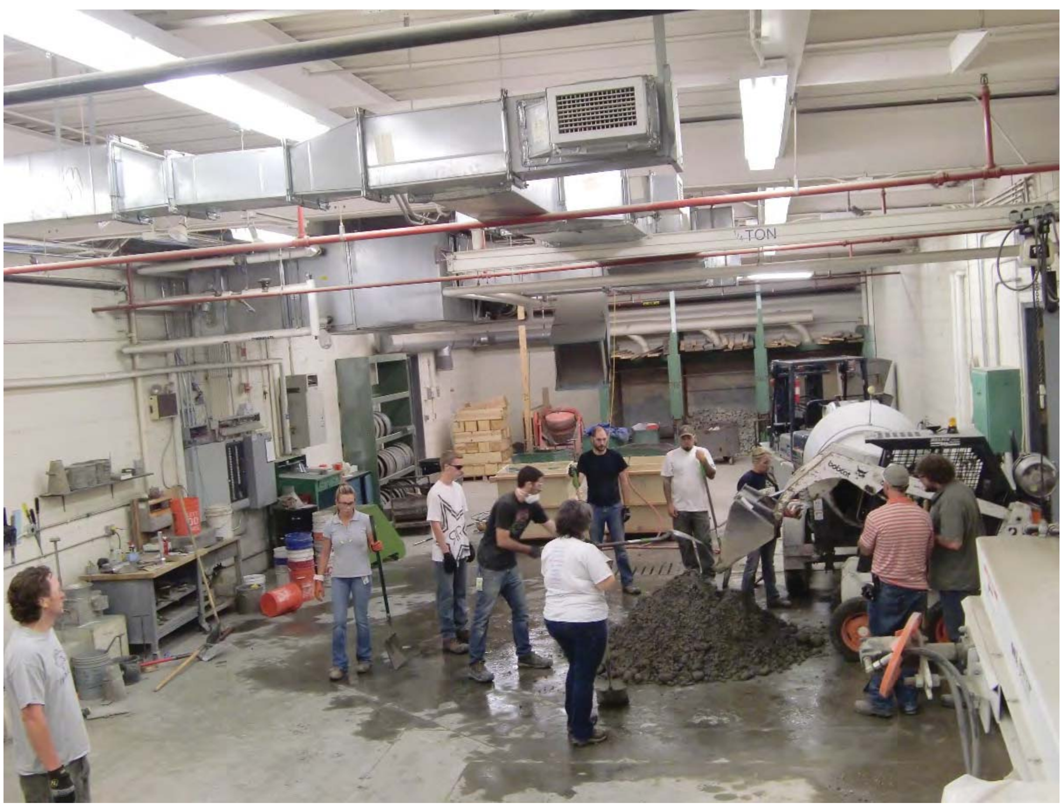


Figure D-6: Unloading 1-cubic yard mixer

Figure D-7: Adding 4- to 8-inch coarse aggregate to concrete

Figure D-8: Mixing 4- to 8-inch aggregate into concrete

Figure D-9: Placing 8-inch NMSA concrete into forms

Figure D-10: Consolidating 8-inch NMSA concrete

Figure D-11: Finishing 8-inch NMSA concrete block

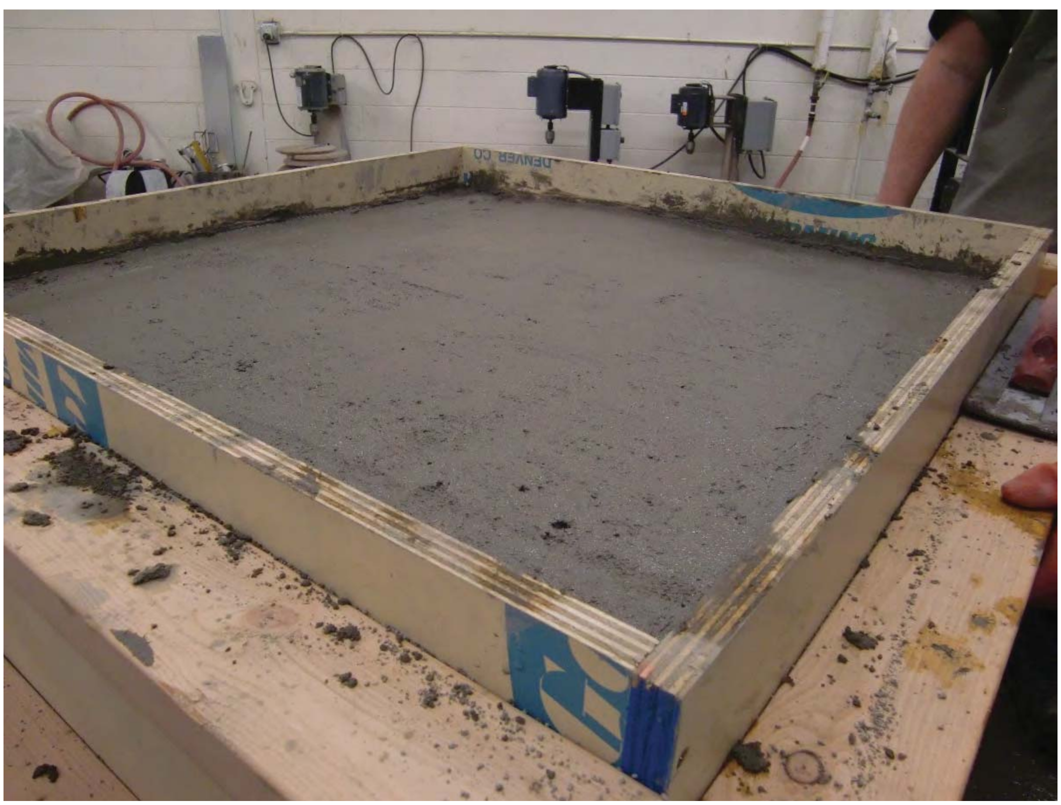
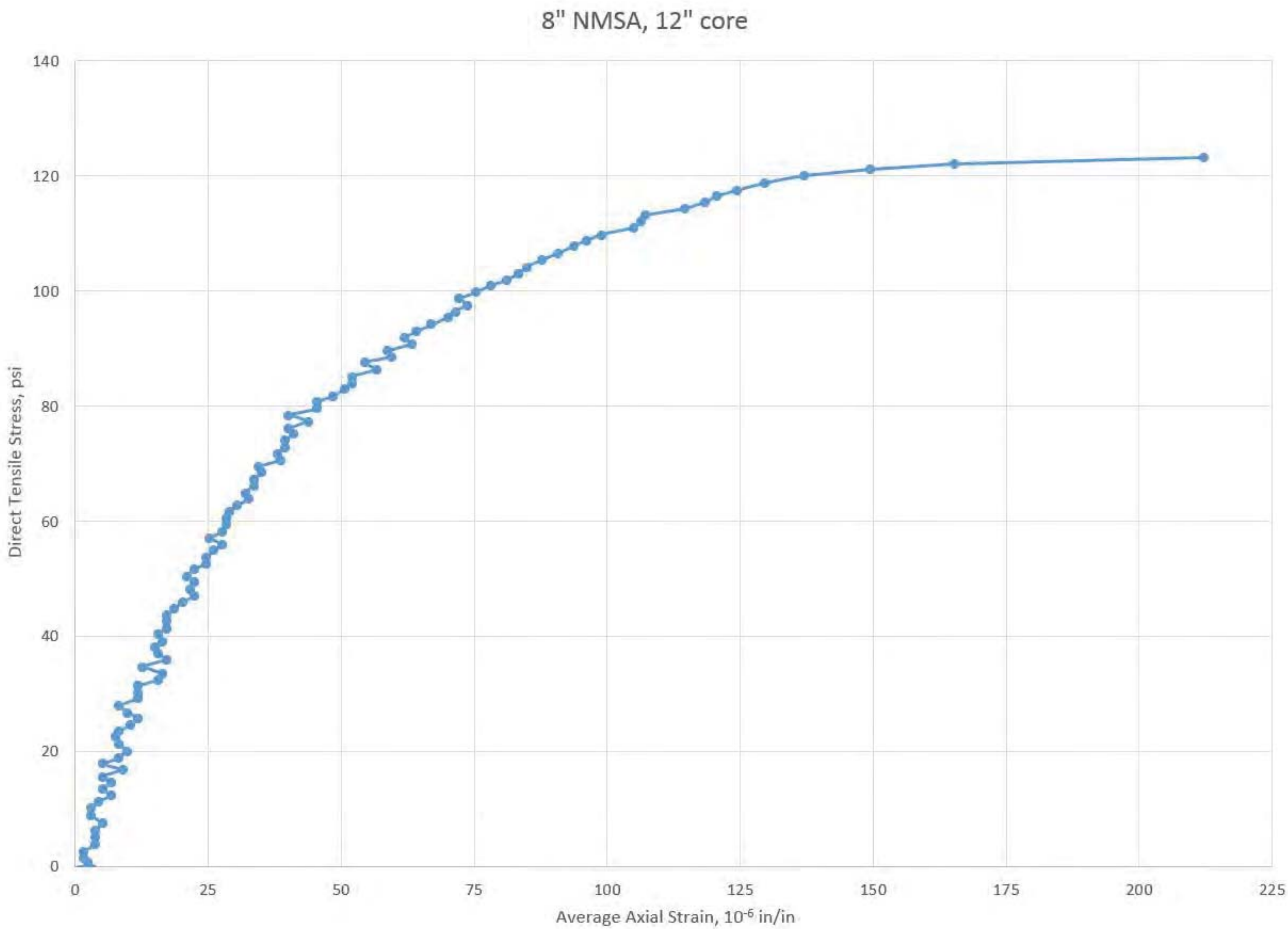
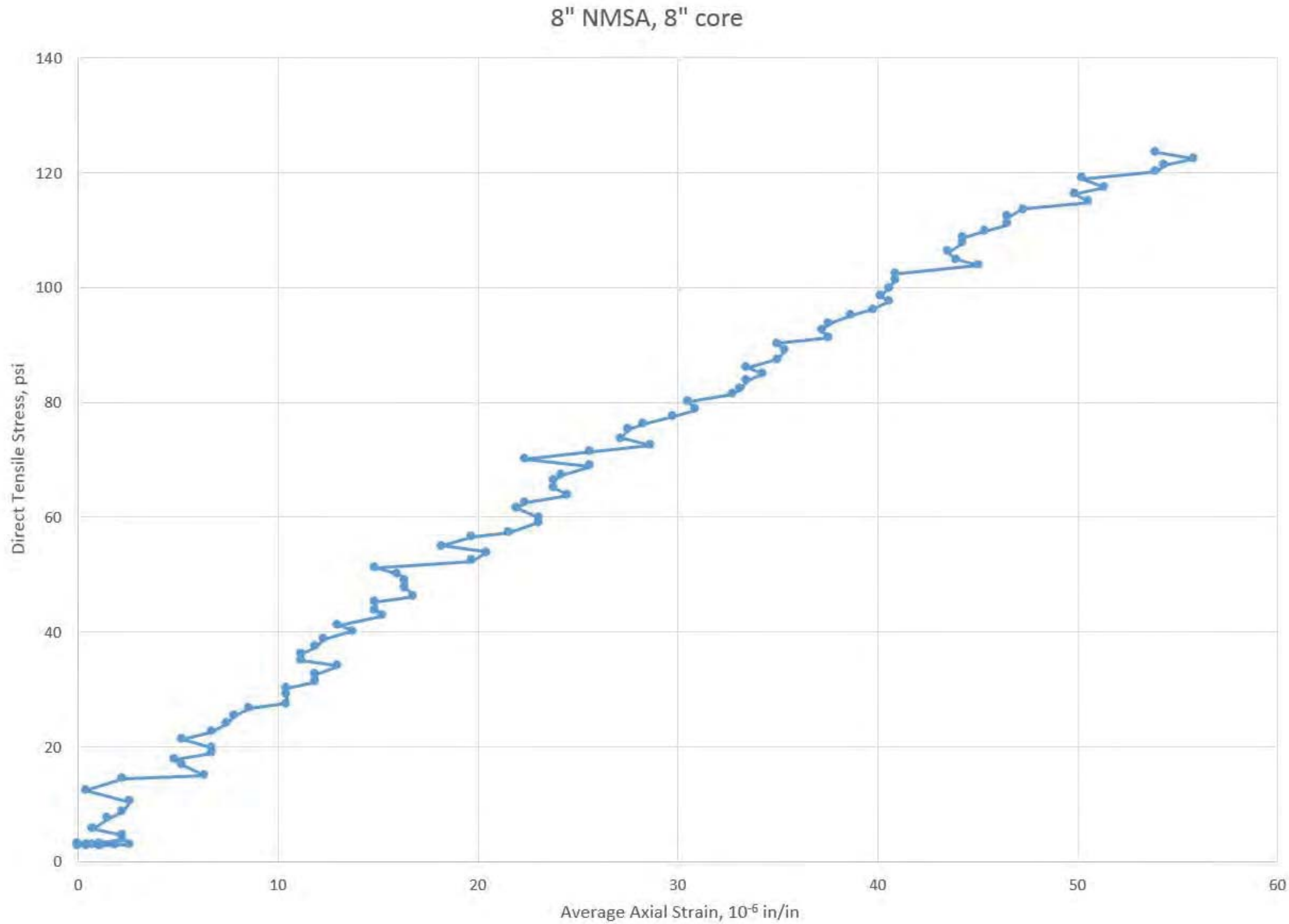


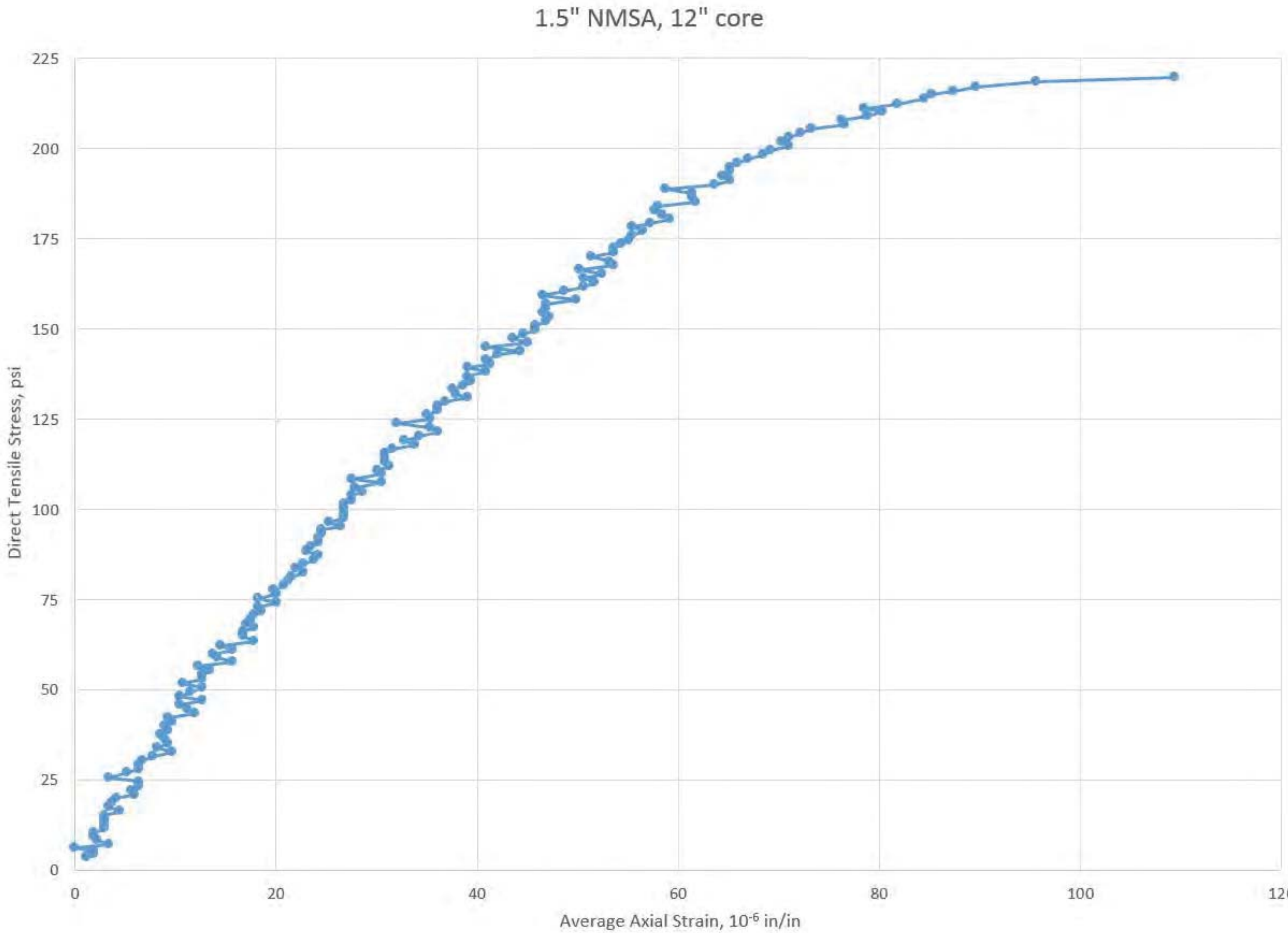
Figure D-12: Completed 8-NMSA concrete block

Appendix E

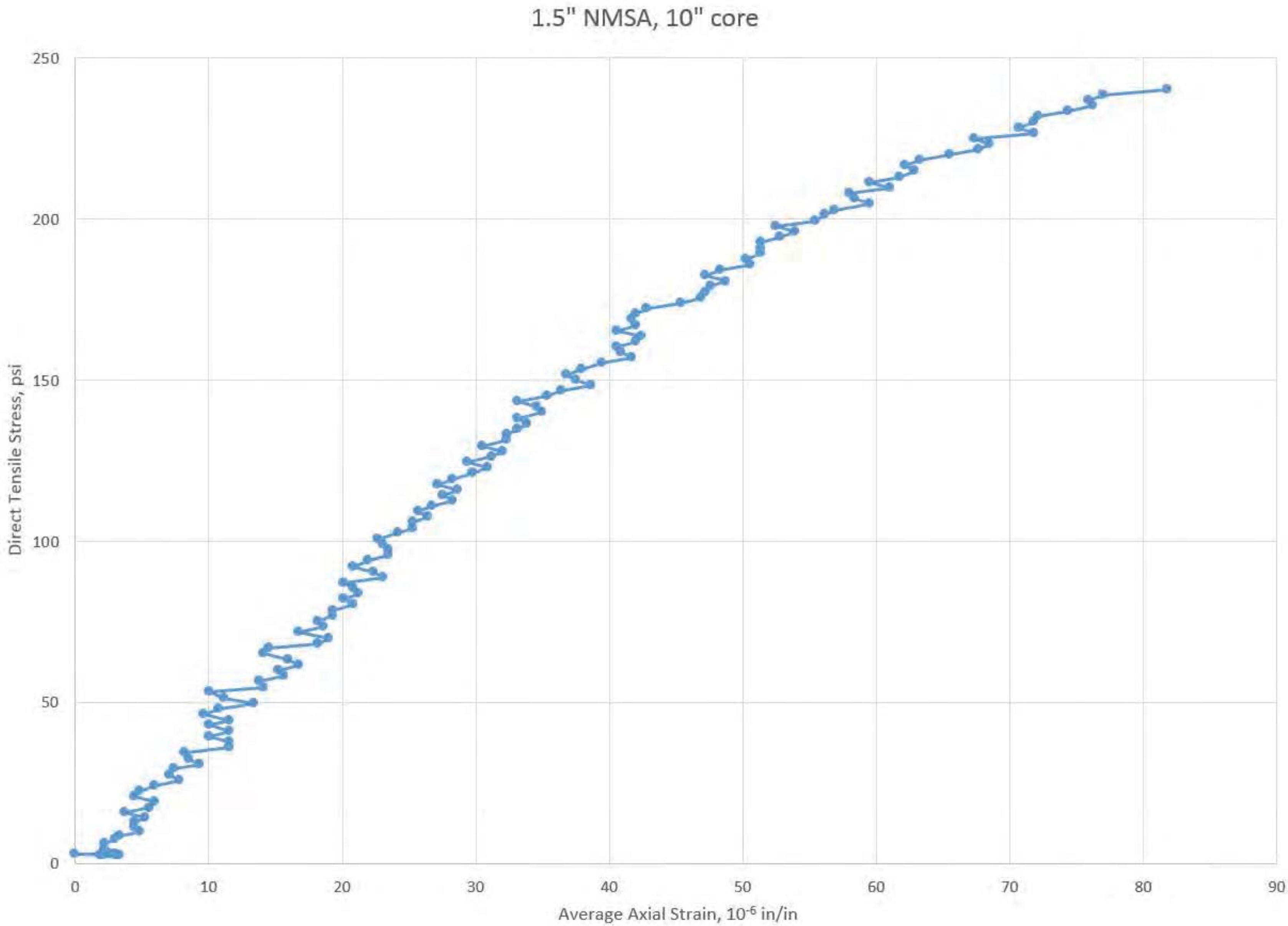
Static Direct Tension Test Results


8" NMSA, 12" core
Direct Tensile Stress, psi
0
20
40
60
80
100
120
140
0
25
50
75
100
125
150
175
200
225
Average Axial Strain, 10-6 in/in

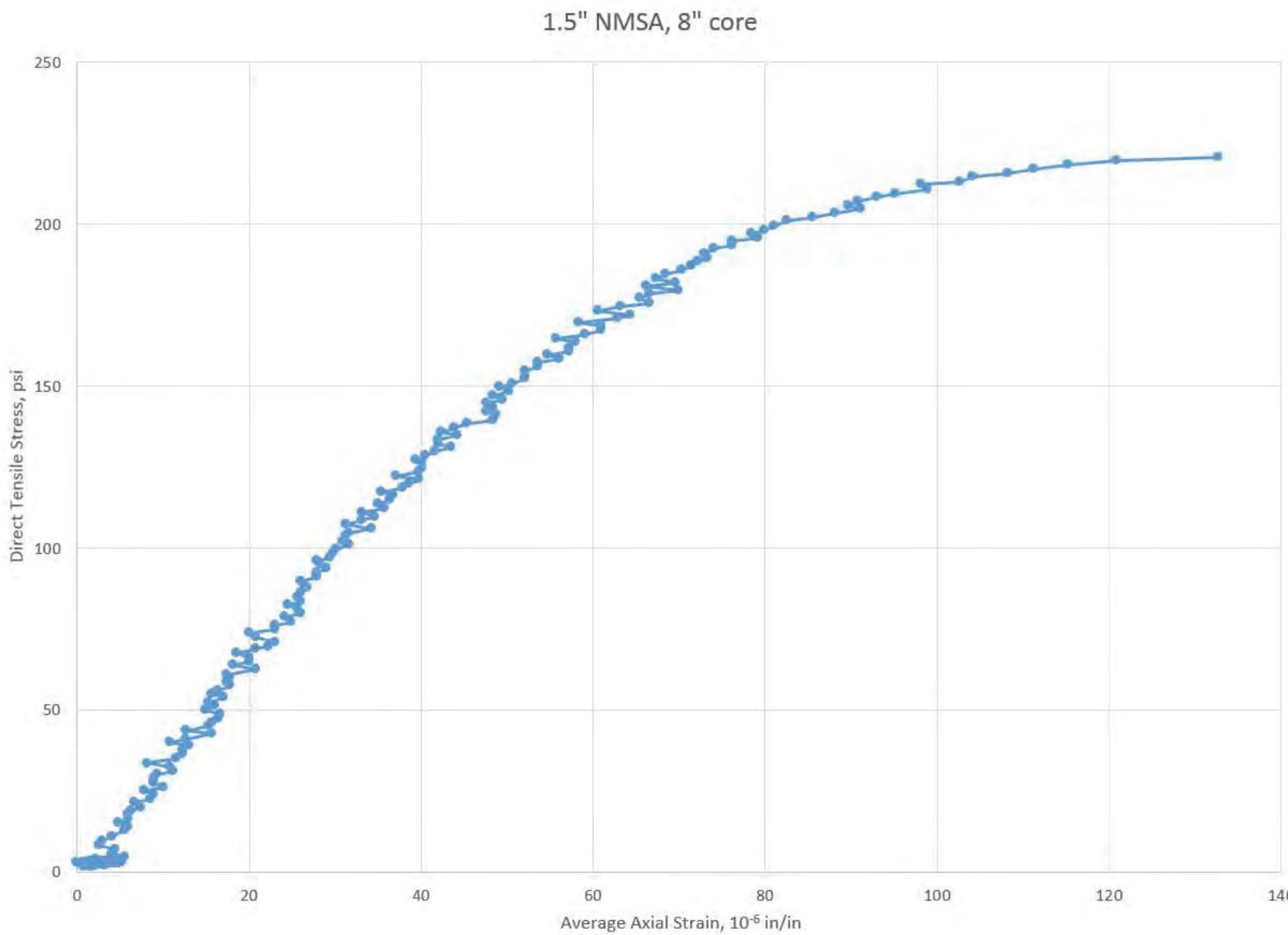

8" NMSA, 8" core
Direct Tensile Stress, psi
Average Axial Strain, 10-6 in/in
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60

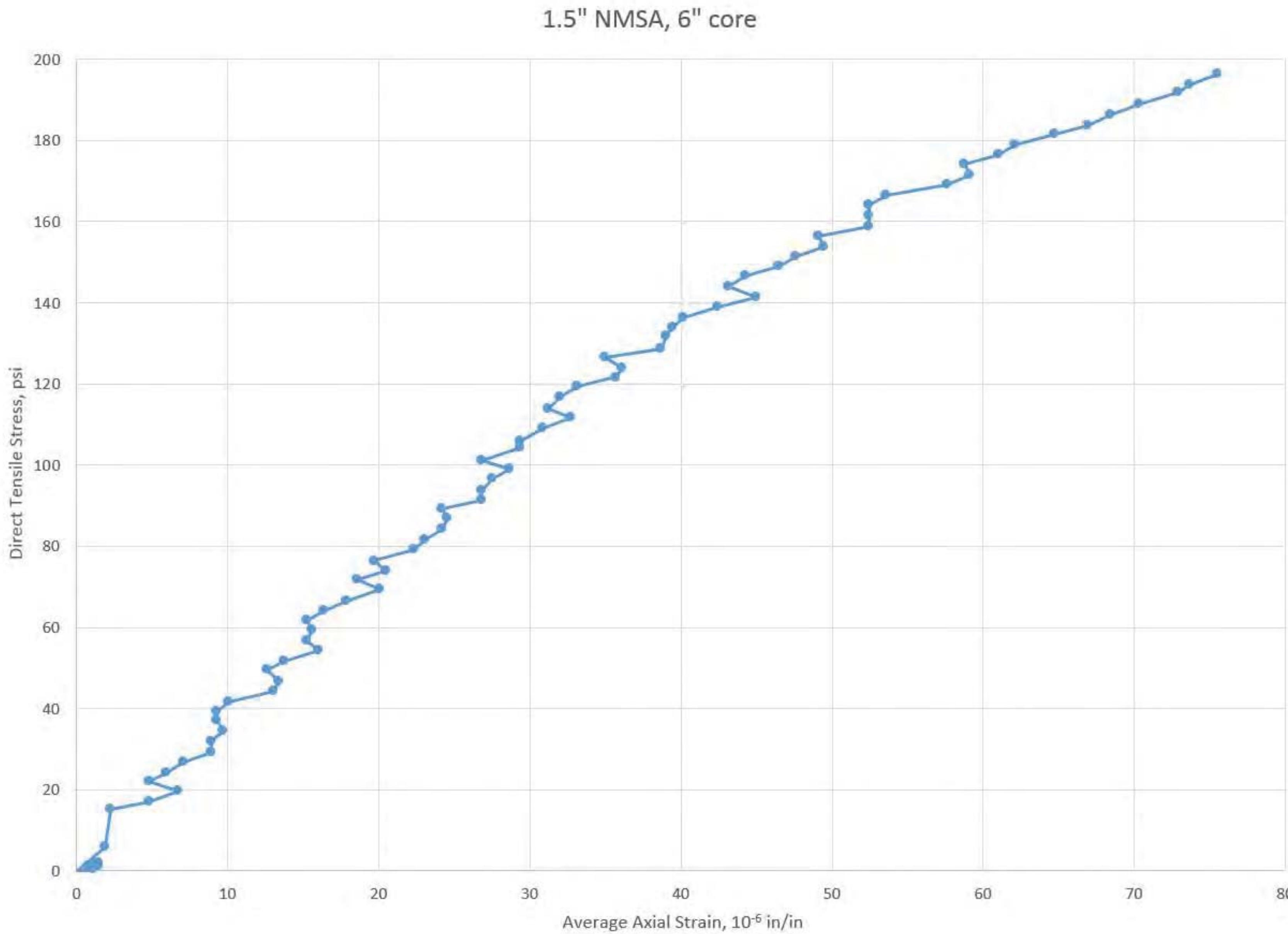


1.5" NMSA, 12" core
Direct Tensile Stress, psi
0
25
50
75
100
125
150
175
200
225
0
20
40
60
80
100
120
Average Axial Strain, 10-6 in/in

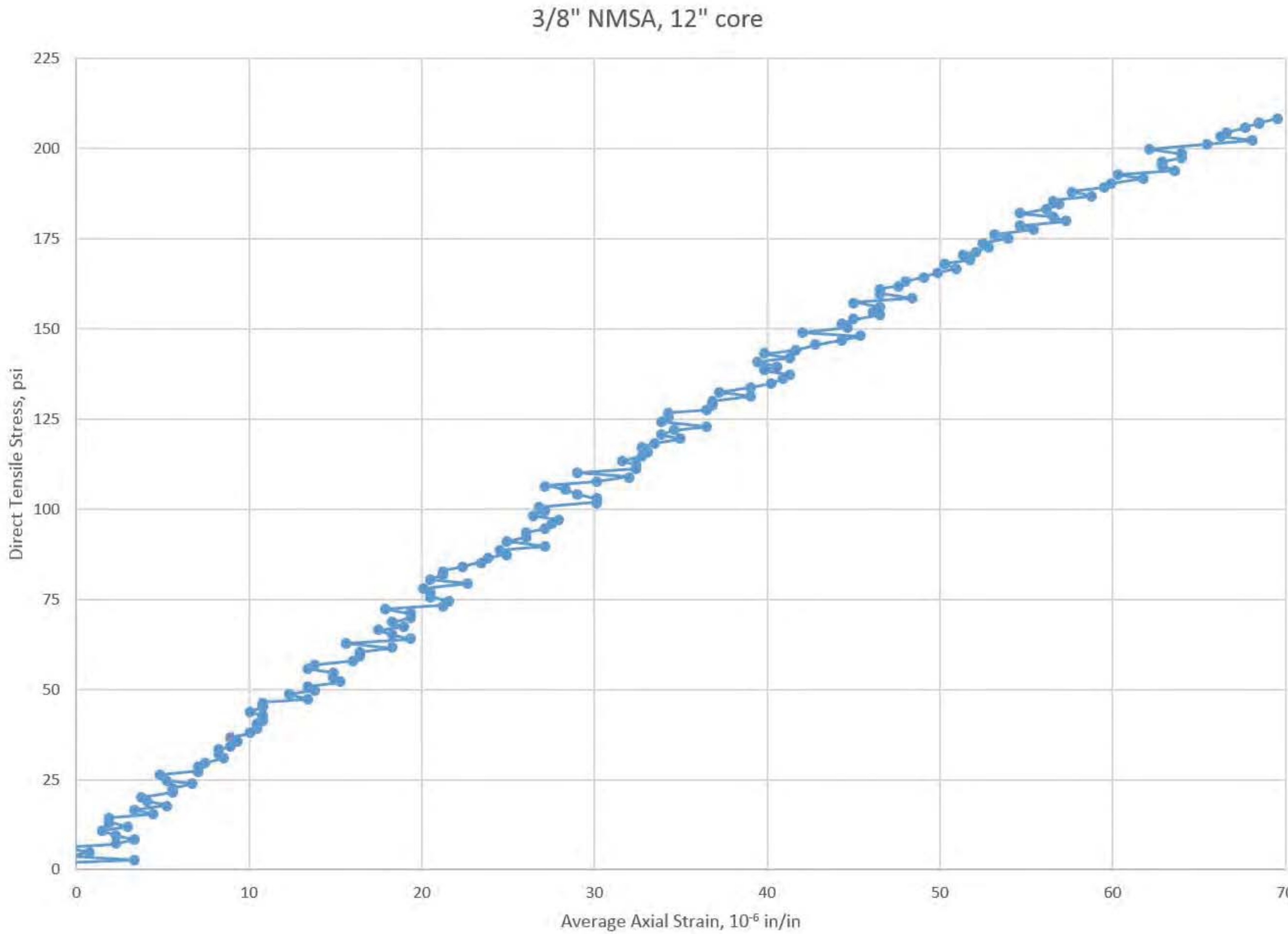


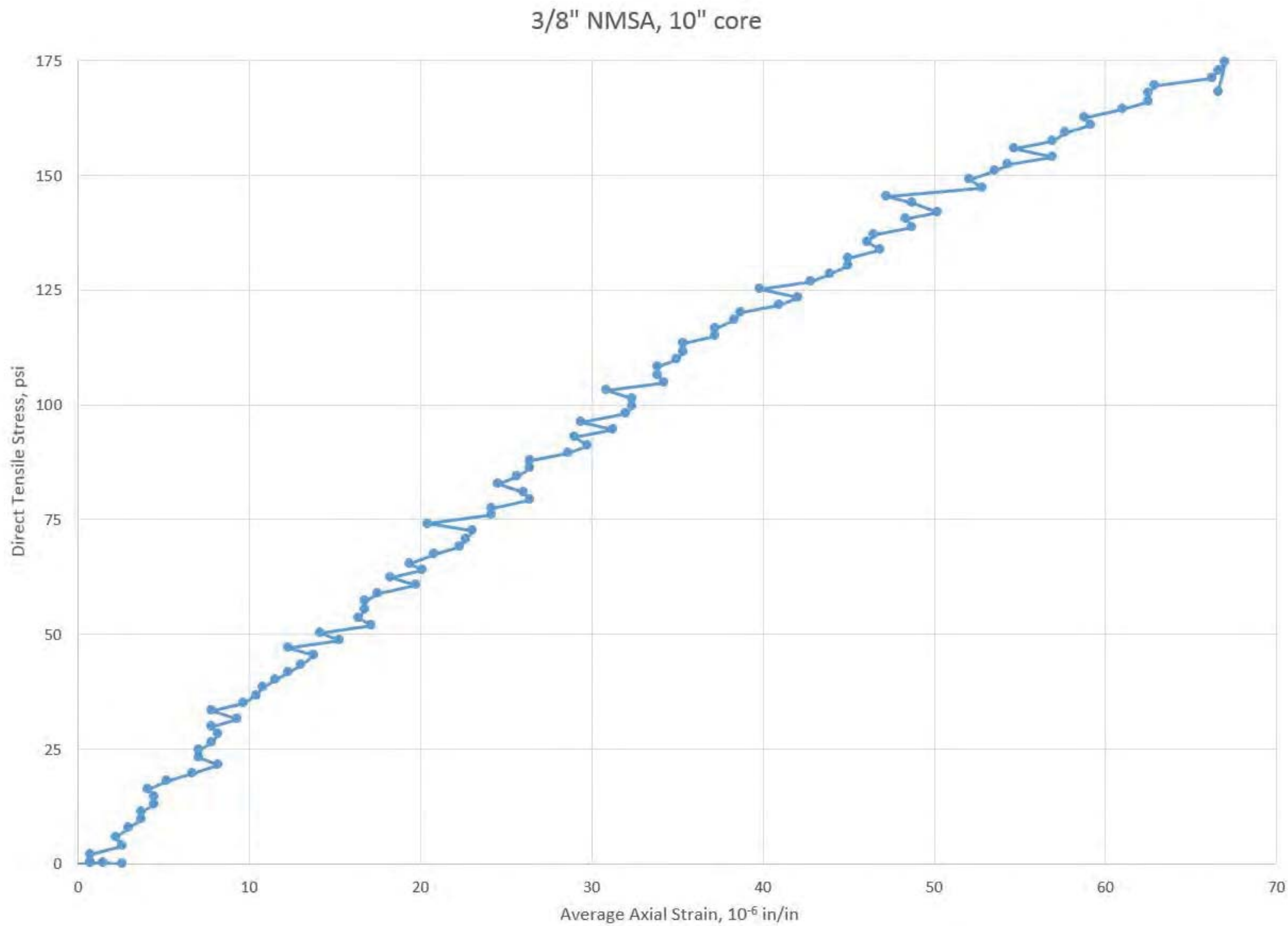
1.5" NMSA, 10" core
Direct Tensile Stress, psi
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
Average Axial Strain, 10-6 in/in


1.5" NMSA, 8" core
Direct Tensile Stress, psi
250
200
150
100
50
0
0
20
40
60
80
100
120
140
Average Axial Strain, 10-6 in/in

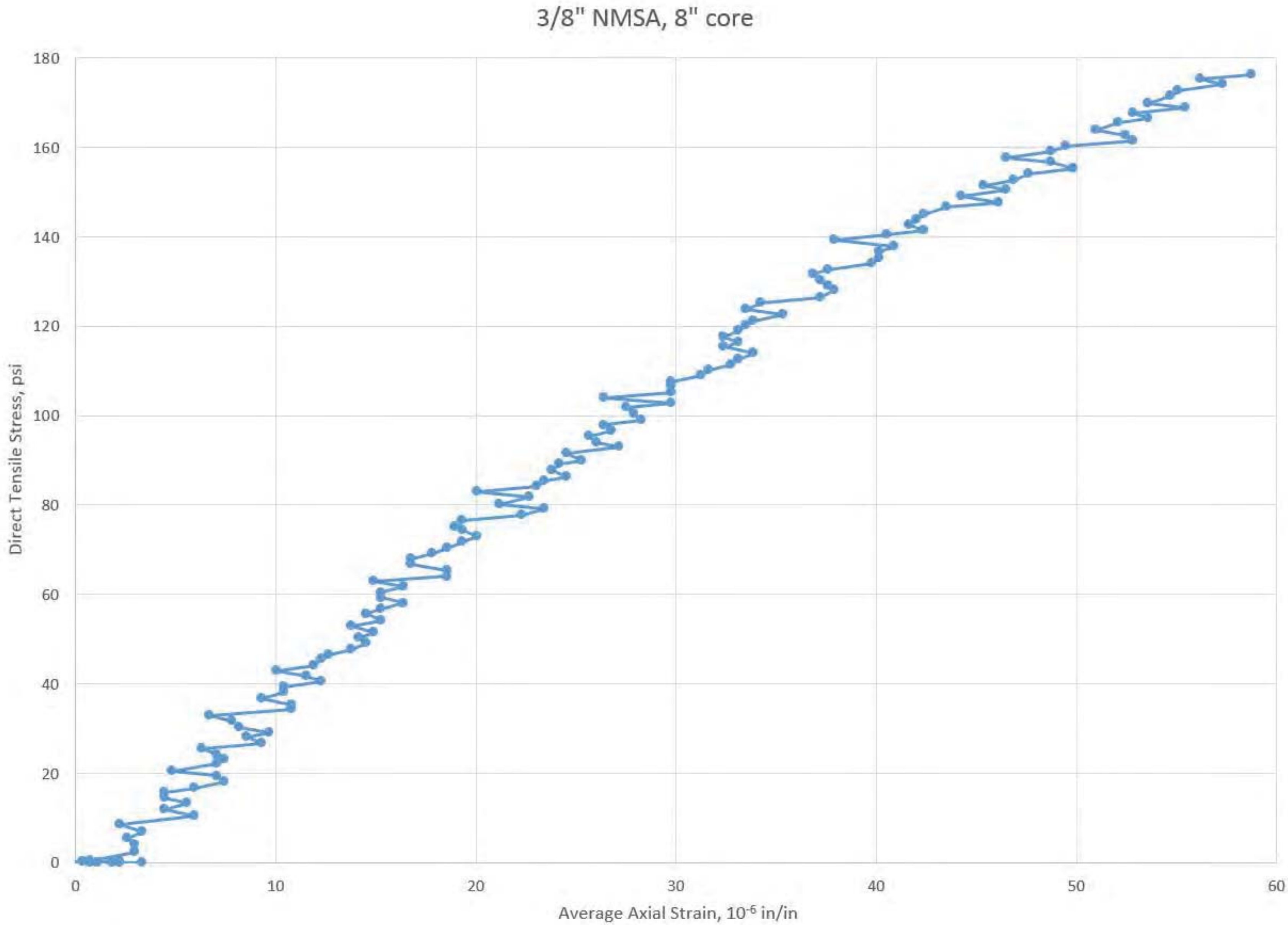


1.5" NMSA, 6" core
Direct Tensile Stress, psi
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50
60
70
80
Average Axial Strain, 10-6 in/in

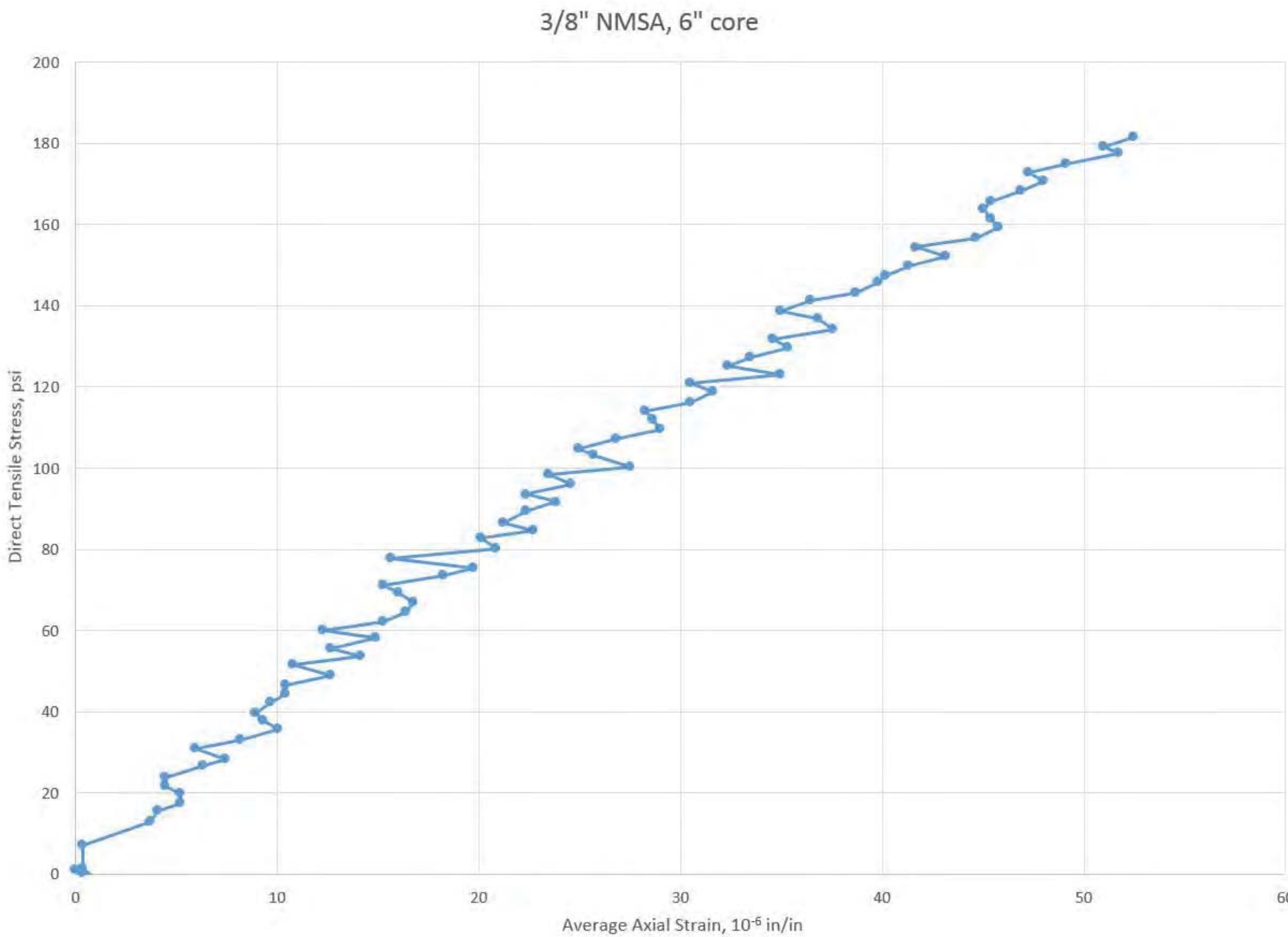

3/8" NMSA, 12" core
Direct Tensile Stress, psi
Average Axial Strain, 10-6 in/in
0
25
50
75
100
125
150
175
200
225
0
10
20
30
40
50
60
70



3/8" NMSA, 10" core
Direct Tensile Stress, psi
175
150
125
100
75
50
25
0
0
10
20
30
40
50
60
70
Average Axial Strain, 10-6 in/in



3/8" NMSA, 8" core
Direct Tensile Stress, psi
Average Axial Strain, 10-6 in/in
0
20
40
60
80
100
120
140
160
180
0
10
20
30
40
50
60

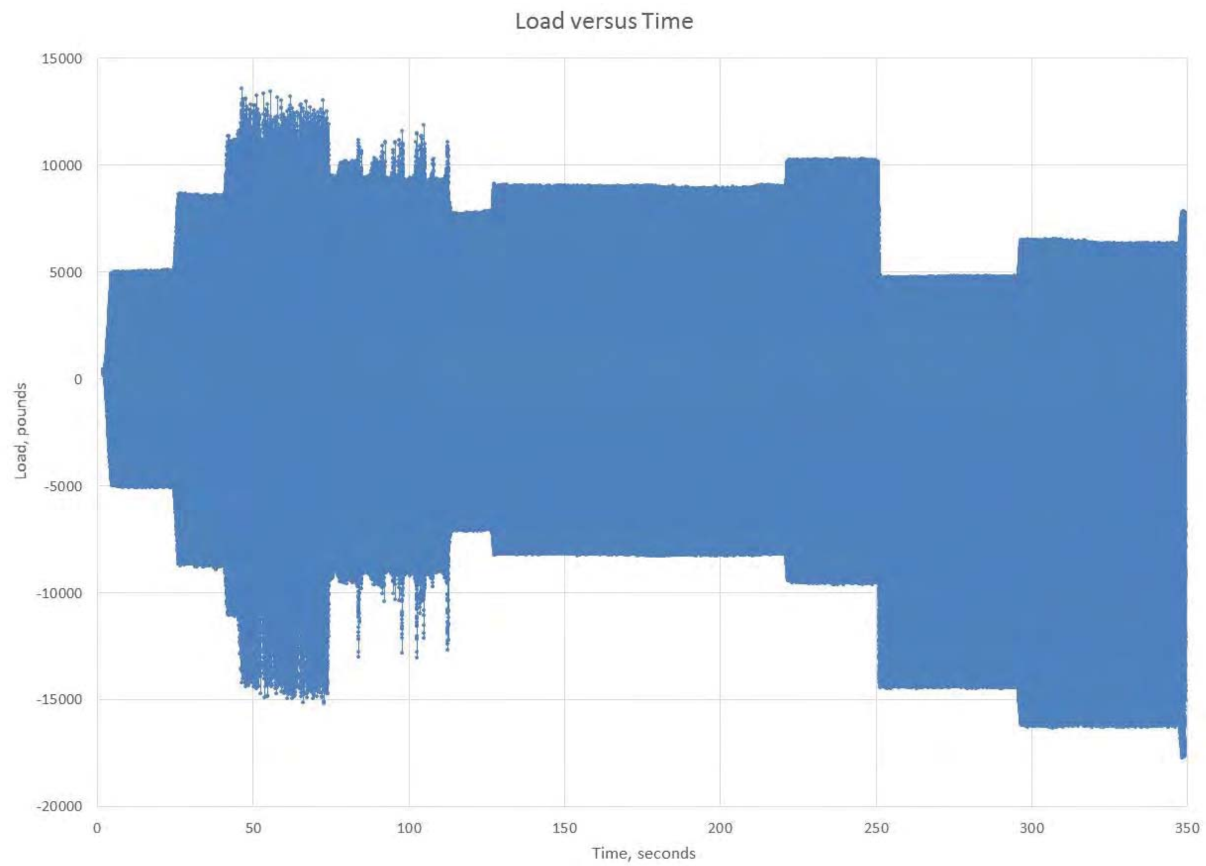


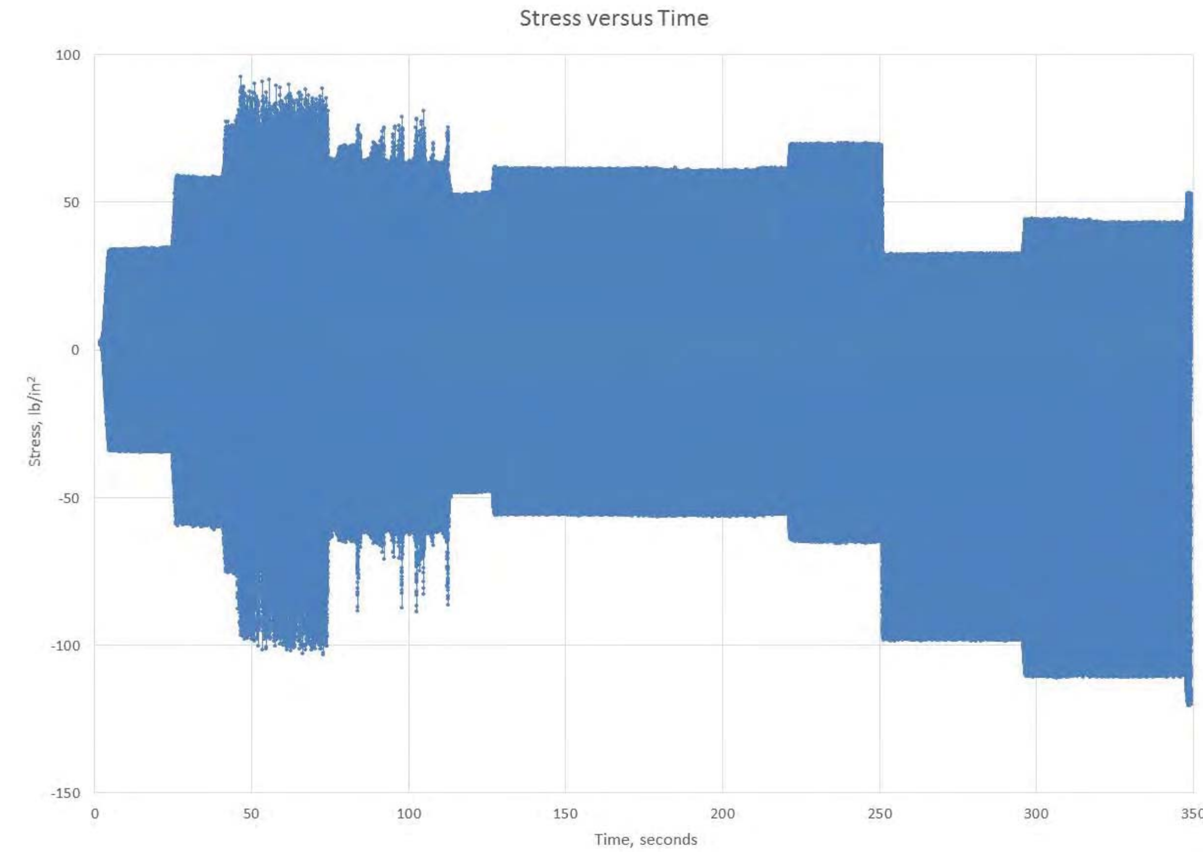
3/8" NMSA, 6" core
Direct Tensile Stress, psi
Average Axial Strain, 10-6 in/in
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50
60

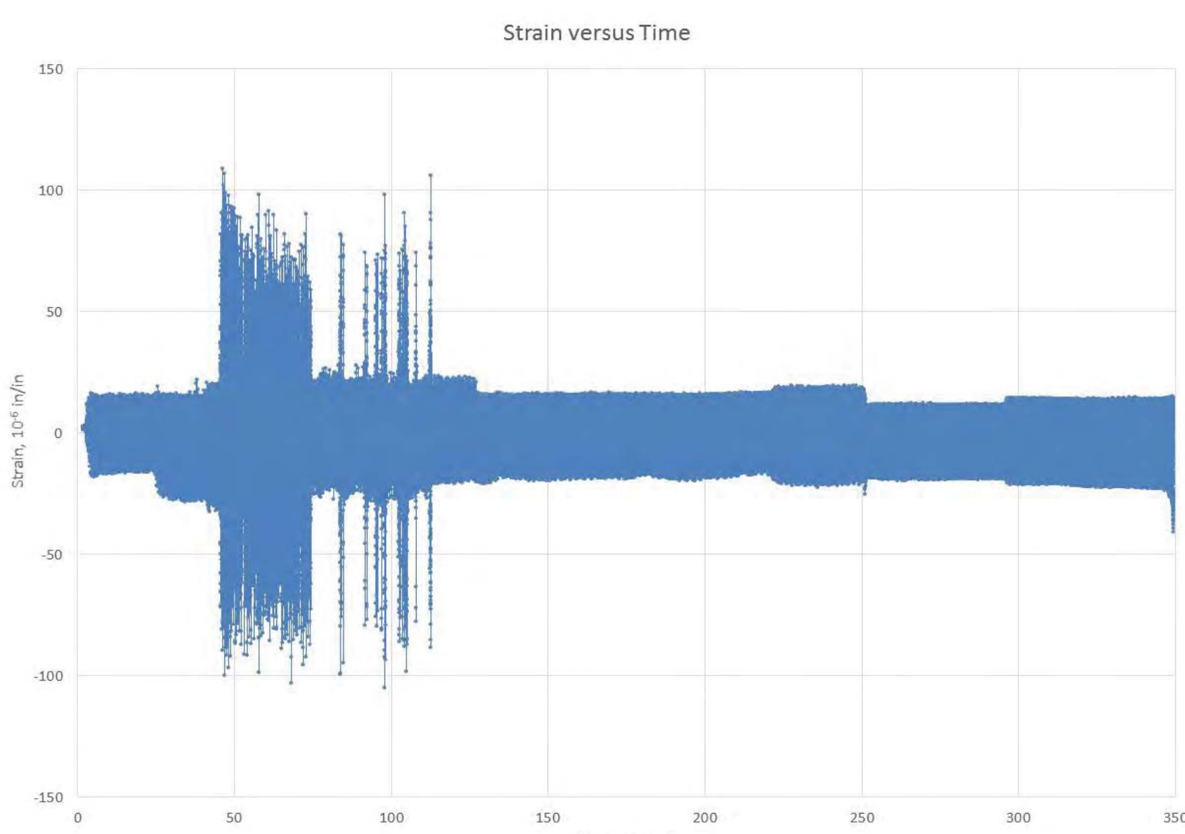
Appendix F

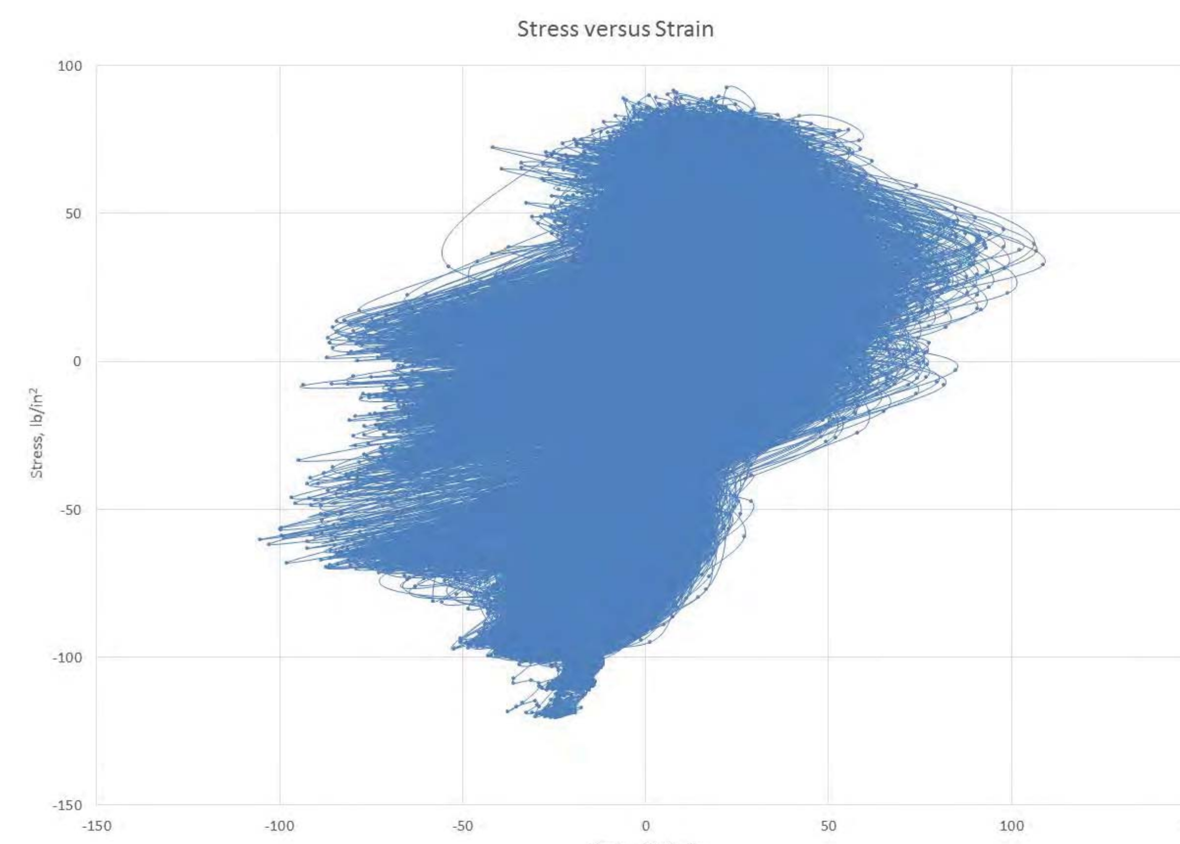
Cyclic Dynamic Direct Tension Test Results

8-inch NMSA 14-inch Diameter Core

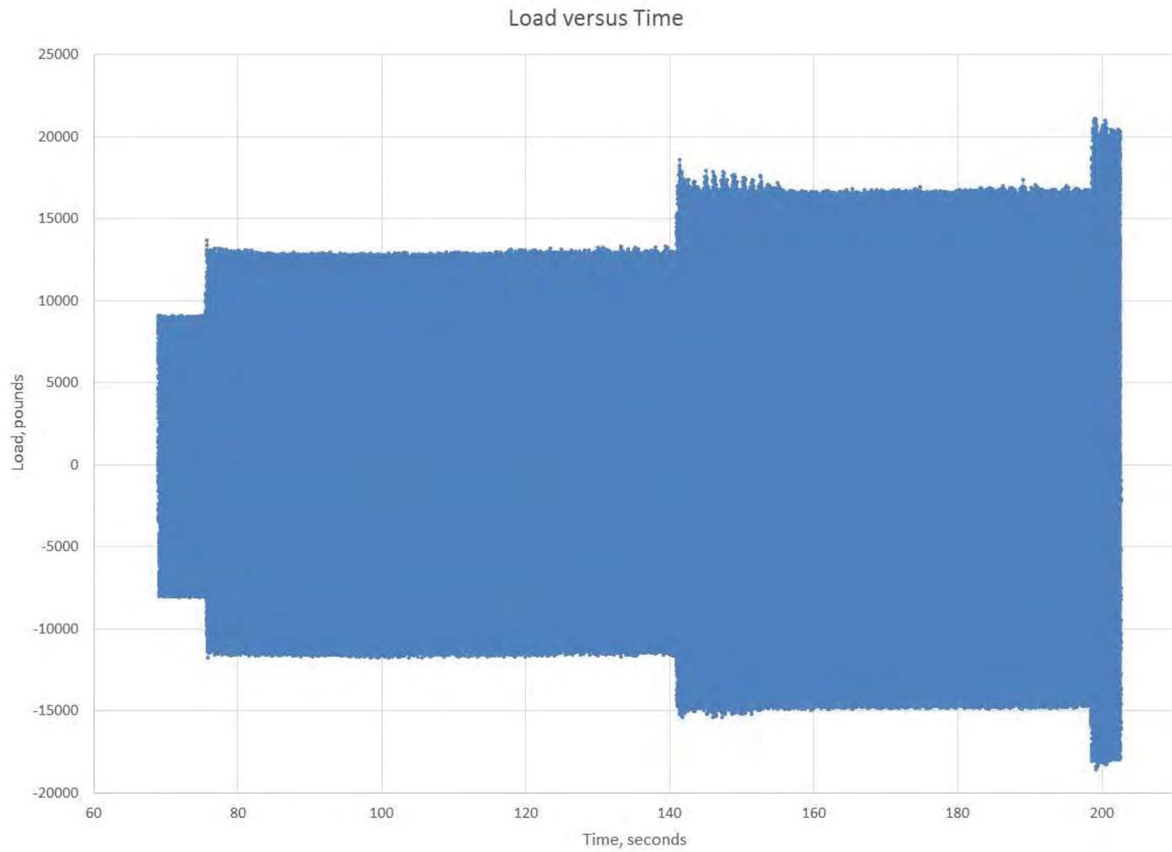


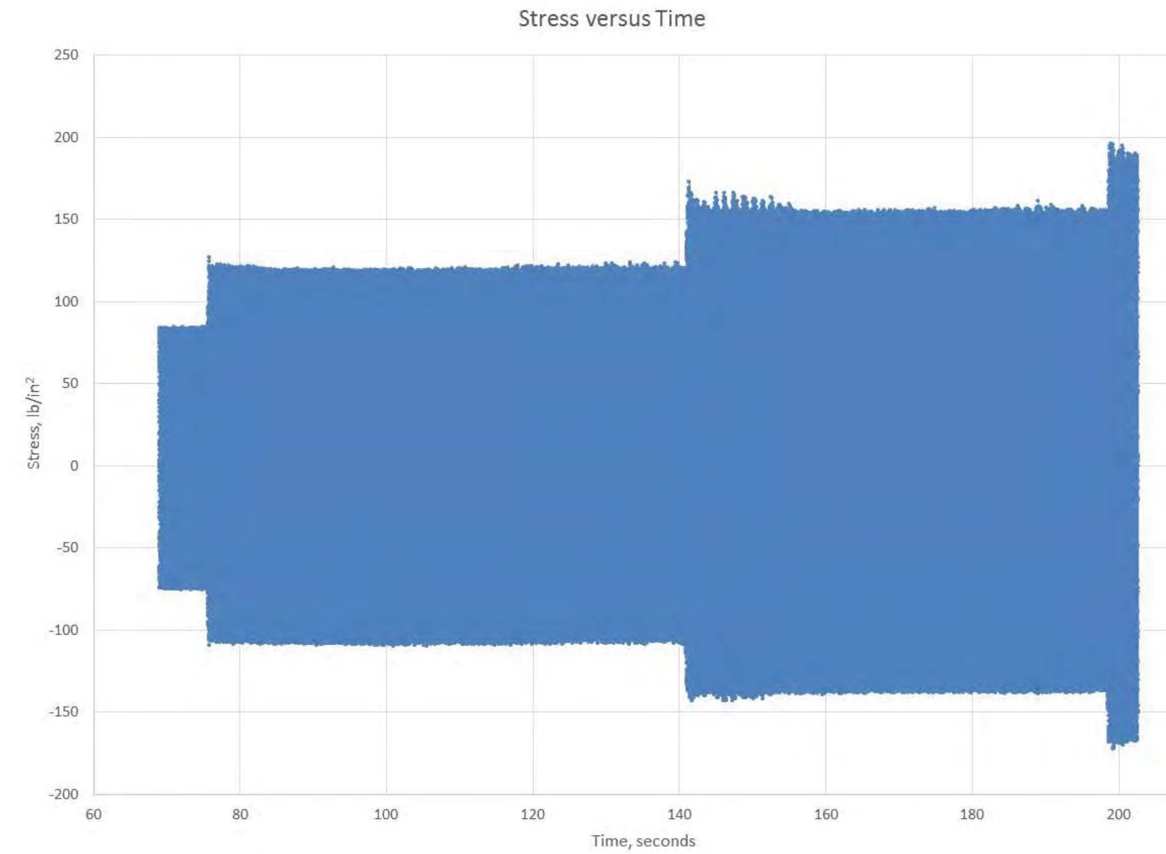


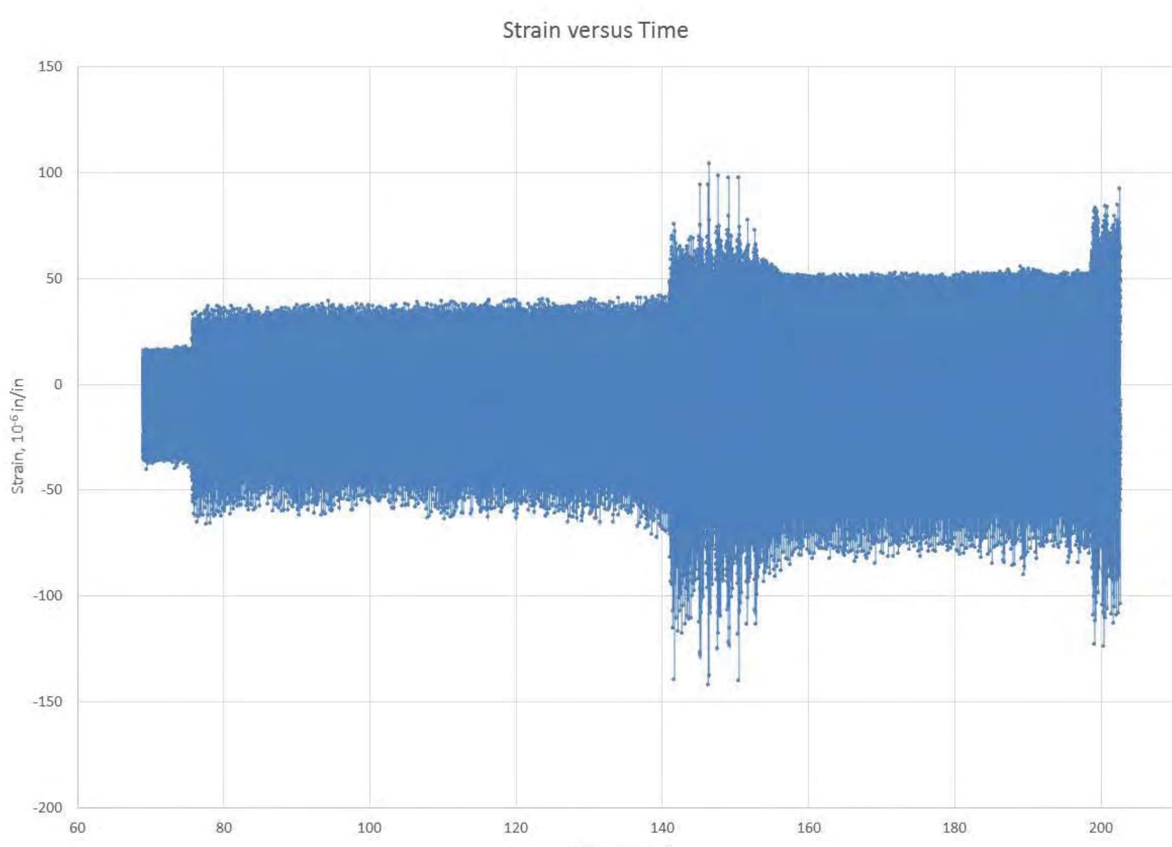


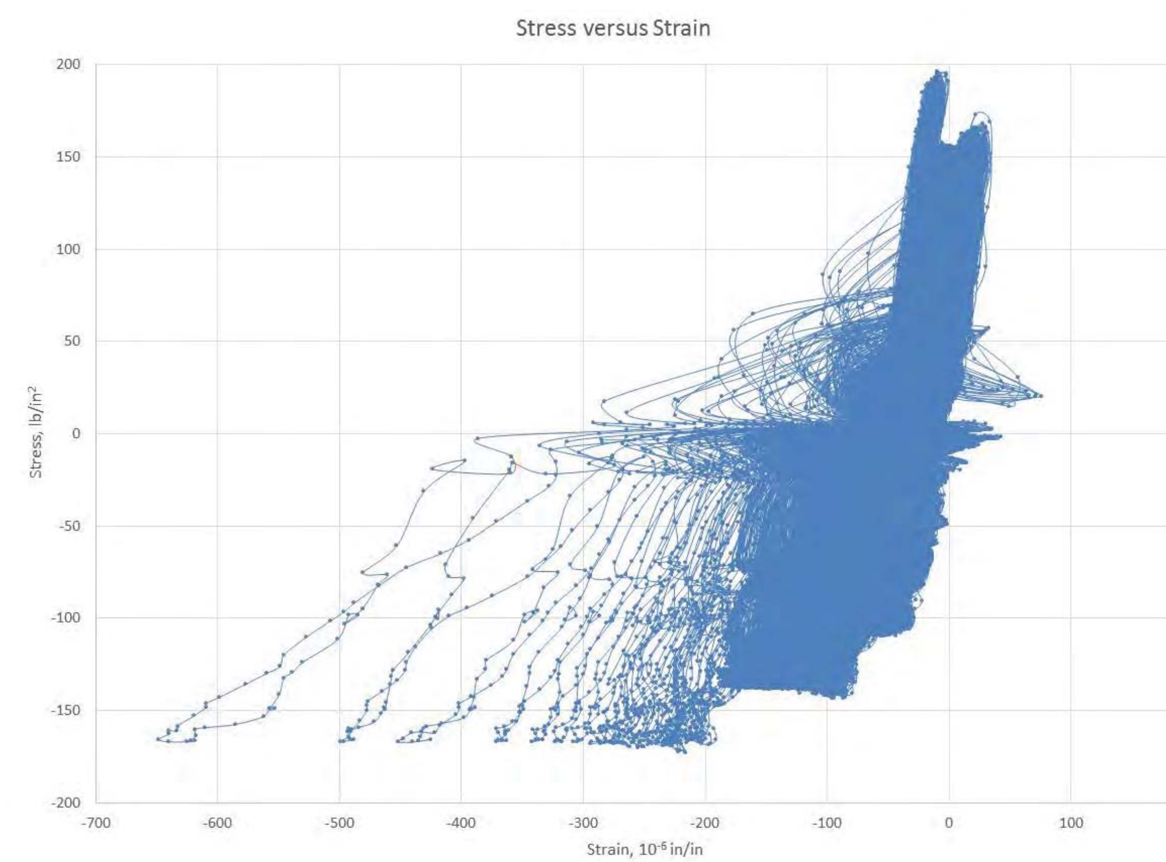


8-inch NMSA 12-inch Diameter Core

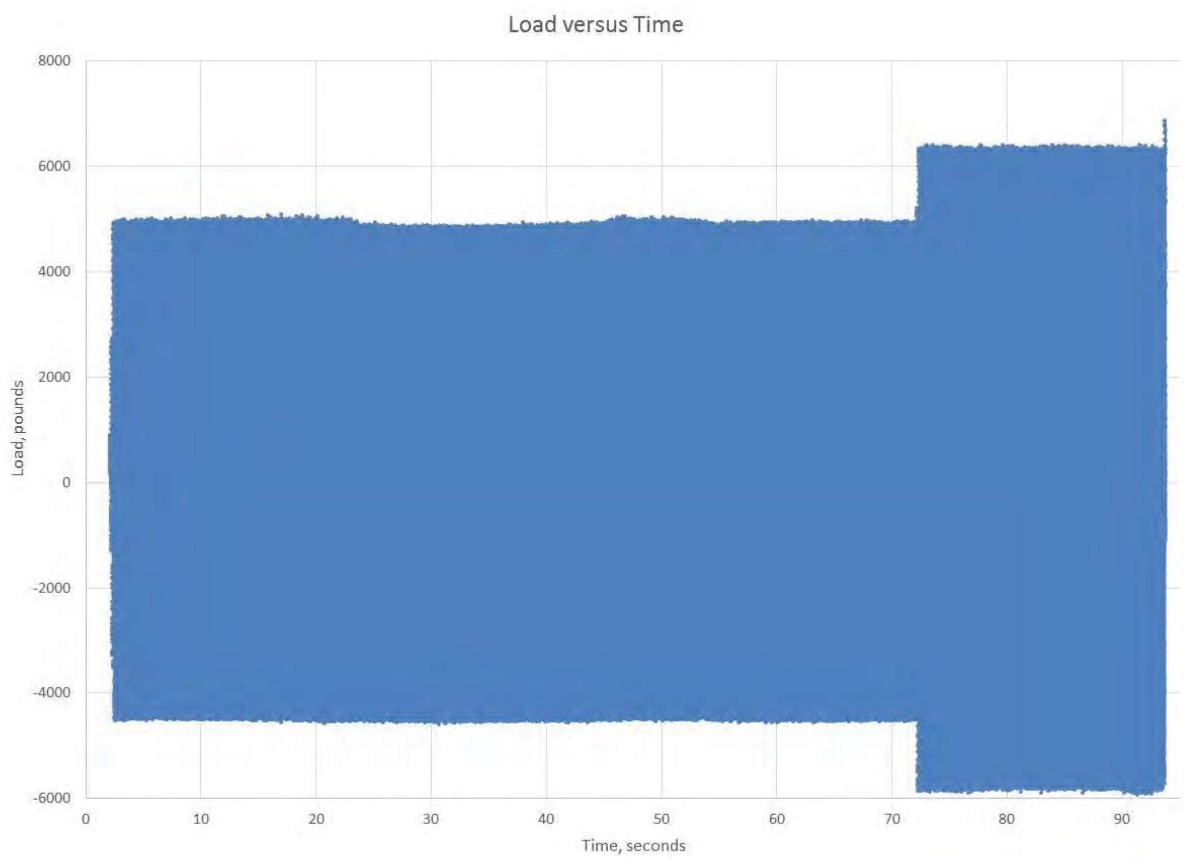


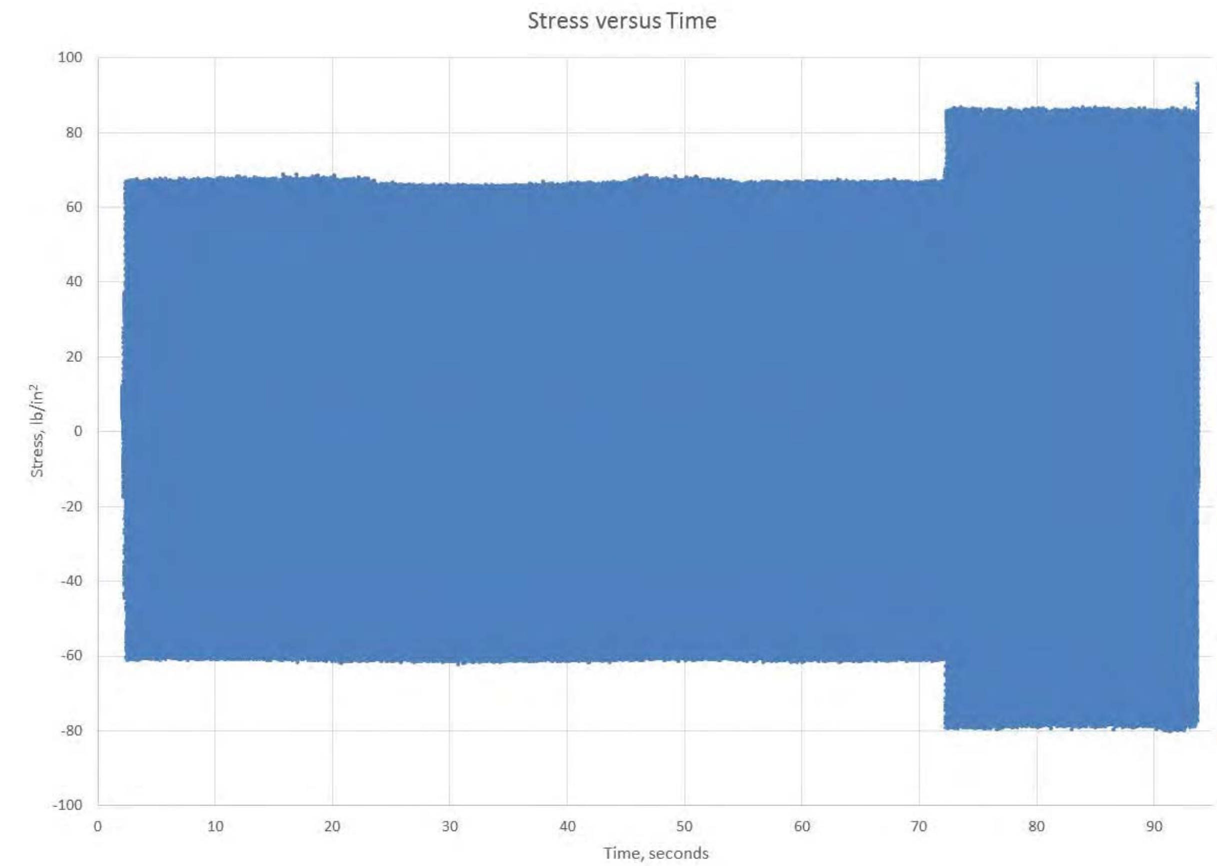


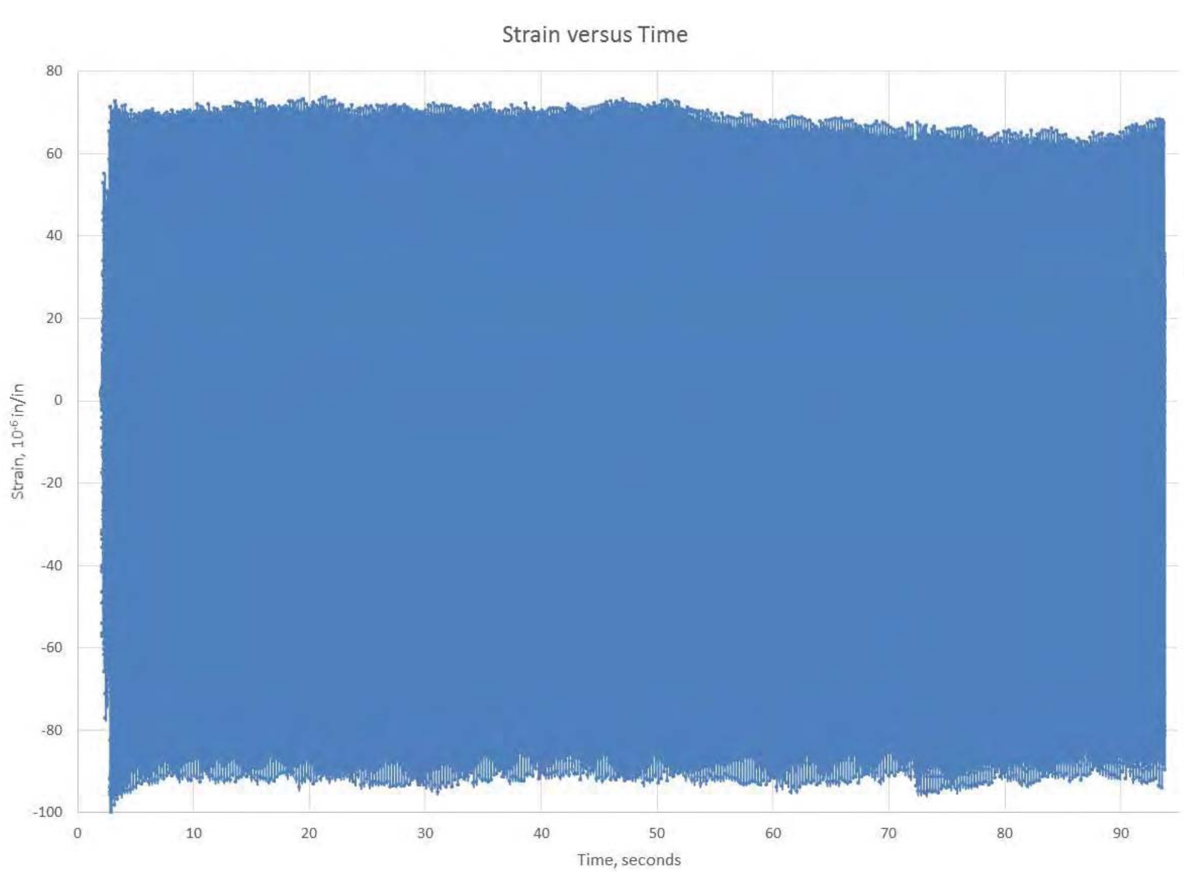


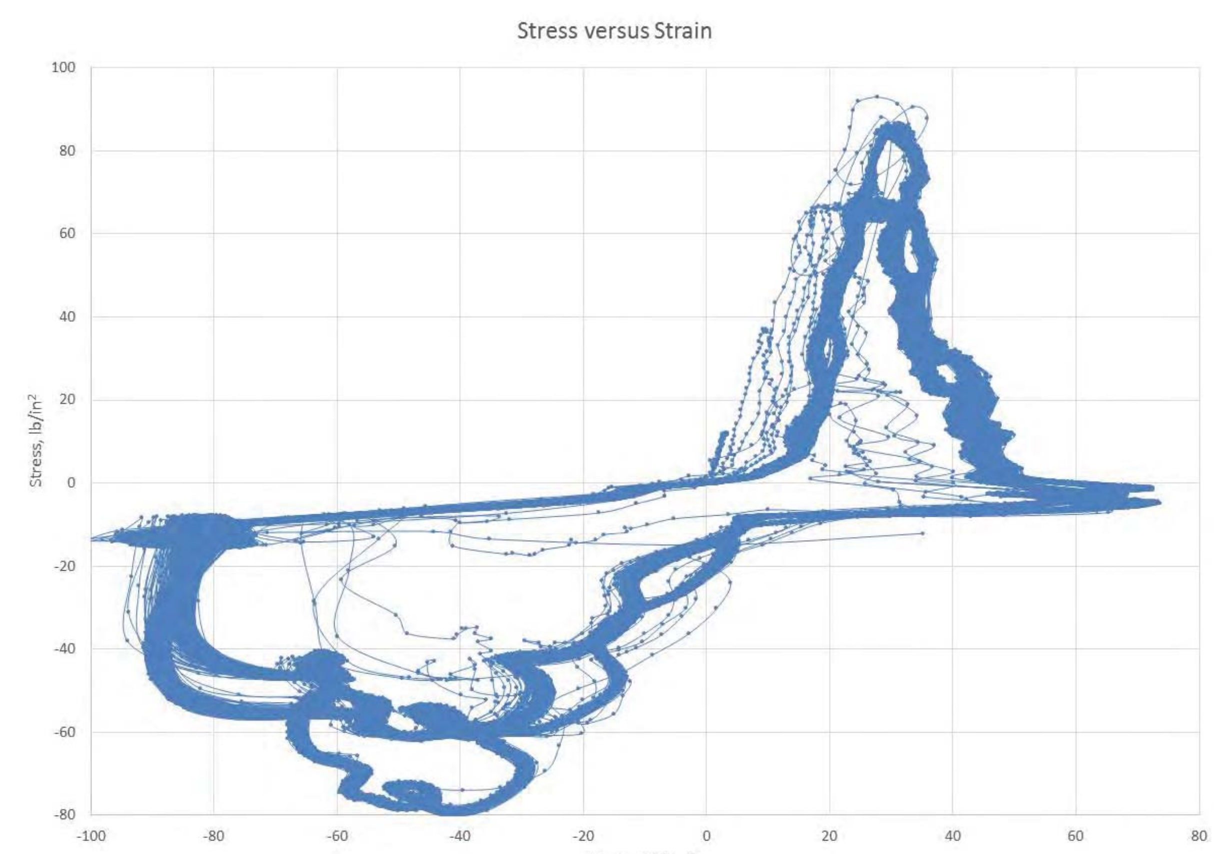


8-inch NMSA 10-inch Diameter Core

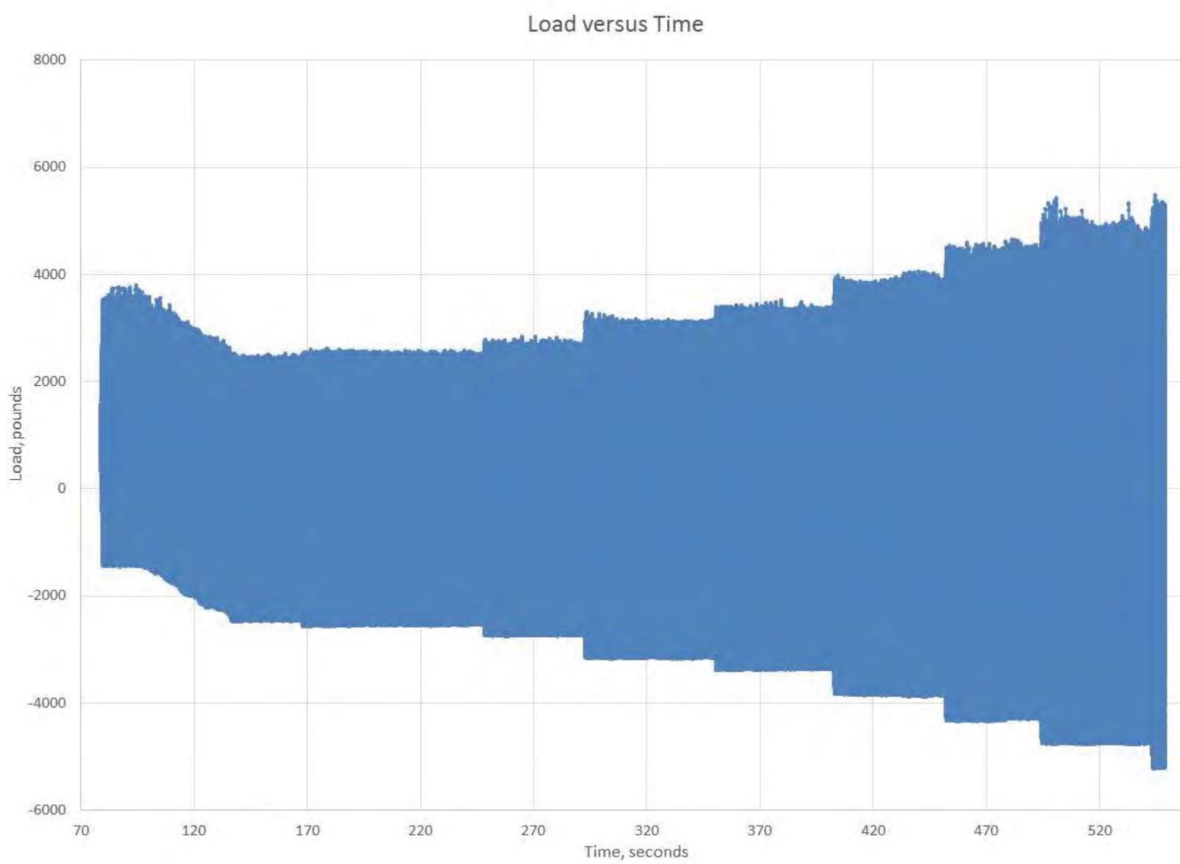


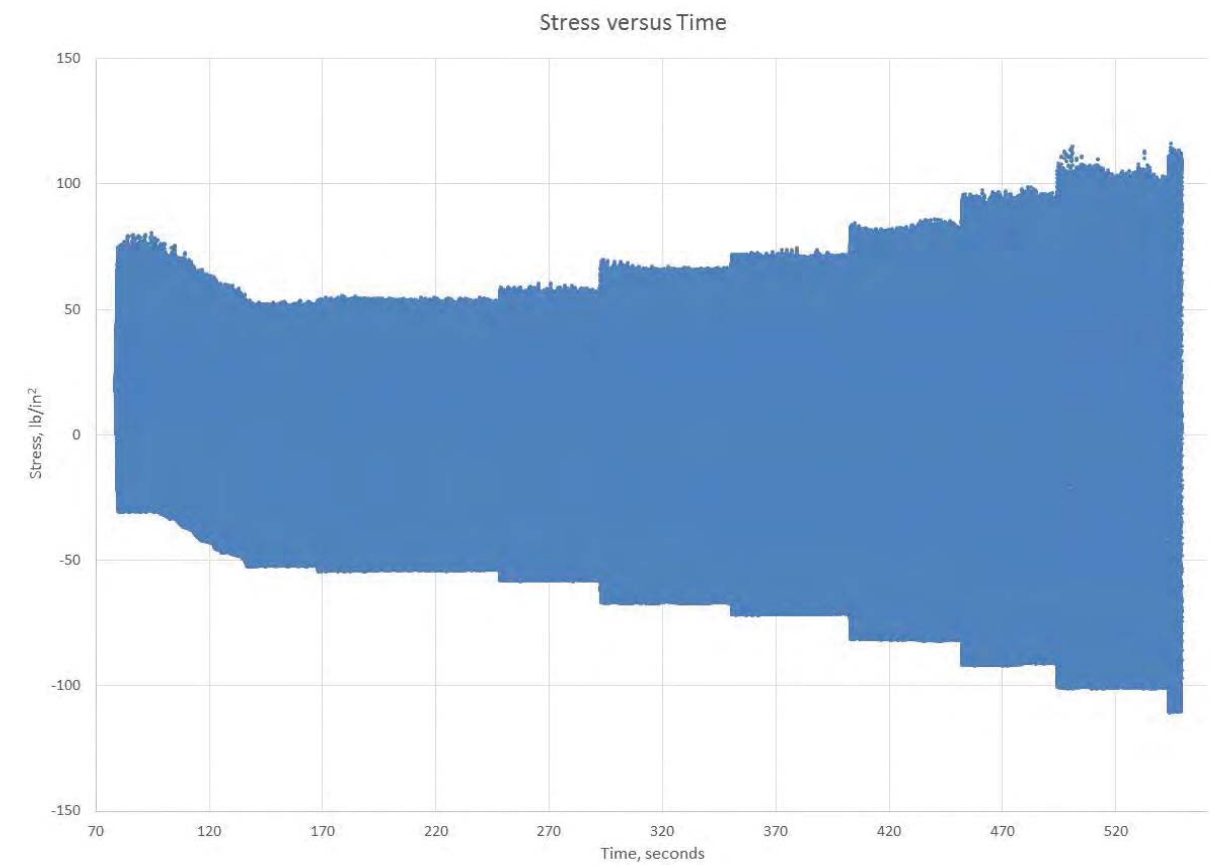


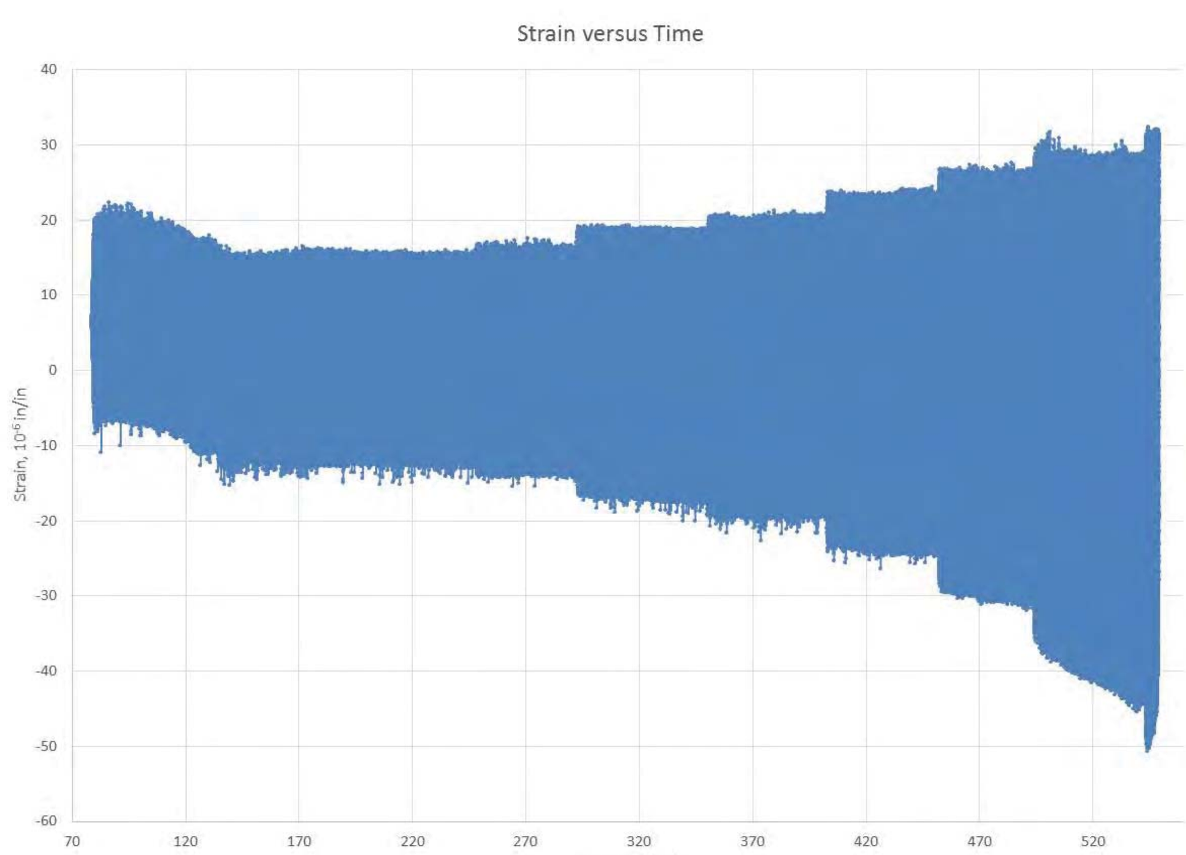


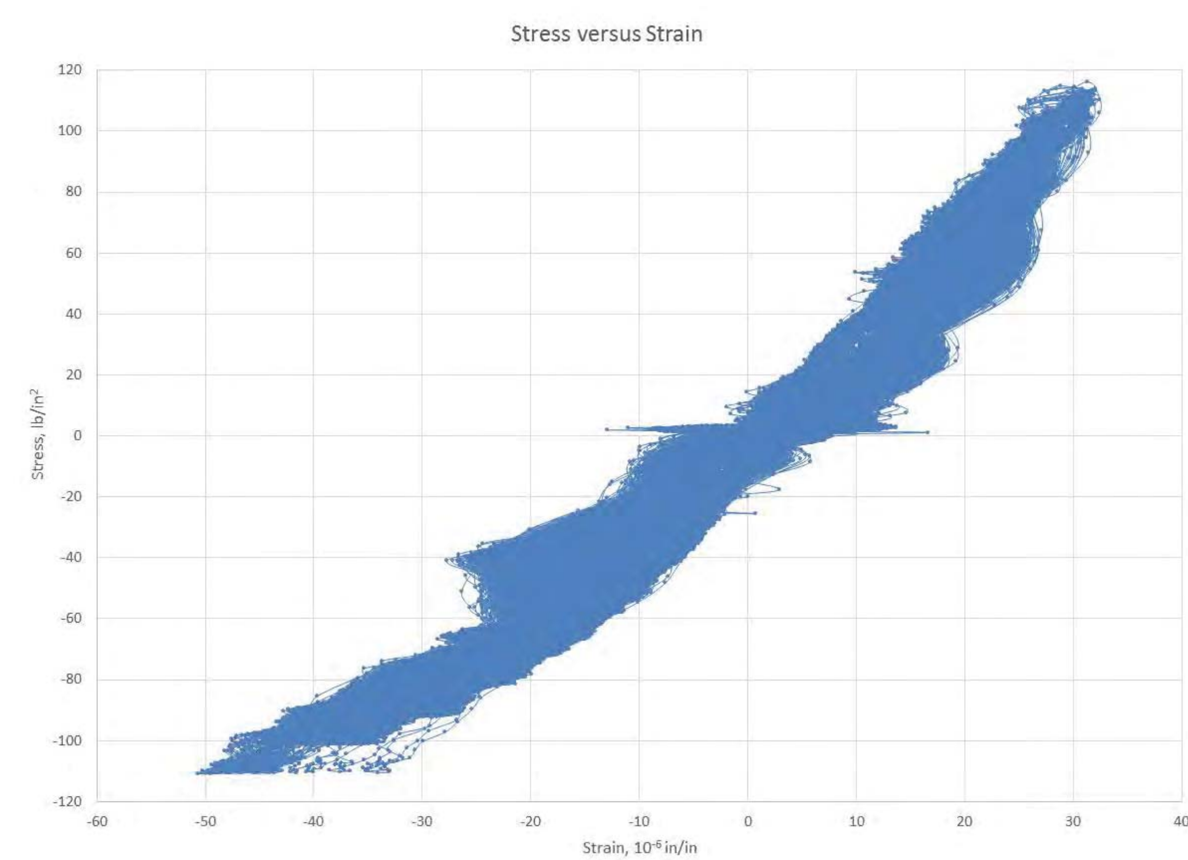


8-inch NMSA 8-inch Diameter Core

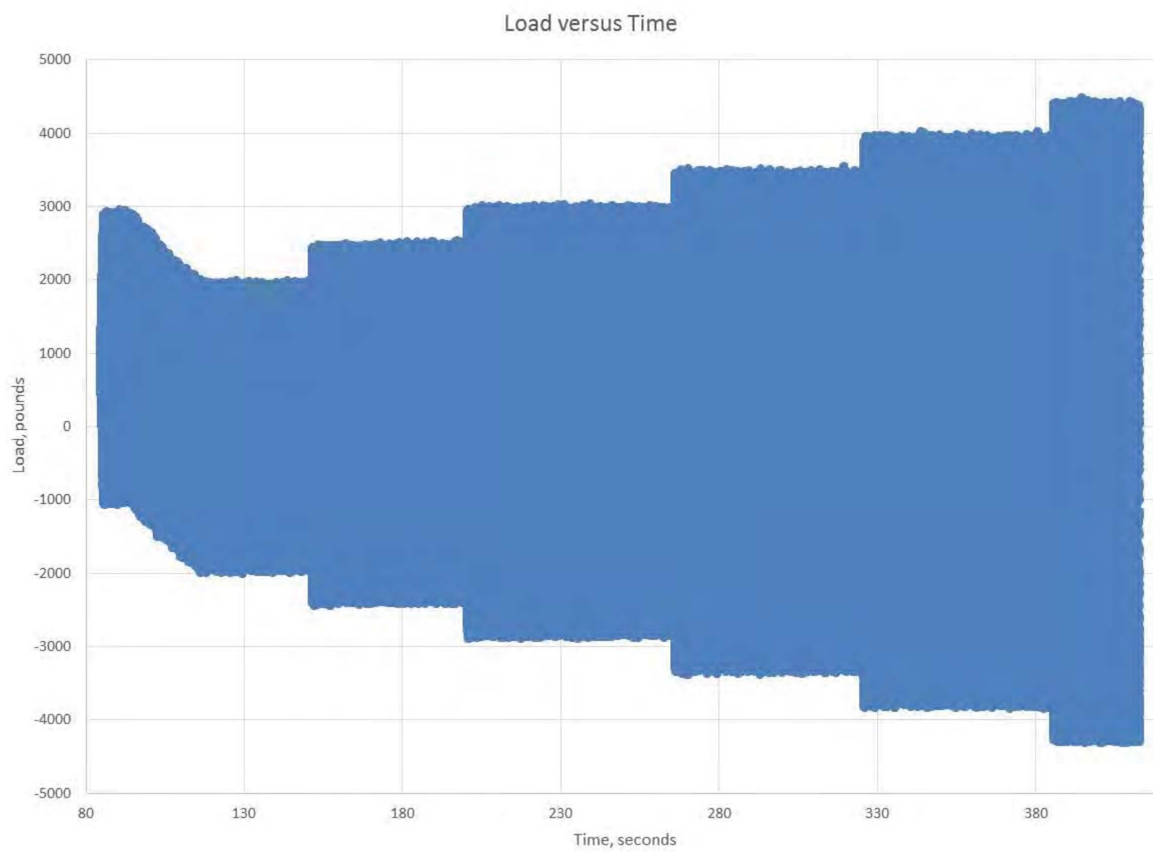


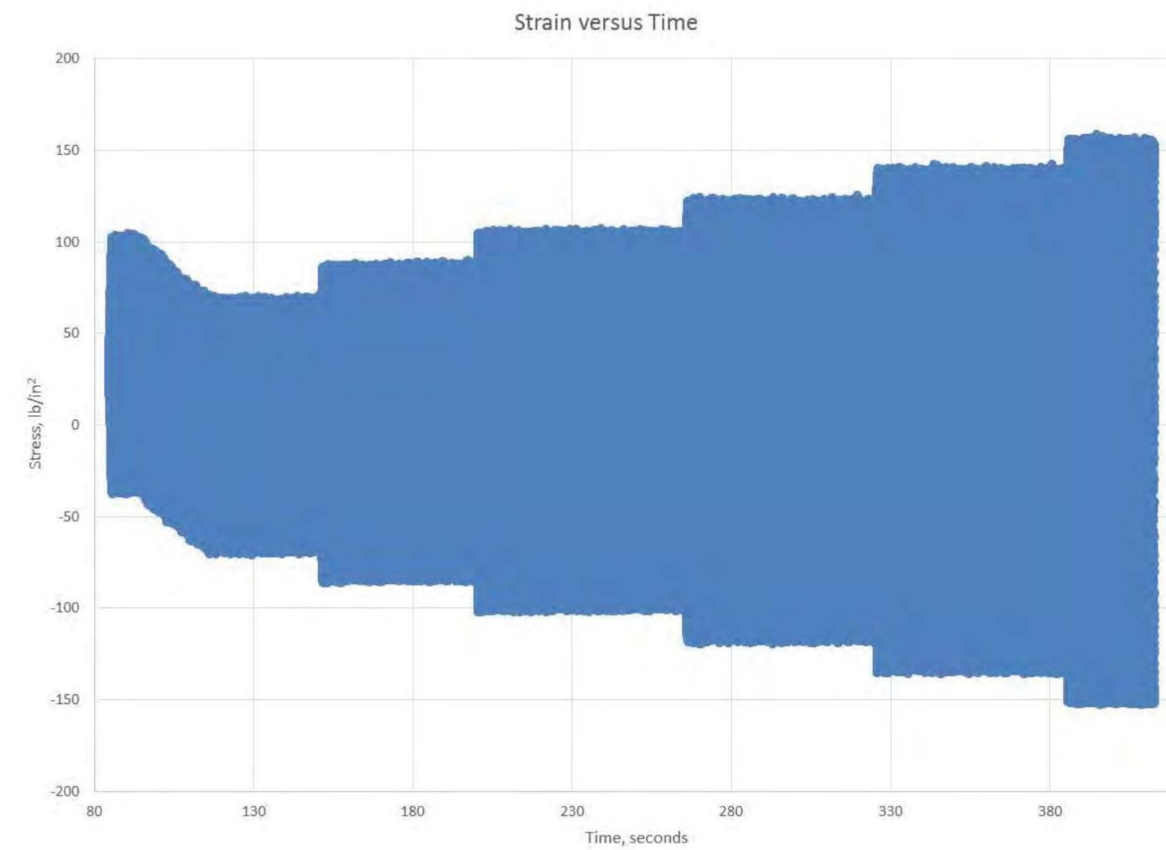


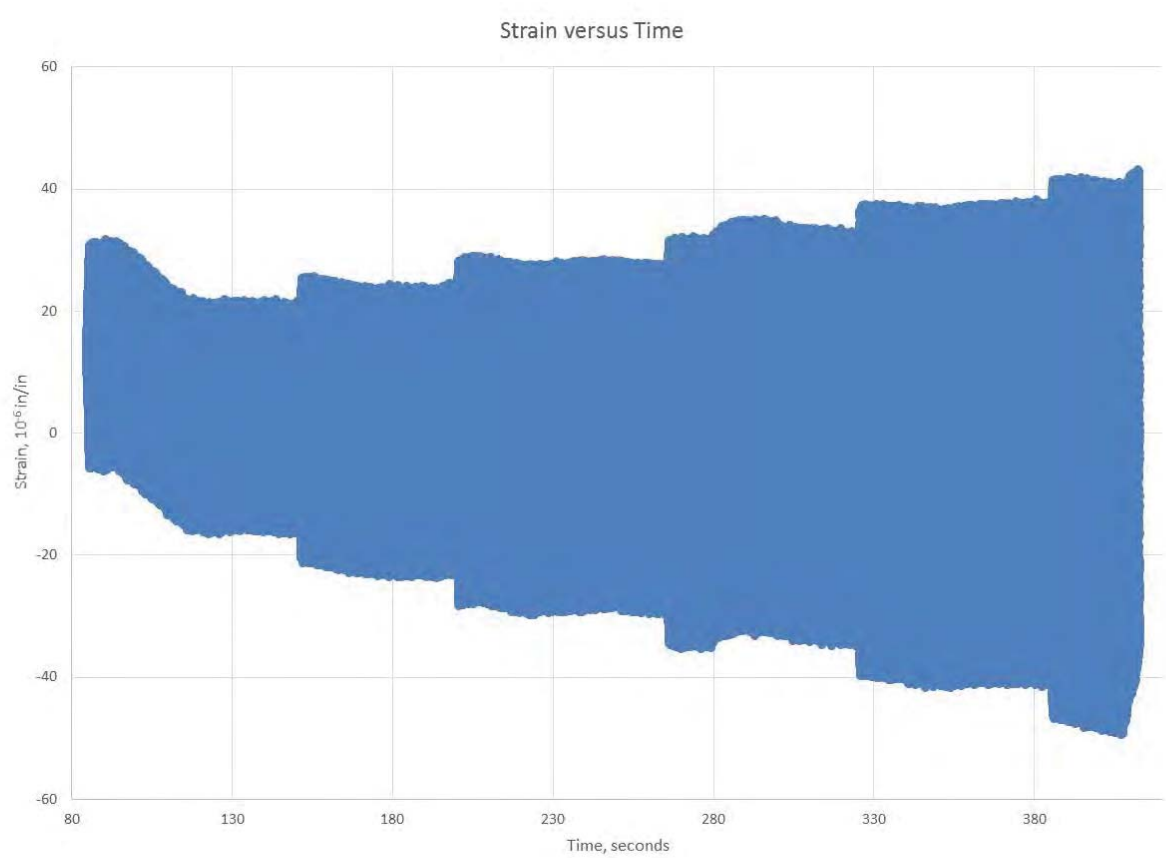


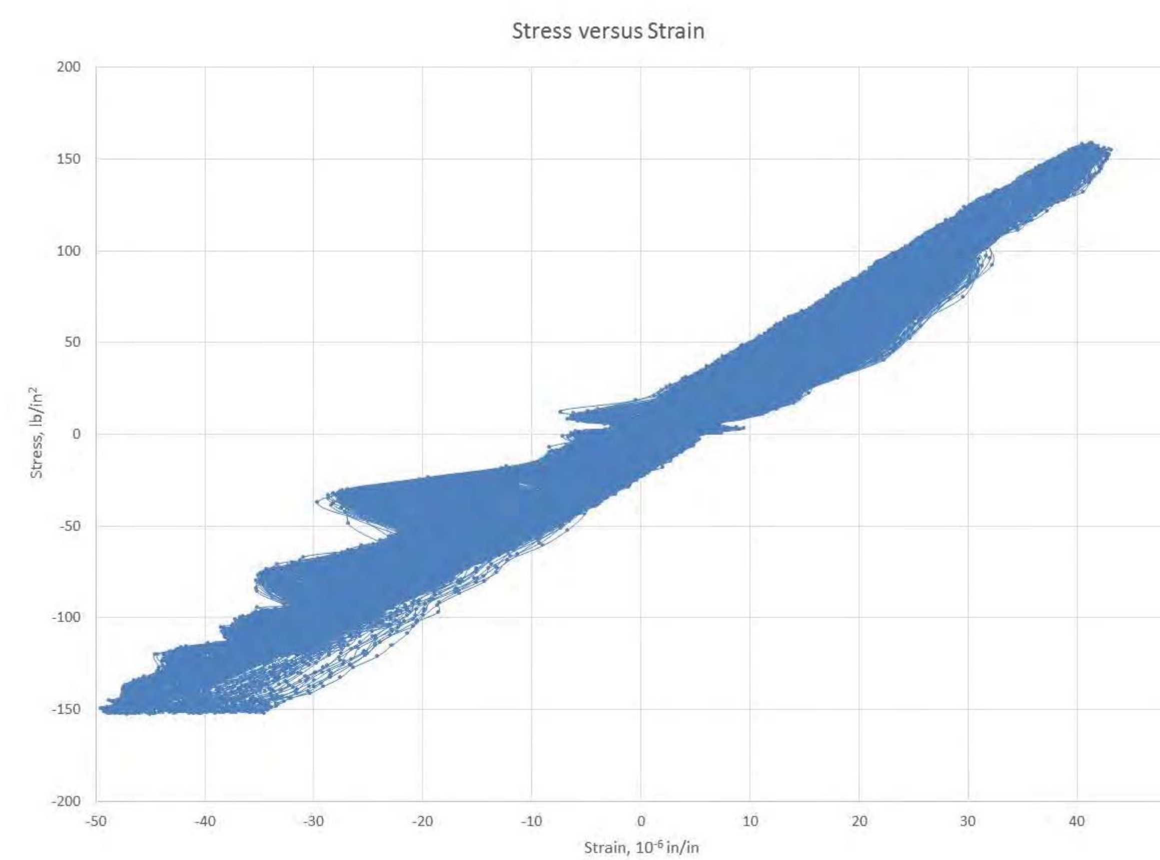


8-inch NMSA 6-inch Diameter Core

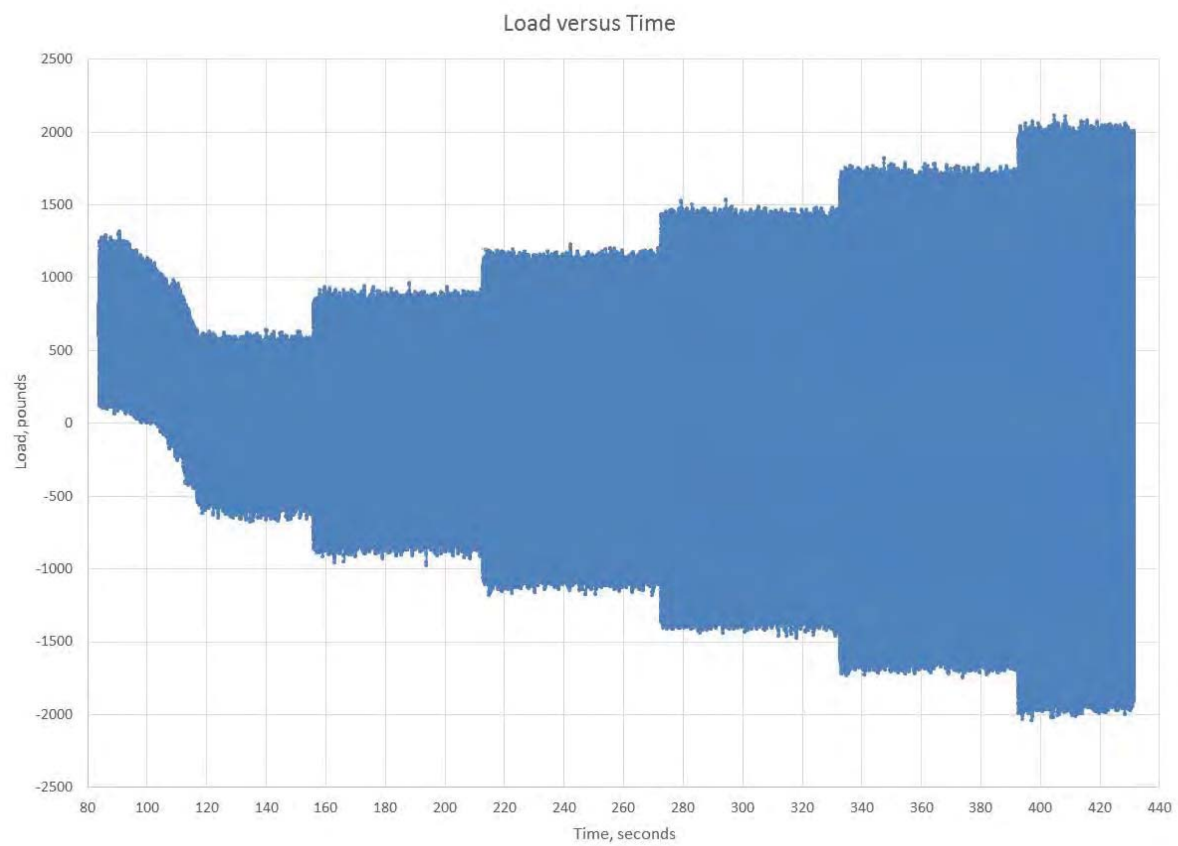


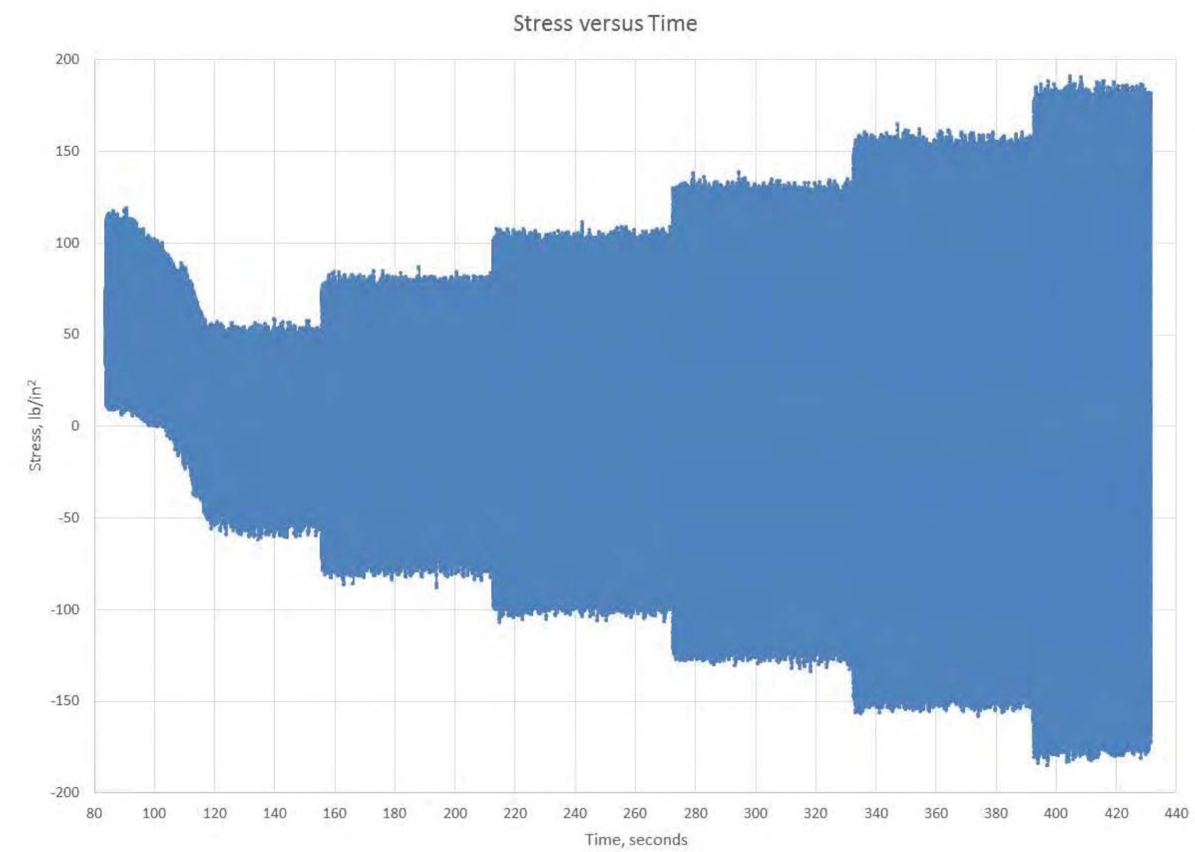


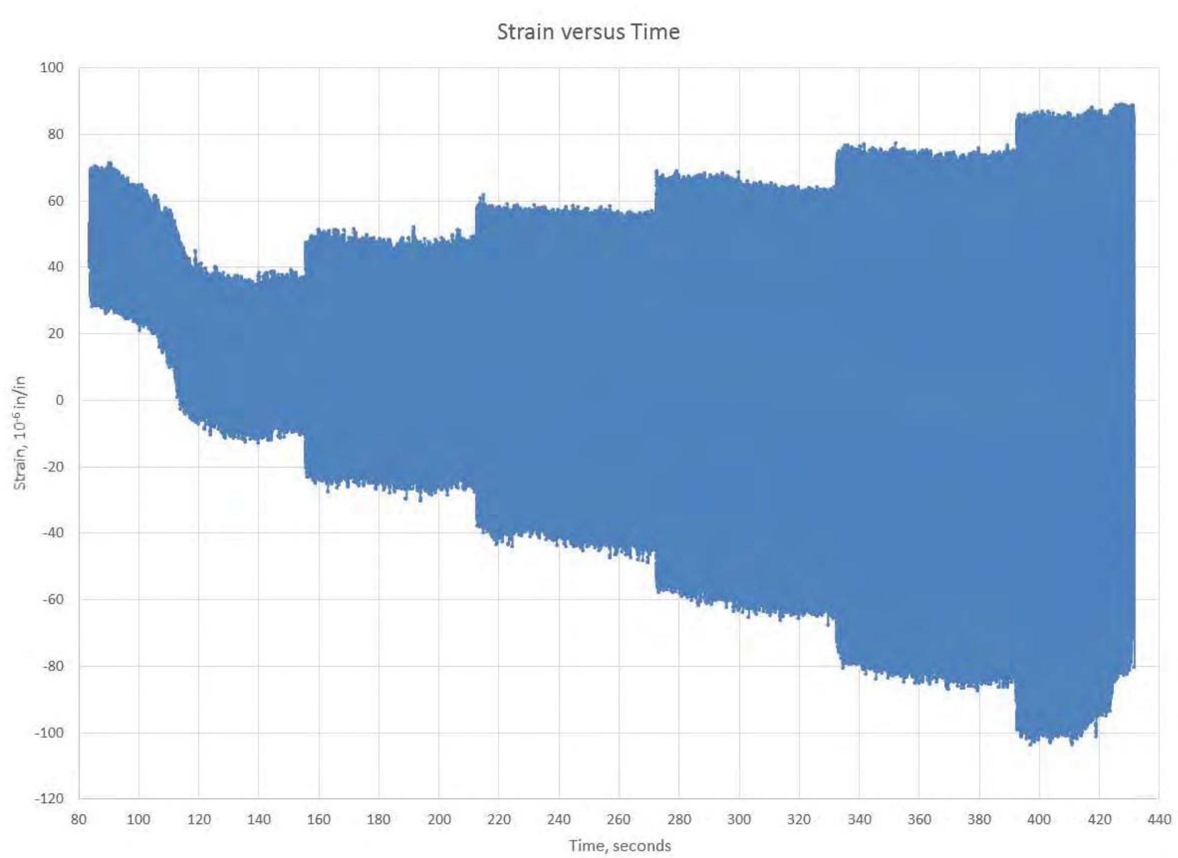


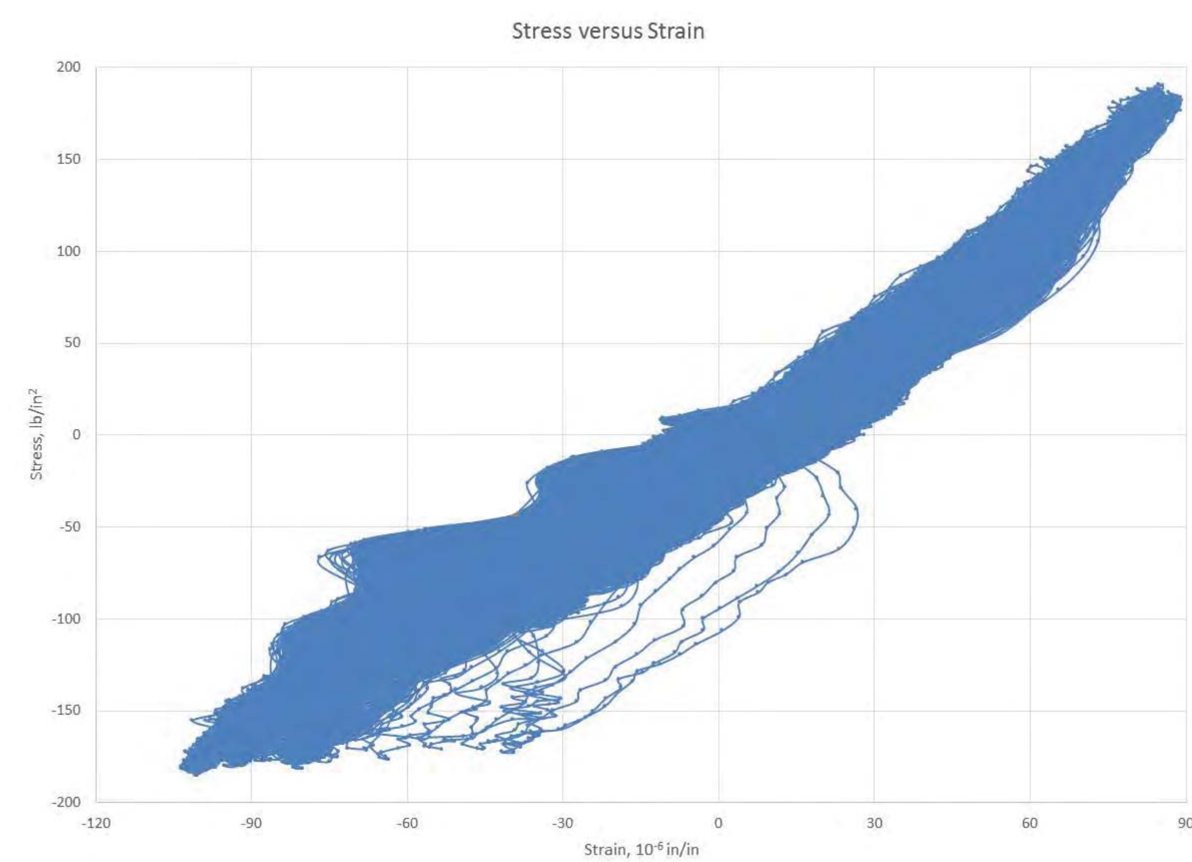


8-inch NMSA 4-inch Diameter Core

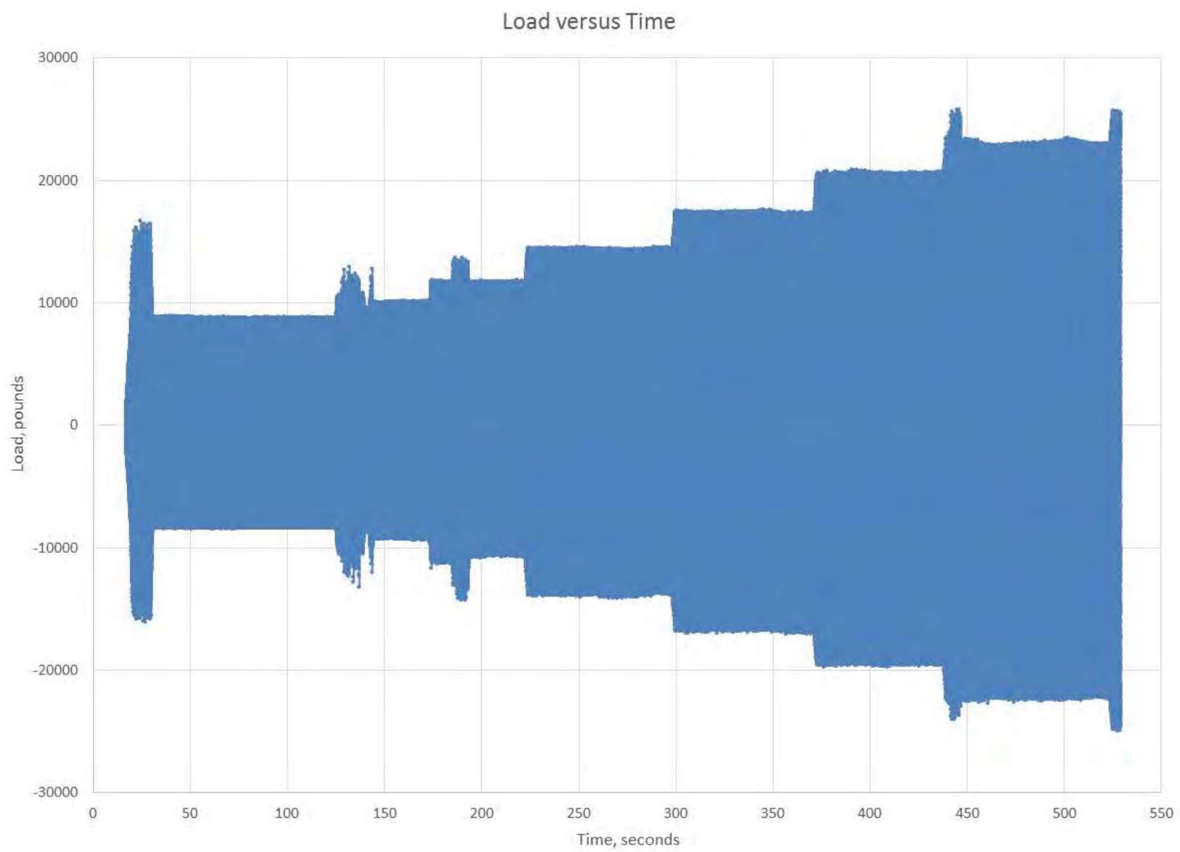


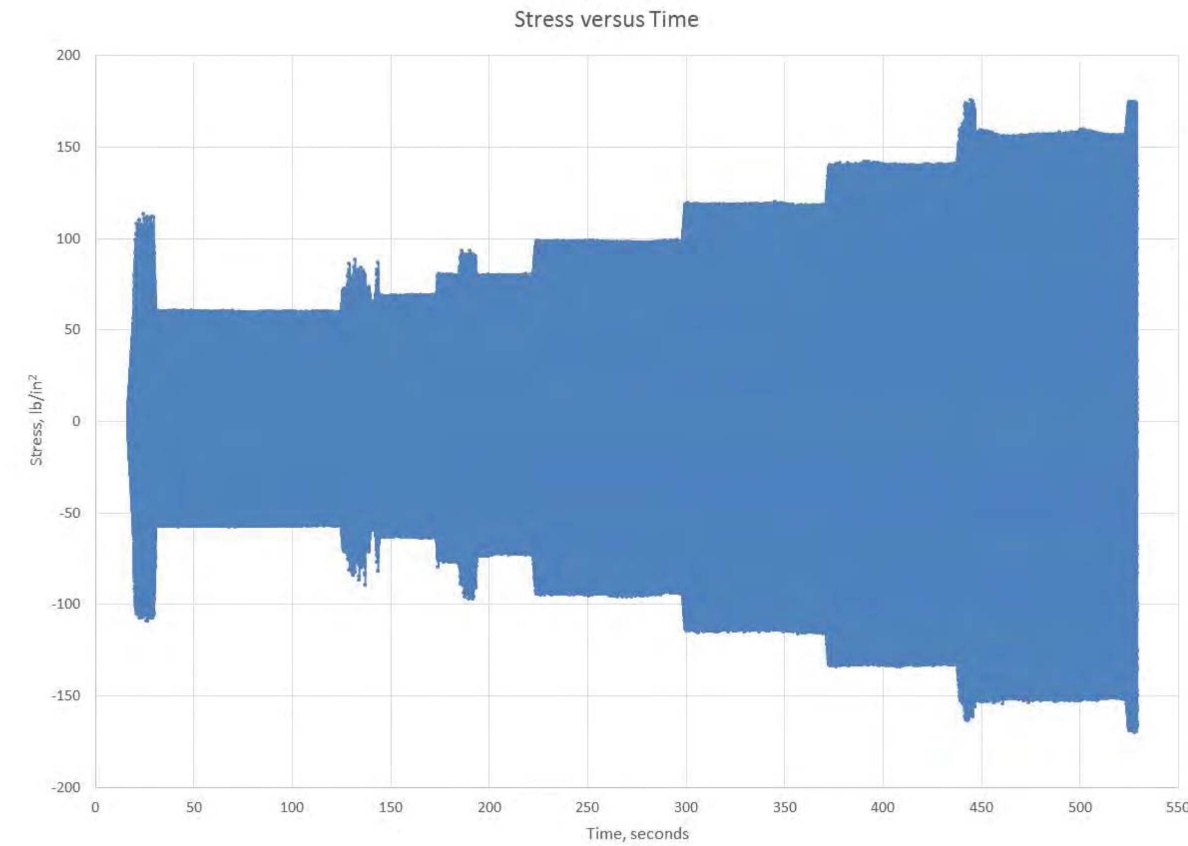


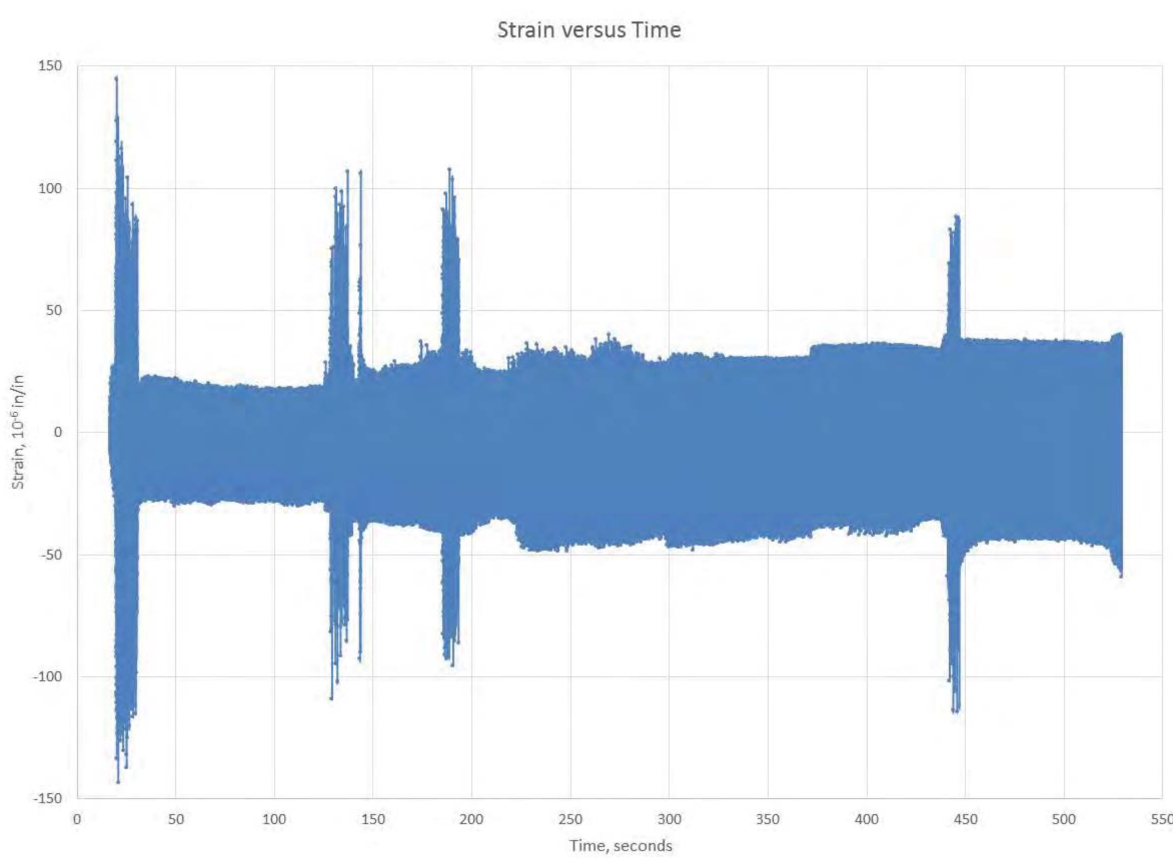


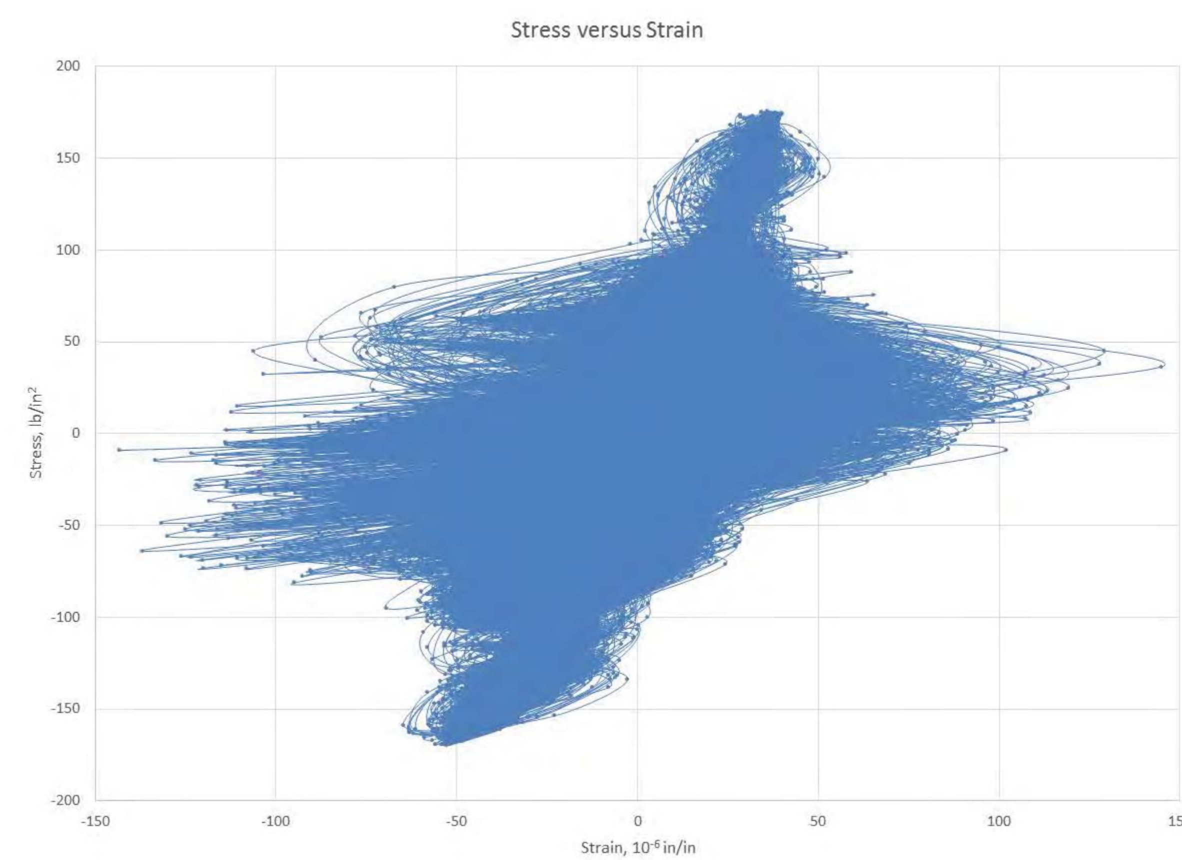


1½-inch NMSA 14-inch Diameter Core

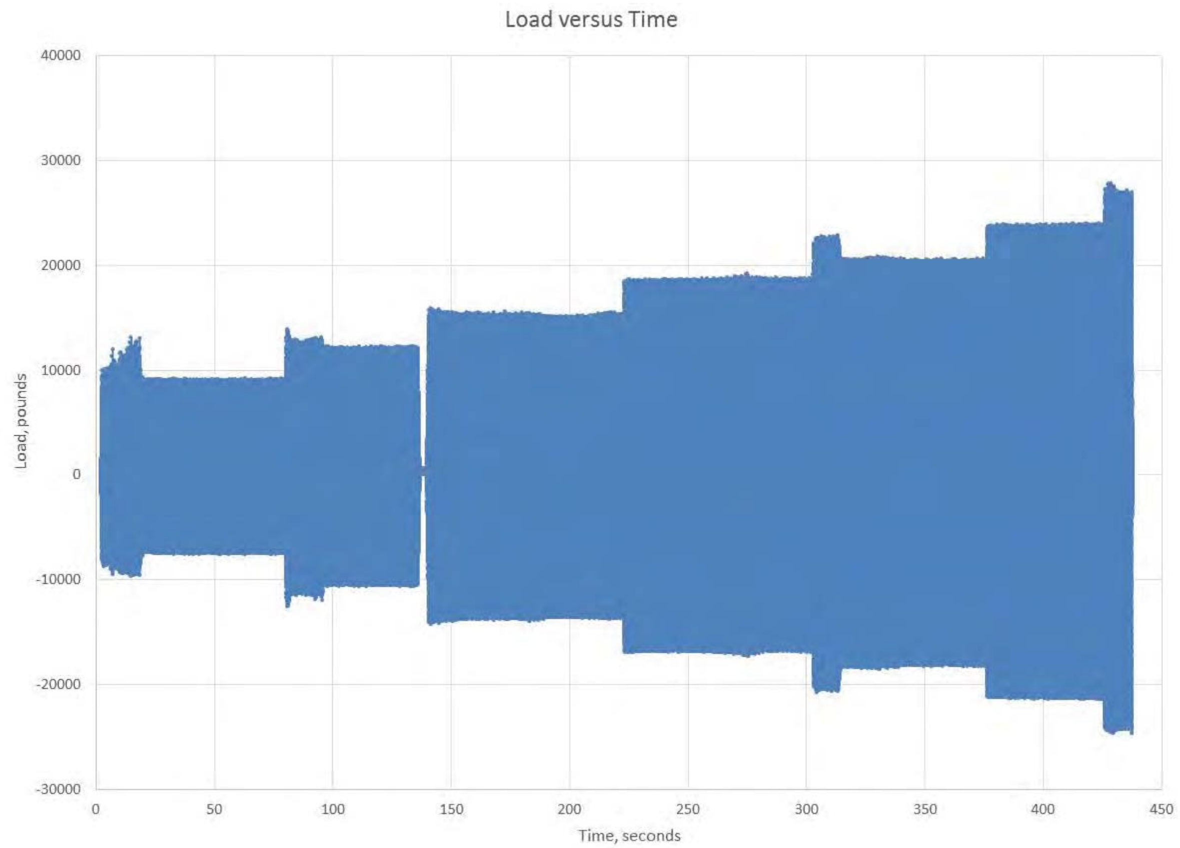


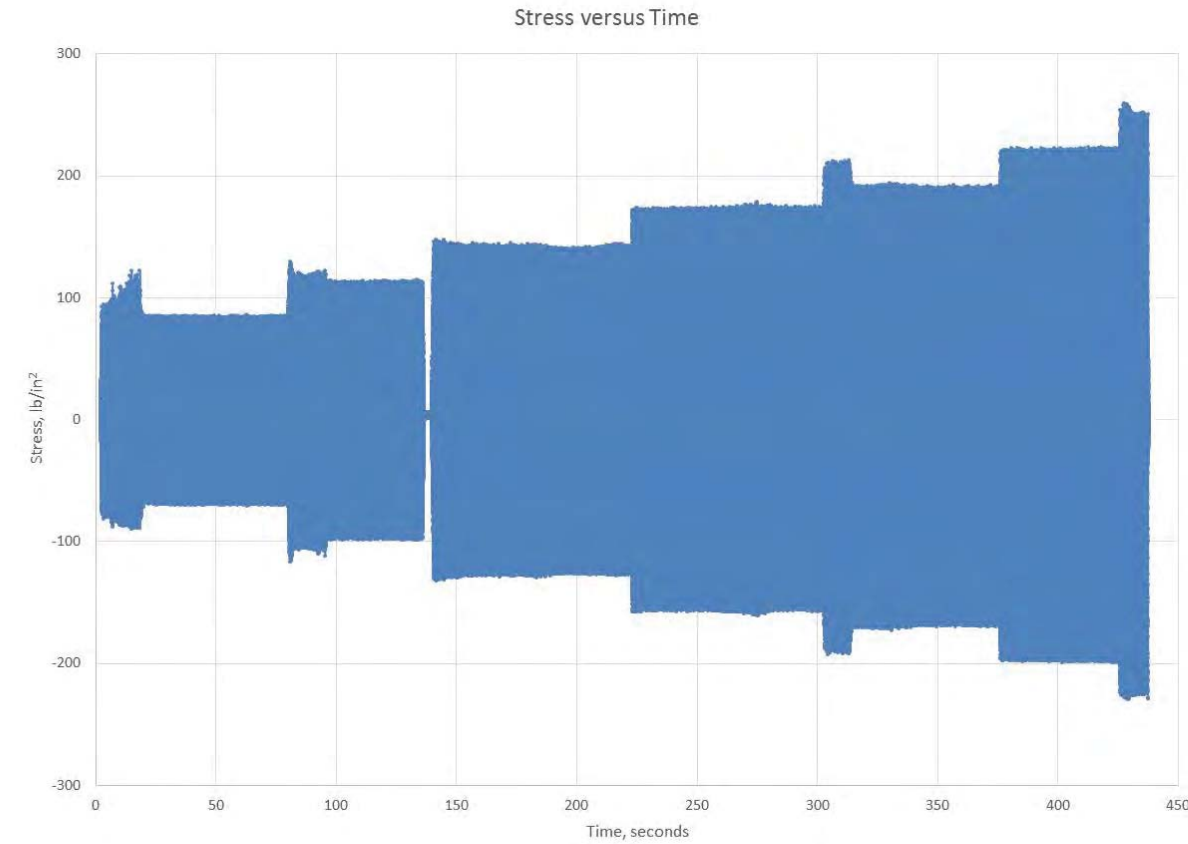


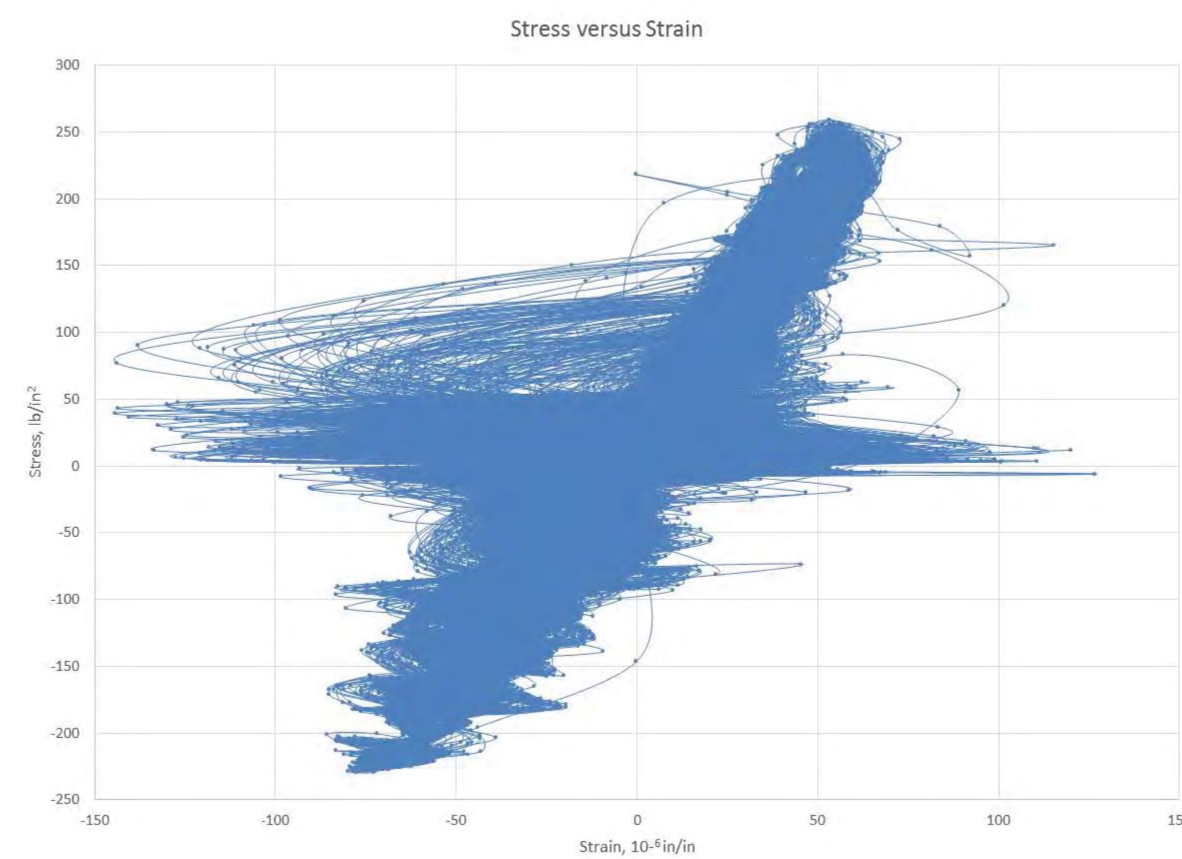




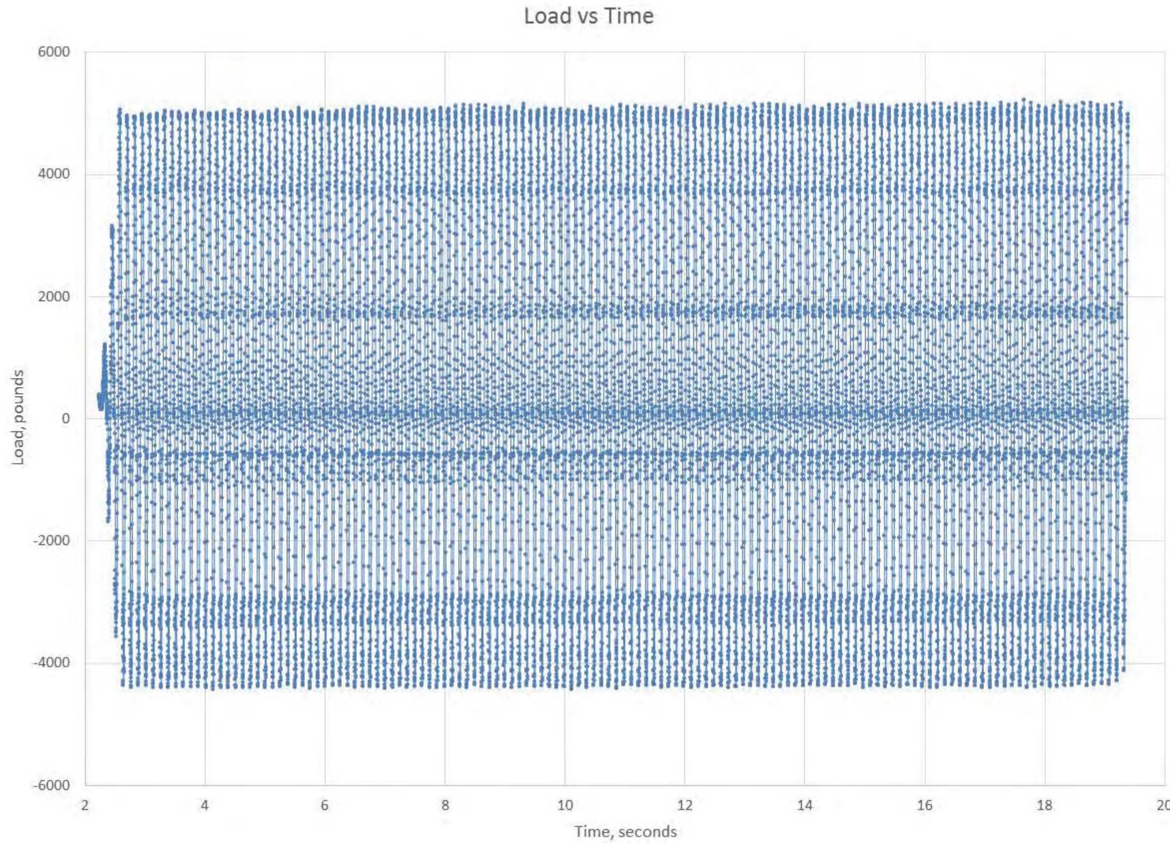
1½-inch NMSA 12-inch Diameter Core

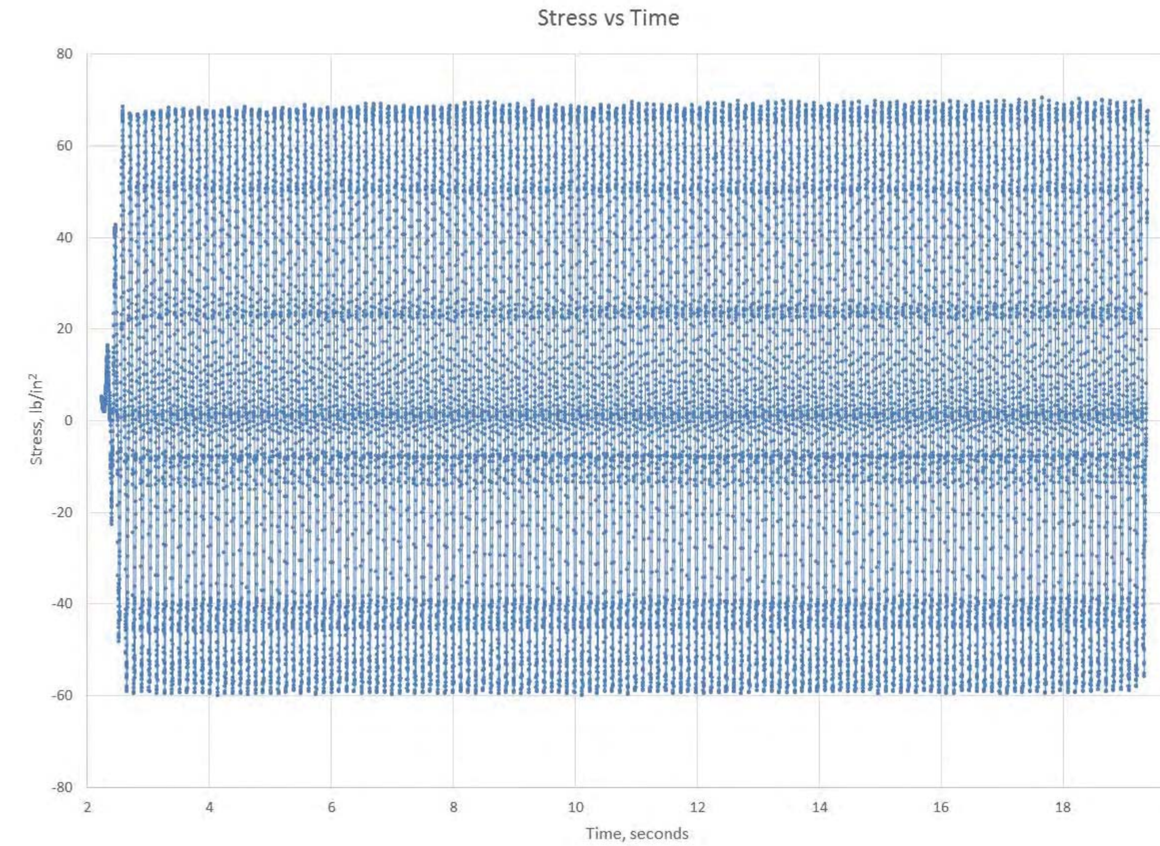


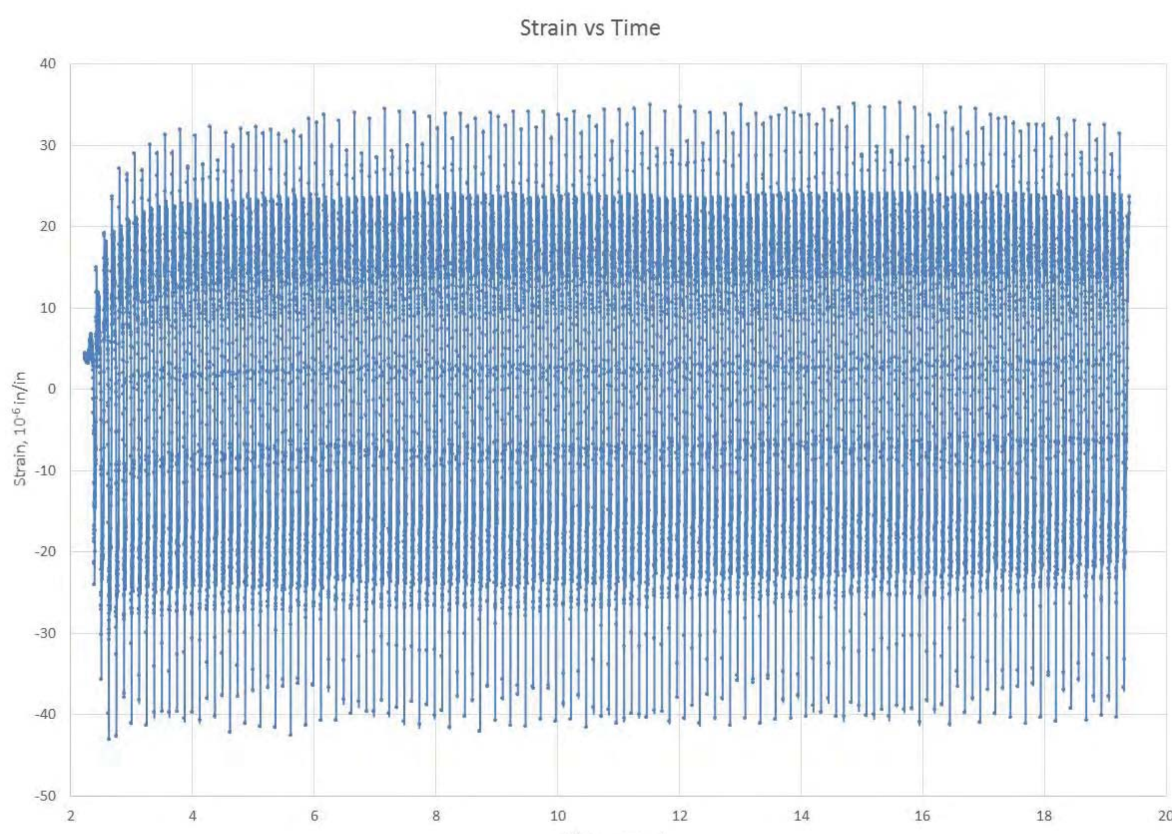


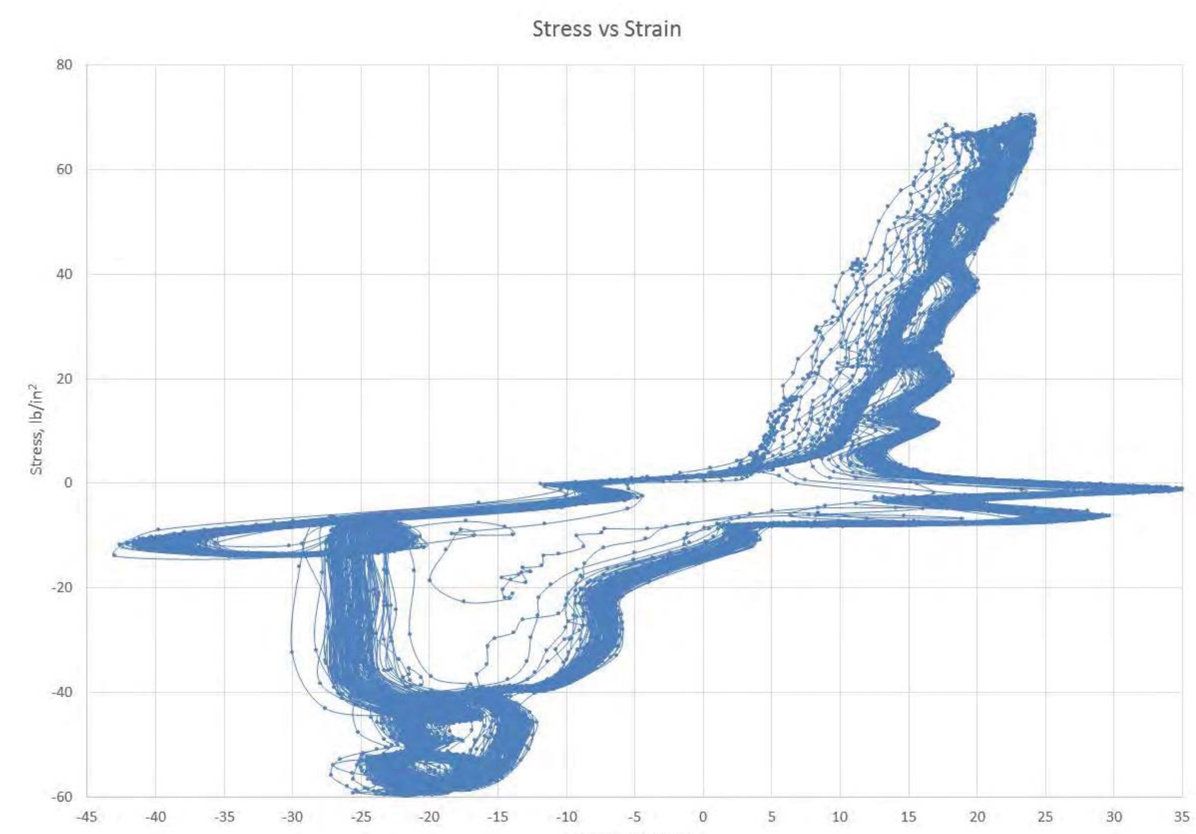


1½-inch NMSA 10-inch Diameter Core

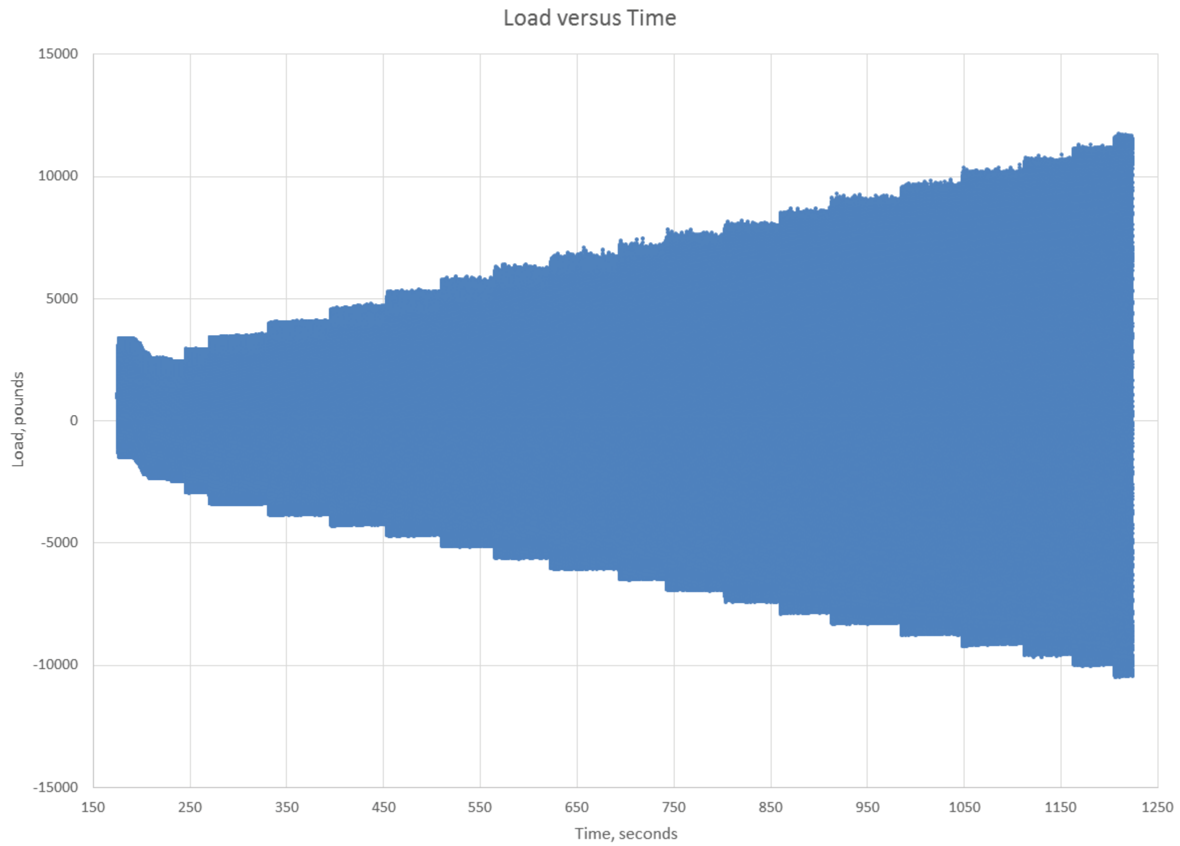


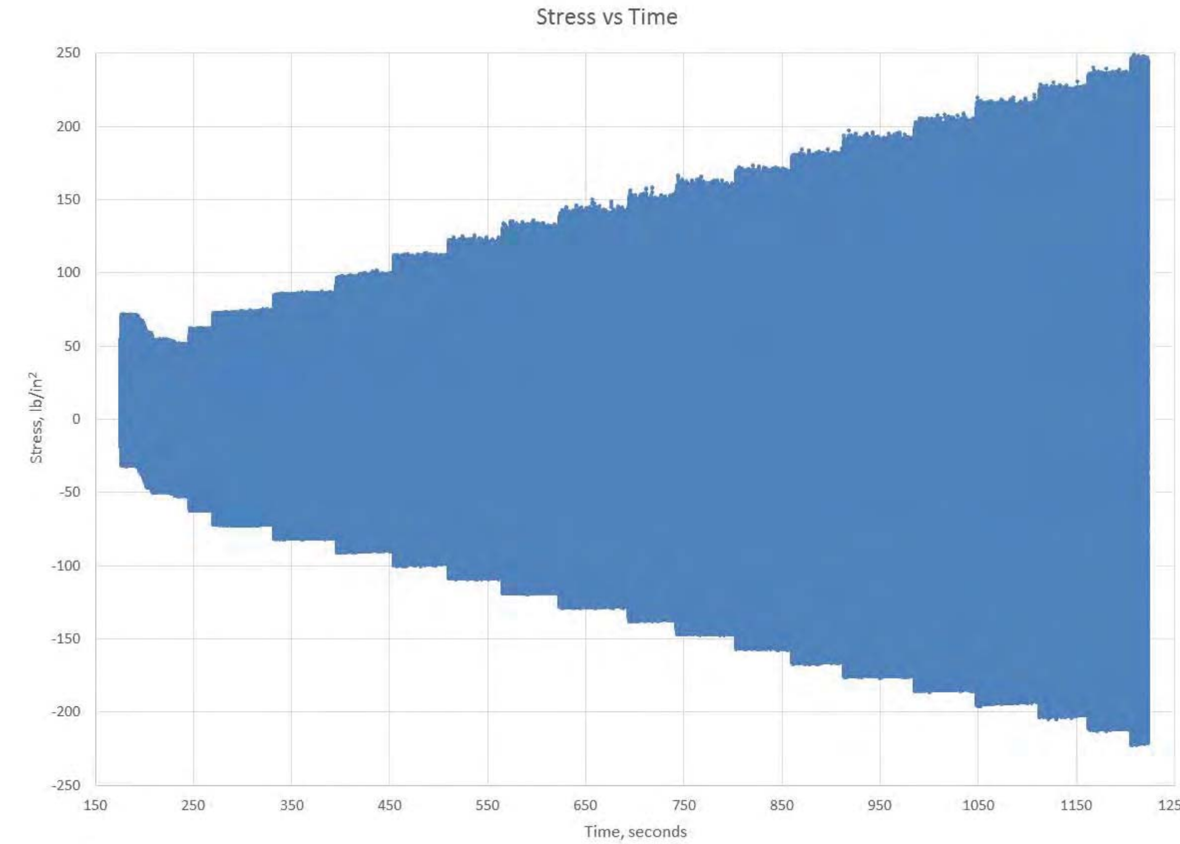


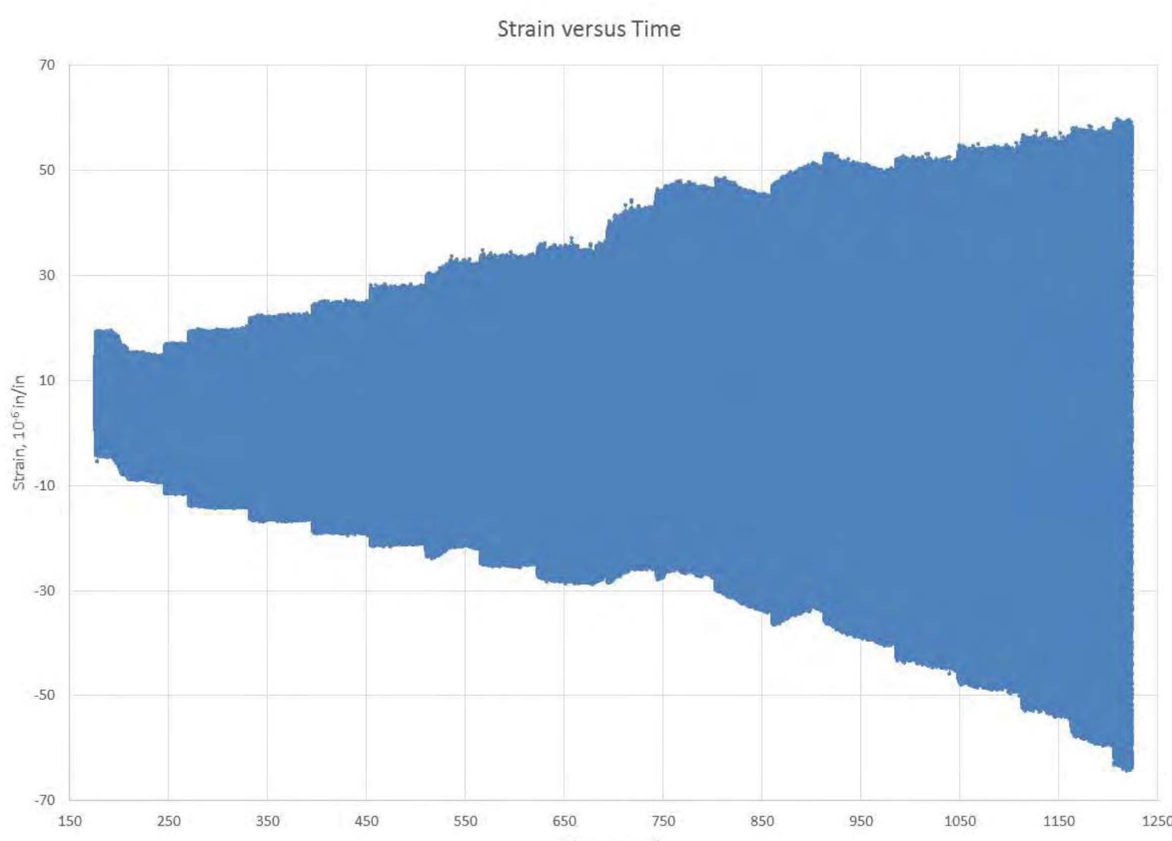


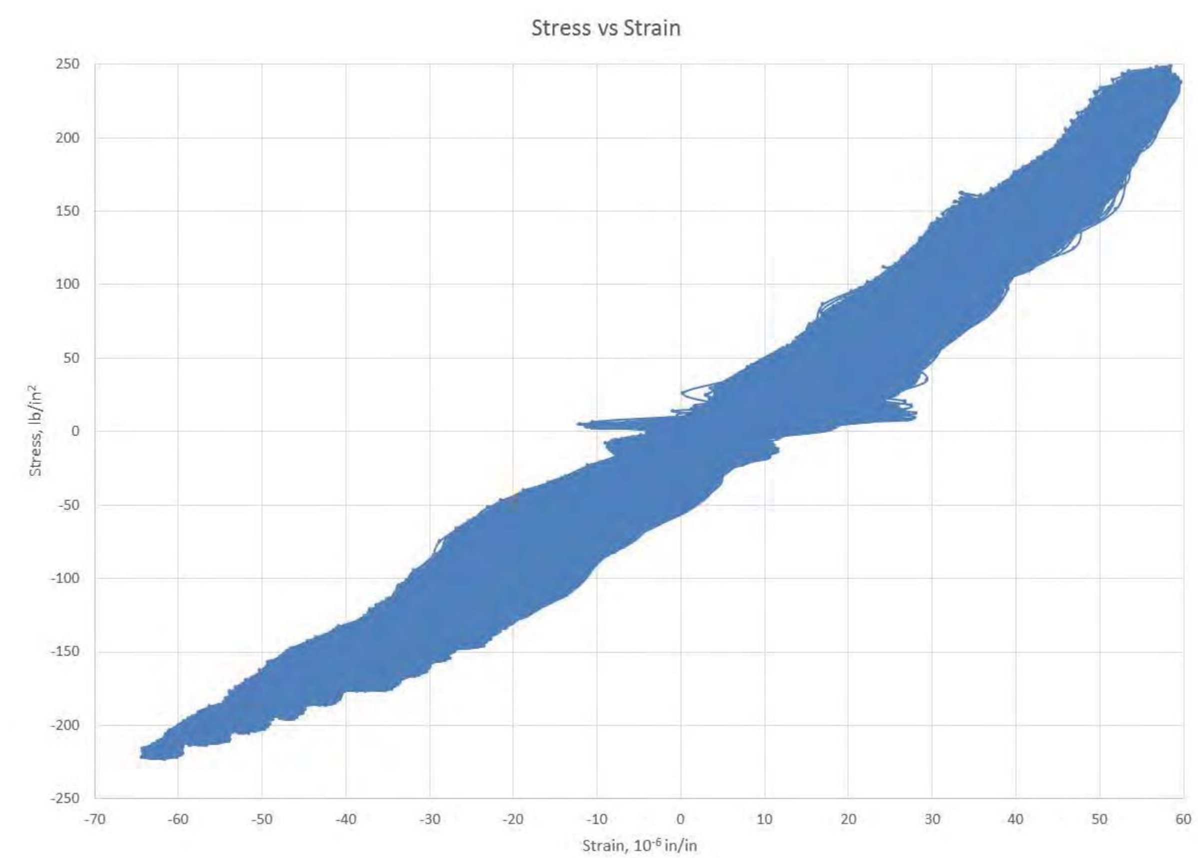


1½-inch NMSA 8-inch Diameter Core

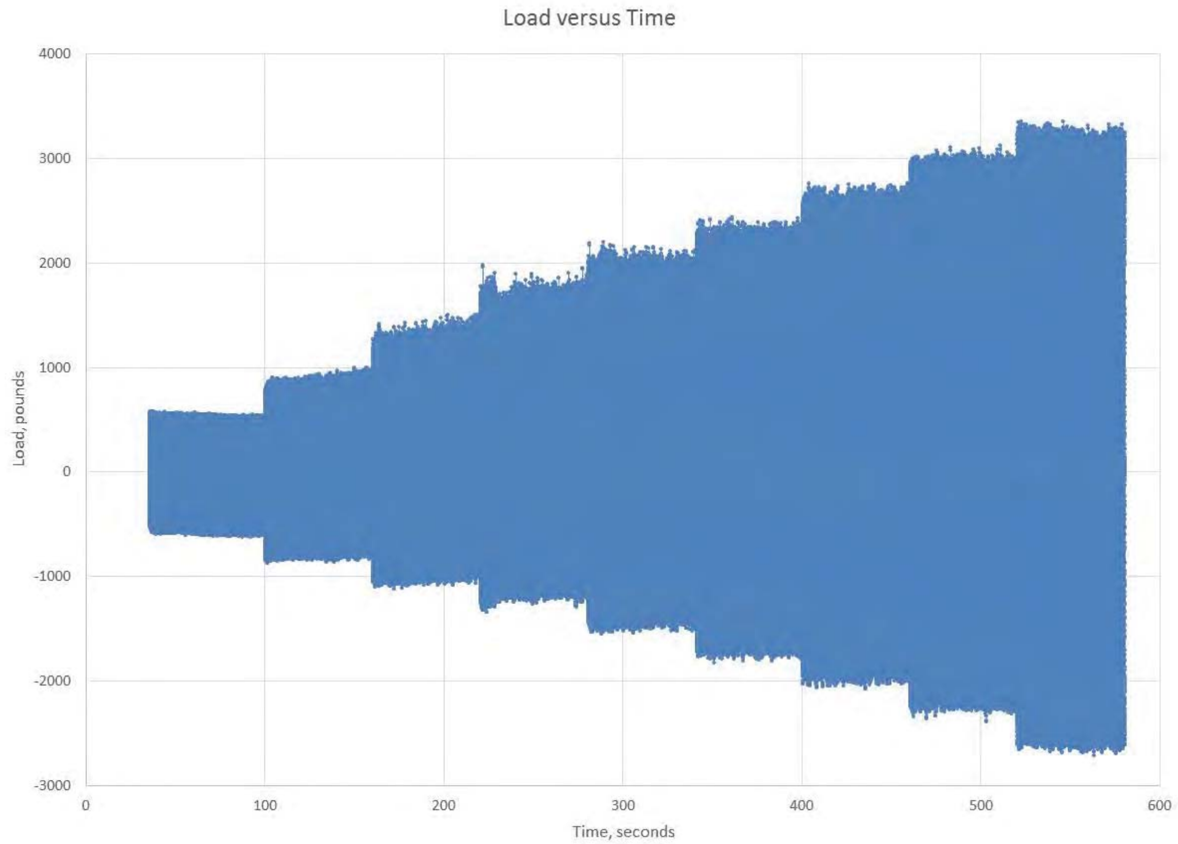


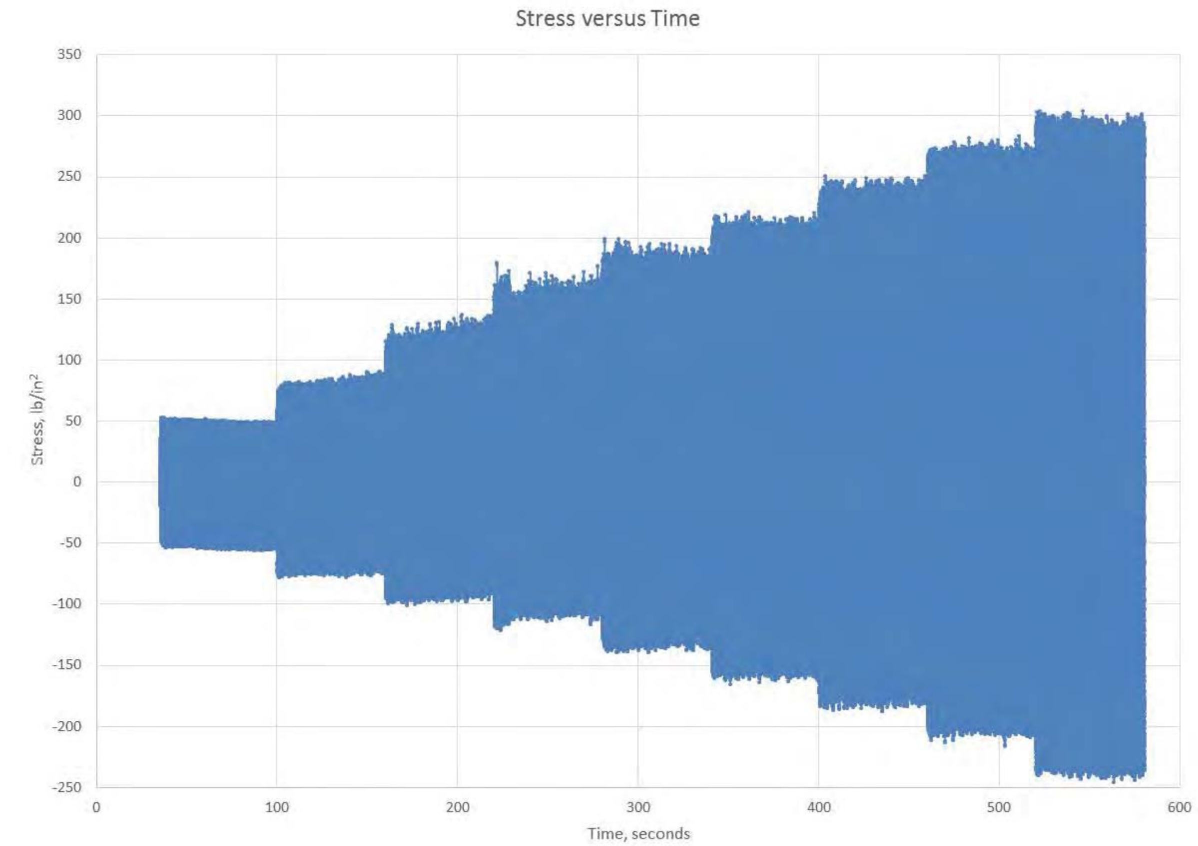


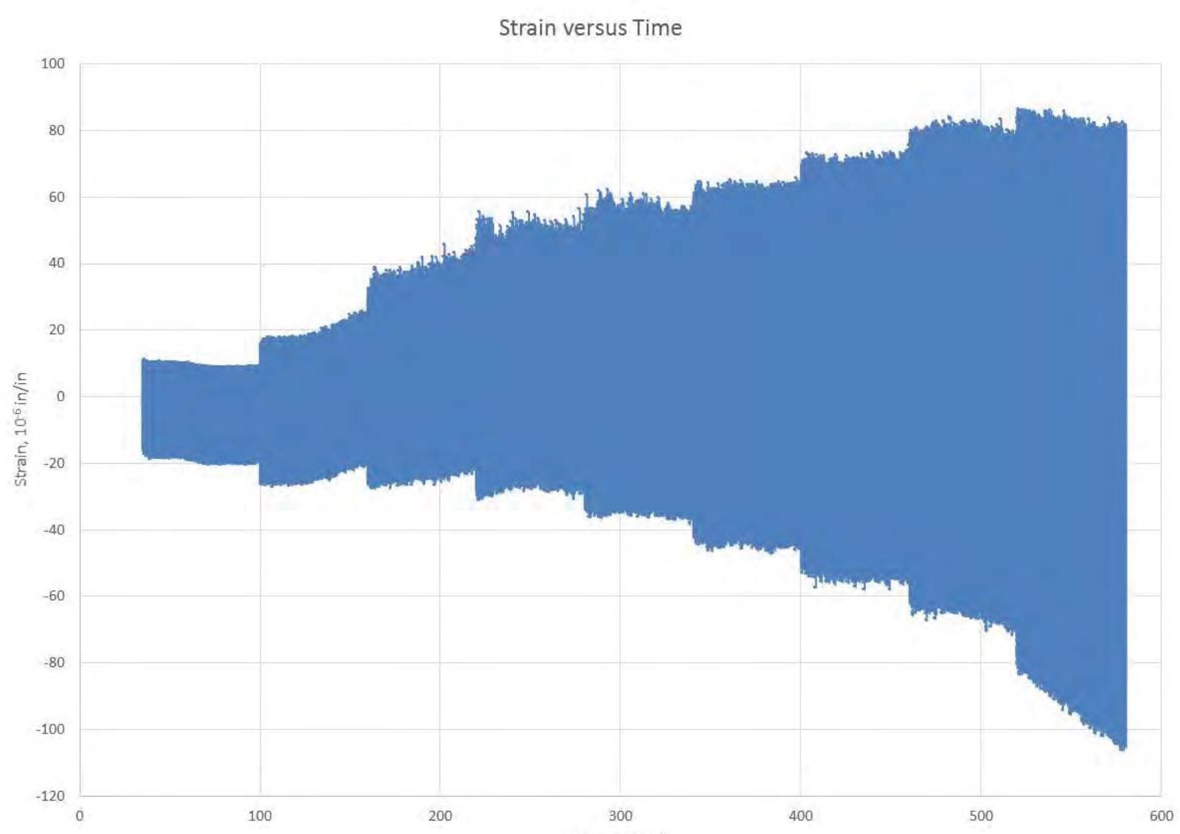


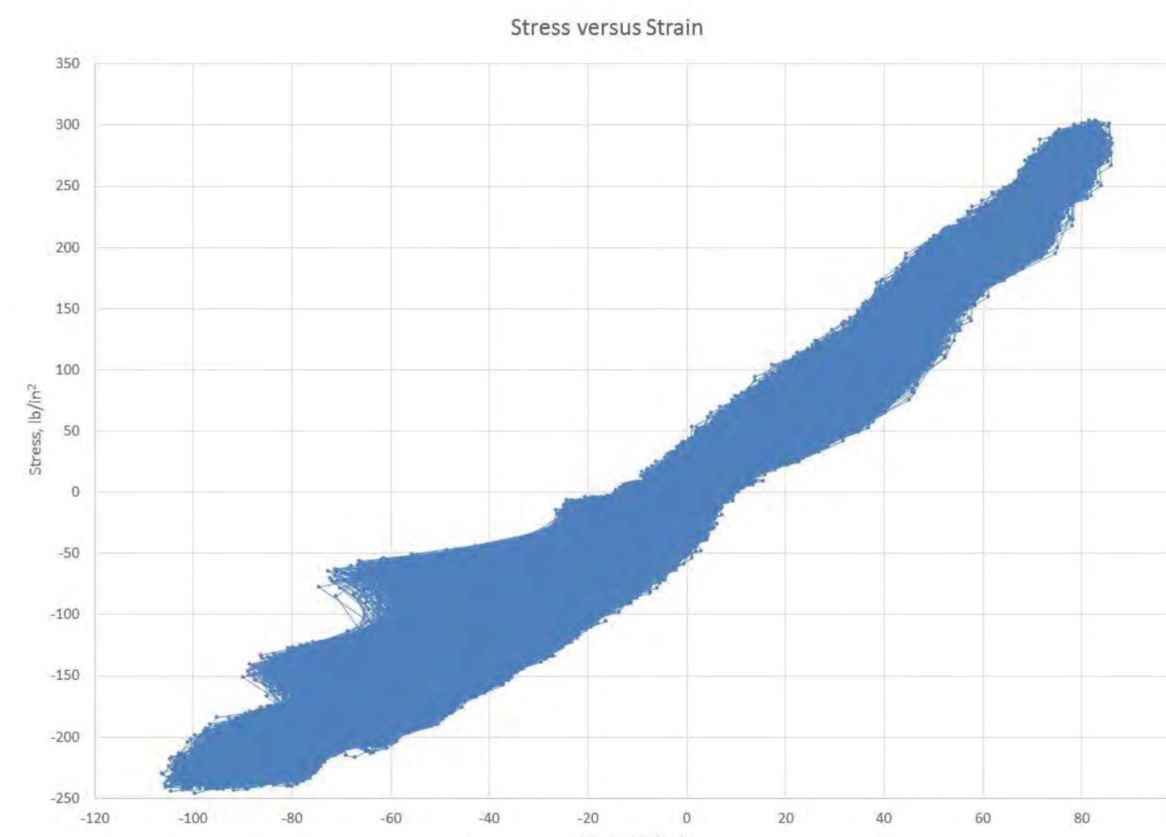


1½-inch NMSA 4-inch Diameter Core

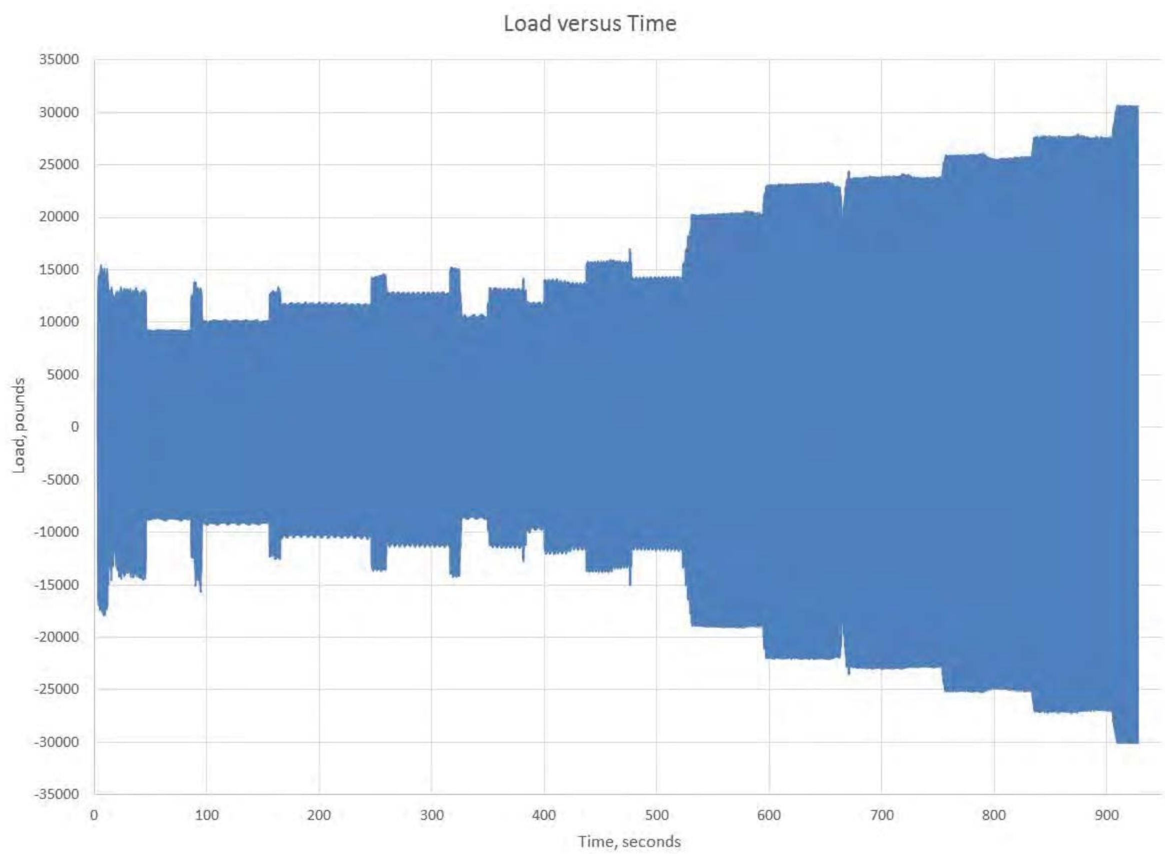


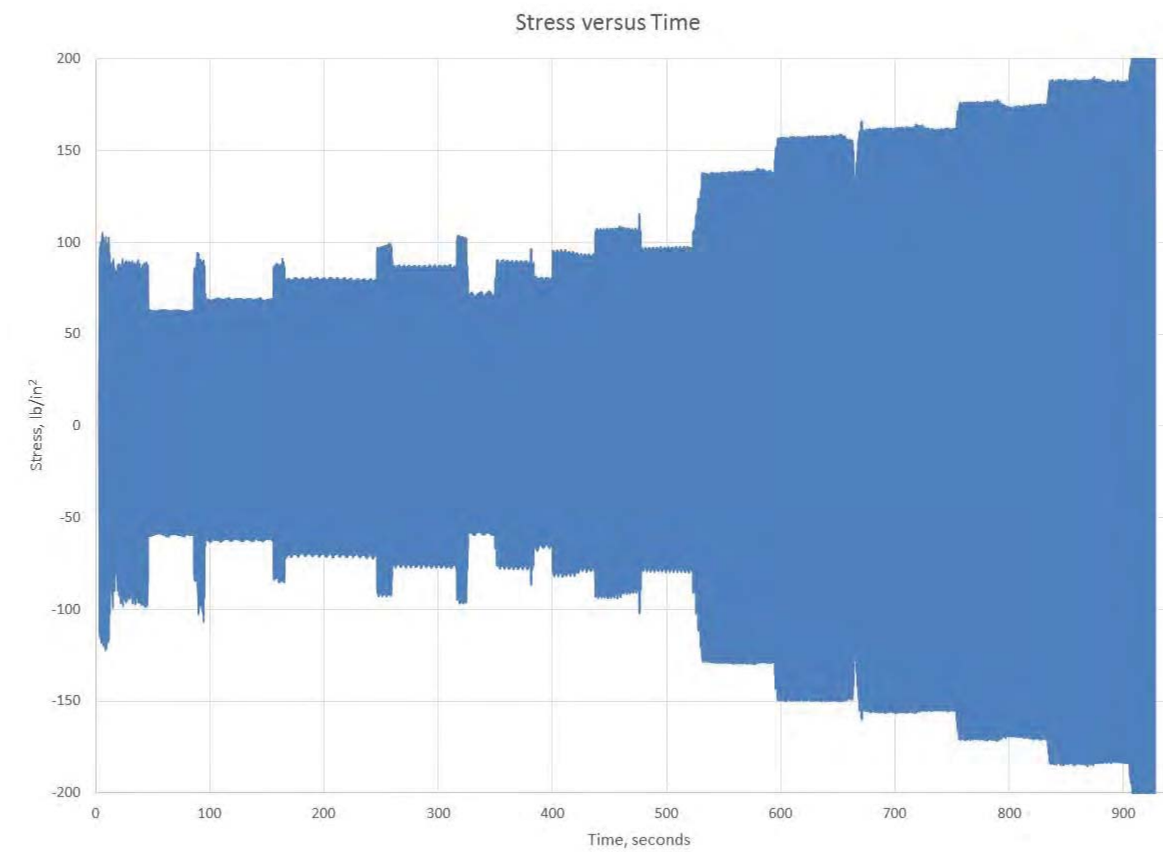


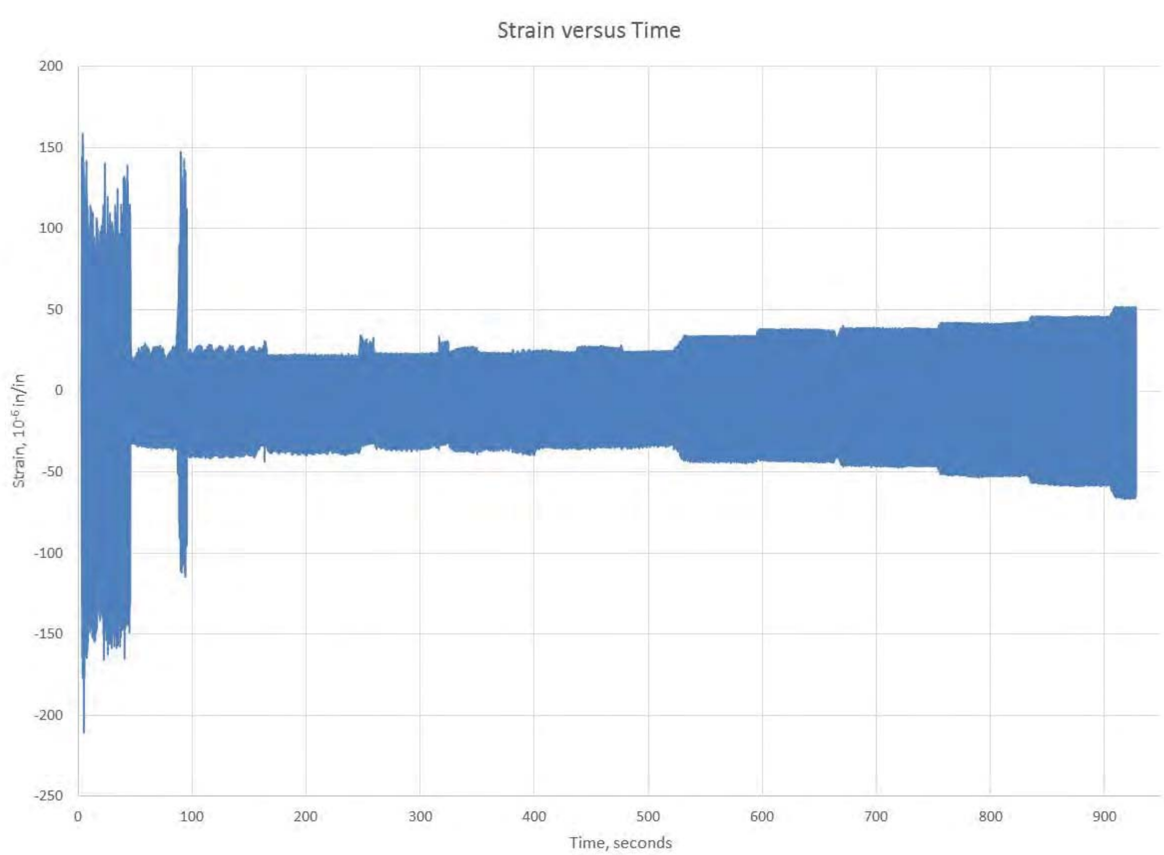


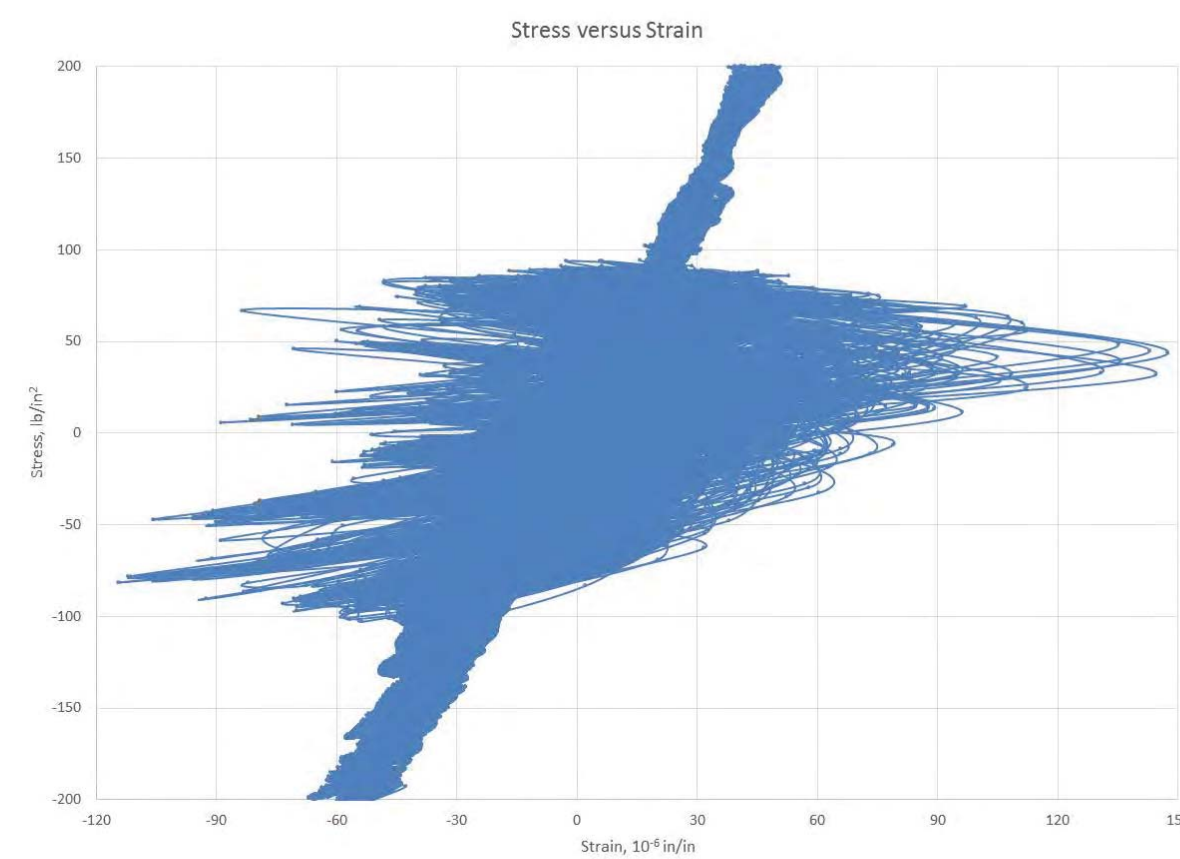


3/8-inch NMSA 14-inch Diameter Core

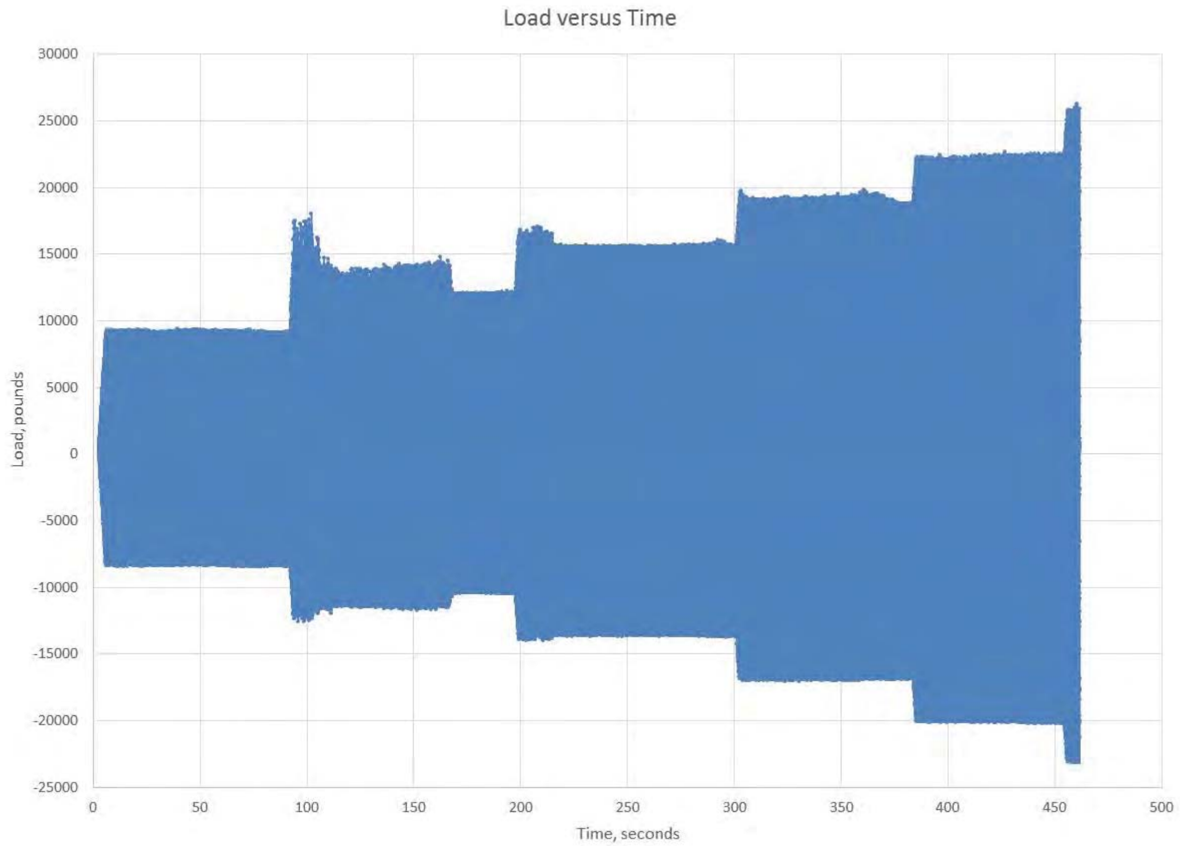


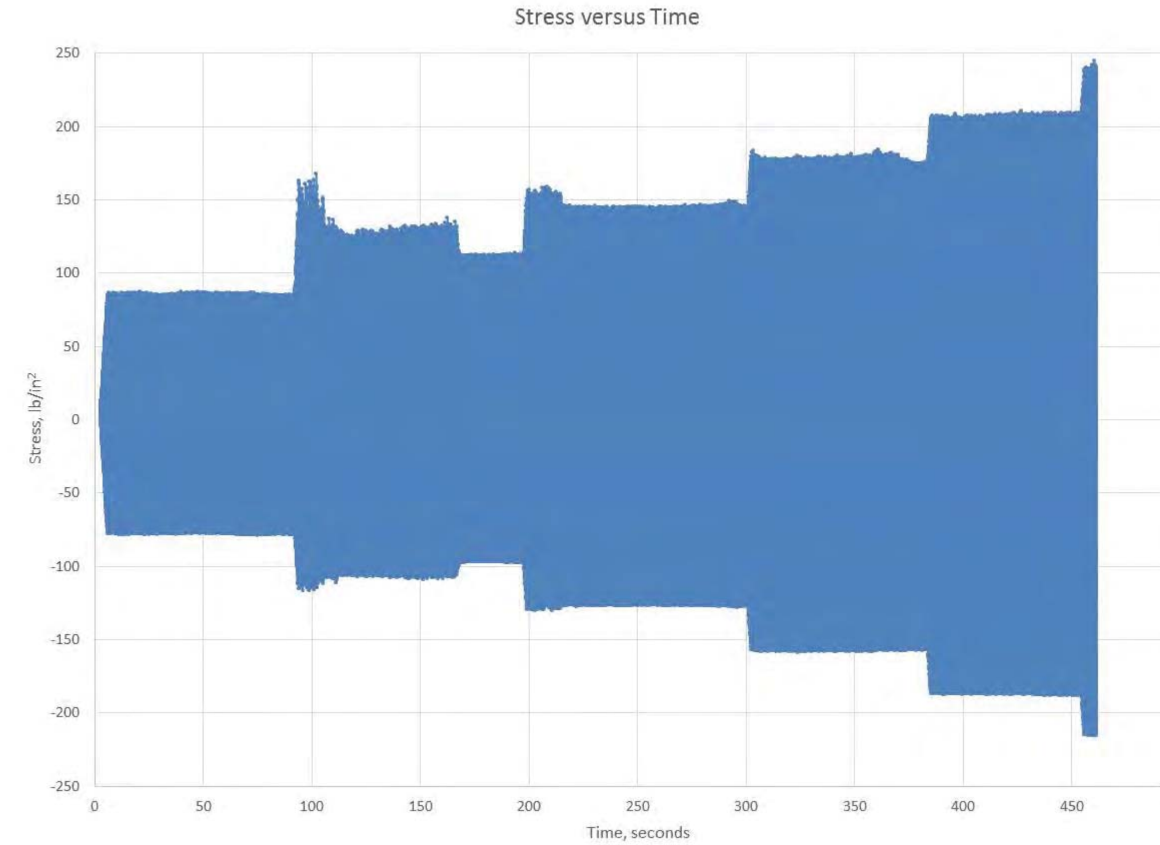


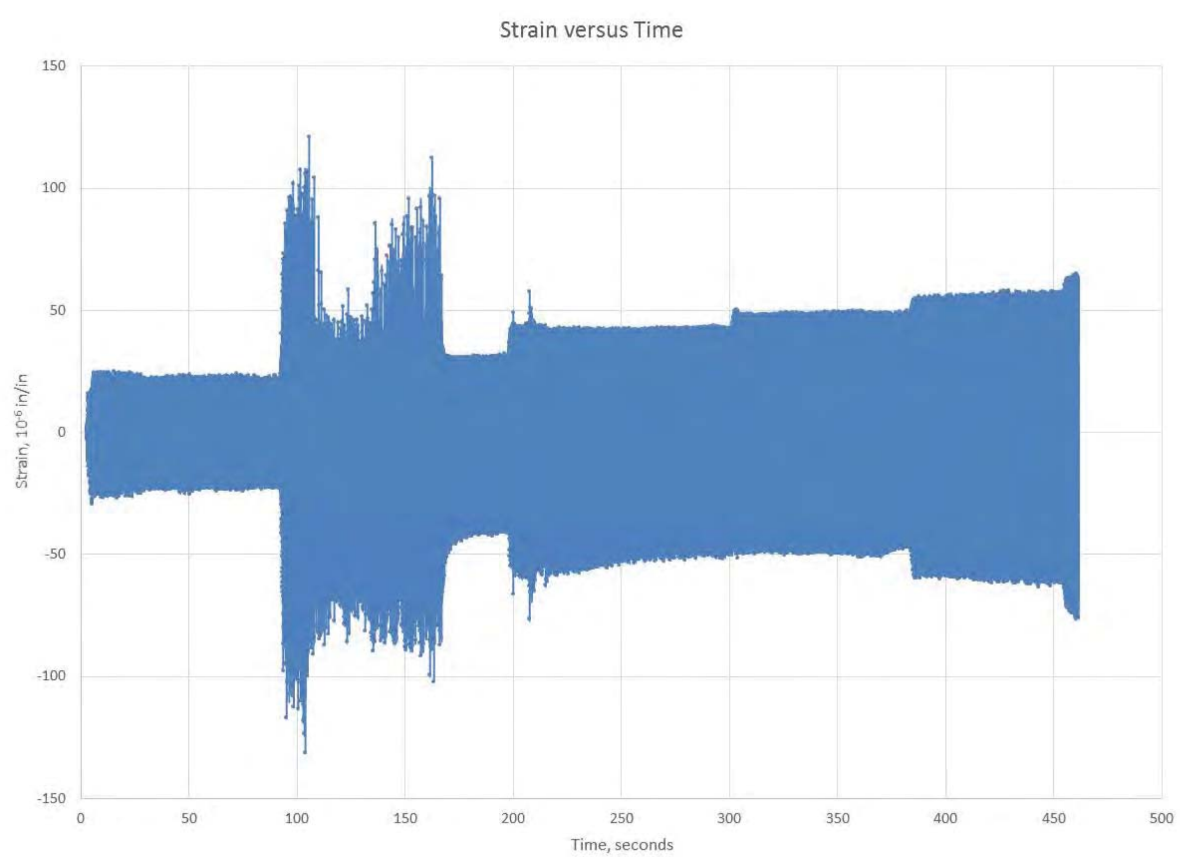


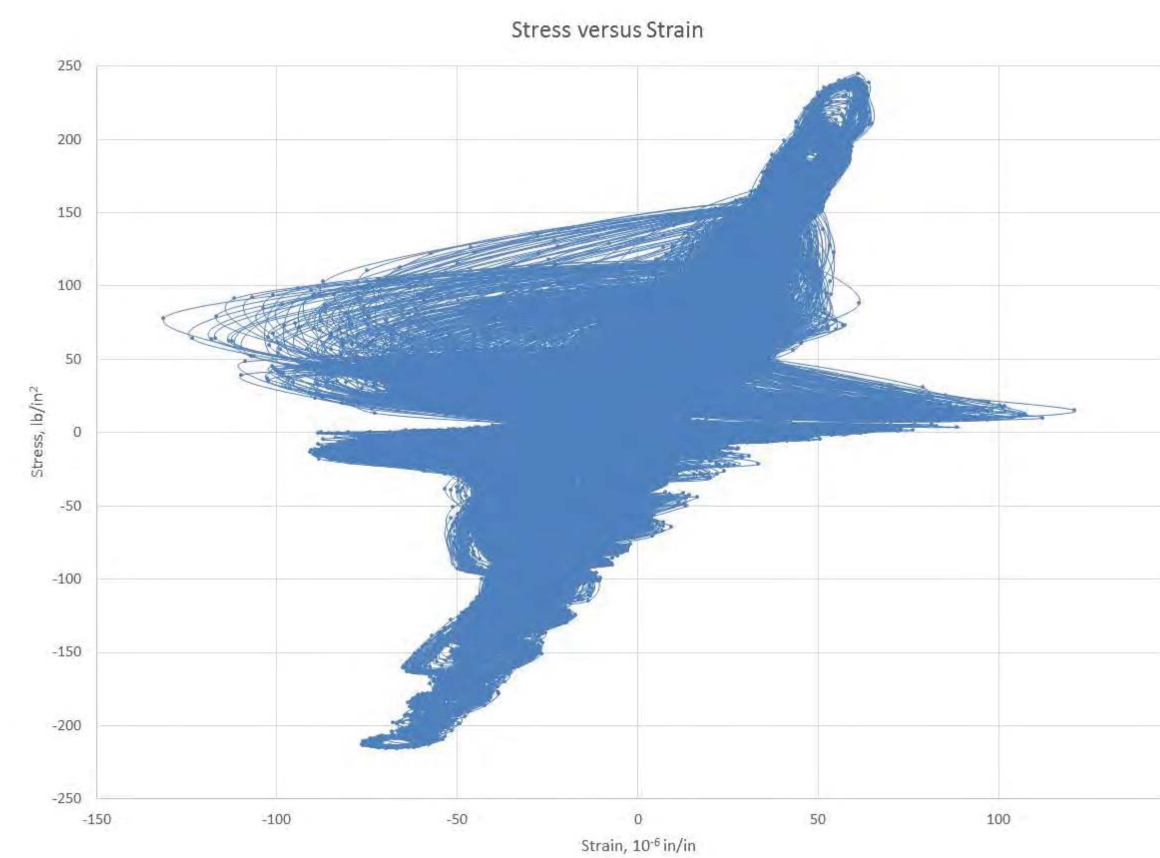


3/8-inch NMSA 12-inch Diameter Core

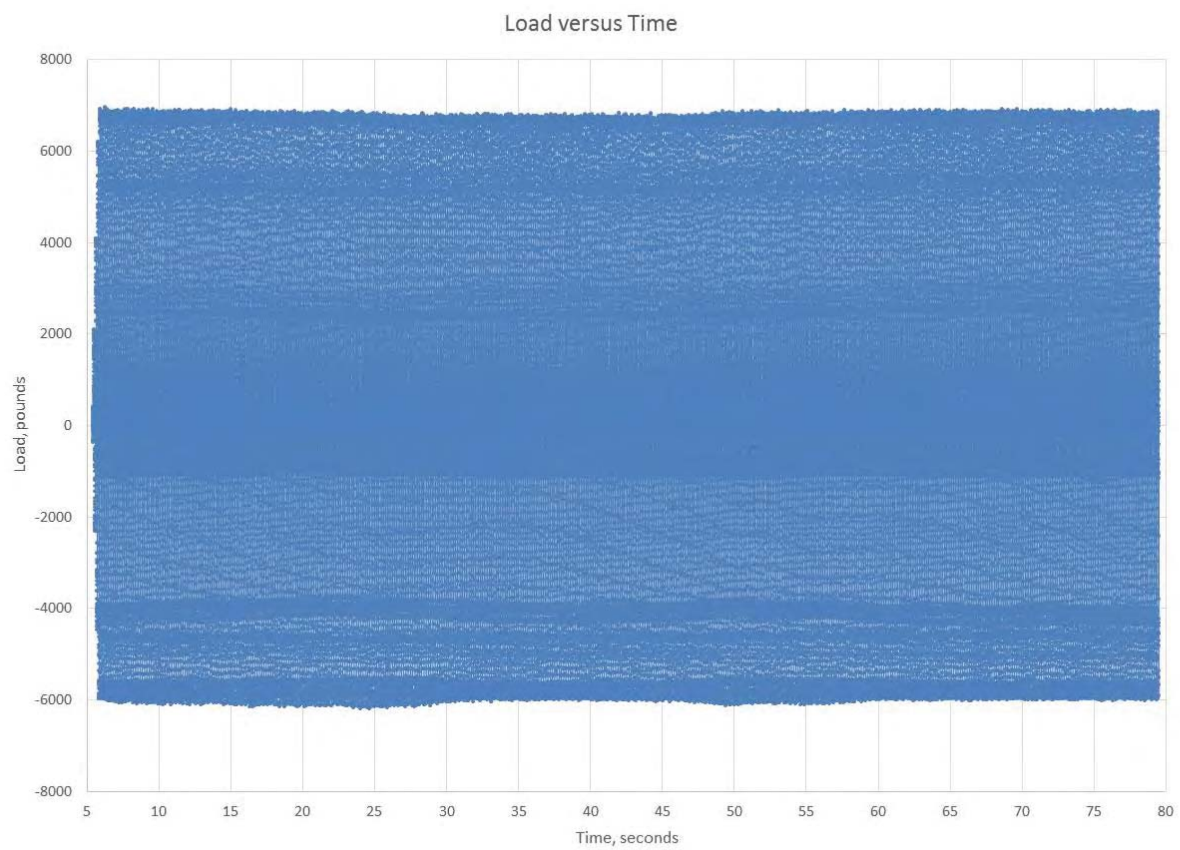


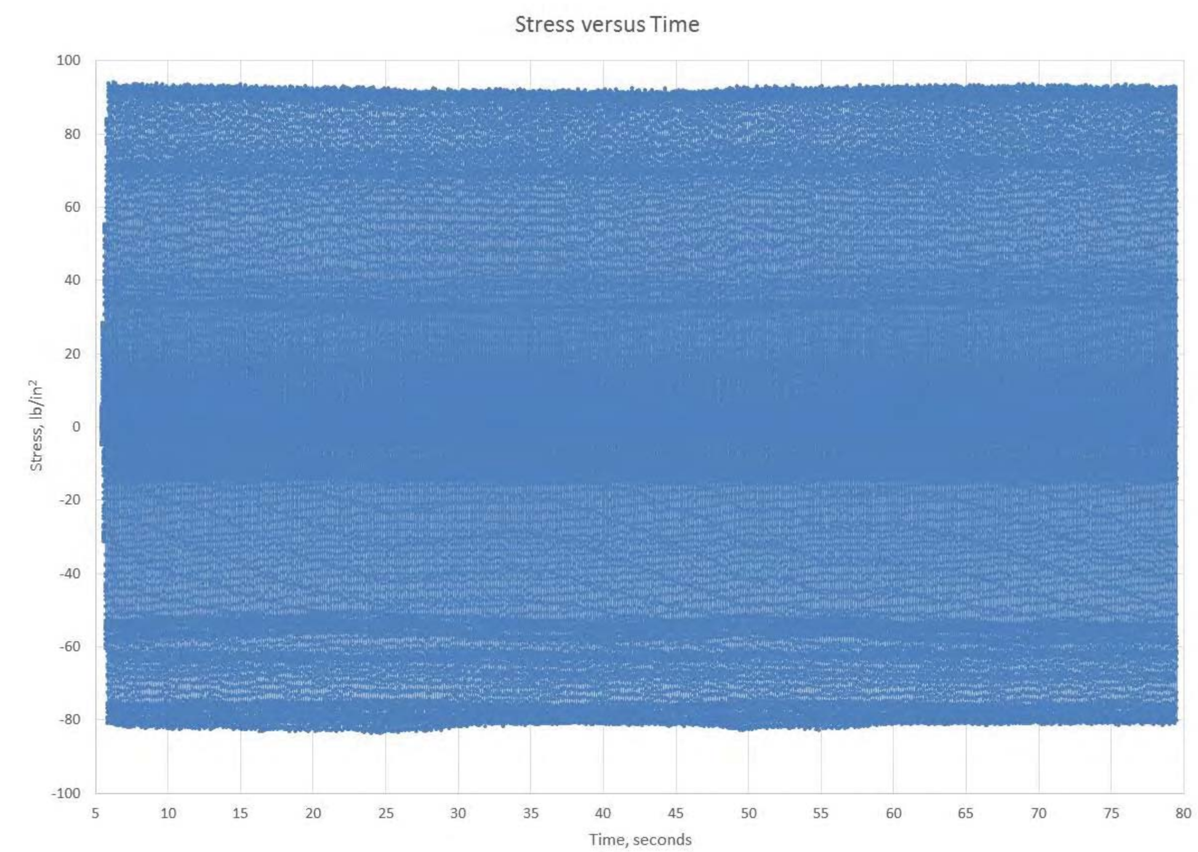


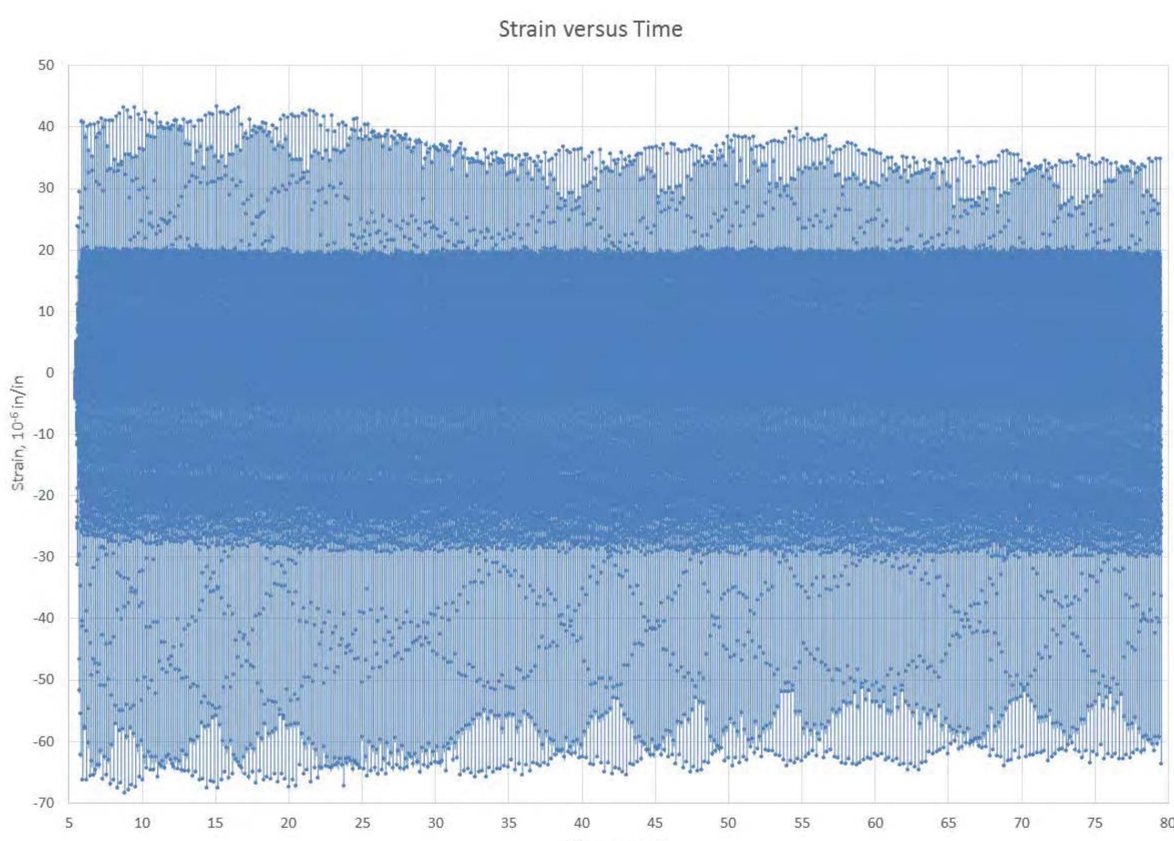


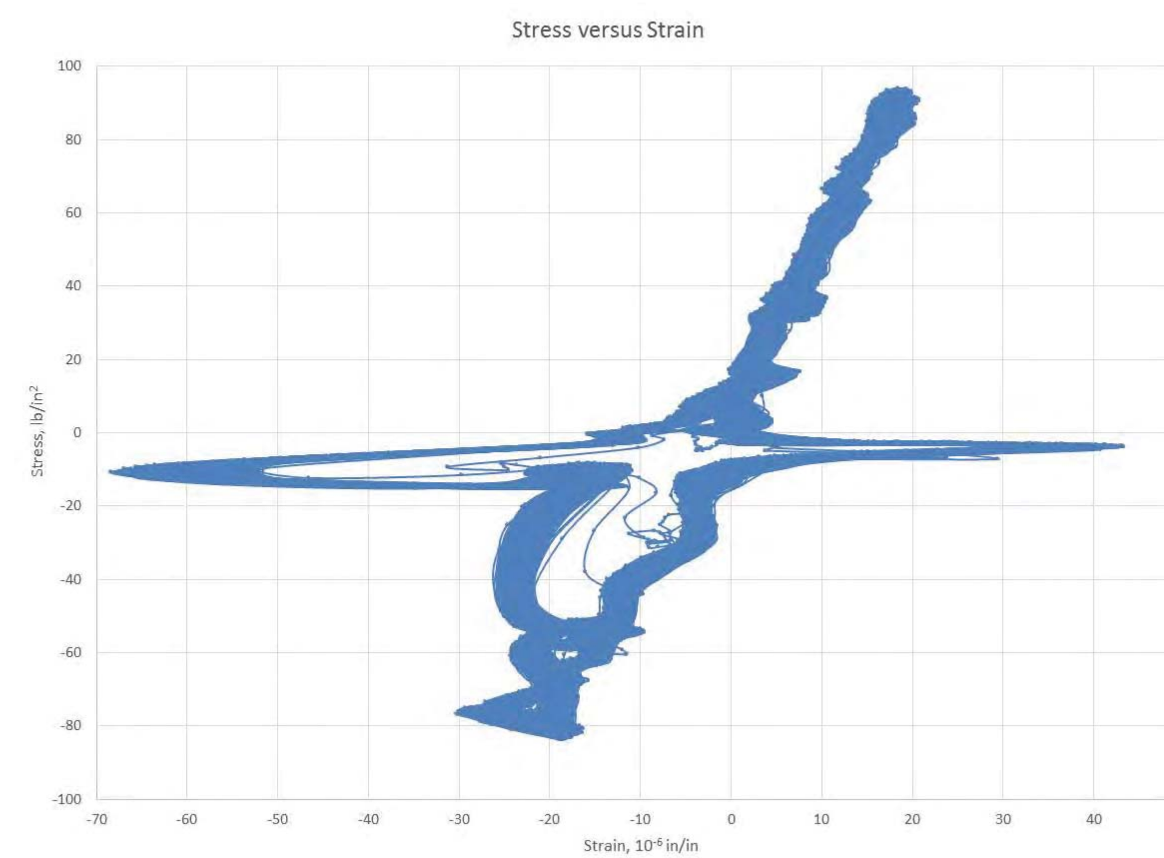


3/8-inch NMSA 10-inch Diameter Core

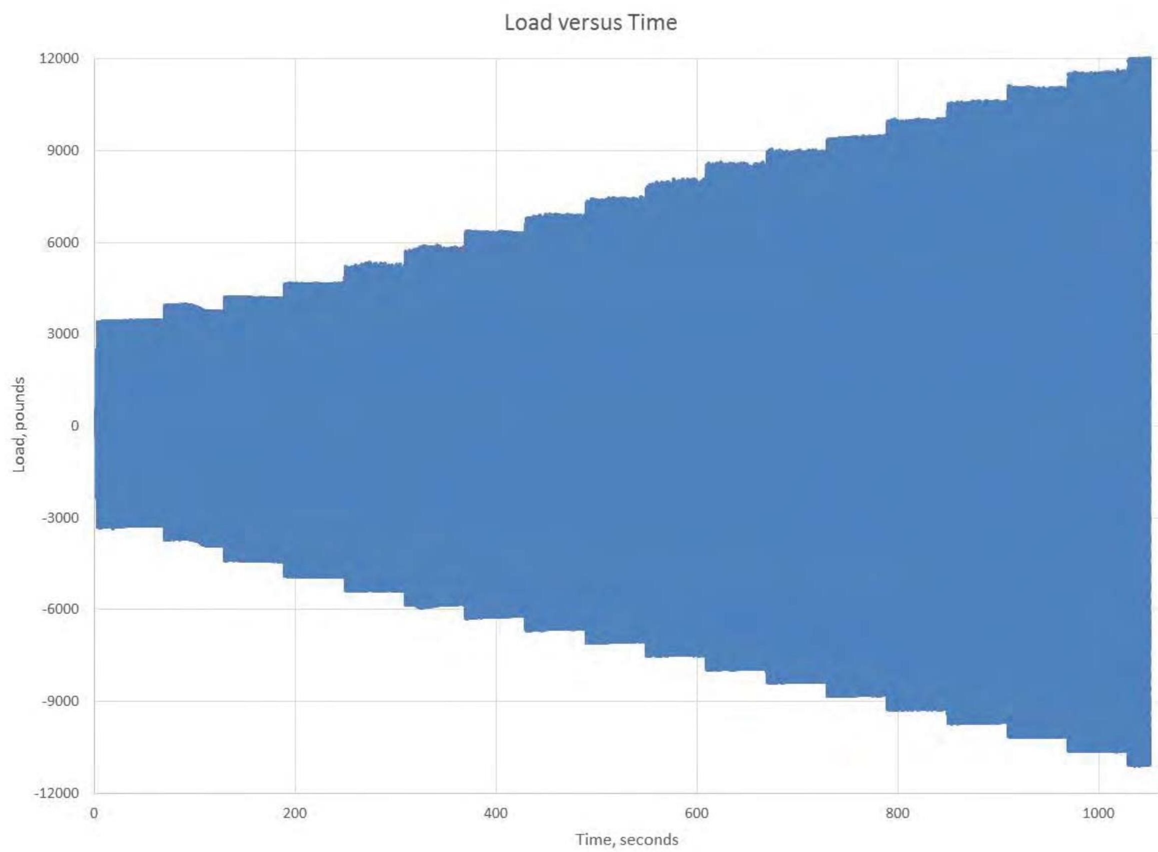


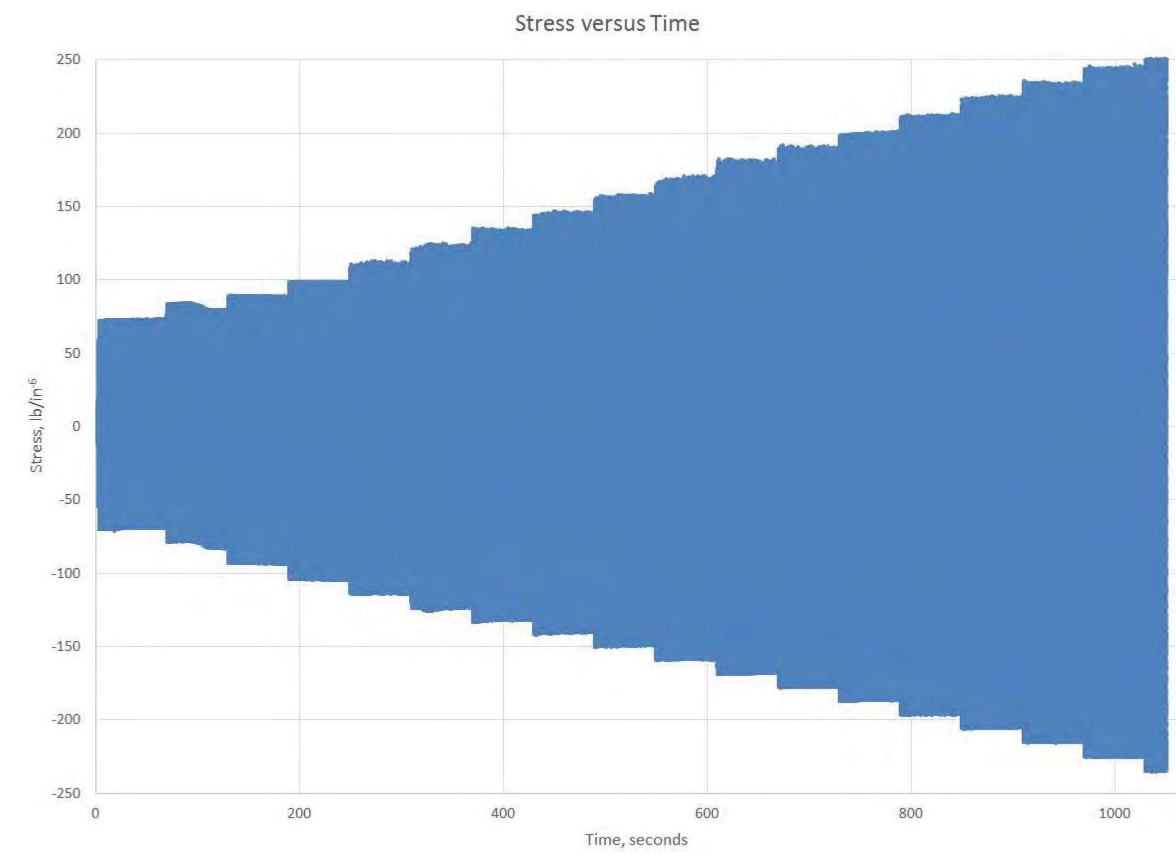


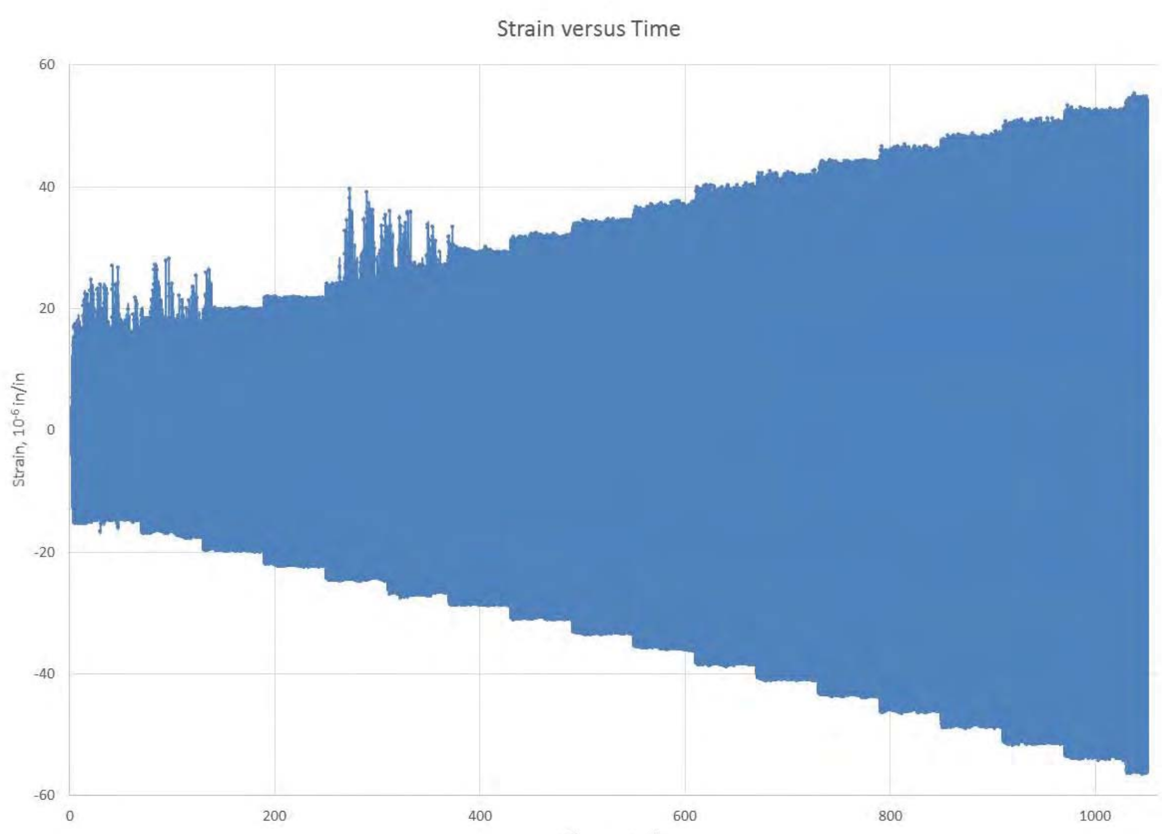


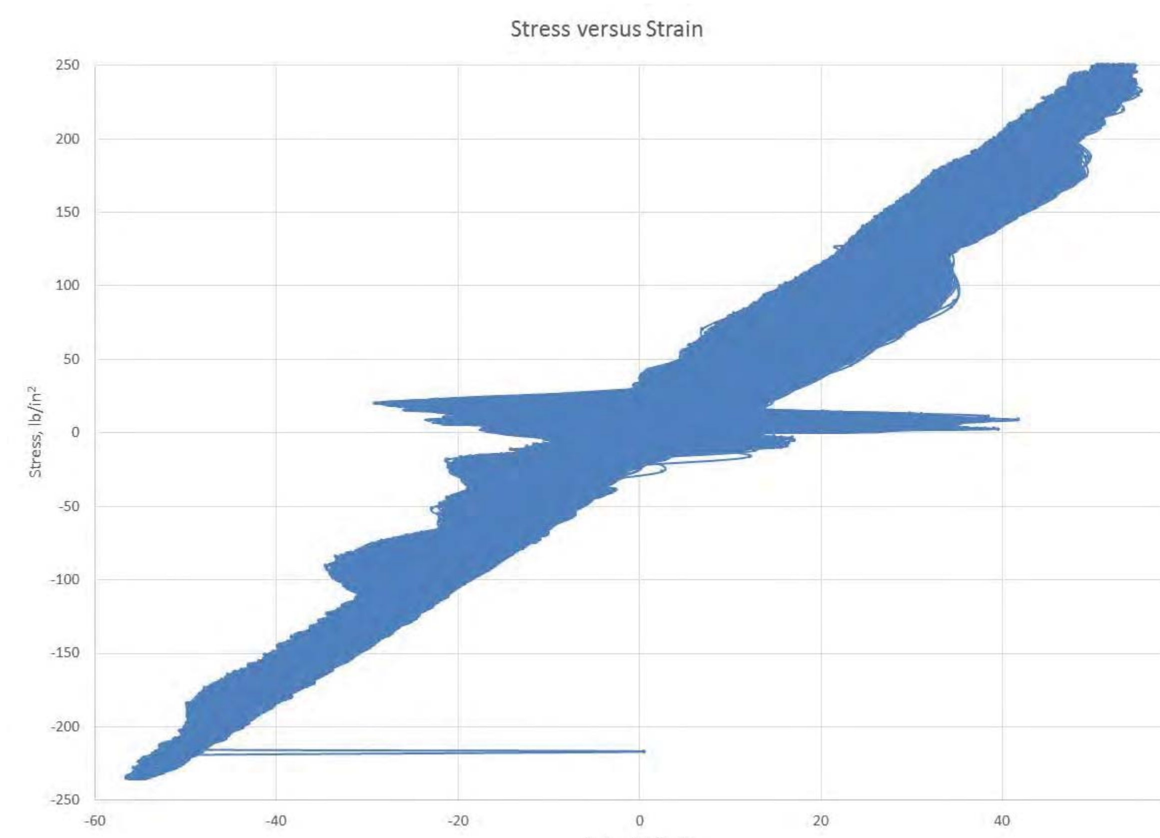


3/8-inch NMSA 8-inch Diameter Core

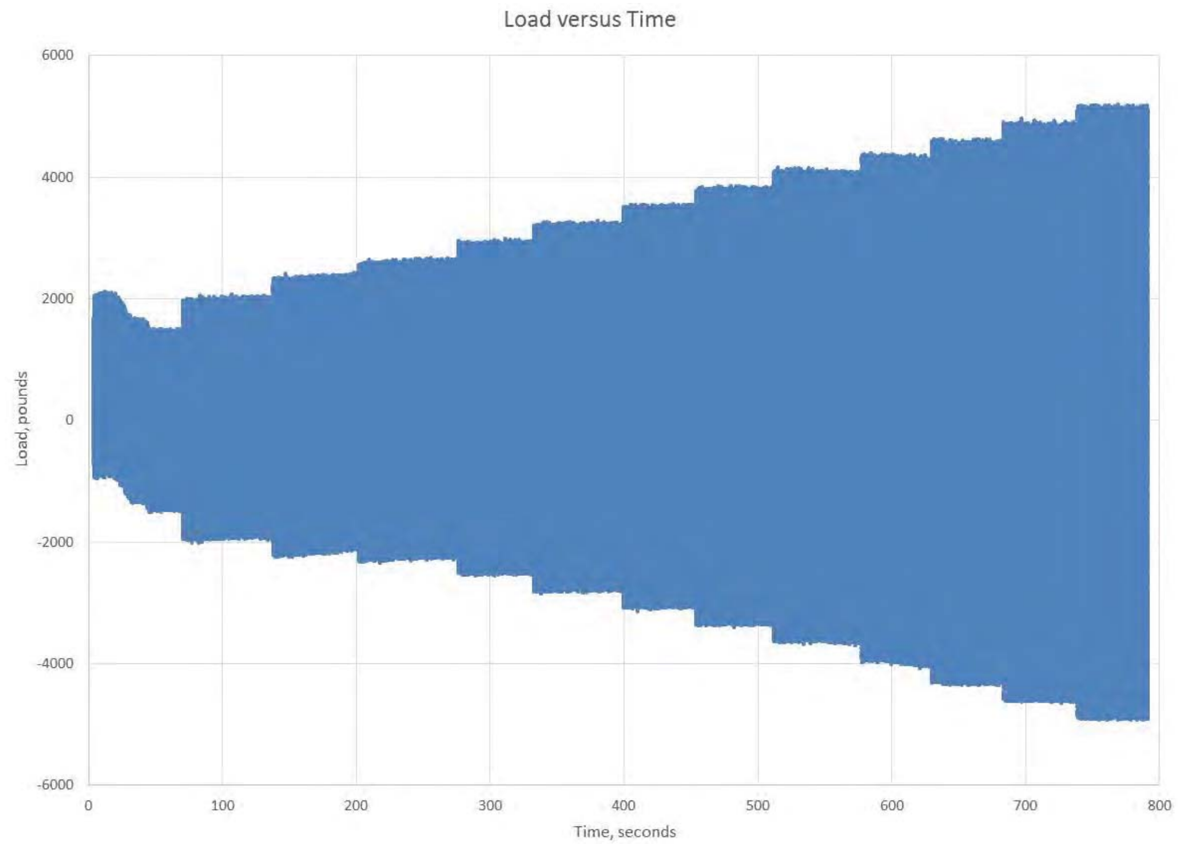


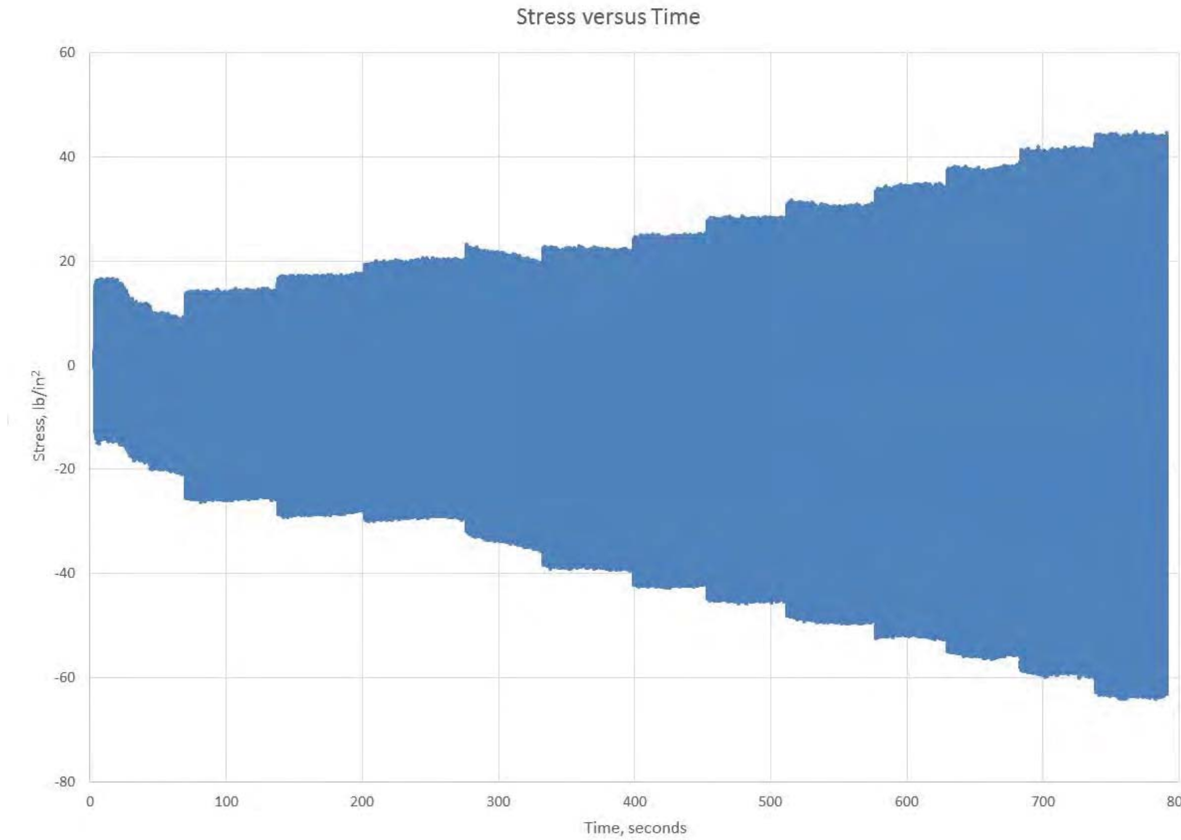


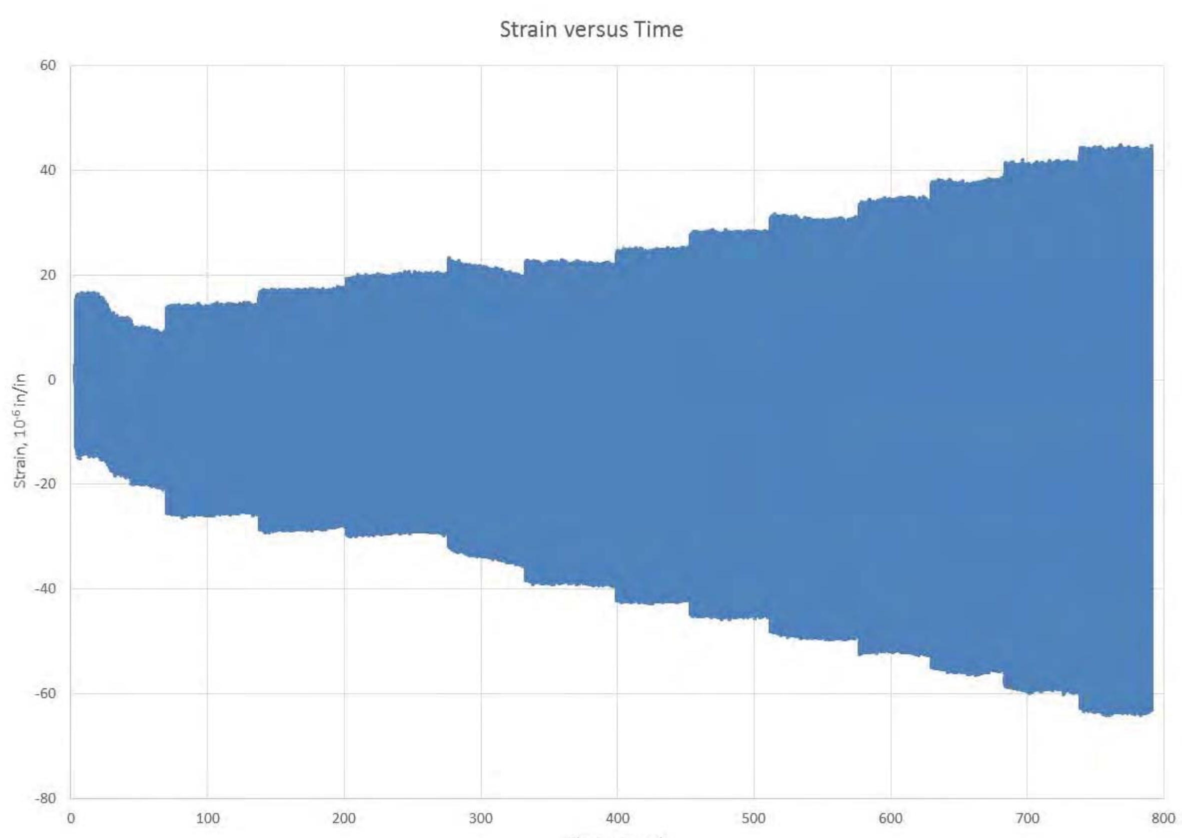


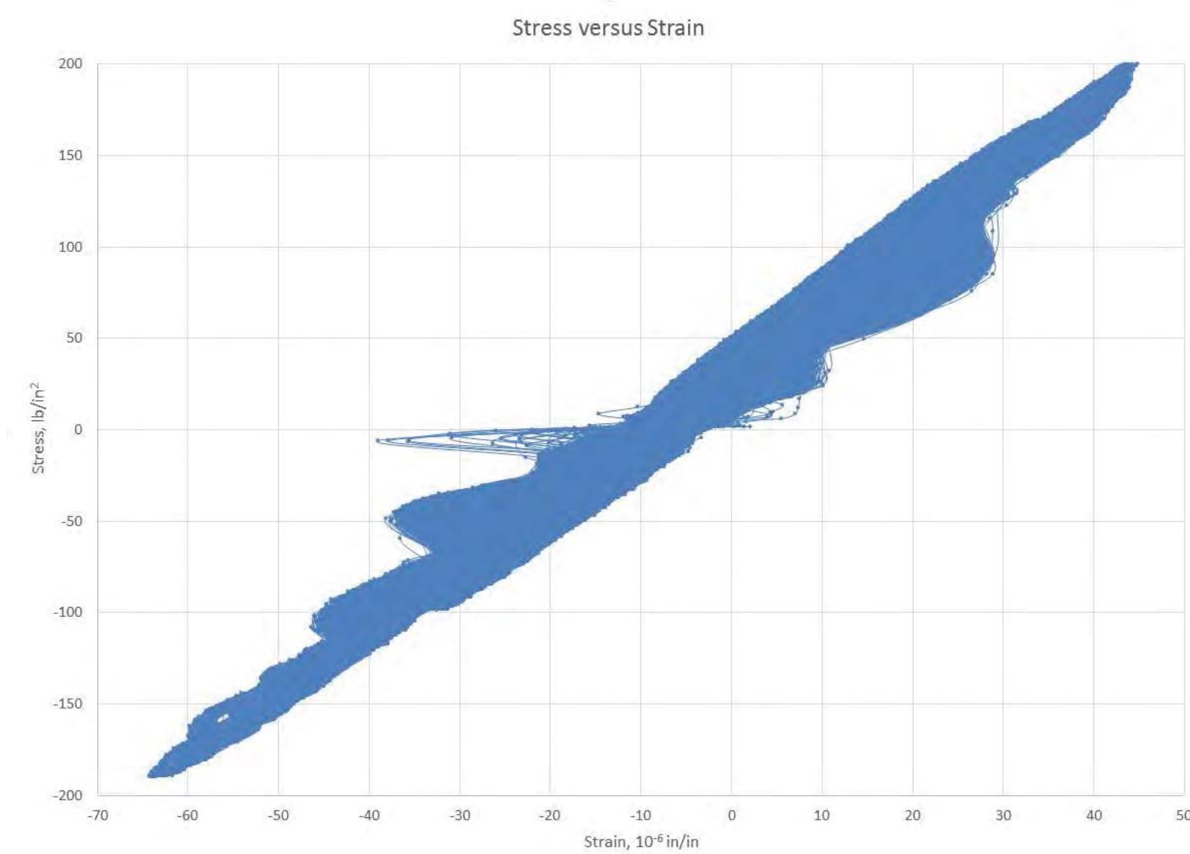


3/8-inch NMSA 6-inch Diameter Core

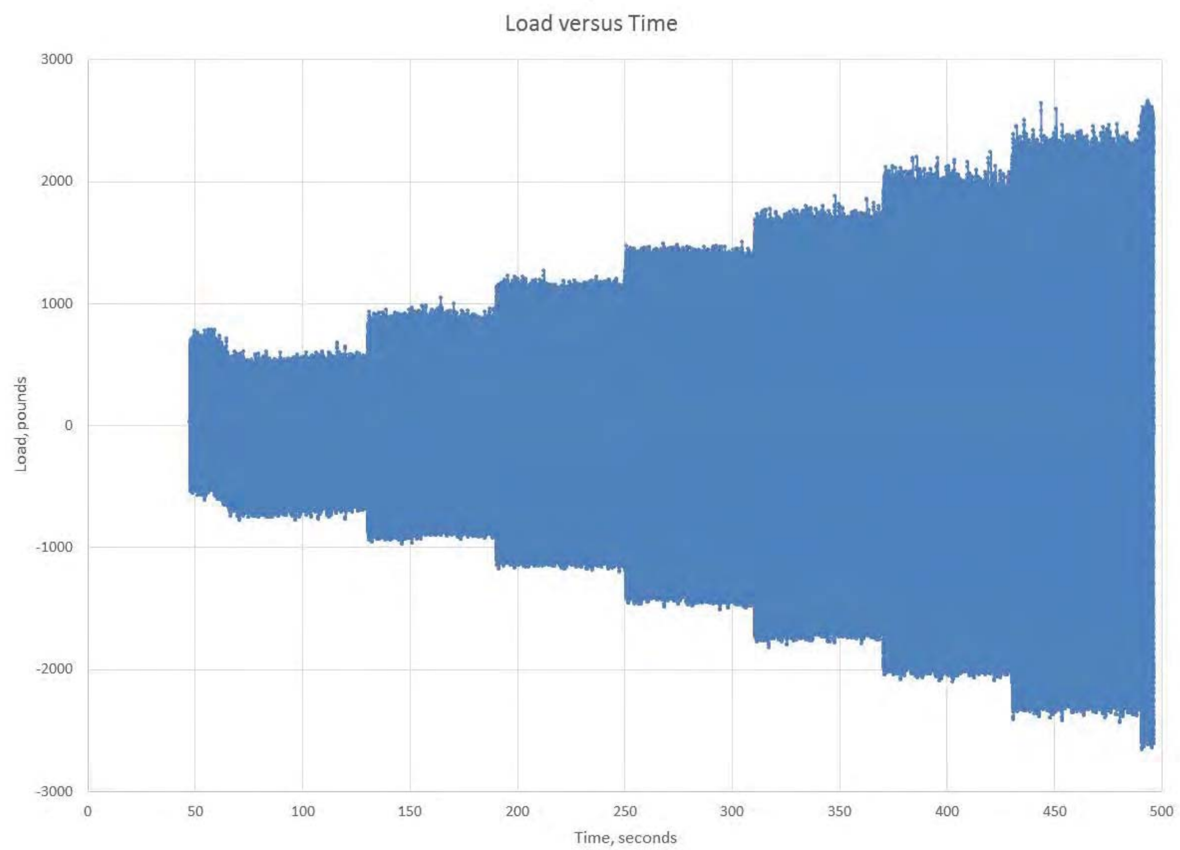


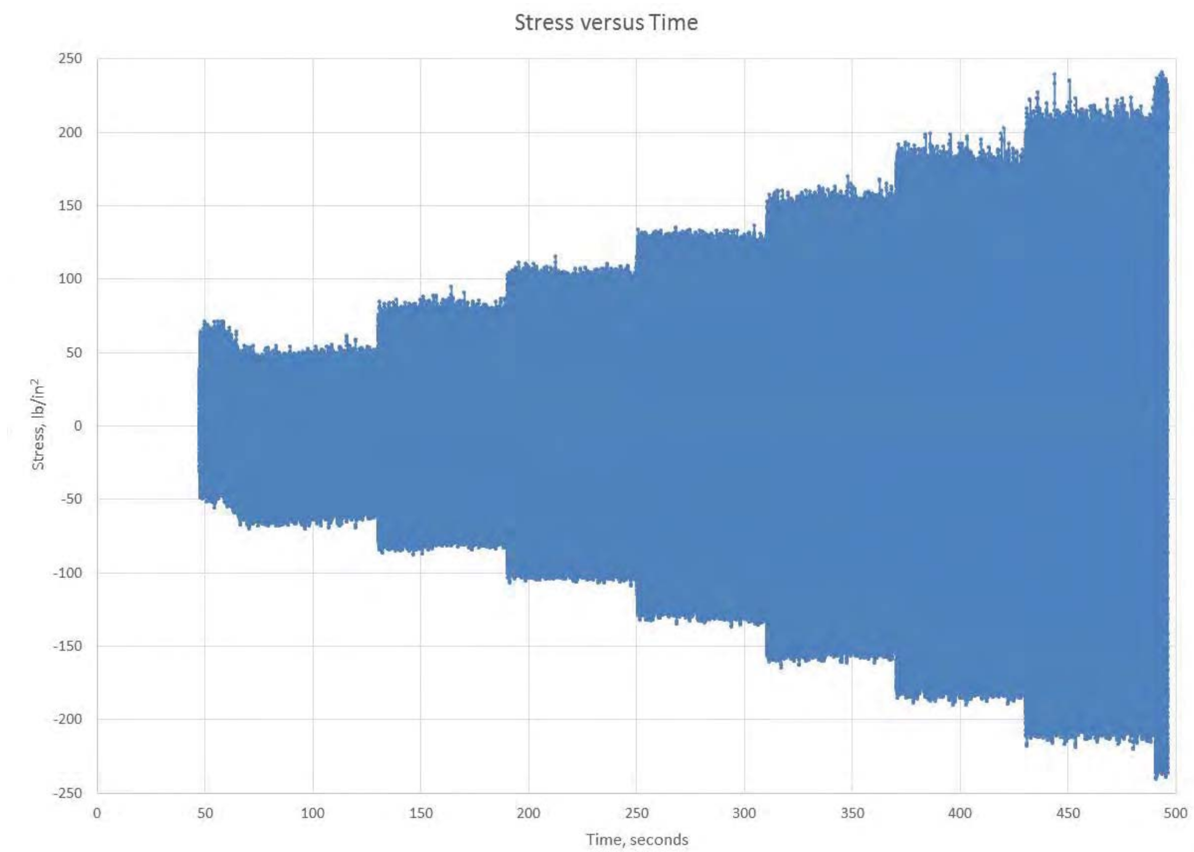


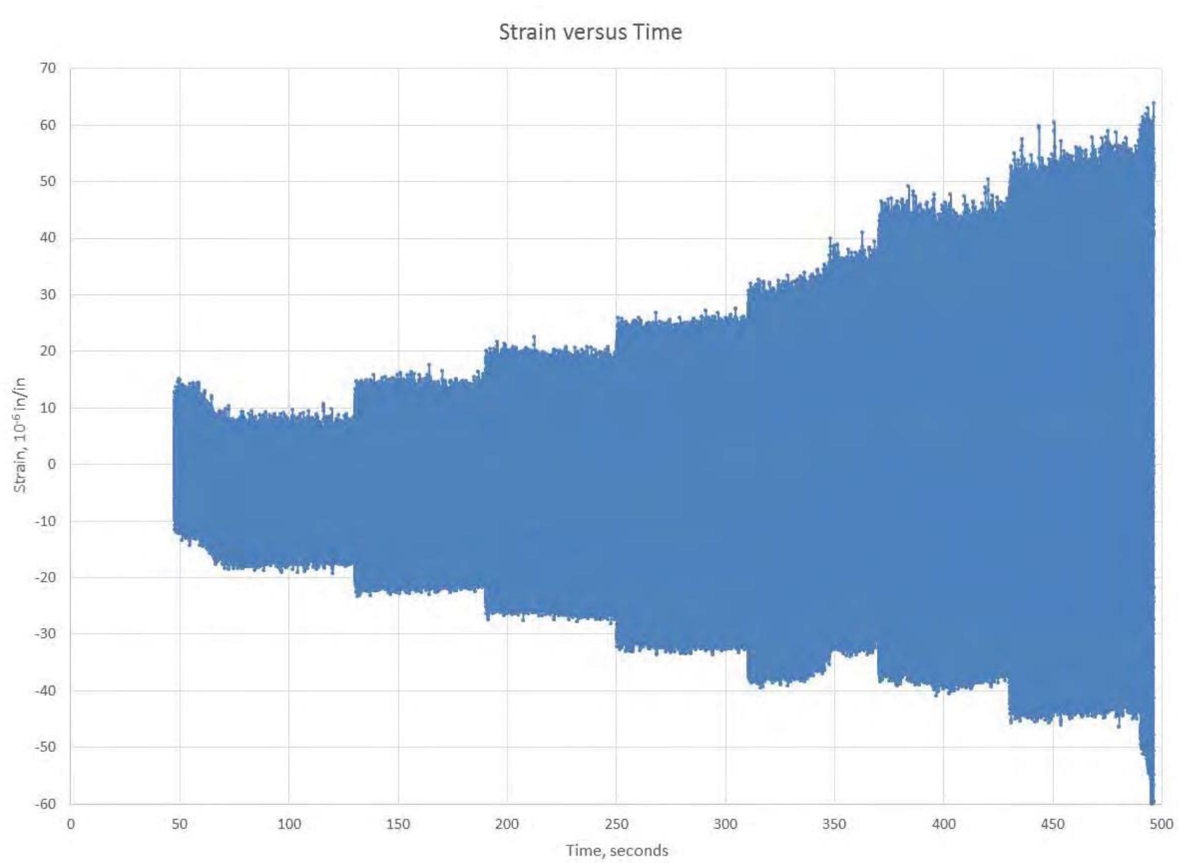


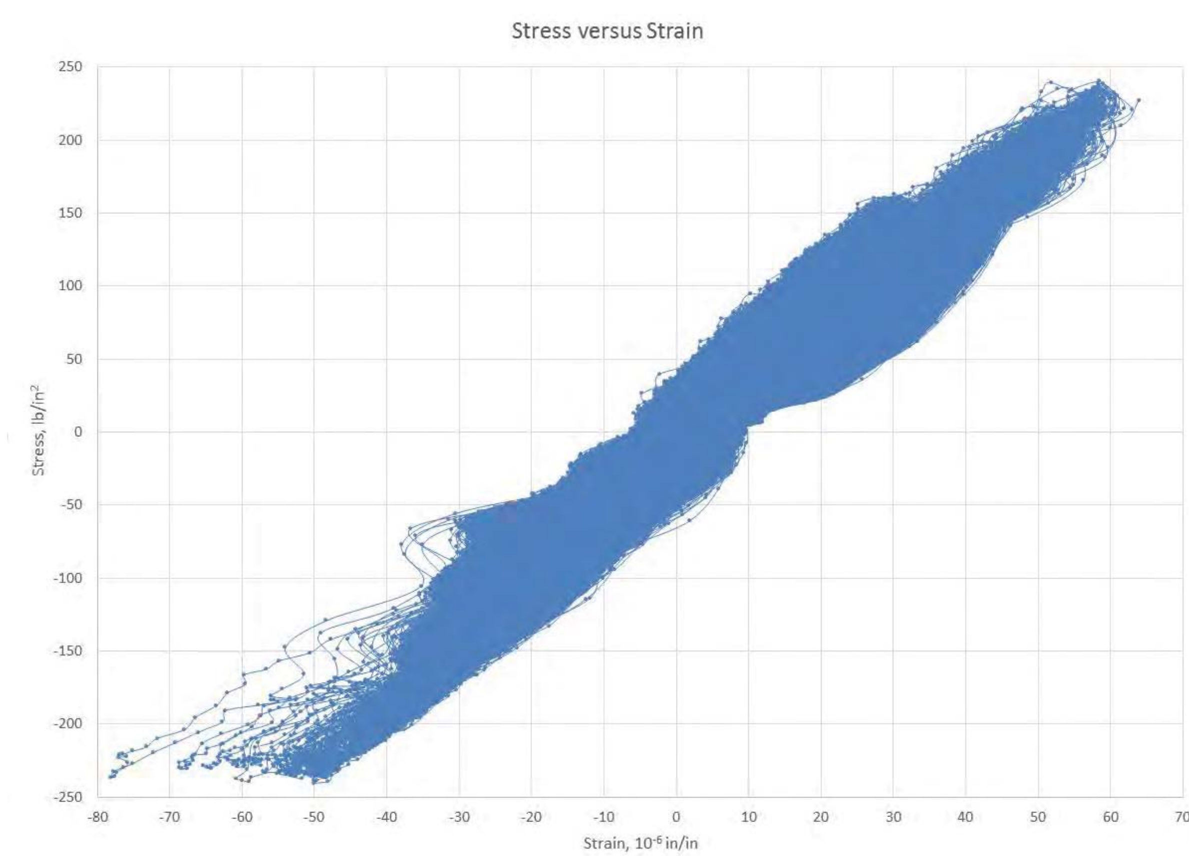


3/8-inch NMSA 4-inch Diameter Core









Appendix G

Photographs of Failed
Splitting Tension Test Specimens

Failed Splitting Tension Test Specimens from 8-inch NMSA Concrete Blocks

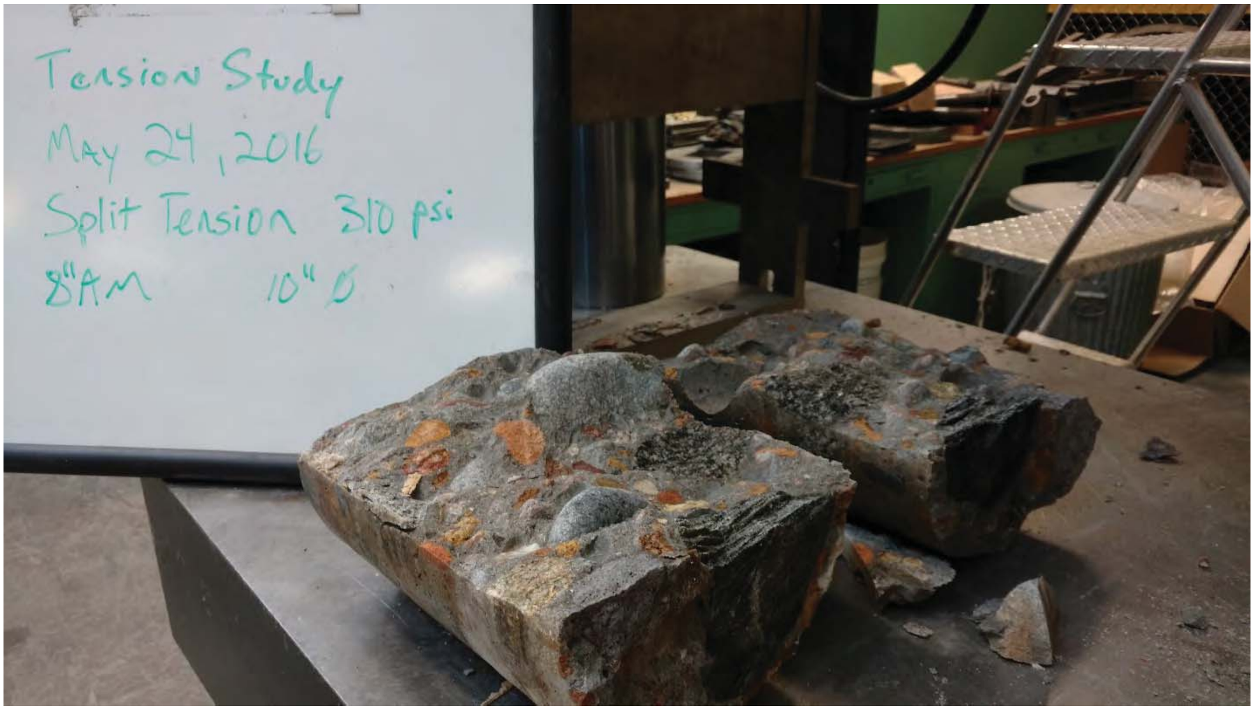


Figure G-1: 10-inch diameter core

Figure G-2: 6-inch diameter core

Failed Splitting Tension Test Specimens from 8-inch NMSA Concrete Blocks

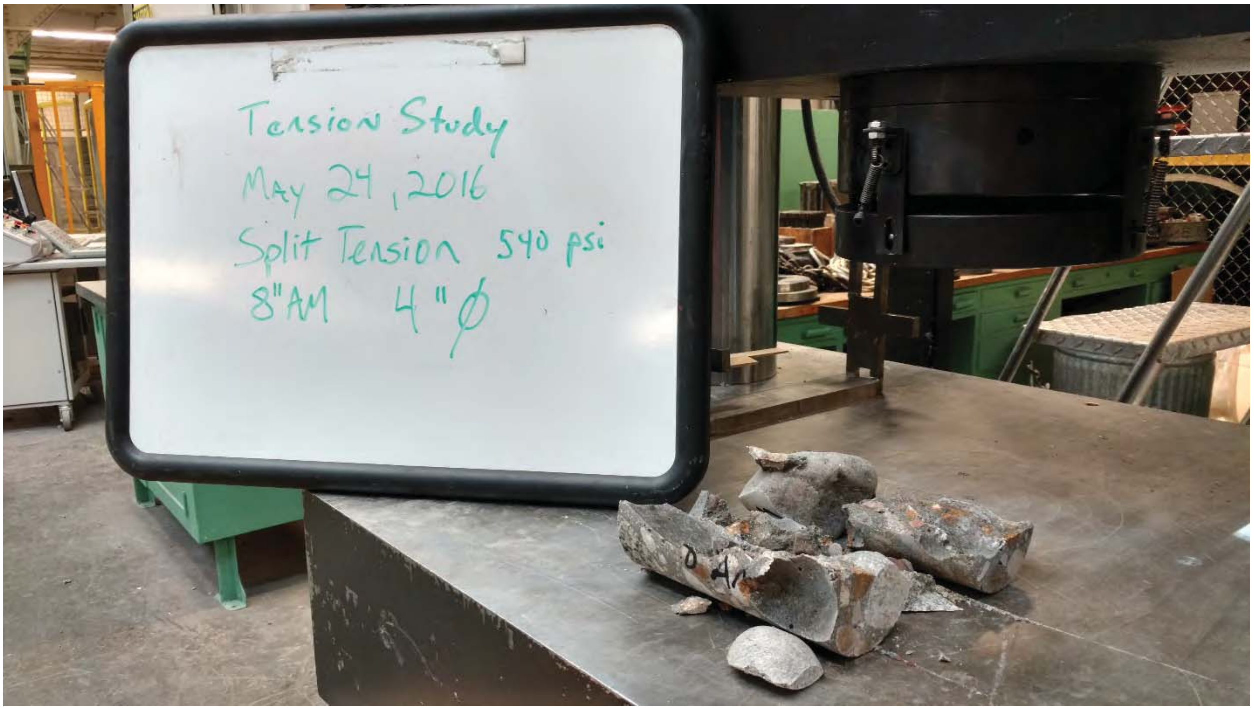


Figure G-3: 4-inch diameter core

Failed Splitting Tension Test Specimens from 1½-inch NMSA Concrete Blocks

Figure G-4: 10-inch diameter core

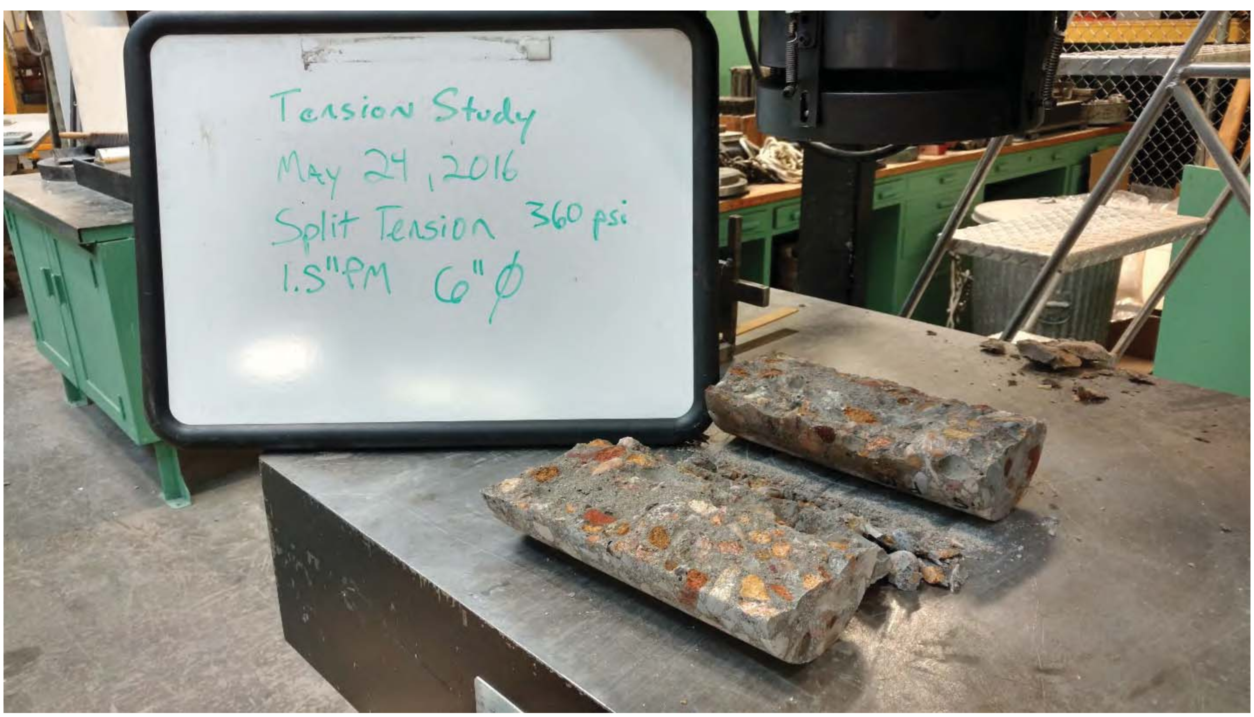


Figure G-5: 6-inch diameter core

Failed Splitting Tension Test Specimens from 1½-inch NMSA Concrete Blocks

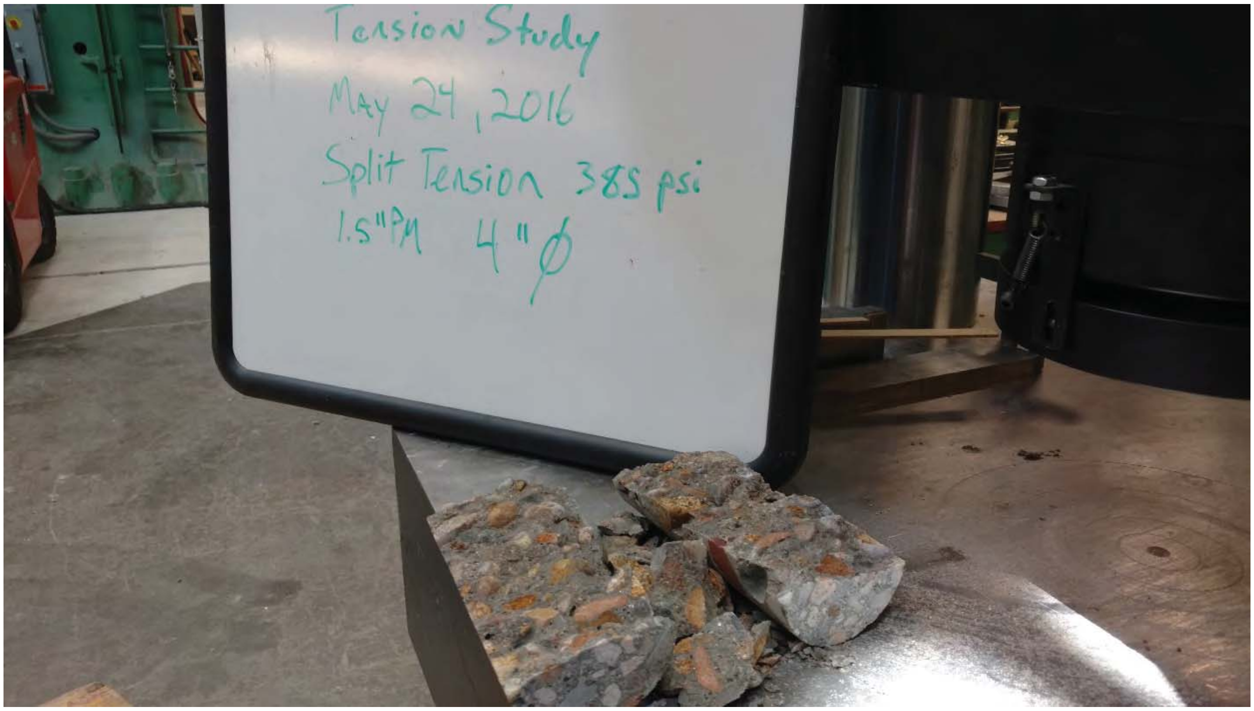


Figure G-6: 4-inch diameter core

Failed Splitting Tension Test Specimens from 3/8-inch NMSA Concrete Blocks

Figure G-7: 10-inch diameter core

Figure G-8: 6-inch diameter core

Failed Splitting Tension Test Specimens from 3/8-inch NMSA Concrete Blocks

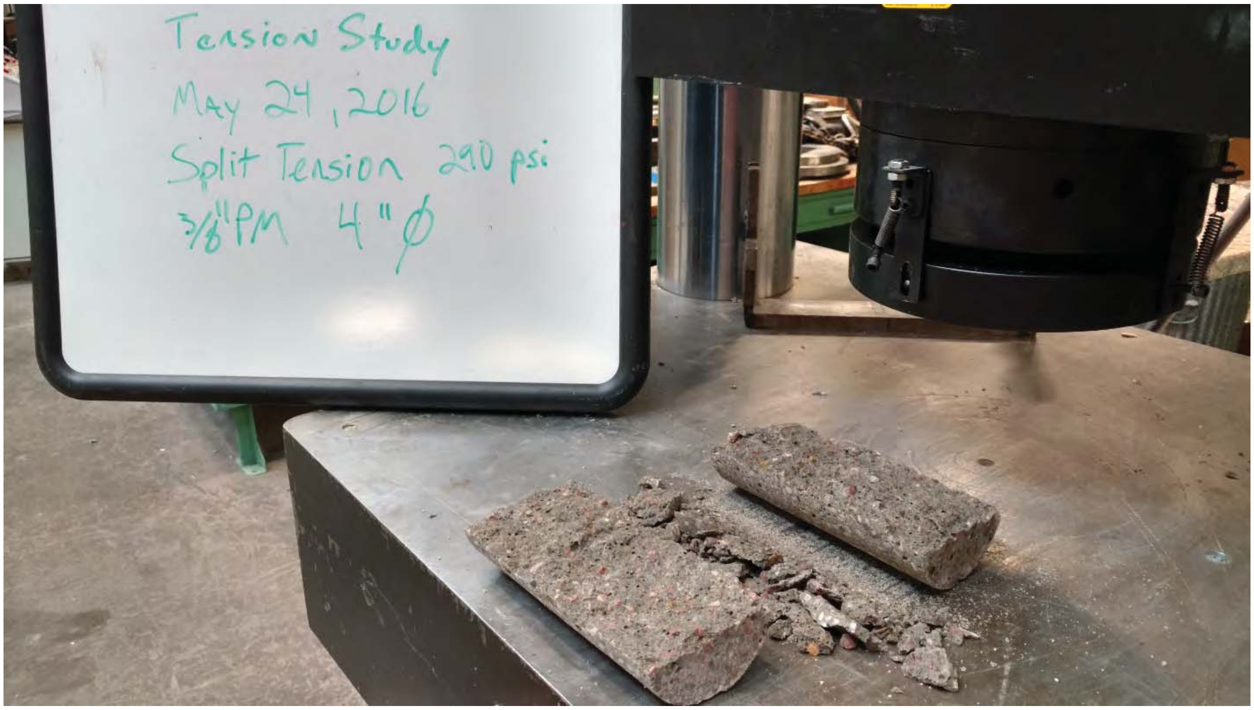


Figure G-9: 4-inch diameter core

Appendix H

Photographs of Failed Static Direct Tension Test Specimens

Failed Static Direct Tension Test Specimens from 8-inch NMSA Concrete Blocks

Figure H-1: 14-inch diameter core

Figure H-2: 12-inch diameter core

Failed Static Direct Tension Test Specimens from 8-inch NMSA Concrete Blocks

Figure H-3: 10-inch diameter core

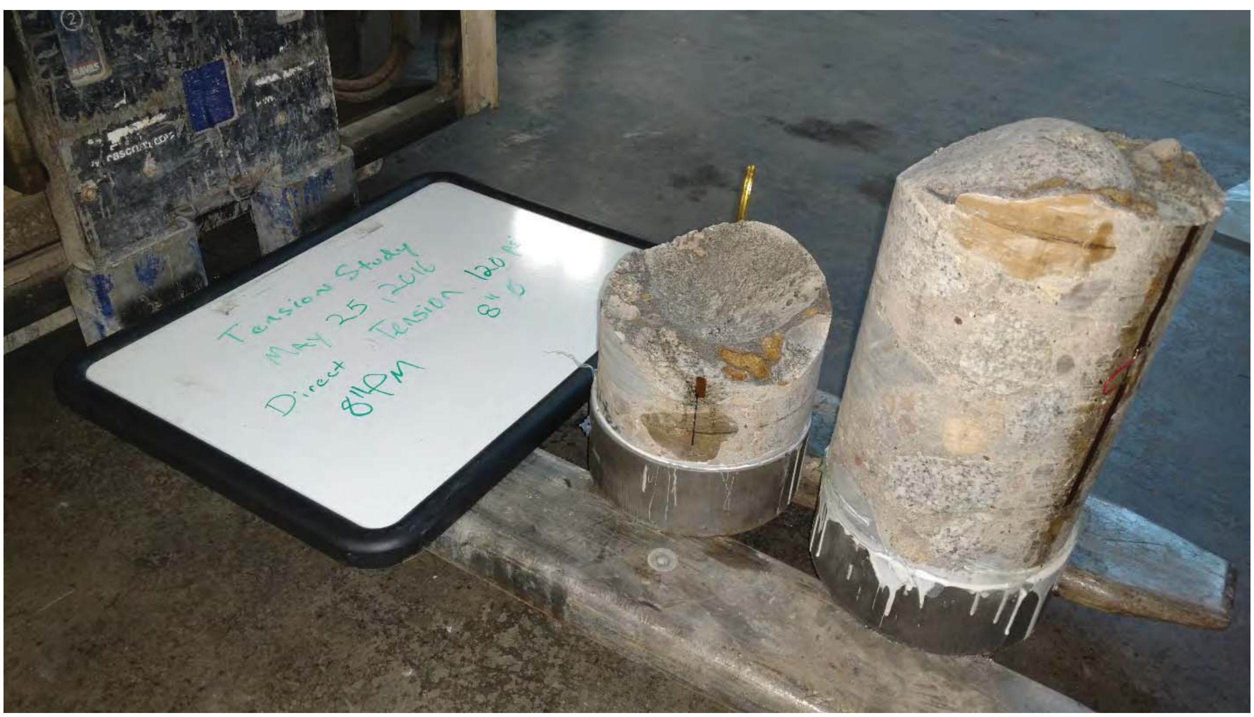


Figure H-4: 8-inch diameter core

Failed Static Direct Tension Test Specimens from 8-inch NMSA Concrete Blocks

Figure H-5: 6-inch diameter core

Failed Static Direct Tension Test Specimens from 8-inch NMSA Concrete Blocks

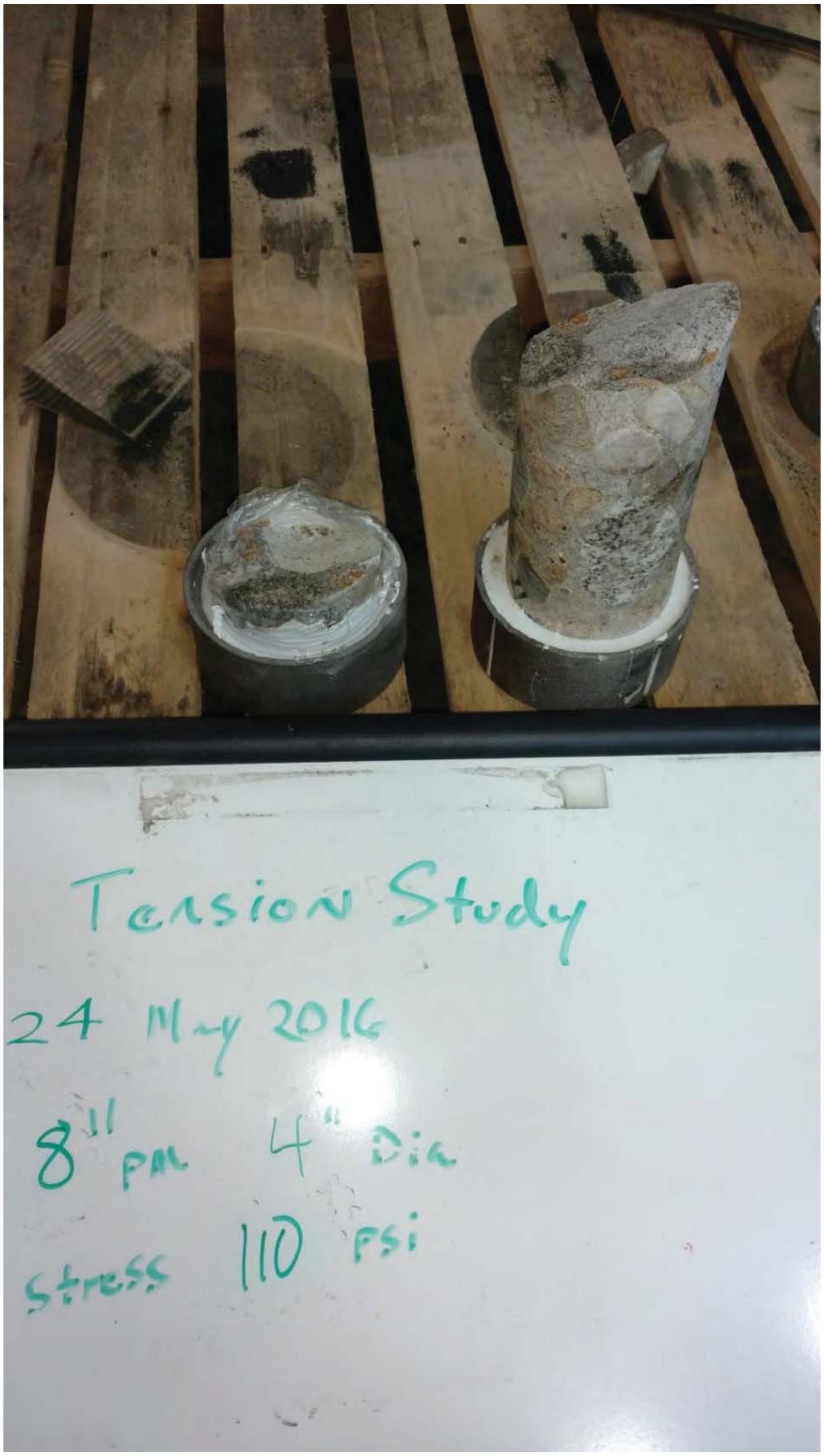


Figure H-6: 4-inch diameter core

Failed Static Direct Tension Test Specimens from 1½-inch NMSA Concrete Blocks

Figure H-7: 14-inch diameter core

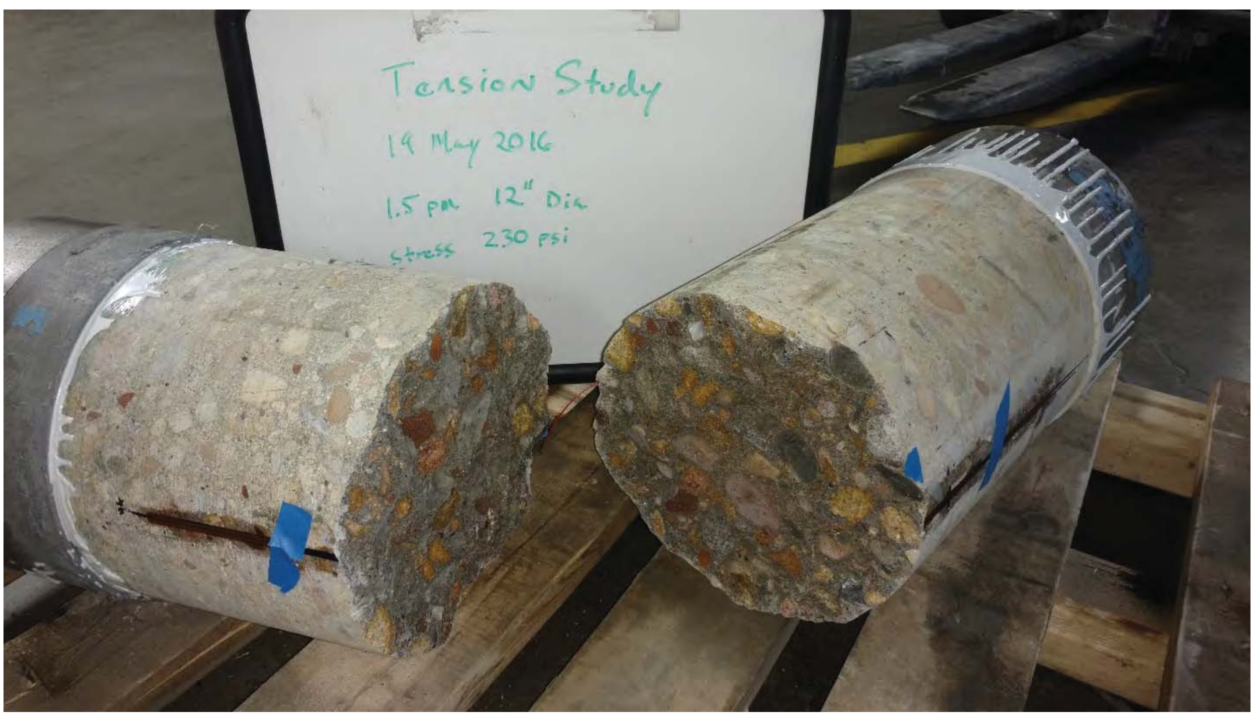


Figure H-8: 12-inch diameter core

Failed Static Direct Tension Test Specimens from 1½-inch NMSA Concrete Blocks

Figure H-9: 10-inch diameter core

Failed Static Direct Tension Test Specimens from 1½-inch NMSA Concrete Blocks

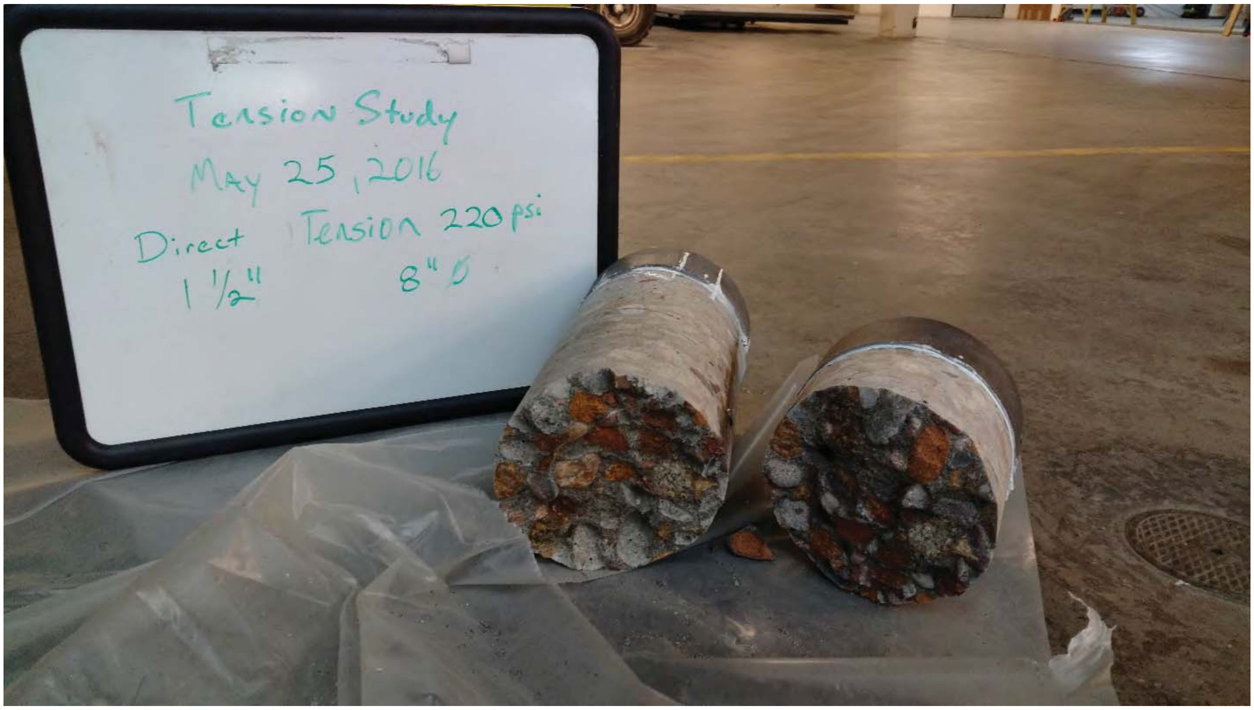


Figure H-10: 8-inch diameter core

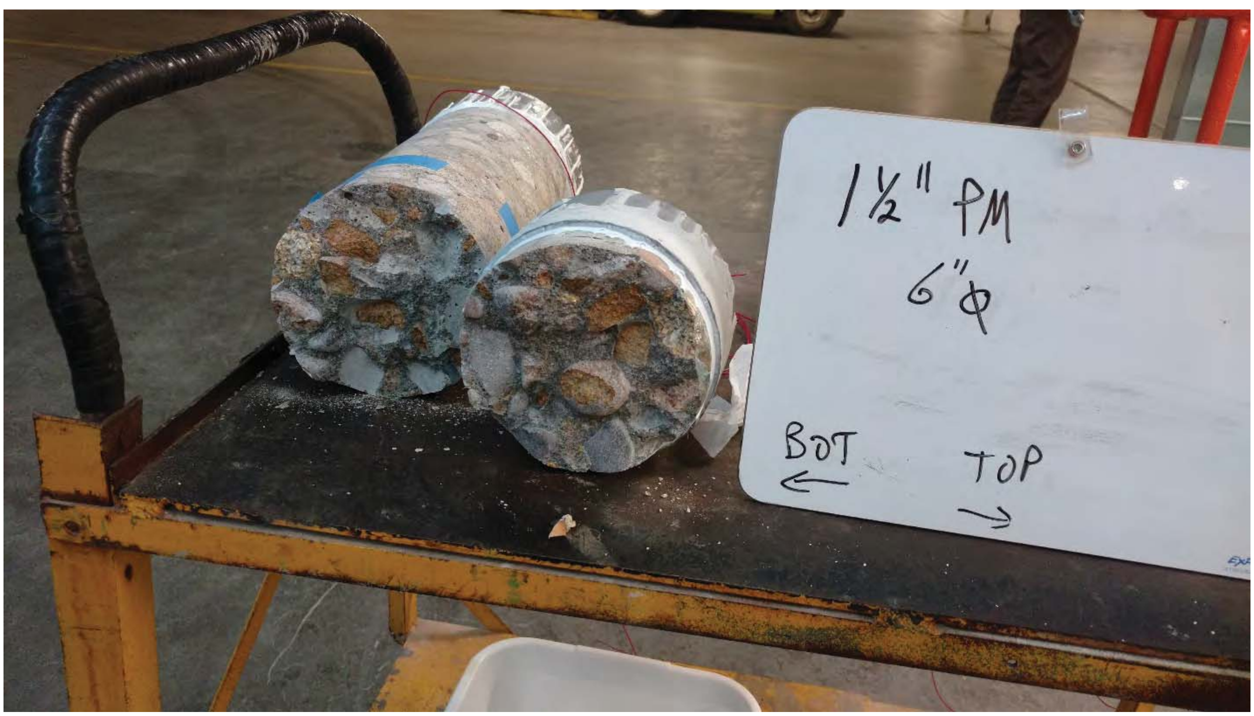


Figure H-11: 6-inch diameter core

Failed Static Direct Tension Test Specimens from 1½-inch NMSA Concrete Blocks

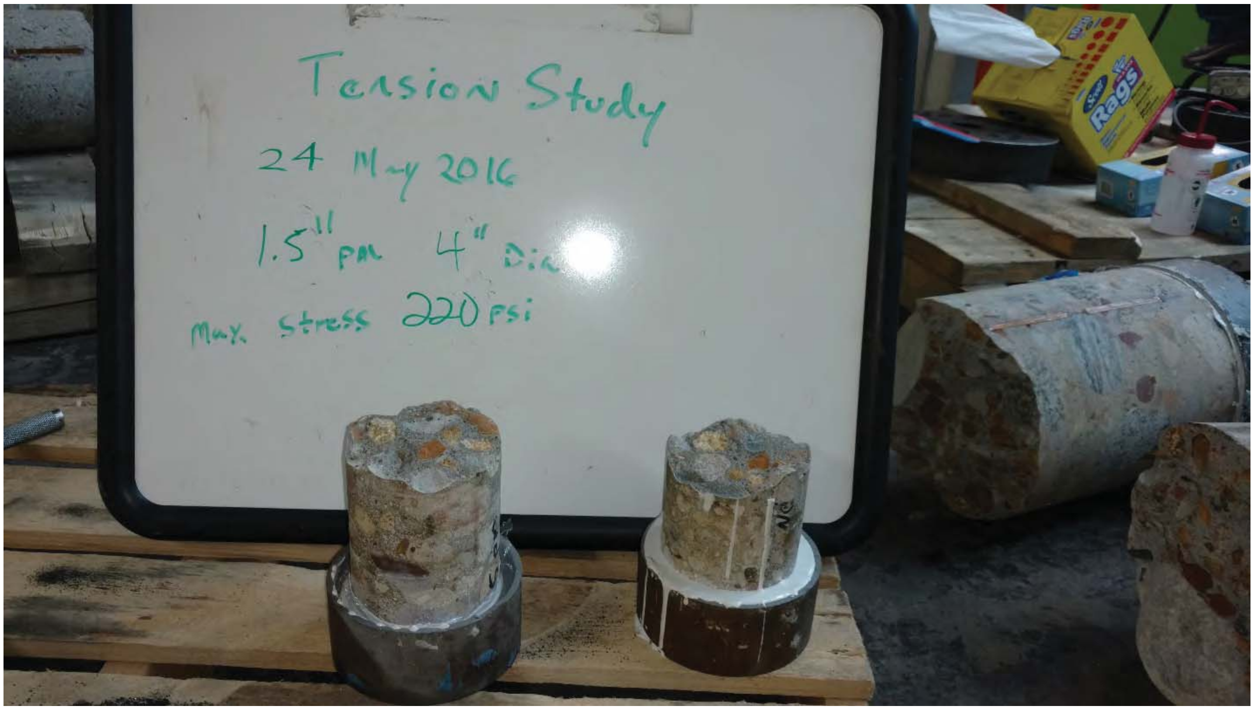


Figure H-12: 4-inch diameter core

Failed Static Direct Tension Test Specimens from 3/8-inch NMSA Concrete Blocks

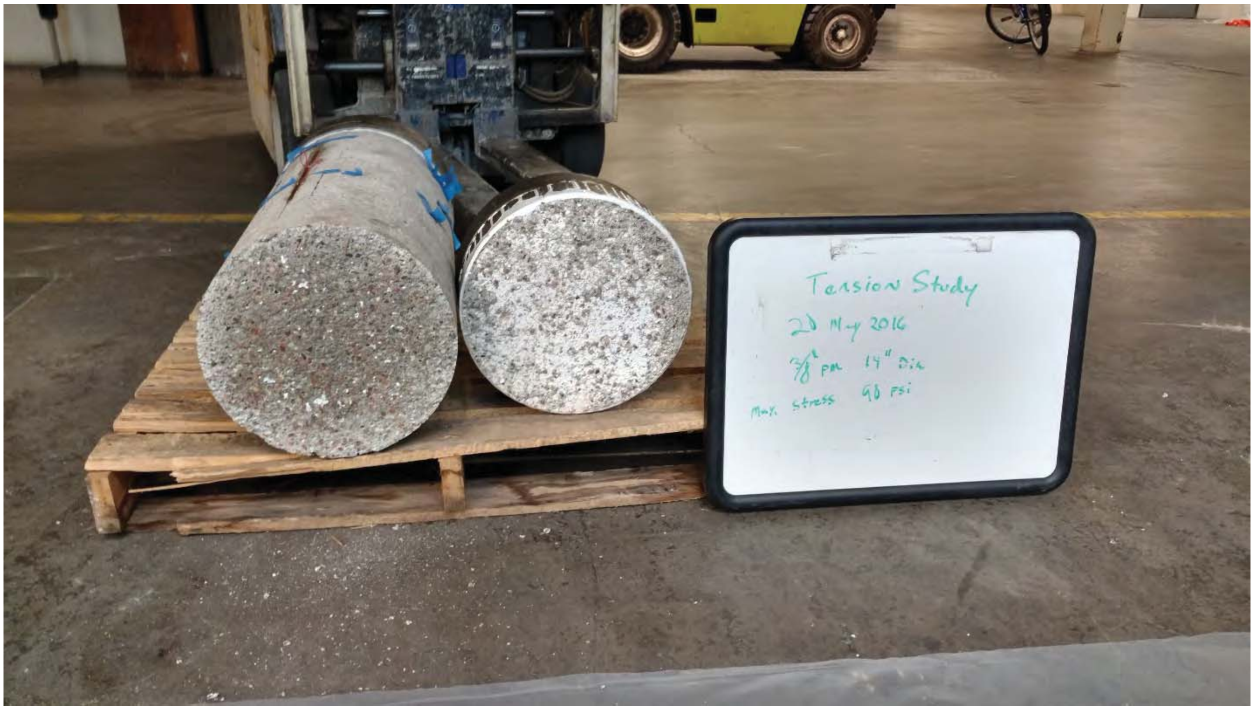


Figure H-13: 14-inch diameter core

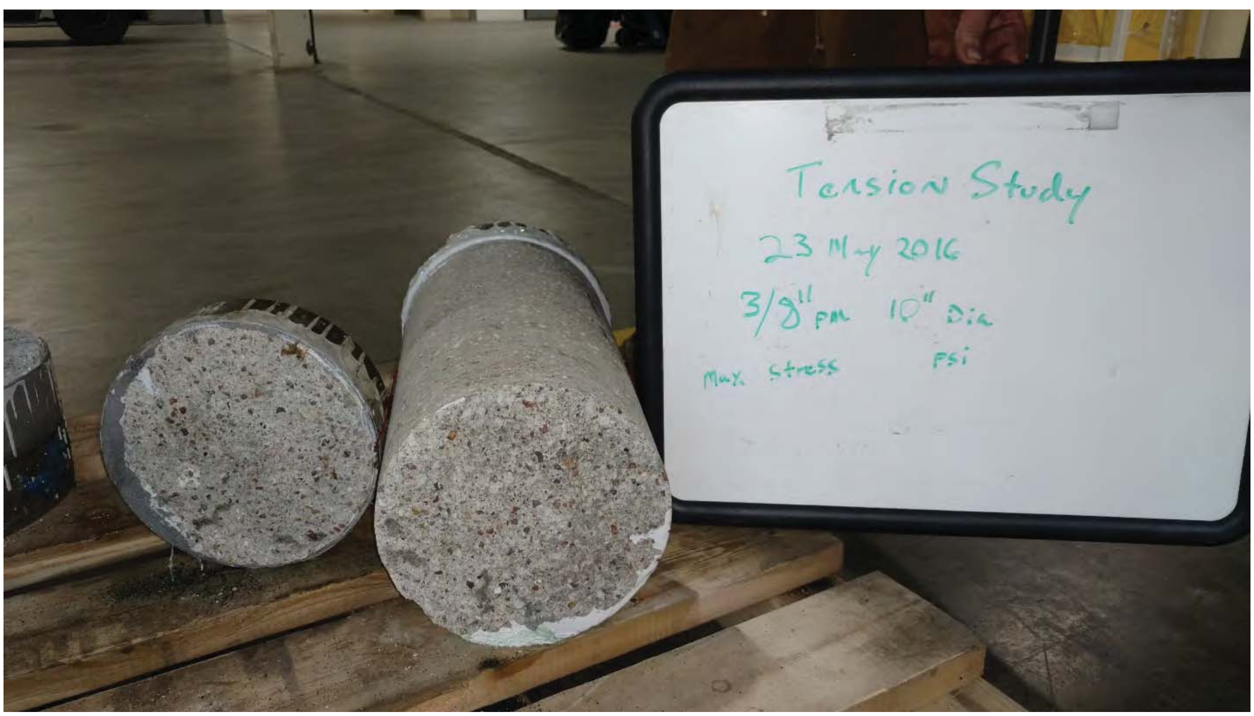


Figure H-14: 10-inch diameter core

Failed Static Direct Tension Test Specimens from 3/8-inch NMSA Concrete Blocks

Figure H-15: 8-inch diameter core

Failed Static Direct Tension Test Specimens from 3/8-inch NMSA Concrete Blocks

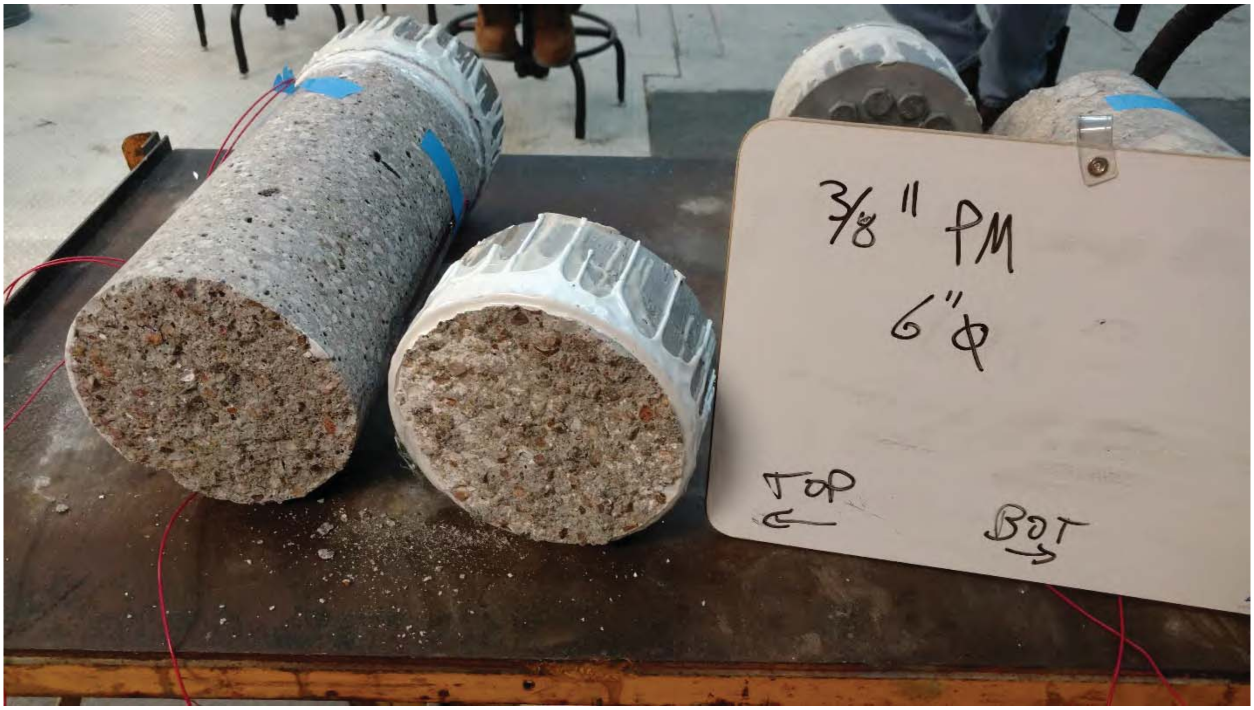


Figure H-16: 6-inch diameter core

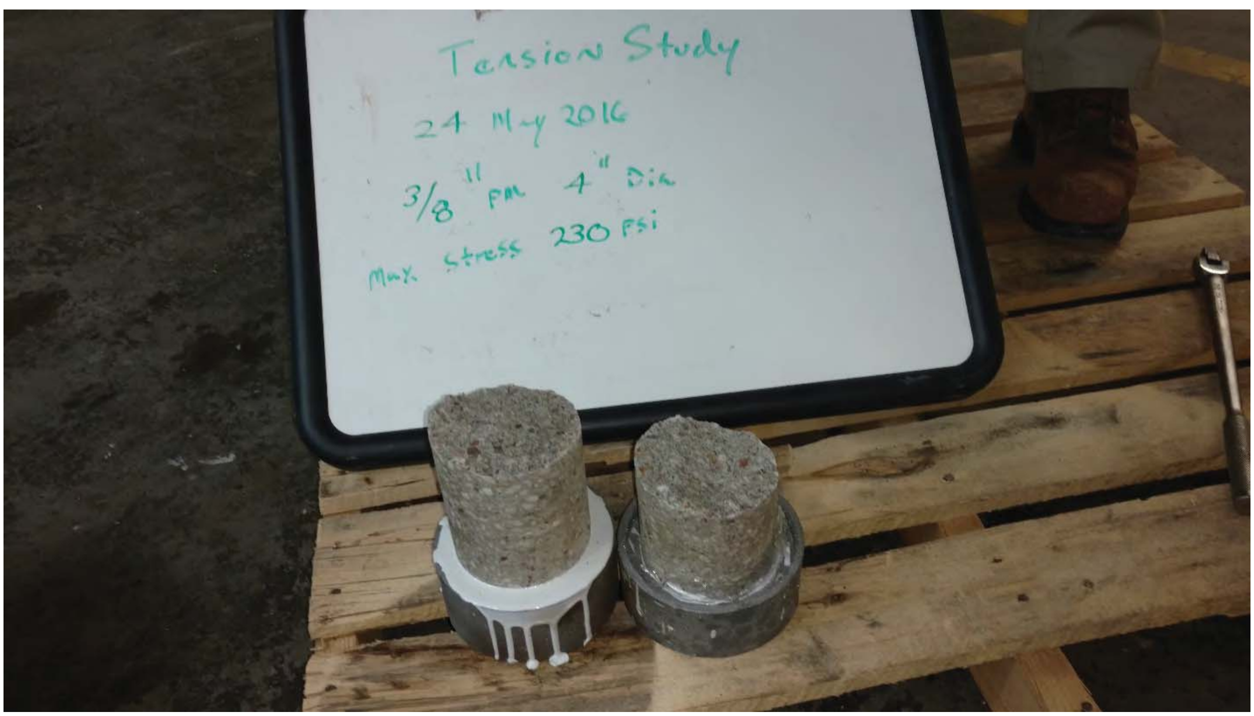


Figure H-17: 4-inch diameter core

Appendix I

Photographs of Failed Cyclic Dynamic Direct Tension Test Specimens

Failed Cyclic Dynamic Direct Tension Test Specimens from 8-inch NMSA Concrete

Figure I-1: 14-inch diameter core

Figure I-2: 12-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 8-inch NMSA Concrete

Figure I-3: 10-inch diameter core

Figure I-4: 8-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 8-inch NMSA Concrete

Figure I-5: 6-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 8-inch NMSA Concrete

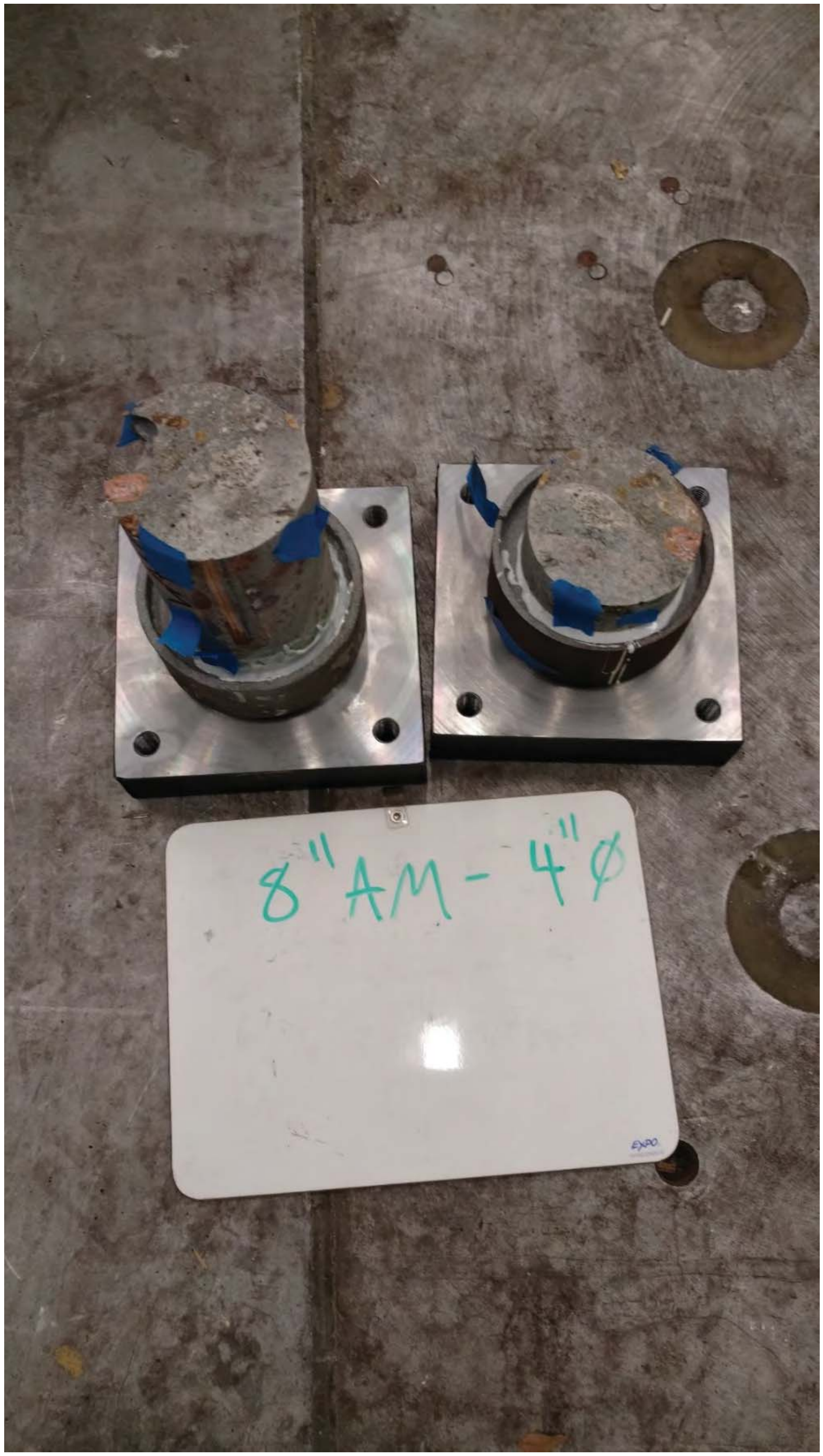


Figure I-6: 4-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 1½-inch NMSA Concrete

Figure I-7: 14-inch diameter core

Figure I-8: 12-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 1½-inch NMSA Concrete

Figure I-9: 10-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 1½-inch NMSA Concrete

Figure I-10: 8-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 1½-inch NMSA Concrete

Figure I-11: 6-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 1½-inch NMSA Concrete

Figure I-12: 4-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 3/8-inch NMSA Concrete

Figure I-13: 14-inch diameter core

Figure I-14: 12-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 3/8-inch NMSA Concrete

Figure I-15: 10-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 3/8-inch NMSA Concrete

Figure I-16: 8-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 3/8-inch NMSA Concrete

Figure I-17: 6-inch diameter core

Failed Cyclic Dynamic Direct Tension Test Specimens from 3/8-inch NMSA Concrete

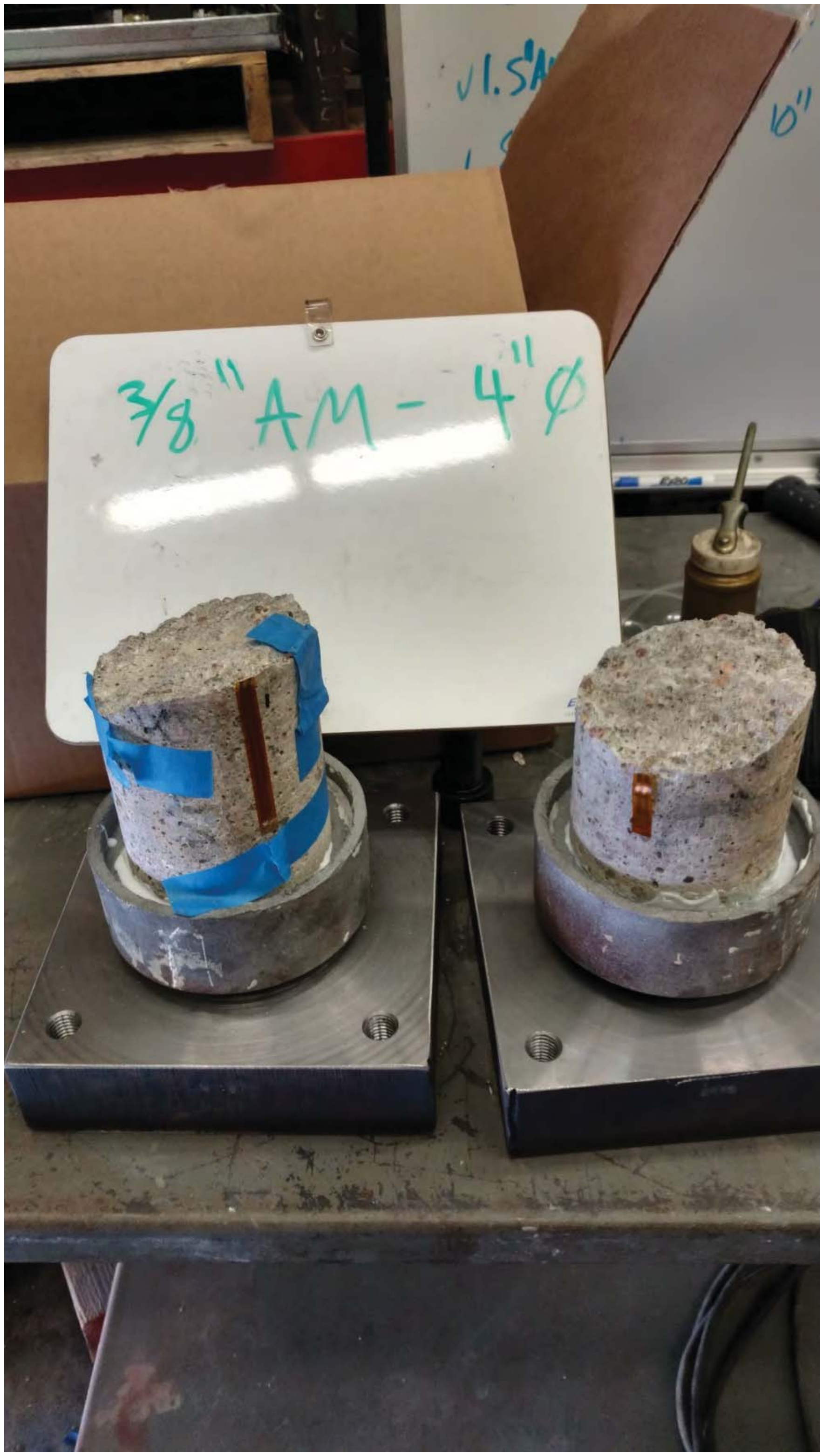


Figure I-18: 4-inch diameter core